Appendix – II

2016-17

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Under UGC Section 2 (f) & 12 (B)
Estd. in 1943 by Padma Vibhushan Dr. G.D. Birla

Details of Technical Research & Consultancy Services Grant received

(AY 2016-17)

Name of the Project	Name of the Principal Investigator	Amount Sanctioned (Rs in Lacs)	Name of the Funding Agency
The effect of selected local admixture on essential properties of cement for housing construction	Dr. Abhay Kumar Sharma	37.5	Kesoram Industries Ltd. Kolkata
Quality improvement in cement manufacturing	Dr A K Patra	37.5	Kesoram Industries Ltd. Kolkata
Supply chain management in cement industries	Prof G K Tyagi	37.5	Kesoram Industries Ltd. Kolkata
Strategic supply chain management & logistic in Kesoram cement Industries	Dr. K.N. Chatterjee	37.5	Kesoram Industries Ltd. Kolkata
Advanced Training in Connection with Excel Travel Accounting Software & Related Consultancy	Dr Mukesh Kumar	50	MSK Travels & Tour Ltd.
Being research & Consultancy Services	Dr R K Anayath	3	Kesoram Industries Ltd. Kolkata
Technical consultancy for project related problem	Dr A K Patra	0.63975	Kesoram Industries Ltd. Kolkata
Being research & Consultancy Services	Dr R K Anayath	1.2	Kesoram Industries Ltd. Kolkata
TOTAL		**204.83975**	

(Finance Officer /Manager Accounts)

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OFFICE ORDER

Dr Abhay Sharma, HOD, Department of Mechanical Engineering, will work as Principal Investigator for the project titled **"The effect of selected local admixture on essential properties of cement for housing construction"** sanctioned from Kesoram Industries Ltd., Kolkata.

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Dr A K Patra, HOD, Department of Textile Chemistry, will work as Principal Investigator for the project titled **"Quality improvement in cement manufacturing"** sanctioned from Kesoram Industries Ltd., Kolkata.

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Prof (Dr.) G K Tyagi, Dean Engineering, will work as Principal Investigator for the project titled **"Supply chain management in cement industries"** sanctioned from Kesoram Industries Ltd., Kolkata.

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Dr. K.N. Chatterjee, HOD, Department of Fashion & Apparel Engineering, will work as Principal Investigator for the project titled **"Strategic supply chain management & logistic in Kesoram cement Industries"** sanctioned from Kesoram Industries Ltd., Kolkata.

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Dr. Mukesh Kumar, HOD, Department of Computer Engineering, will work as Principal Investigator for the project titled **"Advanced Training in Connection with Excel Travel Accounting Software & Related Consultancy"** sanctioned from MSK Travels & Tour Ltd., Kolkata.

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PROJECT REPORT

on

THE EFFECT OF SELECTED LOCAL ADMIXTURES ON ESSENTIAL PROPERTIES OF CEMENT FOR HOUSING CONSTRUCTION

Compiled and Submitted By:

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(HEAD, DEPARTMENT OF MECHANICAL ENGINEERING)

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ABSTRACT

Current trend in cement production is to introduce inorganic admixtures to improve the technical properties such as workability and reduced cracks in concrete. In addition, replacement of clinker or cement greatly reduces environmental pollution due to release of greenhouse gas emissions such as carbon dioxide, carbon monoxide, Nitrogen oxides (No_X) and Sulphur dioxide (SO_2)during cement production. Cement replacement also reduces the high energy cost associated with clinker production and this leads to reduced price of cement.

The objective of this study was to determine the effect and suitability of four local inorganic materials; namely, clay, limestone, clam shells and steel slag (all obtained in Ghana) as mineral admixtures in cement for construction purposes. Blended cements, ranging from binary to quinternary mixes, were produced.

The soundness of the blended cement samples were less than 2.0mm. Water permeability tests showed clearly that addition of the admixtures, except slag, reduced the porosity of the cement by at least 4% and as much as 20%. The water demand of the blended cements ranged from 24.5% to 34.5% and that it increased as the percentage replacements of cement were increased. The water demand of the blended cements ranged from 24.5% to 34.5% and that it increased as the percentage replacements of cement are increased. The setting times of all the blended cements were within the standard limits.

The infrared spectrometry, X-ray Diffraction(XRD), Scanning Electron Microscopy/Energy Dispersive X-ray (SEM/EDX) and Thermogravimetric (DTA/TG) analysis of the study clearly showed that the presence of the four admixtures reduced $Ca(OH)_2$ content considerably and improved impermeability of concrete. The Infrared analysis indicated that when the admixture content was increased from binary to ternarythe accelerating effect of admixtures on hydration was enhanced. This effect manifested in high early strength of the blended cement, especially the $CaCO_3$-based blended cement samples. The ettringite and monosulphonate of $CaCO_3$-based admixtures (that is, limestone and shell cement) bands were almost flat or disappeared compared to others, indicating increased reactivity between CO_3^{2-} and SiO_4^{4-} ions.

Significantly, the study showed that a combination of three admixtures (5% each) or all four (2.5% each) in the cement almost eliminated portlandite content as compared to 36.9% in the reference cement as provided from the X-ray diffraction (XRD) analysis. This is a novel revelation and it was sufficiently corroborated by the EDX and TG/DTA analysis.The EDX and X-ray analysis also showed increased silica and oxygen composition of the blended compared to the control indicating increasing amounts of calcium silicate components.

The mortar compressive strength tests showed that blending *5%x*, 5%x5%y, *2.5%x2.5%y2.5%z and 2.5%x2.5%y2.5%z2.5p* by mass of the admixture(s) produced Class 42.5N cement. These cements can therefore be used for early strength concrete

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works and all types of construction works. 1:2:4 blended cement concretes with water cement ratio of 0.6 reached the targeted strength value of 20 ± 2 MPa at 28 days.

The study showed that the effect of seawater (NaCl) and Na_2SO_4 on strength was reduced as the number of admixtures in the cement were increased. In all, the quinternary *(2.5%x2.5%y2.5%z2.5%p)* cement provided the best blend that could resist the deleterious effect of both seawater and sulphate solution negative action. These give ample proof that a combination of three or four admixtures in cement greatly influenced the reductionofportlandite content leading to high resistance to acidic attack.

Economically, replacing 15% of total clinker imports by these admixtures would amount to a capital saving of at least $33.43 million per annum to Ghana.

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TABLE OF CONTENT

Page

Director,
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Director,
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LIST OF TABLES

LIST OF FIGURES

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CHAPTER ONE

INTRODUCTION

Portland cement production has traditionally involved calcination of limestone and siliceous clay to produce clinker, which is then interground with 3-5% gypsum. It could contain no more than 5% additives or admixtures. However, current trends in cement production involve the addition of minor constituents, also called admixtures, in order to improve the technical properties and durability of cement as a result of the prevailing climatic(such as high temperature differentials),and/or environmental situation. It is also aimed at reducing carbon gases emission to protect the global environment. Admixture composition could be up to 25% - 70% depending on the type of admixtures.

Cement used in Ghana is mainly Portland limestone cement with limestone content between 18% and 25%. Limestone is obtained locally but the clinker and gypsum are imported from Middle East and Europe. Research studies and commercial production elsewhere make use of fly ash, granulated blast furnace slag, among others, in cement production and have been found to have some technical advantages over ordinary Portland cement such as improved workability, sulphate resistance, reduction in concrete cracks and silica alkali reaction, among others. Ghana abounds in several mineral admixtures which researchers have found to be suitable as ingredients in cement such as clay, limestone, clam shells, bauxite waste, steel slag, iron ore and rice husk among others (Tsakiridis*et al*, 2008; Kakali*et al*, 2000; Pèra*et al*, 1999; Atiemo, 1998;

Hammond, 1987; Kesse, 1985). These materials are found in large quantities, produced in sufficient amounts, left untapped or discarded as waste. Of these only *Mankranso* and *GomoaMprumem* clay, and *Oterkpolu* and *Buipe* limestone are used in cement production in Ghana, but the rest have not been considered. Also, most cementsare produced as binary cements using only one type of admixtures for production such as pulverized fly ash and blastfurnace slag with high silica and lime content respectively. The production of cement containing three or more admixtures has not gained popularity so it is vital component of this study. This study looks at the suitability and influence of four local admixtures as vital ingredients in cement production with the aim of reducing cost and carbon dioxide footprints, and making housing delivery cheaper in Ghana. It is also aimed at enriching the knowledge of utilization of industrial waste material and other natural admixtures in cement production.

The study presents a range of materials that are available for use as raw materials in cement for construction. Their utilisation would greatly reduce the cost of a key building material and, therefore, the cost of housing delivery in developing countries with special reference to Ghana.

1.1 Cement additives and Global Environmental benefits

Several research studies have shown that mineral admixtures such as limestone, pozzolana, slag, fly ash, trass, among others, in Portland cement influence hydration of cement and its properties. For limestone fillers, it has been proven that there is

interaction between calcium silicate and $CaCO_3$ and that calcium carboaluminatehydrates precipitate during hydration of cement containing $CaCO_3$. It is also generally accepted that there is a positive effect of limestone on the water demand of the blended cement (Rahhaland Talero 2005; Portland Cement Association, 2004 Pera, *et al* 1999).

The world"s production of cement in 2006 exceeded 2.6 billion tonnes (Cement Global report, 2007). This means an evolution of about 2.6 billion tonnes of carbon dioxide (CO_2) during clinker production since production of one tonne of clinker releases about a tonne of CO_2. Therefore, the addition of mineral admixtures or fillers and consequent reduction of the clinker in ordinary Portland cement production provide both economic and environmental benefits. Based on Portland Cement Association calculations (2004), using 5% limestone in cement productionin 2006, the environmental benefits would include:

- reduction in energy consumption of about 6.6×10^6 MW-hr;
- reduction in carbon dioxide emissions of more than 5 million tonnes; or by approximately 5 percent per ton of cement produced;
- reduction of cement kiln dust of above 450,000 tonnes;
- reduction in raw materials use of 4.0 million tonnes; and
- considerable reduction of NO_x and SO_2 emissions from reduced fuel consumption.

As a result, addition of admixtures leads to significant reduction of greenhouse gas emissions such as carbon dioxide, carbon monoxide, methane or chlorofluorocarbons

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(from fossil fuels). Partial substitution of Portland cement with admixtures/fillers also reduces the cost of cement production thus impacting positively on price of cement.

1.2 Cement Industry

The construction industry is a vital sector of any economy since infrastructural development forms one of the indicators used in measuring a country's development. Cement undoubtedly is one of the most essential commodities in the construction sector. An in-depth analysis by Global Cement Report (2007) showed that cement consumption in 2006 was about 2.56 billion metric tonnes but shot to 2.86 billion tones in 2009, an increase of 12%. Consumption continues to rise globally due to increased infrastructure development despite its high price, especially in third world countries. China is the largest producer of cement in the world, accounting for almost 47% of the world"s total output producing about 1.4 billion tones. The growth of cement consumption in China was measured at between 9% and 14% from 2005 to 2008, representing an increase of 1.05 billion metric tonnes in 2005 to 1.4 billion tonnes in 2008. In India, the second largest world"s consumer, cement production, buoyed by a strong demand, increased to 183 million tonnes in 2008. In the United States, the demand levels of cement reached a peak of about 122million tonnes in 2006 but declined to 100 million tonnes in 2008. Globally, cement production has increased appreciably by 30.5% from 2.2 billion tonnes in 2004 to 2.86 billion tonnes in 2008, West and North Africa constituted about 4% of global consumption of cement as compared to 1% for South and Central Africa in 2008 (Cement Global Report, 2009, 2010).

Across Africa, there have been positive increases in cement production and consumption. Nigeria consumed an estimated 14.8 million tonnes in 2009, giving a per capita consumption of 98kg, compared to about 8.4 million tonnes in 2004 (Access Securities, 2009) whilst Ghana saw a steady rise in cement utilisation from 1.8 million tonnes in 2000 to about 3.3 million tonnes in 2009, giving a per capita consumption of 133kg (Ghacem Limited, 2010). Despite the increase in the usage of cement worldwide, developing countries continue to experience high costs of the commodity due to low production, high freight cost, weak national currencies, and high energy tariffs. Most of the cements used in these countries are either imported wholly or produced from imported clinker and gypsum. Ghana imports all its clinker for the production of ordinary Portland cement whilst Nigeria imports about 43% of its cement requirements (International Cement Review, 2010). Even in countries where cements are produced locally, such as India, Iran, Ethiopia, Nigeria, Togo and Zimbabwe; the high cost of production due to high cost of fuel oil, old machinery and inefficiency in production are some of the reasons for the high prices of cement.

The price of cement has seen approximately 157% increase from year 2001 to 2010 in Ghana, over 55% in Nigeria between 2002 and 2004, and 23% in India in 2003 (Times News Network, 2004; and Omohand Njoku, 2004). It is now retailed between \$8 and \$10 in Ghana, \$7.2 in Ethiopia and Nigeria and about \$4.1 in India per bag of 50kg. This is certainly beyond the reach of the vast majority of people in these developing countries, where income levels are low and about half of the population lives in poverty.

As a result of the afore-mentioned problems of high cost and unavailability of cement, the use of durable local cementitious materials would help to reduce the price of cement in these countries. Several materials exist in Ghana which can be blended with ordinary Portland cement for building and construction without affecting the strength, quality and durability of the cement products. In most cases the quality of the cement is improved and the cost of production greatly reduced.

1.3 Domestic Cement Usage and Demand Analysis

The last study on usage of cement in Ghanain 1996 by Mott McDonaldConsulting Limited showed that the building sector accounted for more than 90% of cement consumption whilst the road sector consumed the remaining 10% mainly for the construction of bridges, culverts, drains, pedestrian pavements, among others. Table 1.1 presents the trend of cement consumption in Ghana from the year 2000 to 2009. It shows that cement usage has increased from 1.8 million tonnes to about 3.3 million tonnes.

Table 1.1: Estimated consumption of Portland cement in Ghana

Year	Cement in million tonnes
2000	1.81
2001	2.05
2002	2.15
2003	2.33
2004	2.50
2005	2.65
2006	2.80
2007	3.02
2008	3.31
2009	3.29

*Sourced from GHACEM and Diamond Cement Ltd (2010)

Cement consumed in Ghana is produced from imported clinker and gypsum from Togo, Middle East and Europe. Since the year 2008 more than $280 million is spent annually on clinker and cement importation in Ghana. Cement consumption will continue to increase because of increasing population growth and increased infrastructure developmental activities by the Government, estate developers, institutions and private individuals.

1.4 Technical and Economic Benefits of Using Blended Cements

Technically, the presence of admixtures like limestone, slag and pozzolana in Portland cement influences the rate and degree of cement hydration as well as the phase composition of hydrated cement paste (Klieger, 1990; Hawkins*et al*, 2003).Their addition may increase the hydration rate of clinker minerals and become more pronounced with greater fineness. The formation of ettringite is also enhanced but its tendency to transform to the monosulphate form is diminished. Mineral admixtures also improve the workability of cement, lower the heat of hydration and energy cost, among others. In some instances their presence increases the resistance of the blended cement to acidic water attack.

Ghana utilizes about 3.3 million tonnes of cement annually. Consumption in West Africa exceeds 150 million tonnes, with more than 70% being imported. A reduction of clinker imports by at least 15% substitution with local admixtures will greatly reduce the cost of locally produced cement and environmental pollution. Utilisation of local limestone, clam shells, pozzolana, slag, among others in production of cement will be expected to decrease the cost of production by at least 10% as a result of energy reduction and reduced cost of materials It will also result in capital retention and increased technical capacity.

1.5 Main Objective

The objective of this study was to evaluate the suitability of four inorganic materials; namely clay, limestone, clam shells and steel slag (all obtained in Ghana) as mineral admixtures in cement for construction purposes. To achieve this aim, the following properties of the materials were studied:

- Physical properties and chemical composition of reference cement (ordinary Portland cement) and admixtures;
- Chemical composition of blended cements;
- Mineralogical composition of raw samples and blended cements;
- Water demand and setting times of blended cement pastes;
- Drying shrinkage of blended cements;
- Soundness of blended cements;
- Infrared (IR) spectrometry analysis of hydrated cement samples;
- X-ray Diffraction (XRD) analysis of hydrated cement products;
- Scanning Electron Microscopic (SEM) and Energy Dispersive X-ray (EDX) analysis of hydrated cement mortars;
- Thermal analysis of blended cements;
- Compressive strengths of blended cement mortars, concrete cubes and prisms;

- Tensile strengths of concrete using blended cements and Class 42.5N CEM I Portland cement;
- Durability tests of cement products using 5% sodium sulphate and sea water by:
  - determining samples appearance after 365 days;
  - determining the compressive strengths after 365 days;
- The economic benefits to be derived from the addition of local mineral admixtures in Portland cement for housing construction in Ghana.

The specific objectives would be to show the influence of these admixtures on the essential properties of cement. This would include the influence of the admixtures in cement reactions andhydration, precipitation of portlandite [$Ca(OH)_2$] and also setting times, soundness and strength even at 20% replacement of cement withinthe standard limits.

In order to achieve these objectives a literature review would be carried out as well as the study of properties and sources of these admixtures. The materials would be assessed for their suitability using GS, BS, EN, ASTM and ISO Standard Testing Methods. The results so obtained would be interpreted and discussed, and their application in construction stated. The resultant conclusions would be made and the economic benefits from the study evaluated. Finally, relevant recommendations which will improve the important properties of cement and the advantage that will inure positively to Ghanaian economy would be presented.

CHAPTER TWO

LITERATURE REVIEW

2.1 Cement

Cement is defined as finely ground inorganic hydraulic binder which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and chemical processes and which, after hardening, retains its strength and stability even under water (EN 197-1, 2000). The production of ordinary Portland cement (oPc) involves the calcination of limestone and clay in a rotary kiln to a temperature of about 1400^{o}C. The clinker produced is then interground with gypsum ($CaSO_4.2H_2O$), which regulates the setting of cement. Cement has revolutionised the building industry because of its early setting and hardening, and its early strength gain and durability were found to be far superior and better than such materials as lime-pozzolana, lime –sand and lime-soil mixtures/mixes.

Portland cement is composed mainly of the four clinker minerals, namely, tricalcium silicate, $3CaO.SiO_2$ (C_3S); dicalcium silicate, $2CaO.SiO_2$ (C_2S); tricalcium aluminate $3CaO.Al_2O_3$ (C_3A); and tetracalciumaluminoferrite (C_4AF) to which 3-5% gypsum ($CaSO_4.2H_2O$) is added. Chemically, CaO, SiO_2, Al_2O_3 and Fe_2O_3 constitute about 80% of Portland cement. The other significant minor oxides are MgO, SO_3, K_2O, and Na_2O. Although the amounts of these oxides are relatively small, they affect the hydration process of Portland cement (oPc) and the composition of hydration products (Lea, 1970).

Alite (tricalcium silicate) forms the bulk of clinker, 40-70% by mass, with hexagonal crystal sizes up to about 150μm. It reacts rapidly with water and is responsible for much of the early-age (≤28 days) strength development. Belite (dicalcium silicate) forms 15-45% of clinker with rounded crystal sizes ranging from 5 to 40μm. It is less reactive than alite but does contribute to later-age strengths (>28 days). Upon hydration, both alite and belite form poorly-crystallized calcium silicate hydrates (C-S-H) and well-crystallized calcium hydroxide (portlandite). Tricalcium aluminate constitutes 1-15% of clinker with a particle size of between 1-60μm and occurs as either cubic or orthorhombic form. It is highly reactive with water. Tetracalciumaluminoferrite (Ferrite; C_4AF) constitutes between 1% and 18% of clinker content (Stutzman, 2004).

2.1.1 Chemical Reactions and Hydration of Cement

The various particles of cement components react chemically when it mixes with water producing various phases. These reactions are by hydration and hydrolysis of these clinker minerals and gypsum leading to the setting and hardening of the cement.The main reactions of the individual cement compounds that take place sequentially are as follows (Lea, 1970; Zhou, 2006):

- The C_3A reacts with both water and gypsum ($CaSO_4.2H_2O$) to produce unstable ettringite (AFt).

$$\underset{C_3A}{3CaO.Al_2O_3} + \underset{gypsum}{3CaSO_4.2H_2O} + 26H_2O = \underset{ettringite\ (AFt)}{3CaO.Al_2O_3.3CaSO_4.32H_2O} \qquad 2.1$$

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This reaction is responsible for the setting of cement. Once all the gypsum is used up, the ettringite becomes unstable and reacts with the remaining C_3A to produce stable calcium monosulphate aluminate hydrate crystals (AFm).

$$2(3CaO.Al_2O_3) + 3CaO.Al_2O_3.3CaSO_4.32H_2O + 4H_2O = (3CaO.Al_2O_3.CaSO_4.12H_2O) \quad 2.2$$

ettringite(AFt) (AFm)

The size of the monosulphate is two and half times that of ettringite.

- The C_3S (alite) and C_2S (belite) react with water in a complete hydration to produce calcium silicate hydrates and calcium hydroxide as follows:

$$2(3CaO.SiO_2) + 7H_2O = 3CaO.2SiO_2.4H_2O + 3Ca(OH)_2 \quad 2.3$$

$$2(2CaO.SiO_2) + 5H_2O = 3CaO.2SiO_2.4H_2O + Ca(OH)_2 \quad 2.4$$

The products of these reactions contribute to the strength of cement products, with C_3S contributing about 75% of it.

- Like C_3A, C_4AF (ferrite) reacts with gypsum and water to form ettringite, lime and alumina hydroxides:

$$4CaO.Al_2O_3.Fe_2O_3 + 3CaSO_4.2H_2O + 30H_2O = 3CaO.Al_2O_3.Fe_2O_3.3CaSO_4.32H_2O + Al_2O_3.Fe_2O_3.3H_2O + Ca(OH)_2 \quad 2.5$$

The complete compound is called garnet, which is produced by the further reaction of C_4AF with ettringite.

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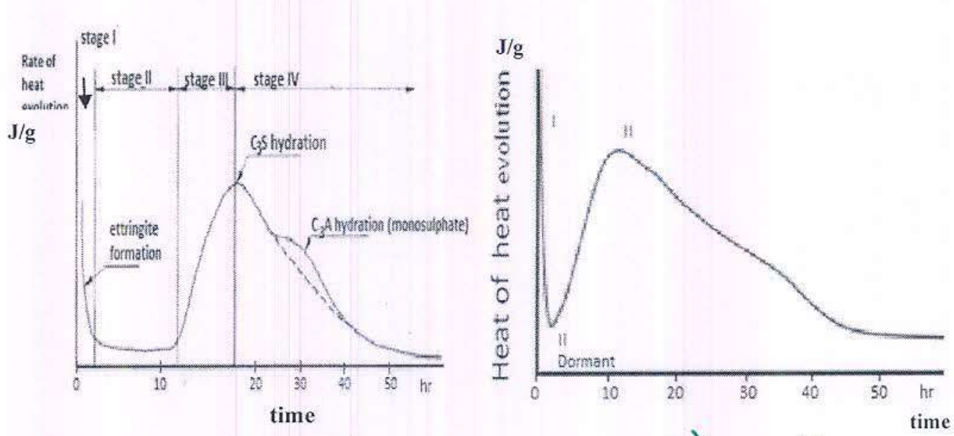
$$4CaO.Al_2O_3.Fe_2O_3 + 3CaSO_4. + 30H_2O = 6CaO.Al_2O_3.Fe_2O_3.3SO_3.32H_2O + Al_2O_3.Fe_2O_3.3H_2O \quad 2.6$$

The above reactions are accompanied by heat liberation. Measuring the liberated heat of hydration is one of the methods of determining the degree of hydration.

2.2.2 Hydration process of Portland cement

The hydration of Portland cement is exothermic. Variation in the liberated heat of hydration mirrors, in one way or another, the hydration mechanisms. The process of hydration can be followed by monitoring the heat evolution by means of conduction calorimetry. Figures 2.1(a) and (b) show a typical heat evolution curve reported by Mindess*et al*,(1981). Fig. 2.1(a) gives a descriptive narration on the heat evolution. This process canbe divided into 4 stages, including the pre-induction (i), dormant (ii), acceleration (iii) and post-acceleration (iv) stages.



(a) (b)

Figure 2.1: Rate of heat evolution (Mindess*and Yong*,1981)

2.2.2.1 Pre-induction stage (Stage I)

Almost immediately on adding water, some of the clinker sulphates and gypsum dissolve, producing an alkaline, sulfate-rich solution. Soon after mixing, the (C_3A) phase - the most reactive of the clinker minerals - reacts with the water to form an aluminate-rich gel (Stage I). The gel reacts with sulfate in solution to form small rod-like crystals of ettringite(Eqn.2.1).Hydration of free lime and the wetting of the cement also occur at this stage (Lee, 1983). C_3A hydration is a strongly exothermic reaction but it does not last long, typically only a few minutes.

The fast heat evolution at the pre-induction period is attributed to the hydration of C_3A, the hydration of free lime and the wetting of the cement (Eqn 2.1). C_3A is the most active at this stage and reacts with gypsum to produce ettringite. The main products are ettringite and calcium hydroxide (Lea, 1970; Zhou, 2006). The duration of this stage is less than 60 minutes. This reaction leads to the initial setting time of cement.

2.2.2.2 Dormant stage (Stage II)

The dormant or induction stage follows stage I, and is characterized by a period of about two hours of relatively low heat evolution. Here, cement exhibits low reactivity. The first part of the dormant period – up to perhaps half-way through - corresponds to when concrete can be placed. As the dormant period progresses, the paste becomes too stiff to be workable. The final setting time is achieved within this stage.

Two of the most often mentioned concepts in the dormant stage are the "membrane or protection layer concept" and the concept of "delayed nucleation and growth" (Breugel, 1997; Guang, 2003).

2.1.2.3 Acceleration stage (Stage III)

At the end of the dormant period, the alite (C_3S) and belite (C_2S) in the cement start to hydrate, with the formation of calcium silicate hydrate and calcium hydroxide (Equations 3 and 4). This corresponds to the main period of cement hydration known as the acceleration stage during which time cement product strength increases. The C_3S and belite C_2S cement grains react from the surface inwards, and the anhydrous particles become smaller through a gradually thickening shell (Breugel, 1997). C_3A hydration also continues, as fresh crystals become accessible to water (Eqn. 2.1).

The period of maximum heat evolution occurs typically between about 10 and 20 hours after mixing and then gradually tails off. In a mix containing Portland cement as the only cementitious material, most of the strength gain occurs within about a month. Ferrite hydration also starts quickly as water is added, but then slows down, probably because a layer of iron hydroxide gel forms, coating the ferrite and acting as a barrier, preventing further reaction (Eqn. 2.5).

2.1.2.4 Post-acceleration stage (Stage IV)

The rate of heat liberation slows down (stage IV) after peaking in Stage III. The hydration of C_2S becomes the main contribution to this stage. Richardson*et al* (1989) suggested that it is also due to the conversion of calcium alumina ferric oxide tri-sulphate hydrates (AFt) to alumina ferric oxide mono-sulphate hydrates (AFm) and the formation of secondary AFt. The main products in this stage are $3CaO.2SiO_2.3H_20$, $Ca(OH)_2$ and $3CaO.Al_2O_3.CaSO_4.12H_2O$ (AFm).

2.1.3 Thermal Analysis of Portland cement

Cement undergoes phase changes when it is subjected to heat treatment between 20^oC and 1100^oC. The reactions that occur with an increase of temperature in cement paste and concrete according to Lea (1970) and Sharma and Pandey (1999) are summarized as follows:

- From 30°C to 105 °C; surface water begins to evaporate and a part of the bound water escapes. It is generally considered that the evaporable water is completely eliminated at 120 °C.
- Between 110°C and 170°C: the decomposition of gypsum (with a double endothermal reaction) and ettringite occurs and the loss of water from part of the carboaluminate hydrates takes place.
- Between 180°C and 500 °C: the loss of bound water from the decomposition of the C-S-H and carboaluminate hydrates occurs and
- From 450°C to 550 °C: dehydroxylation of the portlandite (calcium hydroxide) takes place.
- 700–900 °C: decomposition of calcium carbonate.

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2.2 Limestone

Limestone is a sedimentary rock that is composed primarily of $CaCO_3$. It forms from both the chemical precipitation of calcium carbonate and the transformation of shell, coral and algal debris into calcite during diagenesis over several thousand years. Limestone is also formed as a deposit from the precipitation of calcium carbonate. Marble is a metamorphic rock that forms when limestone is subjected to heat and pressure. If it contains more than 95% of calcium carbonate it is referred to as high-calcium limestone or calcite (Boynton, 1980). When a considerable part of the calcium molecules is replaced by magnesium, it is known as magnesium limestone or dolomite limestone.

The physical and chemical properties of a typical limestone are presented in Table 2.1 (Boynton, 1980; Kesse 1985). It gives a hardness of 3 – 4 on the Moh"s scale and has a density of between 1800 and 2100 kg/mm^3. Chemically, it is composed mainly of CaO (38% - 42%), and SiO_2 (20% -25%).

2.2.1 Portland Limestone Cement (PLC)

Limestone is an important material for cement manufacture. The addition of limestone to Portland cement significantly improves several cement properties such as compressive strength, water demand, workability and durability. The addition of limestone increases the hydration rate of the clinker minerals.

Table 2.1: Properties of a typical limestone (Boynton, 1980)

Physical properties	Value
Hardness, Moh"s scale	3 – 4
Bulk density, kg/mm^3	2000 – 2800
Specific gravity	2.5 - 2.9
Compressive strength, N/mm^2	20 – 195
Shear strength, N/mm^2	4 – 20
Water absorption, %	< 1.0
Porosity, %	0.3 – 12
Weather Impact	Resistant
Chemical properties	
Lime (CaO) , %	38-42
Silica (SiO_2) , %	20-25
Alumina (Al_2O_3), %	2-4
Other Oxides like Na, Mg, %	1.5 to 2.5
Loss On Ignition, %	30-32

Several research studies have shown that limestone filler acts both as inert and active additive in the hydration of cement. It has been proven that there is interaction between calcium silicate and calcium carbonate ($CaCO_3$) and that calcium carboaluminate hydrates precipitate during hydration of cement containing $CaCO_3$ (Sprung and Siebel, 1990; Neto and Campiteli, 1990; Livesey, 1991; Bertrandyand Poitevin, 1991;Cochetand Sorrentino,1993; Pèra*et al,* 1999). The presence of limestone in Portland cement influences the rate and degree of cement hydration as well as the phase composition of hydrated cement paste. The addition of limestone increases the hydration rate of clinker minerals ($3CaO.SiO_2$ and $2CaO.SiO_2$). The acceleratory effect is more pronounced with increased content and greater fineness of limestone.The formation of ettringite is also enhanced but its tendency to transform to monosulphate is diminished (Klieger and Hooton, 1990; Hawkins, *et al* 2003). The monosulphate is further converted into a more stable monocarboaluminate; the remaining monosulphate reacts with the liberated SO_4^{2-} anions and ettringite is formed. Calcium silicate hydrate can include CO_3^{2-} anions in its structure and, consequently, calcium silicocarbonate hydrates form. Calcium carboaluminate hydrates usually form in cements that are rich in 3CaO; Al_2O_3 (Pèra*et al*, 1999; Sharma *and* Pandey,1999; Catinaud, *et al*2000; Kakali*et al* 2000; Bonavetti*et al,*2001;Rahhal and Talero,2005).

2.2.2 The effect of limestone addition on C_3A hydration

The presence of ground limestone affects the hydration of Portland cement. Kakali*et al.* (2000) found that $CaCO_3$ suppresses the conversion of Alumina Ferric oxide trisulphate (Aft) to Alumina Ferric oxide monosulphate (AFm) and reacts with C_3A to produce monocarbonate hydrate from the beginning in the $C_3A + CaCO_3$ system. According to Bonavetti*et al* (2001), in the $C_3A+CaCO_3+Ca(OH)_2+H_2O$ system, the phases of calcium tricaboaluminate and calcium hemicarboaluminate are observed, but no calcium tricaboaluminate is formed. In the $C_3A+CaCO_3+CaSO_4 \cdot 2H_2O+CH+H_2O$ system, Aft, AFm, calcium monocarboaluminate and calcium hemicarbonate hydroxide are the hydration products. Zhang *and Zhang* (2008) blended pure C_3A with 40% $CaSO_4.2H_2O$ (Sample A), 8% $CaCO_3$ + 32% $CaSO_4.2H_2O$ (Sample B), 24% $CaCO_3$ + 16% $CaSO_4.2H_2O$ (Sample C) and 40% $CaCO_3$ (Sample D). The isothermal

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calorimetrycurves showing the rate of heat development of pure C_3A blended with limestone are presented in Fig. 2.3.

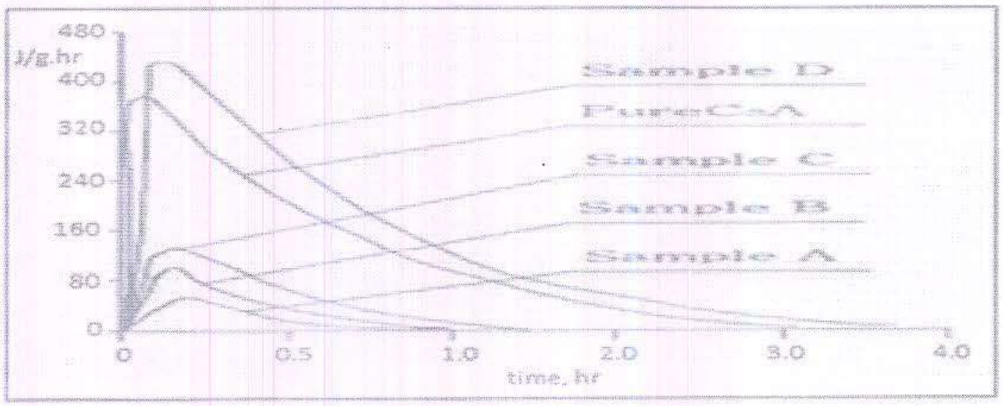

Figure 2.2: Rate of heat development of C_3A–$CaCO_3$– $CaSO_4 \cdot 2H2O$ paste (Zhang andZhang, 2008)

The maximum peaks of heat development and total heat resulting from samples A, B and C were lower than that of pure C_3A, with sample A giving the lowest value. However, values obtained for sample D were higher than those of C3A sample. The result indicated that hydration of C_3A was greatly stayed by gypsum $CaSO_4.2H_2O$), while $CaCO_3$ accelerated the hydration of C_3A. It therefore showed that $CaCO_3$ was an active player during hydration. However, the hydration was controlled when $CaSO_4 \cdot 2H_2O$ and $CaCO_3$ coexist. As shown in Fig. 2.4, there was only ettringite in the paste of sample A. In the paste of sample D, there were calcium aluminate oxide hydrate $3CaO.Al_2O_3.6H_2O$ and calcium aluminate monocarbonate $3CaO.Al_2O_3.CaCO_3 \cdot 11H_2O$. There were ettringite and $3CaO.Al_2O_3.CaCO_3 \cdot 11H_2O$ as products of sample C but $3CaO.Al_2O_3.6H_2O$ was not.

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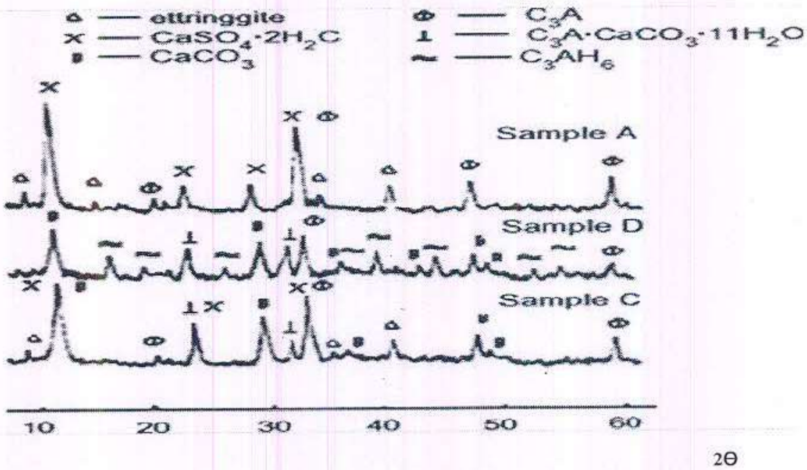

Figure 2.3: XRD patterns of $C_3A–CaCO_3–CaSO_4 \cdot 2H_2O$ pastes hydrated for 1day (Zhang andZhang, 2008)

2.2.3 The effect of limestone addition on C_3S hydration

Addition of $CaCO_3$ accelerates the hydration of C_3S and results in the formation of calcium carbosilicate hydrate (Pera*et al.* 1999; Kakali*et al,* 2000). Figure 2.5 presents the isothermal calorimetry curves showing the rate of heat development of pure C_3S blended with limestone powder at 5% (E), 10% (F) and 15% (G) (Zhang and Zhang, 2008).

Isothermal calorimeter curves (figure 2.6) show that the rate of the heat evolution of a blended system is always higher than that of pure C_3S system according to Zhang and Zhang (2008). The X-ray diffraction (XRD) study shows that the formation of calcium carbosilicate hydrate starts after 60 days. The above observations indicate that $CaCO_3$ not only modifies the hydration of C_3S, but also reacts with it to form calcium carbosilicate hydrate.

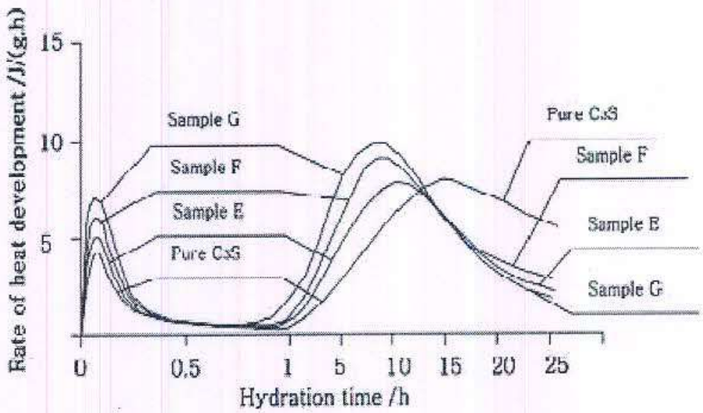

Figure 2.4: Typical heat evolution curves of Portland cement blended with limestone (Zhang and Zhang, 2008)

It shows that higher rates of heat development were obtained with higher $CaCO_3$ levels. The total heat resulting from pure C_3S was much less than that of blend samples by 15 hours. This means $CaCO_3$ cannot be considered as an inert addition when C_3S hydrates. It rather takes part in the hydration process.

2.2.4 Microstructure of Portland cement blended with Limestone

Apart from hydration acceleration of Portland clinker grains (especially the C_3S) at early ages, addition of milled limestone improves the particle packing of the cementitious system. It also provides new nucleation sites for formation of larger size of calcium hydroxide at early stage, and produces the formation of calcium carboaluminates as a result of the reaction between $CaCO_3$ from limestone and C_3A from Portland clinker (Soroka and Setter, 1977; Ramachandran, 1984; Cochetand Sorrentino, 1993). Fig. 2.6 shows the XRD patterns corresponding to the plain cement and limestone cement pastes. For the plain cement, the hydration products at one day were ettringite and calcium hydroxide from silicate hydration reactions. In the XRD pattern at 3 days, the ettringiteconversion to monosulphoaluminate was detected. This conversion implied a progressive increase of the monosulphoaluminate peak up to 90 days.

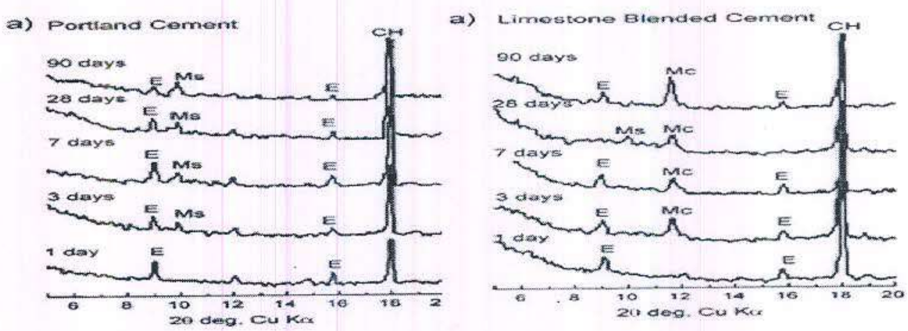

Figure 2.5: XRD patterns of hydrated Portland and blended limestone cement pastes (Soroka and Setter, 1977)
E=ettringite, Ms=monosulphoaluminate, Mc=monocarboaluminate and CC=calcium carbonate

This conversion implied a progressive increase of the monosulphoaluminate peak up to 90 days. Several XRD studies (Barker and Cory, 1991; Pèra,*et al,* 1999; Bonavetti*et al*, 2001; Voglis*et al*, 2005) indicated the formation of monocarboaluminate and calcium carbosilicate hydrate in the PC paste blended with limestone.

2.2.5 Properties of Portland Limestone Cement (PLC)

Several research works and experiments by reputable researchers the world over have adequately shown that PLC is a durable and good cement that can be used for all types of concrete construction works in both tropical and temperate regions. This cement has been used in Europe, especially France and Germany, since 1980 for all types of construction without any adverse effect (Pera*et al,* 1999). Portland limestone cement was introduced in Ghana in 2003 and has been the predominant type of cement used for construction.

2.2.5.1 Thermo and infrared analysis of cement

Zhang and Zhang(2008) studied the hydration of a C_3S blended with 10% by mass of calcium carbonate using Differential Thermal Analysis (DTA) and infrared analysis. The analyses were run from 28°C to 1000°C with a 10°C/min heating rate and 100 ml/min of air as the purge gas. Figure 2.7 presents thevarious endothermic peaks of phase changes of the Portland cement, pure $CaCO_3$ and PLC pastes. It shows that thedehydroxylation of the portlandite (calcium hydroxide) occurred at 487°C for C_3S as compared to 579°C for PLC. This gives the influence of $CaCO_3$ on cememt hydration.

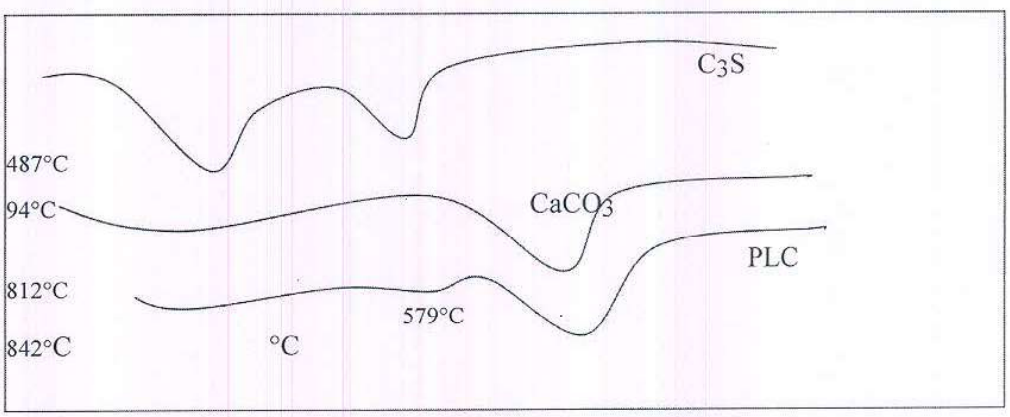

Figure. 2.6: DTA patterns of PLC paste compared with $CaCO_3$ and C_3S paste at 28 days (Zhang and Zhang, 2008).

The IR spectrum for blended cement (treated sample) was compared with that of $CaCO_3$ in Fig. 2.8. In the treated sample, all of characteristic bands of CO_3 ion appeared and new wave numbers at 525 cm^{-1}, 760 cm^{-1}, 1160 cm^{-1}, 1250 cm^{-1}, 1460 cm^{-1}, 24

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1540 cm^{-1}, 1600 cm^{-1} and 1620 cm^{-1} could be observed. That might mean other ions went into the structure of $CaCO_3$.

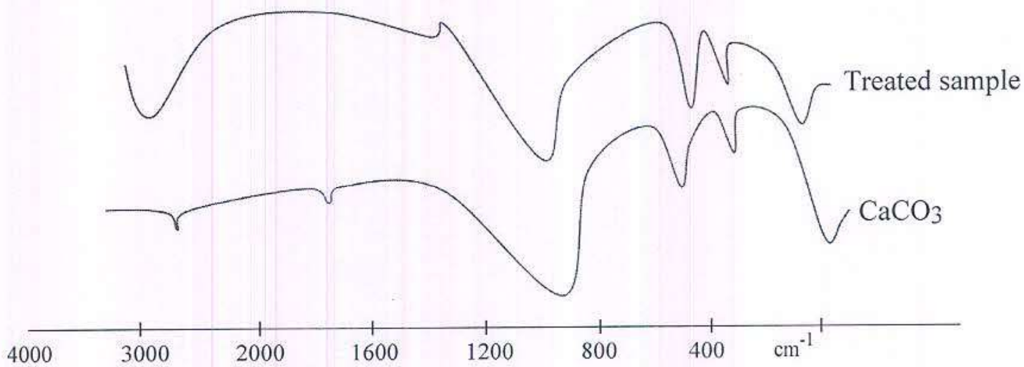

Figure. 2.7: Infrared spectra of PLC (treated sample) paste compared with $CaCO_3$ at 28 days (Zhang and Zhang, 2008).

2.2.5.2 Physical, Chemical and Mechanical Properties

Work by Tsivilis*et al* (2002) on PLC gave various results of its physical, chemical and mechanical properties. Their study involved the inter-grinding of clinker, limestone and gypsum in a laboratory using a ball mill. The limestone content ranged from 10% to 40%. The properties of the cements and other materials are shown in Tables 2.2- 2.4. The results of Tables 2.3 and 2.4 clearly show that addition of $CaCO_3$ to cement up to 35% give strengths suitable for general construction and concrete works. $CaCO_3$ content of 20% gives early higher strength than the reference cement. Even though strengths of the limestone cement concretes were lower than the reference they were above 25N/mm^{2}at 28 days.

Table 2.2: Chemical and mineralogical composition of clinker and limestone used (Tsiviliset al, 2002)

Oxide	Chemical Composition (%)		Composition	
	Cement	Limestone	Mineral compound	Cement (%)
SiO_2	21.96	0.55	C_3S	61.59
Al_2O_3	5.15	0.40	C_2S	16.48
Fe_2O_3	3.78	0.17	C_3A	7.27
CaO	65.95	53.47	C_4AF	11.50
MgO	1.76	1.02		
K_2O	0.56	0.03	Moduli	
Na_2O	0.12	0.01	LSF	94.20
SO_3	0.52	-	SR	2.46
LOI*	-	43.13	AR	1.36
			HM	2.14

**LOI – loss on ignition, LSF –lime saturation factor , SR – silica modulus, AR – alumina modulus, HM –hydraulic factor*

Table 2.3: Properties of Portland limestone cement mortar (Tsiviliset al,2002)

Sample	Limestone Content, %	Specific surface, (cm^2/g)	Compressive Strength, N/mm^2			
			1 day	2 days	7 days	28 days
C	0	2600	11.9	21.3	35.3	51.1
PLC1	10	3400	11.2	20.9	36.3	47.9
PLC2	15	3660	12.9	22.7	37.7	48.5
PLC3	20	4700	14.9	24.3	38.1	48.1
PLC4	35	5300	9.8	17	26.2	32.9

C – Reference cement; P LC1..4 – Portland limestone cement

Table 2.4: Properties of Portland limestone cement concretes (Tsiviliset al,2002)

Sample	Slump mm	Flow mm	Unit weight kg/m^3	Compressive strength, N/mm^2	
				7 days	28 days
C	130	460	2400	26.7	31.9
PLC1	120	440	2395	21.9	27.4
PLC2	120	420	2400	22.5	27.3
PLC3	110	420	2394	22.1	28.0
PLC4	110	400	2390	21.6	26.6

C – Reference cement; P LC1..4 –Portland limestone cement

2.3 Clam shells

Clam shells are purer form of $CaCO_3$in Ghana than limestone (<49%) containing more than 50% of lime (CaO) on heating above 800°C. They are usually found on river beds as fresh type of shell fish or empty shells after thousand years of accumulation (Kesse, 1985). Table 2.5 shows clam shells found in Ghana and their average chemical composition respectively.

Table 2.5: Average Chemical Analysis of Clam Shells (Atiemo, 1997)

Chemical Composition	Clam Shells, wt%
CaO	53.4
SiO_2	2.1
Fe_2O_3	0.5
Al_2O_3	0.3
MgO	0.6
Loss on ignition	43.4

2.3.1 Properties of Clam shell-filled cement

Atiemo (1997) studied the suitability of clam shells as filler in Class 32.5 ordinary Portland cement for masonry works. The masonry cement was prepared by first blending ordinary Portland cement with the ground clam shells. The percentage by mass of the filler in the masonry cement varied from 10% to 40%. The study was carried out on 1:3 and 1:5 cement to sand mortar mixes as stipulated by EN 196-2 and BS 4551 respectively. Table 2.6 gives the mortar mix designs whilst results of the compressive strength tests of the composite and masonry cements containing 10%-40% by mass of ground clam shells are given in Table 2.7. Each strength value represents an average of 5 cubes.

The 28-day compressive strength of the masonry cement with up to 25% filler content was higher than the minimum standard value of 3.6N/mm^2 for type (iii) mortar stipulated by BS:5628-2.It is also observed that the compressive strength of the mortar cubes increased in all cases with time. The compressive strengths of the 1:5 mortarss with 10% filler content were higher than that of the control at all times. This is attributed to the accelerated rate of hydration with the filler serving as the crystallization nuclei (Soroka andSetter 1977). The strength, however, decreased with increased percentage of filler content, always below that of the control. This is expected because the excess filler material rather acted as a dilutant thus affecting the strength of the mortar eventually. Fig. 2.9 gives the 28-day compressive strengths of the masonry cement with up to 40% clam shells content as compared to the minimum strength of 3.6N/mm^2.

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Table 2.6: Mix design of cement mortar mixes (Atiemo, 1997, 1998)

Specimen	Cement, g	Clam shells, g	Sand, g	Water:binder ratio
Control (C)	300	-	900	0.4
M1	270	30	900	0.4
M2	240	60	900	0.4
MS1	180	20	1000	0.9
MS2	160	40	1000	0.9

M1,M2,MS1,MS2 – blended cement containing clam shells; C – reference cement

Table 2.7: Compressive strengths of clam shell cement mortar mixes (Atiemo, 1997, 1998)

Sample	$CaCO_3$ Content, %	mortar mix	Compressive Strength N/mm^2			
			3days	7 days	28 days	42 days
M0	0	1:3	8.7	20.5	31.6	39.4
M1	10	'	8.6	19.8	31.3	38.7
M2	20	"	7.6	16.5	22.4	28.4
M3	25	"	7.1	12.3	19.6	25.7
M4	30	"	5.9	9.0	17.8	23.9
M5	40	"	4.5	7.8	12.5	18.7
MS0	0	1:5	2.8	3.0	7.0	10.6
MS1	10	"	3.0	3.2	7.2	11.8
MS2	20	"	2.7	2.9	5.2	8.3
MS3	25	"	2.1	2.3	4.2	6.8
MS4	30	"	2.1	2.1	3.1	5.9
MS5	40	"	1.0	1.2	2.2	4.3

M0,MS0 = OPC; M1 ... M.5,MS1 .... MS5= blended cement containing clam shell

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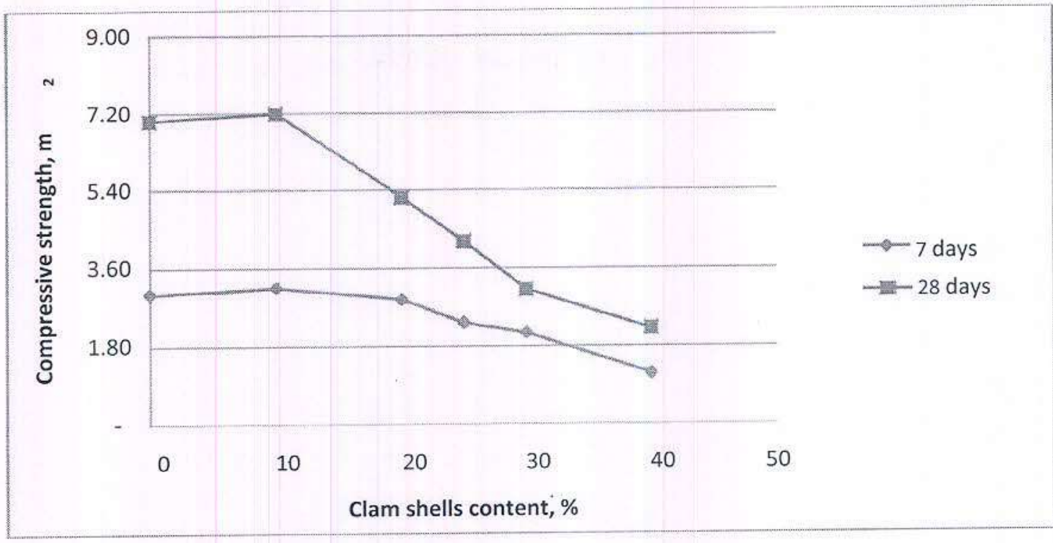


Figure 2.8: Compressive strength of 1:5 cement mortars containing clam shells

It is noted from the graph that the 28-day compressive strengths of the masonry cement mortar cubes containing up to 25% clam shells filler produced strengths above 3.6 N/mm^2 as specified for type (iii) mortars and plasters (BS 4551).

From the various tests and analysis, it has been shown that ground clam shells can be used as filler up to 25% by mass for the production of masonry cement. The 28-day compressive strength of mortar cubes of the masonry cement containing up to 25% of ground clam shells as filler was higher than the standard value of 3.6N/mm^2. Therefore, the masonry cement can be used to bond and render hollow and solid sandcrete blocks for housing construction.

2.4 Steel Slag

Steel slag (SS) is an industrial waste resulting from the steel refining process in a conversion furnace. An estimated fifty million (50) tonnes steel slag are produced in the world and nearly 12 million tons in Europe annually as residue. Owing to the 30 intensive research work in the past 30 years, about 60% of the steel slag is currently used in fields of technological application. The remaining 35% of these slags are still dumped as waste (Wu *et al,* 1999; Tsakiridis*et al*, 2008).

In Ghana, steel slag waste is produced by four main steel companies; namely, Western Casting and Forming Company, Wahome Steel Works, Tema Steel Works and Ferro Fabric Co. Ltd., all based in Tema. An estimated 5,000 tonnes of slag are dumped as waste every year for the past 20 years.

The chemical composition of a typical steel slag is given in Table 2.8. It consists mainly of calcium oxide, iron oxide, silica and aluminium oxide, which constitute more than 70% of the material.

Table 2.8: Chemical composition of a typical steel slag (Tsakiridis*et al*, 2008)

Chemical compound	Percentage, %
CaO	45–60
SiO_2	10–15
Al_2O_3	1–5
Fe_2O_3	3–9
FeO	7–20
MgO	3–13
P_2O_5	4

The common mineral compositions of steel slag, among others, include C_3S, C_2S, C_4AF, C_2F, RO phase (a solid solution of MgO, FeO, and MnO), olivine and free lime (Tsakiridis*et al*, 2008). Steel Slag could be classified into four groups such as the olivine group, merwinite group (A =1.4–.6), dicalcium silicate group (A=1.6–2.4), and tricalcium silicate group (A = 2.4); where A (Alkalinity) is calculated as:

$$A = \frac{CaO + MgO + Al_2O_3}{SiO_2} \qquad 2.7$$

The presence of C_3S, C_2S, C_4AF and C_2F generates the cementitious properties of steel slag. However, the C_3S content in steel slag is much lower than in Portland cement. Slag cement also contains amorphous silica (S) which reacts with calcium hydroxide (CH) to form additional C–S–H thereby improving strength (Eqn. 2.8).

$$3Ca(OH)_2 + 2SiO_2 + H_2O = 3CaO.2SiO_2.4H_2O \qquad 2.8$$

Slag cement is not only pozzolanic but is also hydraulic, meaning the slag cement will hydrate when mixed with water (Hale *et al*,2008).

Thus, steel slag can be regarded as a weak Portland cement clinker and can be used as partial substitution for clinker to produce composite Portland cement (CPC). Steel slag cement can be used for general construction purposes, and it is especially suitable for mass concrete and pavement applications due to its special features. This type of cement has the advantages of lower energy cost, higher abrasion resistance, lower hydration heat evolution and higher latter strength development. Its usage also reduces greenhouse and noxious gases such as CO_2, SO_2, NO_xetc because of replacement of clinker. Furthermore, steel slag is used as asphalt concrete aggregate in some countries (Daimon, 1980; Mehta, P.K., 1981; Tüfekçi*et al* 1997; Dongue*et al* 1997; Tsakiridis*et al*, 2008). Studies by Tüfekçi (1997) show that the mineralogical phases of a typical steel slag produced by steel plants, and determined by X-ray diffraction (XRD) are belite, alite, ferrite, wustite, quartz, periclase, (Fig. 2.10).

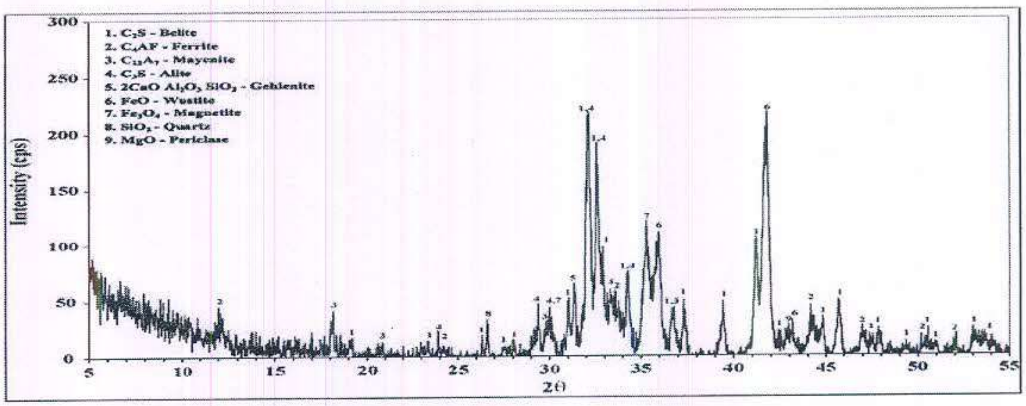


Fig. 2.9: X-ray diffraction of a typical steel slag (Tüfekçi*et al,* 1997)

The main problem with using steel slag in civil engineering works is the possible presence of free lime, especially large-sized components of heated undissolved limestone. When the free lime hydrates it is converted to $Ca(OH)_2$, its volume increases causing swelling so its presence in cement affects the quality of concretes. However, steel slag cement, which is composed mainly of steel slag, blast furnace slag and cement minerals (C_3S, C_2S etc.), has been commercially produced and marketed in China for more than 20 years. It uses approximately 40% of the total steel slag production in China. Blended cements comprising mainly of OPC with mixture components of slag and other admixtures as cheap raw materials have gained recognition for low porosity which imparts high ultimate compressive strength (Tüfekçi*et al* 1997; Dongue*et al* 1997).

Steel slag cement has the disadvantage of longer setting time and lower early strength when compared with ordinary Portland cement. But these are compensated by the addition of other admixtures and usage of high-strength cement or high quality clinker and higher fineness.

Today, most metallurgical steel slags are used as aggregates for different applications, and only the ground granulated blast furnace slag is used for a partial Portland cement replacement. It also improves the microstructure and durability of hardened Portland cement and concrete very significantly. Existing literature has given little attention to the use of steel slag in combination with other admixtures like pozzolana and clam shells in the raw meal for the production of Portland cement.

2.4.1 Properties of Steel Slag Cement

2.4.1.1 Hydration of steel slag cement

The hydration of steel slag is basically the dissolution of the silicate chain structure and aluminate in the slag by hydroxyl attack. For the slag to continue hydrating, Ca^{2+} and OH^- from the slag are not enough, so an external supply becomes necessary. In low water/cement concrete, the supply of external OH- is drastically diminished. The elution of selective ions istherefore delayed; the reaction rim only begins to be visible from theseventh day of hydration. Ettringite crystal formation in the early stages of ordinary slag hydration in concrete acts as a binder, resulting in the higher strength. A number of researchers have observedettringite (AFt) rods on slag particles during their initial hydration. In concrete with low lime slag, ettringite may be lower (Daimon, 1980; Mehta, 1981; Cook *et al*, 1987; Kourounis*et al,* 2007).

Kourouniset *al* (2007) studied the hydration products of steel slag cements mineralogically by x-ray diffraction. The cement pastes were cured in tap water at 20 $\pm 2°C$ and observed at 2,7,28 and 90 days. Fig. 2.11 shows the X-ray diffraction patterns of cement with 15% steel slag hydrated for 1, 2, 7, 28 and 90 days. It can be seen that the main hydration products were calcium silicate hydrates ($CaSiO_2.H_2OH$), calcium hydroxide ($Ca(OH)_2$) and ettringite ($6CaO.Al_2O_3.3CaSO_4.32H_2O$) as well as unhydrated C_3S and C_2S. The peaks of the calcium silicates phases diminished, especially at the age of 90 days.

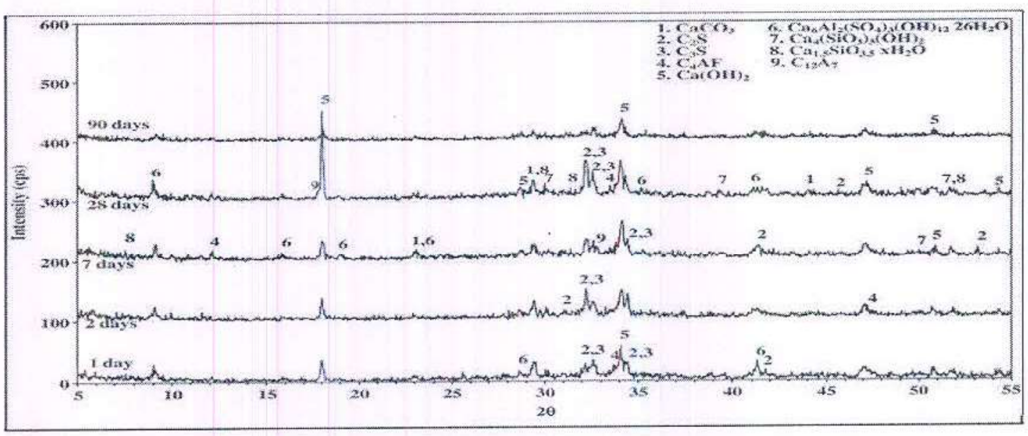
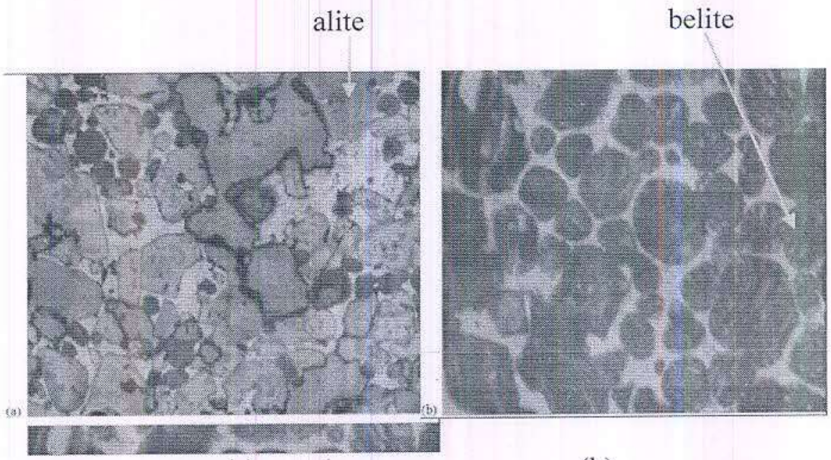


Figure 2.10: X-ray diffraction of cement with 15% steel slag, hydrated at various ages (Kourouniset *al*, 2007).

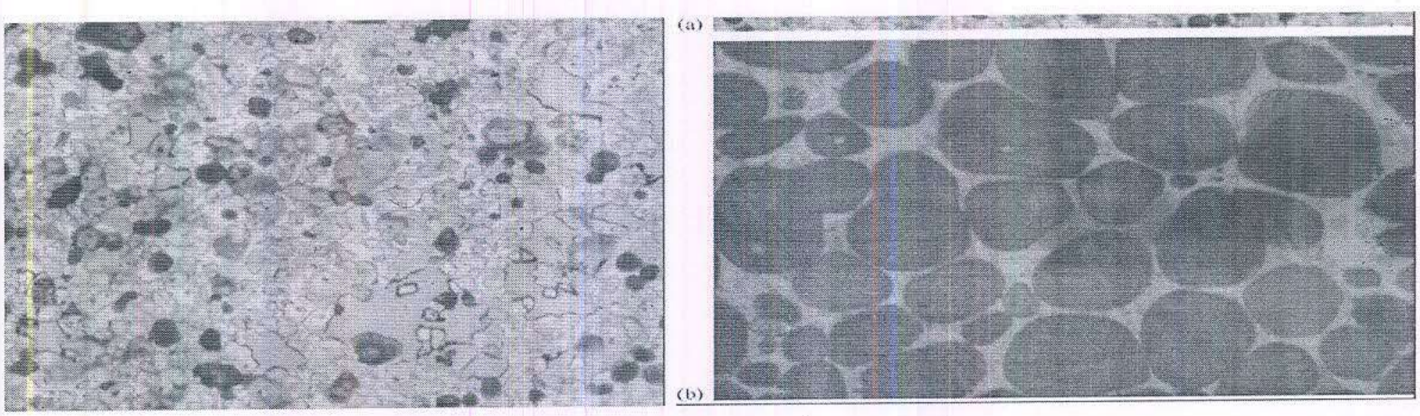
2.4.2 Microstructure of steel slag cement

The microstructure of the ordinary Portland cement (oPc) clinkers and steel slag cement (SSC) were also examined by optical microscopy in polished sections by Tsakiridiset *al* (2008). The addition of the steel slag by 10.5% did not seem to affect its microstructure and the formation of its characteristic mineralogical phases (Figs. 2.12 and 2.13). Both clinkers contained more or less euhedralalite and they exhibited coalescence of alite crystals. The alite crystals appeared well formed, with average size 40μm, whereas no decomposition of C_3S was observed. In the optical microscope, belite was observed as bluish or brownish rounded crystals, rich in lamellas. No differences in the microstructure of belite between Portland cement and steel slag cement clinkers were detected. In both cases, the brownish belite crystals were evenly distributed in relation to alite. Finally, the liquid phase solidified as uniformly distributed fine crystals (Tsakiridis*et al*, 2008).



(a) (b)

Figure 2.11: Microstructure of Portland cement clinker without steel slag.
(a) Large alite crystals (500x). (b) brownish rounded belite crystals (500x).



(a) (b)

Figure 2.12: Microstructure of Portland cement clinker with steel slag
(a) alite crystals (500x). (b) brownish rounded belite crystals (500x) (Tsakiridis*et al,* 2008)].

2.4.3 Physical, Chemical and Mechanical properties of steel slag cement

Tüfekçi*et al* (1997) also undertook a research study on steel slag for cement production. Portland cement (PC) was blended with 5% and 10% of two industrial steel slag samples, named A and B respectively. The chemical compositions of the steel slag samples and their blends with cement are given in Table 2.9. The mechanical properties of the slag cement mortars and pastes are also given in Table 2.10. It shows that the steel slag cement blends required less water than that of the control. Also, both blended cements gave strengths higher than 41.0MPa at 28 days. The results also show that the slag cements initially set slowly comparatively but set finally before the oPc. The setting times of the slag cements were higher than the control but within the standard limits of EN 197-1 (2000).

Table 2.9: Chemical compositions of SS-A and SS-B and their mixtures (Tüfekçi*et al,* 1997)

	Composition, %						
Material	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	LOI*
Control (oPc)	22.82	5.28	5.85	62.95	1.45	1.05	0.60
Steel slag, A	41.39	31.39	3.58	4.22	0.66	0.20	18.46
Steel slag, B	57.48	33.73	2.19	1.53	0.47	0.14	2.39
10%A+ 90%oPc	24.67	6.78	5.63	57.08	1.44	1.04	3.25
5%A + 95%oPc	23.75	6.09	5.75	60.01	1.41	1.03	0.97
10%B + 90%oPc	26.22	8.14	5.49	56.83	1.37	0.95	0.90
5%B + 95%oPc	24.55	6.70	5.67	59.97	1.40	0.98	0.73

*LOI – Loss on ignition

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Table 2.10: Results of Cement Mortar Tests (Tüfekçi*et al,* 1997)

Cement Sample	Slag Content %	Compressive strength, MPa			Expansion Mm	Water Demand %	Setting time, Min	
		2days	7days	28days			Initial	Final
oPc	0	26.2	34.8	45.4	10	100	60	600
Cement A	10	22.9	31.0	41.3	9	98	185	255
Cement B	5	25.5	33.5	44.5	4	96	180	255

The aggregate data and compressive strength test results, performed according to Turkish standard, for concretes compared to the control mix are summarized in Table 2.11. It indicates that the compressive strength of the concrete with cement mix of 10% SS-Al + 90%C increases slowly when compared with 5% SS-B1 + 95% C mortar mix. This is due to the 5% higher replacement of cement by a less reactive material. In all cases, slag b cements performed better than that of slag A.

It shows that slag cements have lower early strength, which is attributable to the slow growth of calcium silicate hydrates gel. In the case of very high-strength concrete, however, this is compensated by the density of the solid body.

The chemical, physical and mechanical properties of slag blended cement were also researched by Wu *et al* (1999). In this case clinker, steel slag (SS), fly ash (FA) and gypsum were ground together to the fineness of 2-4% of the residue on a 0.08mm standard sieve to produce the desired cement. The total amount of SS and FA was 50%, and the amount of SS and FA was fixed at 30 and 20% respectively. The slag contained mainly CaO (48.2%) whilst FA consists of 48.5% silica.The mix compositions for the control cement (C) and blended slag cement with varying quantities of slag, fly ash and gypsum (M1 to M4) as well as the mechanical properties are shown in Table 2.12. The results obtained showed that all the specimens of slag blended cement could reach the required strength grade of 42.5N. The flexural strengths for the control and blended cements were almost the same as the control. The setting time was, however, relatively long for the requirement of construction work, which may be related to the low-alumina content (2.58%) of steel slag. The results showed that the admixtures gave strengths that satisfy standard specifications for Class 42.5N cement (EN 197-1).

The afore-mentioned extensive studies really show that steel slag has the potential as ingredient in cement production in Ghana; it is already being utilized in China and other countries as pozzolana. This makes a serious case for the evaluation of steel slag waste obtained in Ghana for cement production and usage for construction. The added advantages include reducing cost of cement, elimination of environmental degradation and greenhouse effects. About 5000 tonnes of steel slag waste are produced annually in Ghana.

2.5 Clay Pozzolana

Pozzolanas are defined as siliceous and aluminous substances which are by themselves not cementitious but in their finely-divided form react with lime in the presence of water at ordinary temperature to produce hydraulic compounds. They occur naturally or are produced artificially. Natural pozzolanas are materials which in their natural state and finely-divided form react with lime to produce hydraulic compounds. They are mainly produced from volcanic matter and are described as incoherent pyroclastic materials.

Table 2.11: Test Results for Concretes from Cement and Slag Mixtures (Tüfekçi*et al,* 1997)

Materials (g)						Expansion	Compressive strength (MPa)			
Cement	Slag A	Slag B	Sand	Crushed stone	Water	mm	1 day	7 days	28 days	56 days
410	0	0	1215	1540	260	10.7	26.3	32.9	35.6	38.7
390	21	-	1210	1520	250	8.9	19.1	26.7	28.0	30.5
370	42	-	1210	1530	240	7.9	22.1	28.7	30.0	34.5
350	60	-	1212	1520	232	7.3	19.1	26.7	28.6	30.9
390	-	21	1213	1522	245	9.9	25.2	31.7	34.9	37.6
370	-	42	1210	1525	235	9.7	24.8	30.9	33.7	37.0
350	-	60	1212	1530	225	9.4	24.2	30.1	32.8	36.7

Table 2.12: Properties of slag blended cement mortar (Wu *et al*, 1999)

Specimen	Clinker	Steel slag	Fly Ash	Gypsum	Setting time, Min		Compressive strength MPa			Flexural strength		
	Content, %				Initial	final	3days	7 days	28 days	3 days	7 days	28 days
Control	93	-	-	7	100	145	23.4	39.6	51.6	4.7	7.0	8.4
M1	47	30	20	3	285	366	20.5	27.5	43.8	4.3	5.8	7.4
M2	46	30	20	4	254	333	21.4	29.0	44.2	4.3	5.9	8.1
M3	45	30	20	5	206	359	20.8	28.5	44.7	4.4	5.7	8.0
M4	44	30	20	6	193	293	20.8	28.5	45.9	4.4	5.9	8.2

The chemical compositions of the natural Italian pozzolanas are related to that of magma. Examples are Italian pozzuolli, tuff, trass, pumicite and diatomaceous earth (Lea, 1970). Artificial pozzolanas are materials that have to undergo heat treatment before they become pozzolanic. Examples are clays, fly ash, blast furnace slag, bauxite waste, shales and spent oil.

2.5.1 Clays and Clay Minerals

Clay is defined as a fine-grained earthy material which contains clay minerals and is plastic and cohesive (Ayetey,1977; BS.1377:1990). Clays differ mineralogically and chemically, and consequently in their physical properties. They shrink when dry and expand when wet and show gains in strength with retention of shape on firing.

Clay minerals are very tiny crystalline substances that are evolved primarily from chemical weathering of certain rock-forming minerals. Chemically, they are made up of hydrous alumino-silicates and other metallic ions. They are either the two-layer sheet (kaolinite) or the three-layer sheet (montmorillonite) in which silicon and aluminium ions have tetrahedral coordination with respect to oxygen while aluminium, magnesium, iron ions and other ions have octahedral coordination with oxygen or hydroxyl ions as shown in Figs 2.14 and 2.15 (Grim, 1962; Holtz and Kovacs, 1981)

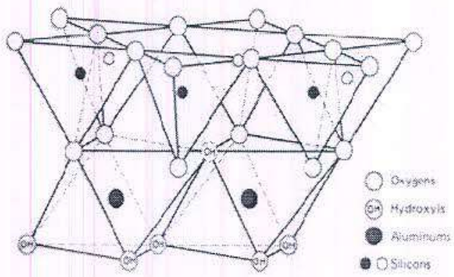

Figure 2.13: Atomic structure of kaolinite (Holtz and Kovacs, 1981)

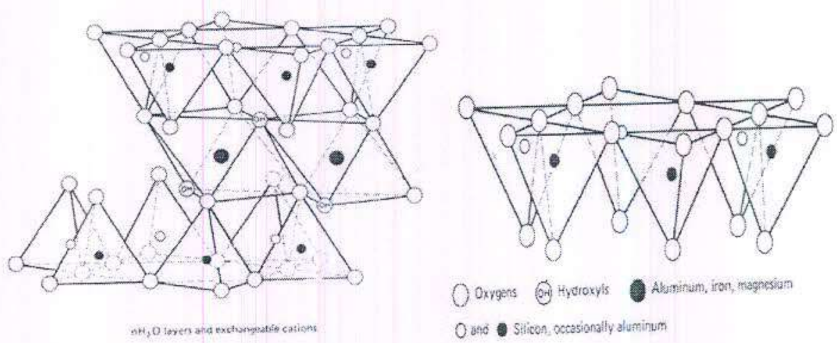

Figure 2.14: Atomic structure of montmorillonite(Holtz and Kovacs, 1981)

All clay minerals are very small, colloidal-sized crystals (diameter less than 2 μm), and they can only be seen with an electron microscope The particular way in which these sheets are stacked, together with different bonding and different metallic ions in the crystal lattice, constitute the different clay minerals.

Table 2.13 presents the physical and chemical composition of three samples of clay in Ghana (Atiemo, 2005). It shows that the clay samples contain mainly silica (>60%). The clay contents, with particle size of <2μm, range between 27% and 39.0%.

The pozzolanic activity of clays depends on the type of clay minerals present in the clay which in turn control the chemical composition (Millienz*et al*, 1949). The crystalline clay minerals in their natural state are stable, non-reactive and thus non-pozzolanic. However, imperfections in the crystal structure due to disorderliness and huge internal strains lead to high reactivity. This desirable condition is achieved by calcining and milling the clay beyond 600°C (Uppal and Singh, 1964).

Table 2.13: Properties of three clay deposits in Ghana (Atiemo, 2005)

Property	Mankranso	Mfensi	Bibiani
Physical			
Specific gravity	2.58	2.64	2.58
Plastic limit, %	42.80	43.50	44.45
Liquid limit, %	75.00	78.00	24.48
Plasticity Index, %	37.2	34.5	20
Clay, %	36.0	39.0	27.1
Silt, %	35.0	32.0	52.6
Sand, %	29.0	31.0	20.3
Chemical			
SiO_2, %	69.8	60.3	67.6
Al_2O_3, %	15.70	18.2	16.3
Fe_2O_3, %	4.60	9.1	4.4
CaO, %	0.20	1.2	0.7
MgO, %	0.10	-	0.1
SO_3, %	0.02	0.1	0.04
Loss on ignition	5.30	4.5	4.8

2.5.2 Calcination of Clays and Pozzolannic Activity

Calcination of clays is an important process in the development of satisfactory pozzolanic properties. The pozzolanic reactivity is induced by the destruction of the clay minerals: kaolinite [$Al_2(Si_2O_5)(OH)_4$], montmorillonite [$Al_2(OH)_2Si_4O_{10}).nH_2O$], and illite $K_2O_3Al_2O_36SiO_2.3H_2O$.]. On heating, clay first loses free water at 100°C - 150°C, and from 150°C to 500°C it further loses water that is adsorbed on or between lattice planes of the lattice structure. Disintegration of the lattice structure occurs between 550°C and 650°Cwith the liberation of H^+ and OH^- ions producing amorphous aluminous and siliceous compound called meta-kaolinite. All these reactions are endothermic. The rate of loss of water becomes high as the temperature rises to 650°C. Dehydration is complete at 750°C (Nutting, 1943; Millienz*et al,* 1949, Uppaland Singh, 1964).

The structure is completely disrupted between 800°C - 980°C. Between 940°C and 980°C an exothermic reaction occurs. Mullite ($2Al_2O_3.3SiO_2$) appears at around 950°C for kaolinite, 1050°C for montmorillite and 1100°C for illites. The optimum calcination temperature for kaolinitic and montmorillonitic clays for maximum pozzolanic reactivity is between 600°C and 800°C, and 900°C for illites (Millienz *et al,* 1949, IS:1344). Kaolinite loses more than 14% of its mass on complete calcination whilst typical montmorillonites and illites lose 5 and 10% of their mass respectively. When the crystalline structure of the clay is ruptured they release siliceous and aluminous compounds and become very unstable and chemically active.

2.5.3 Clay Pozzolanic Action

During hydration of cement, hydrated silicates formed remain stable in contact with lime solution and in the presence of water undergo hydrolysis liberating more lime into the solution (Lea, 1970). The silicate compositions of cement minerals contribute mainly to the structural and strength properties of cement products. They form about 70% of the bulk of cement. The presence of pozzolana active components reduce the amount of free $Ca(OH)_2$ in cement products considerably. The unstable but reactive siliceous and aluminous compounds of the calcined clay react chemically with the lime producing mostly hydrated silicates of low solubility as given in a simplified form in Equations 2.9 and 2.10.

$$2SiO_2 + 3Ca(OH)_2 = 3CaO.2SiO_2.3H_2O \qquad 2.9$$

$$3Al_2O_3 + 3SiO_2 + 6Ca(OH)_2 = 3CaO.Al_2O_3.3\,SiO_2.32H_2O \qquad 2.10$$

The products from the pozzolanic reaction add up to the strength of cement products and enhance water-tightness. Extensive studies as well as X-ray diffraction evidence show that pozzolanic reactions are by direct combination of lime and the pozzolana compounds and not by ion exchange (Lea, 1970).Studies on the effect of alumina in pozzolana proved that the presence of alumina in the pozzolana enhances the strength properties of pozzolana cement, particularly during brief curing (Murakami, 1952). They react with lime to form compounds which are very complex. The effects of iron oxide in clay pozzolana were also studied by other researchers. Comparing two clay types which were montmorillonite, Gippsand Britton (1960) observed that the red and yellow clays which contained large amounts of free Fe_2O_3 were more pozzolanically reactive than the black cotton soils, which did not have free Fe_2O_3,even though the black soils contain more clay minerals and have higher silica content.

2.5.4 Mechanical Properties of clay Pozzolana cement

Studies on the pozzolanic activity of some clay samples in Ghana for housing construction have been carried out recently in Ghana (Atiemo, 2005; Momade and Atiemo, 2004). Some of the results are presented in Table 2.14. The studies showed that pozzolana cements absorb more water in the preparation of the paste as compared to ordinary Portland cement and the water demand increased in all cases as the replacement of cement was increased. However, the setting times (initial and final) of the pozzolana cements were lower than that of ordinary Portland cement and decrease with increasing amount of pozzolana.

The results also showed that the 28-day compressive strengths of the pozzolana cement mortars up to 30% pozzolana content satisfied the class 32.5 cement as recommended by EN 197-1 (2000) for concrete works and general construction. The Mfensi samples gave the highest strength values in all cases. Generally, the strengths reduce with increasing amount of pozzolana. The study concluded that the clay pozzolana cements are suitable for both concrete and general construction with 25 -30% clay pozzolana content.

Wild *et al* (1997) also reported on pozzolanic properties of selected burnt brick samples produced from clays from four European countries. Clay bricks are burnt at between 800↑8C and 900°C. The bricks were ground in a ball mill and the brick powder samples were used as partial cement replacement materials (at replacement levels of 10%, 20%, 30% by mass) to prepare mortars. The water/binder (w/b) ratio of 0.4 and the sand to binder (cement plus ground brick) ratio was kept constant at 2.5:1. The average values of compressive strength together with the standard deviations are reported in Table 2.15. The values obtained at 20% were comparable to that of oPc (control).

Table 2.14: Mechanical properties of pozzolana cement mortar (Momade and Atiemo, 2004)

Sample	Cement Content, %	Pozzolana Content, %	Water, Demand, %	Setting time, min		Water Absorption,%	Compressive strength, N/mm^2		
				Initial	Final		3 days	7 days	28 days
Control	100	0	36.9	108	275	2.1	24.9	36.8	40.2
Bibiani	80	20	37.5	98	265	2.3	21.8	35.2	38.8
	75	25	39.0	92	225	2.1	19.5	31.8	35.6
	70	30	-	-	-	2.1	16.9	25.3	33.5
	60	40	-	-	-	1.85	12.6	22.6	27.1
Mfensi	80	20	38.2	102	250	2.2	23.6	35.5	39.8
	75	25	39.6	90	210	2.2	22.6	33.3	36.8
	70	30	-	-	-	2.0	21.3	27.8	34.1
	60	40	-	-	-	1.8	16.8	23.5	28.8
Wenchi	80	20	38.7	86	241	2.5	22.8	34.1	44.3
	75	25	40.1	75	194	2.3	20.4	31.4	40.8
	70	30	-	-	-	2.2	18.9	28.4	36.8
	60	40	-	-	-	2.4	16.6	24.8	31.3

Table 2.15. Average values of compressive strength for mortar mixes (Wild *et al*, 1997)

Sample	Pozzolana Content, %	Compressive strength, N/mm^2		
		7 days	28 days	90 days
Control	0	51.5 $\pm$ 2.5	60.5$\pm$ 2.9	65.6 $\pm$1.6
Brick B	10	48.3 $\pm$ 202	61.6 $\pm$2.5	66.3 $\pm$3.8
	20	42.8 $\pm$ 4.2	58.3 $\pm$ 3.6	67.5 $\pm$2.1
	30	38.4 $\pm$ 2.5	56.0 $\pm$ 1.3	64.9 $\pm$1.9
Brick D	10	48.5 $\pm$ 1.2	58.0 $\pm$ 2.8	64.1 $\pm$2.5
	20	48.0 $\pm$ 1.3	54.6 $\pm$ 0.9	63.9 $\pm$2.9
	30	42.3 $\pm$ 0.6	51.8 $\pm$ 1.6	59.2 $\pm$1.9
Brick L	10	47.5 $\pm$ 3.4	56.9 $\pm$ 2.0	60.4 $\pm$1.8
	20	43.4 $\pm$ 3.5	51.8 $\pm$ 4.5	55.6 $\pm$2.9
	30	38.7$\pm$ 1.6	50.0 $\pm$ 3.7	49.5 $\pm$2.0
Brick P	10	51.3 $\pm$1.7	64.7 $\pm$ 3.5	67.8 $\pm$3.0
	20	47.5 $\pm$1.1	57.8 $\pm$ 3.5	64.1 $\pm$1.2
	30	37.7 $\pm$ 2.9	56.1 $\pm$ 3.1	60.8 $\pm$1.2

CHAPTER THREE

MATERIALS

The materials used for this study were all obtained in Ghana. The limestone deposit is located at Oterkpolu in the Eastern region, the clam shells at DoforGbokpor in the Volta region, clay from Mankranso in the Ashanti region, and steel slag was obtained from Wahome Steel works in Tema in the Greater-Accra region. The other materials included CEM I Portland cement (Class 42.5N), crushed granitic aggregates, and river pit sand used locally for constructional works. The physical properties and chemical composition of the materials were determined during the study.

3.1 Oterkpolu limestone

The limestone deposit is located about 6.5 kilometers east of Oterkpolu village, which is about 25km from Koforidua, in the Eastern region of Ghana. It occurs within the arenaceous rocks of the Lower Voltaian range. The limestone is overlain by brown sandstone containing small iron-rich concretions which weather out to give a characteristically pitted surface with a purplish coloured transition zone at the base of the limestone. The rocks dip eastward into the hillside at angles from 20^{0} and beyond, however, local variations may occur due to folding. Several investigations by the Ghana Geological Survey have estimated reserves of limestone at Oterkpolu to be over 3.7 million tonnes(Kesse, 1985).The limestone is grey in colour with a specific gravity of 2.76 as indicated in Table 3.1,The chemical composition of the limestone, determined during the study, contains about 42% CaO (indicating a $CaCO_3$ content of about 74.7%), 17% SiO_2 and 6.5% Fe_2O_3, as shown in Table 3.2.X-ray diffraction pattern of Oterkpolu limestone (Fig. 3.1) shows that the limestone consists mainly of calcite ($CaCO_3$),the essential mineral needed for hydration effect on cement (Hawkins, 2003), and quartz.

Table 3.1: Physical Properties of Materials

Property	Reference cement	Limestone	Clam shells	Steel slag	Mankranso Clay	Pozzolana
Colour	Grey	grey	white	deep grey	Yellow	Red
Specific Gravity	3.16	2.76	2.82	2.85	2.64	2.59
Particle size of milled admixtures, %						
<0.002 mm		-	-	-	32	35
0.002 – 0.06 mm		76	85	30	30	62
0.05 mm – 0.6 mm		20	14	70	38	3

Table 3.2: Chemical composition of Materials

Chemical compound	Reference cement	Limestone	Steel slag	Clam shells	Clay	Clay Pozzolana
SiO_2	18.80	17.27	21.31	2.10	59.95	62.08
Al_2O_3	3.57	0.03	7.50	0.25	0.82	7.23
Fe_2O_3	4.36	4.58	31.52	0.50	6.51	9.96
MgO	1.89	0.05	7.61	0.60	1.30	0.31
CaO	57.04	41.97	12.44	52.41	0.14	5.01
Na_2O	4.78	1.20	4.30	0.77	1.60	1.70
K_2O	4.43	2.58	1.03	1.68	1.29	1.92
MnO	0.14	0.07	5.29	0.06	0.12	0.02
TiO_2	0.16	1.05	0.05	0.16	1.05	0.10
P_2O_5	0.22	0.04	1.20	0.05	0.23	1.66
Cl	0.01	0.01	0.00	0.01	0.01	0.21
SO_3	0.85	0.24	0.26	0.35	0.07	0.30
LOI	3.60	31.00	7.50	41.07	26.00	9.50

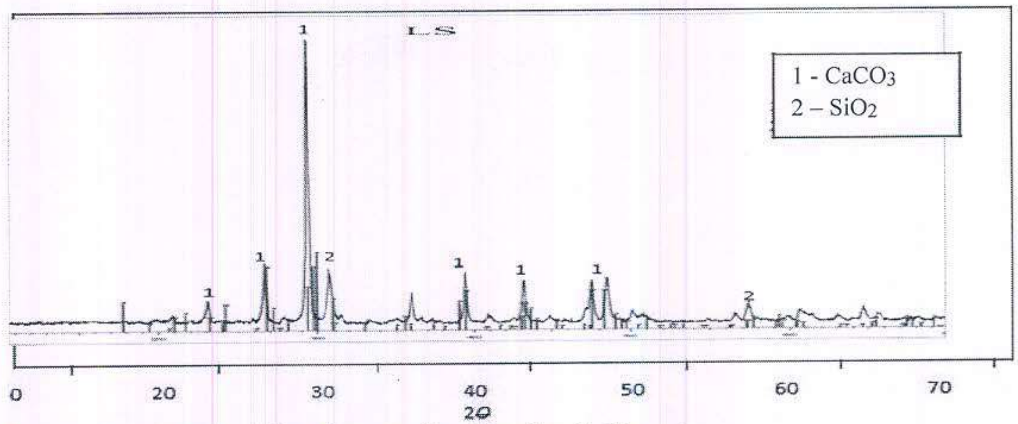

Figure. 3.1: X-Ray diffraction graph of Oterkpolu limestone

3.2 Clam shells

Clam shells are found in large deposits, usually interbedded with loose soil, along both the southern banks and the bed of the Volta river from Akuse to Ada in the Eastern, Greater-Accra and Volta regions of Ghana. They are mined and sold in the raw state to the poultry and mining industries. A small proportion of the mined shells are burnt and sold as lime for whitewashing of buildings. Clam shells are the purest source of calcium carbonate in Ghana. The shell deposit is estimated at more than 4 million tonnes (Kesse,1985). The shell becomes very white in colour when washed.The main chemical compound is CaO (52.4%) and mineralogically contains calcite (Fig. 3.2).

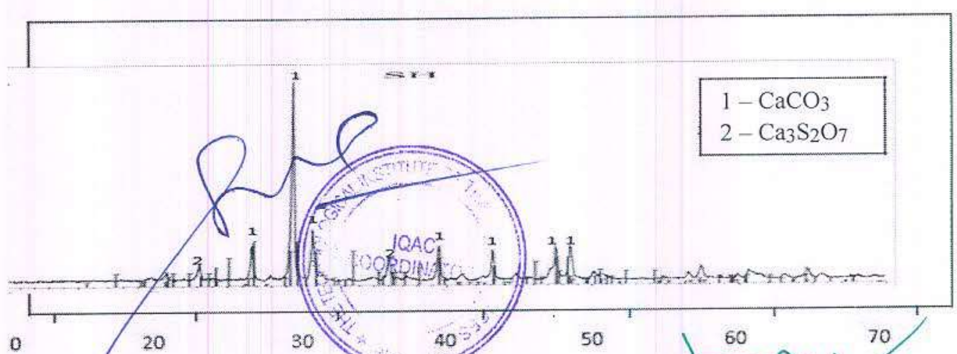

Figure. 3.2: X-Ray diffraction graph of clam shells

3.3 Steel slag

The steel slag samples were collected from Wahome Steel Company Ltd in Tema. It is regarded as a waste product in the production of structural steel sections and reinforcing bars. There are four main steel companies in Ghana, namely Wahome Steel Ltd,Western Steel and Forgings Limited, Ferro Fabric Gh Ltd, and Tema Steel Works all in Tema, which produce more than 5,000 tonnes of slag waste annually. Some of these companies have been in operation for more than 20 years.Due to increasing activities in infrastructure development, the tonnage of steel produced in Ghana is increasing. The wastes are dumped haphazardly at refuse sites, creating environmental nuisance and hazards in the areas. Chemical analysis of the sample showed it contains 31.5% Fe_2O_3, 21.3% SiO_2 and 12.4% CaO. The main minerals are wustite, portlandite, calcite, quartz and belite (Fig. 3.3).

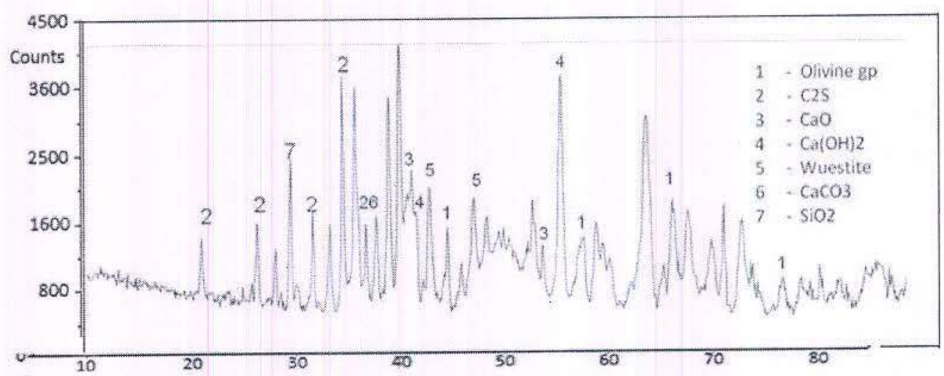

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Figure 3.3: X-Ray Diffraction graph of Wahome steel slag

3.4 Mankranso clay

The clay sample was obtained from Mankranso which is located about 41km west of Kumasi on the Kumasi - Sunyani road. The clay is derived from the weathering of Lower Birimian (Middle Precambrian) phyllites, schists, tuff and greywacks and is yellow in colour(Kesse, 1985). The deposit area is drained by the Mankranriver and has an overburden thickness of less than 0.2m. The clay deposit spans more than 10 km on both sides of the Kumasi - Sunyani road. The Mankranso clay is presently used by CSIR-Building and Road Research Institute for pozzolana production and by small-scale industries for the production of burnt bricks for housing construction.

The main minerals obtained from X-RD analysis are kaonilite, quartz, geothite and chlorite. The silica and iron oxide contents, from the chemical analysis (Table 3.2) of the clay were 59.9% and 6.5% respectively.

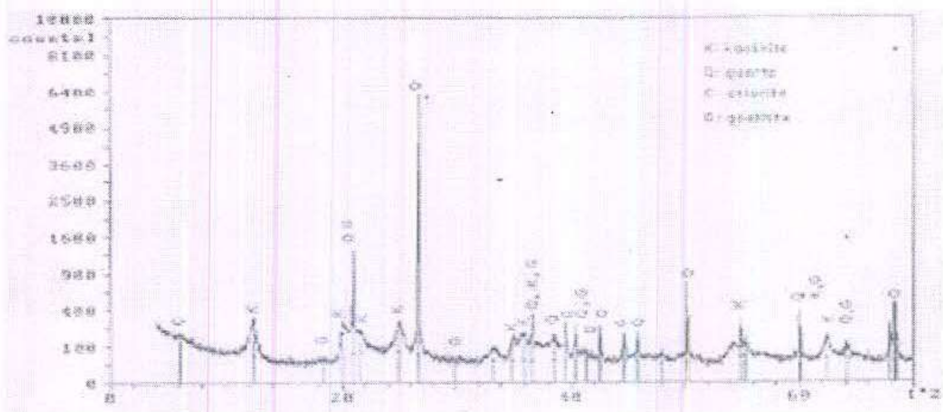

Figure. 3.4: X-Ray diffraction graph of Mankranso clay

3.5 Cement

The cement used for the study was CEM I Class 42.5N, produced by GHACEM Ltd, Ghana. It is used in Ghana for the construction of housing facilities, drains, culverts, bridges, flyovers, among others and satisfies all specifications of EN 197-1. The chemical (oxide) composition of the cement as given shows 57% CaO, and 18.8% SiO_2 content.(Table 3.2).The alumina (Al_2O_3) and iron oxide (Fe_2O_3) contents were 3.57% and 4.36% respectively. Table 3.3 gives the mineralogical composition and moduli of the reference cement with total calcium silicate content of 77.62 and a silica modulus (SR) of 1.39.

Table 3.3: Mineralogical composition and moduli of reference cement

Bogue potential composition, %				Moduli			
C_3S	C_2S	C_3A	C_4AF	LSF	AR	SR	HM
59.25	18.37	7.57	11.54	93.42	2.42	1.39	2.11

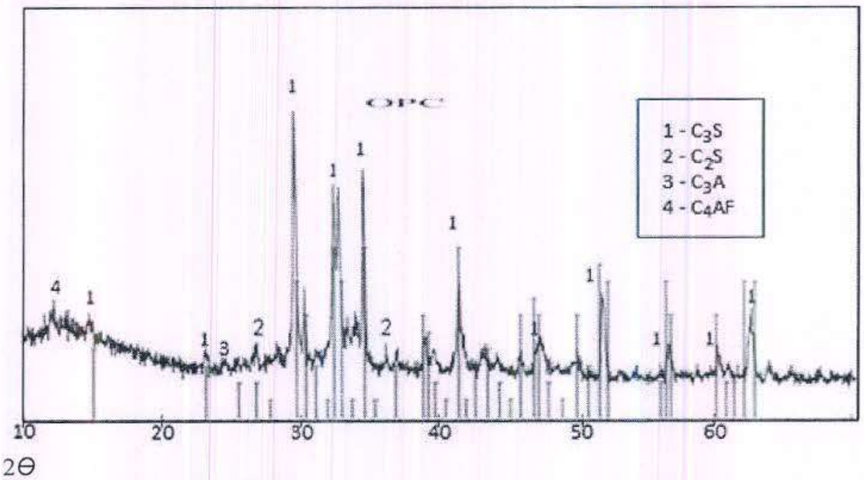

Figure. 3.5: X-Ray diffraction graph of ordinary Portland cement

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CHAPTER FOUR

METHODS

4.0 Introduction

This section describes the various experimental methods adopted to determine and analyse the physical, chemical, mineralogical, mechanical and engineering properties of blended cements and very essential ones of the materials used for this study. It is important to obtain these properties in order to ascertain the suitability of the materials for the specific objectives of this study.

The test methods and analysis adopted conformed to those specified by International Standards Organisation (ISO), European Standards (CEN), British Standards (BS), Indian Standards (IS), Ghana Standards (GS) and other conventional standard methods.

4.1 Physical Properties

4.1.1 Moisture Content

The moisture contents of the clay sample were determined in accordance with BS 1377 (1990). About 30g of the natural clay from the site was placed in a covered container of known weight (m_1) and weighed (m_2). The container containing the clay was uncovered, and together with the cover was placed in an electric oven and dried at 105°C for 4 hours. The container with the clay was taken out, covered and placed in a dessicator to cool, after which it was weighed again (m_3). The moisture content, MC, of the sample was calculated as:

$$MC = \frac{m_2 - m_3}{m_3 - m_1} \times 100\% \qquad 4.1$$

4.1.2 Particle Size Distribution

The particle size distribution for each of all four materials under investigations was determined by the hydrometer method of sedimentation as specified by BS 1377. About 500g of the samples were air-dried for 48 hours. After that about 200g of air-dried sample was passed through a 2.36mm standard sieve and the undersize dried in an oven at 105°C for 4 hours. The dry sample was then quartered and 50g of it was transferred into a 600-ml brass container. 100 ml of a dispersant solution, made from 7g of sodium metahexaphosphate and 33g of sodium oxalate in 1000 ml of distilled water, was added to the clay and made up to 250 ml with distilled water.

The suspension was agitated with a vibrating stirrer for 15 minutes and later transferred to a 1000-ml measuring cylinder. The contents were made up to 1000 ml with distilled water and left to stand for 24 hours to effect the decoagulation of the various soil particles. The cylinder was agitated manually for a minute to disperse the particles and placed on a bench. The timer was immediately switched on. The hydrometer was then immersed in the suspension and allowed to float upright. The hydrometer readings were first taken at 30 seconds and then at 1 minute, 2 minutes, 4 minutes and specific intervals for 8 hours and at 24 hours. Afterwards, the sample was washed through a 75 m sieve and the retained was dried at 105°C for 24 hours. The dry sample was passed through 2.4, 1.2, 0.6, 0.4, 0.2, 0.15 and 0.075mm standard sieves and the mass of fractions retained on each sieve were recorded.

4.1.3 Materials Preparation

In order to carry out the remaining tests of the study the raw materials were prepared and blended as described subsequently. The clam shells, steel slag and limestone were separately crushed and milled in a hammer mill for one hour and then passed through a 75μm BS standard sieve. The under-size were bagged, labelled and used for the study. The clam shells were thoroughly washed, to get rid of the dirt, before grinding. The clay samples were milled, nodulised and fired in a kiln at the optimum temperature of 800°C according to the works of Atiemo (2005) to produce a pozzolanic material. The calcined clay nodules were milled in a pulveriser and bagged for subsequent test preparation.

4.1.3.1 Mix Design of blended cement

The milled and sieved mineral admixtures (limestone, clam shells, clay pozzolana and steel slag) were blended with the Class 42.5N Portland cement using various mix designs given in Table 4.1. 5% of reference cement was first replaced by the four admixtures in turn to form the binary mix. Secondly, 10% cement was replaced by 5% by mass each of the two admixtures (ternary mix); for example, 5% by mass of cement was replaced by slag and 5% by mass of limestone constituting 10% cement replacement. Then, a cement replacement of 15% by either 5% each of the three admixtures was made constituting a quaternary mix or 10% replacement by one material and 5% by another admixture. A quinternary blend was obtained by replacing reference cement by 2.5% or 5% each of the admixtures. The blended cement samples, as presented in Table 4.1, were used to produce cement paste, mortar and concrete samples respectively for the study.

Table 4.1: Mix designs of blended cements for tests

Sample/ Type	Material, %				
	Cement	Slag	Pozzolana	Shells	Limestone
Reference	100	-	-	-	-
	95	5	-	-	-
Binary	95	-	-	5	-
	95	-	-	-	5
	95	-	5	-	-
	90	5	-	5	-
	90	5	5	-	-
	90	-	5	5	-
	90	5	-	-	5
	90	-	5	-	5
-	90	-	-	5	5
Ternary	85	10	-	5	-
	85	5	-	10	-
	85	-	10	5	-
	85	-	5	10	-
	85	10	5	-	-
	85	5	10	-	-
	85	-	10	-	5
	85	-	5	-	10
	85	-	-	5	10
	85	-	-	10	5
	85	10	-	-	5
	85	5	-	-	10
	80	10	-	10	-
	80	-	10	10	-
	80	10	10	-	-
	80	10	-	-	10
	80	-	10	-	10
	80	-	-	10	10
	92.5	2.5	2.5	2.5	-
	92.5	2.5	2.5	-	2.5
	92.5	2.5	-	2.5	2.5
	92.5	-	2.5	2.5	2.5
Quaternary	85	5	5	5	-
	85	5	5	-	5
	85	5	-	5	5
	85	-	5	5	5
Quinternary	90	2.5	2.5	2.5	2.5
	80	5	5	5	5

4.1.4 Specific Gravity

Determination of the specific gravity of materials in cement concrete is necessary in calculating thepercentage of voids and the solid volume of aggregates in computations of yield. The determination of specific gravity of the raw and all cement samples were carried out as specified by BS 1377 (1990). A 50-ml density bottle with the stopper was dried at 105°C in an oven for 24 hrs and weighed (m_1).

25g of ground, oven-dried sample, which had been passed through 75µm sieve, was transferred into the density bottle. The bottle and its contents with the stopper were weighed again (m_2). The bottle was then half-filled with kerosene. The container was afterwards placed in a vacuum dessicator, with the stopper removed, and the air in the container gradually evacuated. When no air was seen to be released, the bottle was removed and weighed (m_3). The bottle was afterwards emptied of its contents, cleaned and completely filled with kerosene, stoppered and reweighed (m_4). The specific gravity (G_S) of the sample was calculated as:

$$Gs = \frac{G_l\,(m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_1)} \times 100\% \qquad 4.2$$

where G_L = specific gravity of kerosene.

4.1.5 Soundness Test

After cement has set it must not undergo any appreciable expansion beyond 10mm, which could disrupt a mortar or concrete. It is a measure of durability of cement. The soundness test was done in accordance with the EN 196-3 (2000) specified method. Cement paste of standard consistency was prepared. A lightly-oiled Le Chateliermould was placed on a lightly-oiled glass plate and filled immediately with the blended cement paste to the top surface. The mould was covered with the lightly oiled glass plate, a standard small weight placed on it and then the complete apparatus was immediately placed in the humidity cabinet. The cabinet environment was maintained at 20 $^{o}C \pm 1^{o}C$ and not less than 98% relative humidity for 24 h $\pm$ 0.5 h.

At the end of the period, the distance (A) between the indicator points was measured to the nearest 0.5mm. The mould was gradually heated to boiling during (30±5) min and the water-bath was maintained at boiling temperature for 3 h ± 5min. At the end of the boiling period the distance (B) between the indicator points was measured to the nearest 0.5mm. The method was repeated. The difference between B and A was recorded and the mean of the 2 values of the difference calculated.

The percentage expansion (E) was calculated as:

$$E = \frac{B-A}{A} \times 100\% \qquad 4.3$$

4.1.6 Water permeability

Water permeability is a measure of the porosity of cement products and gives indication of ease of attack of such products by aggressive fluids. In the present study, the overall porosity is determined by water absorption which measures the pore space indirectly by the procedure given in ASTM C 642-90 by oven-drying.For this test, 100mm x 100mm x 100mm size concrete cubes were cast in duplicate. After demoulding, the specimens were kept immersed in water. The experiment was conducted at the end of28 days evaluate the effect of curing on overall porosity. At the end of curing period, the specimens were taken from the curing tank and air-dried to remove surface moisture. After this, the specimens were dried in an oven at a temperature of 100±10^{0}C for 48h, allowed to cool to room temperature, and the weight of the specimens measured to an accuracy of 1g using a digital balance. Then the specimens were kept immersed in water for one hour and the increase in weight was measured. From this the co-efficient of water absorption was calculated using the following formula.

$$Ka = \frac{(Q / A)^2}{t} \qquad 4.4$$

Where K_a is the co-efficient of water absorption, Q the quantity of water absorbed by the oven-dry specimen in time, t, and A the total surface area of concrete specimen through which water penetrates, t=60 min. The co-efficient of water absorption was calculated for each curing period.

4.1.7 Water Demand

The Vicat method, specified by EN 197-3 (2000), was used to determine the water demand and setting times of the various reference and blended cement pastes. This method gives the quantity of water needed to produce a cement paste of standard consistency and also for the setting times of the cements.

The Vicatmould, resting on a non-porous plate, was filled completely with the blended cement paste in one layer and the surface smoothened off level with the top of the mould as quickly as possible. The test block, confined in the mould and resting on the plate was placed under the rod bearing the plunger. The plunger was lowered gently into contact with the surface of the test block and quickly released and allowed to sink in. Trial blended cement pastes, made with varying amounts of water, were used until the plunger settled at 6mm from the bottom of the mould. The amount of water used was recorded as standard consistency (water demand) and expressed as a percentage by mass of the dry cement.

4.1.8 Setting Time

The setting of cement is used to describe the stiffening of cement paste which is mainly caused by the hydration of C_3A compounds in cement. The initial setting time is the interval between the mixing of the cement with H_2O and the time when the mix loses its plasticity, stiffening to a certain degree. It marks the end of the period when the wet mix can be moulded into shape. The final setting time is the point at which the set cement has acquired a sufficient firmness to resist a certain defined pressure. The amount of water, in percentage, to reach the normal stiffness is the water demand of the cement.

4.1.8.1 Initial Setting Time

The Vicat method was used for the determination of the initial setting time of the blended cement. Here, the cement paste, using the percentage of water recorded for the standard consistence, was gauged into the Vicatmould. The test block, confined in the mould and resting on the plate, was placed under the rod bearing the needle. The needle was then lowered gently into contact with the surface of the test block and quickly released and allowed to sink in. This process was repeated until the needle, when brought into contact with the test block and released as described above, did not penetrate beyond a point approximately 5mm from the bottom of the mould. The period elapsed between the time when the water was added to the cement and the time at which the needle ceased to pierce the test block beyond the prescribed depth was noted as the initial setting time.

4.1.8.2 Final Setting Time

For the determination of the final setting time, the needle used for the initial setting time was replaced by the needle with an annular attachment in the Vicat apparatus. The cement was considered as finally set when, upon applying the needle gently to the surface of the test block, only the needle made an impression, while the attachment failed to do so. The time lapse at which the needle ceased to pierce the test block, as described above, was noted as the final setting time.

4.2 Chemical Properties

The chemical compositions of the mineral admixtures and cement were determined by X-ray Fluorescence analysis using Spectro X-LAB 2000 equipment at the Ghana Geological Survey Department in Accra. The admixtures and ordinary Portland cement were blended separately at specific proportions and packaged. 4g of the blended sample presented was measured and placed in a special vessel purposely made for this kind of analysis. About 0.9g of Hoechst Micro powder was then added to blend, and the resulting mixture put in a mill. Two small round balls were added to the resulting mixture before placing it in the mill. The purpose of the milling phase was to reduce particles size further to about 100 microns and preferably less. The action of the mill also helped to achieve a homogeneous mixture.

The balls which assisted to reduce the particle size were then removed, and the remaining mixture placed in a die. The die was placed in a press, and a force of between 5 to 8 tonnes applied to produce the pellet for the chemical analysis.

4.3 Mineralogical Properties

The various minerals present in the test materials and the hydrated products of reference and blended cements were determined and analysed using infrared spectrometry (IR), X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive x-ray (EDX) and thermoanalysis methods (TG/DTA).

4.3.1 Infrared Spectrometry Analysis

Infrared spectroscopy is used to identify compounds or investigate sample composition. It exploits the fact that molecules have specific frequencies at which they rotate or vibrate corresponding to discrete energy level (vibrational modes). The infrared spectrum of a sample is collected by passing a beam of infrared light through the sample. From this, an absorbance can be produced, showing at which IR wavelengths the sample absorbs. Analysis of these absorption characteristics reveals details about the molecular structure of the sample. This technique works almost exclusively on samples with covalent bonds (Demirdöven*et al*, 2004).

IR analysis was used for the study to determine the effect of admixtures during cement hydration. The infrared analysis was recorded with hydrated blended cements at 7 and 28 days respectively. 2mg of the solid sample (blended cement) that was obtained was mixed with 400mg of potassium bromide powder in an agate mortar. 200mg of the mixture was then pressed for about 5 minutes into a pellet (disc) using a special mould and a hydraulic press with an estimated force of about 8 tonnes. The pellet was then passed through a FTIR-8201A single beam laser Shimadzu Infrared Spectrophotometer, where the specific functional groups were determined. The samples were analysed at the Physical Science Department of the University of Cape Coast.

4.3.2 X-Ray Diffraction Analysis

X-ray Diffraction (XRD) analysis is a non-destructive analytical method by which X-rays of a known wavelength are passed through a sample in order to identify the crystal structure, chemical composition, and physical properties of the sample. The wave nature of the X-rays means that they are diffracted by the lattice of the crystal to give a unique pattern of peaks of 'reflections' at differing angles and of different intensity, just as light can be diffracted by a grating of suitably spaced lines.

For this study, the hydrated cement blend was removed from water at the test date and immersed in acetone to stop hydration. About 0.5g of the cement specimen was then ground to a mesh size of below 75µm and pressed into the holder with a 10mm x 30mm thin glass plate using the thumb. The holder was then placed in a PHILIPS PW 1830 X-ray diffractometer for the determination. The tests were performed at the Materials Science Dept. Laboratory of the University of Manchester, in the United Kingdom.

4.3.3 Scanning Electron Microscopic (SEM) analysis

Scanning electron microscopy (SEM) is a technology used in studying the microstructure of cement paste. The electron microscope images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity (Stultzman, 2004).

The cement specimens were removed from water and acetone was added to them to inhibit hydration. The specimens were broken and ground to powder (about 50μm). A few of the powder was spread thinly on the adhesive surface of the holder and placed in the ZEISS SEM analyser equipment for analysis.

4.3.4 Energy Dispersive X-ray Analysis (EDX)

Energy Dispersive X-ray (EDX) analysis is a modern technique used for identifying the elemental composition of the specimen, or an area of interest thereof. The EDX analysis system works as an integrated feature of a scanning electron microscope (SEM), and cannot operate on its own without the latter. During EDX Analysis, the specimen is bombarded with an electron beam inside the scanning electron microscope. The bombarding electrons collide with the specimen atoms' own electrons, knocking some of them off in the process. A position vacated by an ejected inner shell electron is eventually occupied by a higher-energy electron from an outer shell. To be able to do so, however, the transferring outer electron must give up some of its energy by emitting an X-ray.

The amount of energy released by the transferring electron depends on which shell it is transferring from, as well as which shell it is transferring to. Furthermore, the atom of every element releases X-rays with unique amounts of energy during the transferring process. Thus, by measuring the amounts of energy present in the X-rays being released by a specimen during electron beam bombardment, the identity of the atom from which the X-ray was emitted can be established. The output of an EDX analysis is an EDX spectrum. EDX spectrum plots how frequently an X-ray is received for each energy level. An EDX spectrum normally displays peaks corresponding to the energy levels for which the most X-rays had been received. Each of these peaks is unique to an atom, and therefore corresponds to a single element. The higher a peak in a spectrum, the more concentrated the element is in the specimen. An EDX spectrum plot not only identifies the element corresponding to each of its peaks, but the type of X-ray to which it corresponds as well.

The samples were treated with acetone to halt hydration after 28 days and ground in an unglazed porcelain mortar and pestle to a particle size of less than 75μm . The powders were applied smoothly and thinly on 5mm diameter magnetic holders, labelled and stored in sealed containers to prevent moisture exchange and carbonation. The SEM/EDX tests were performed at the Materials Science Laboratory of the University of Manchester, using a ZEIS SEM/EDX equipment (Fig. 4.1).The EDX analysis of the samples was performed simultaneously as the SEM analysis.

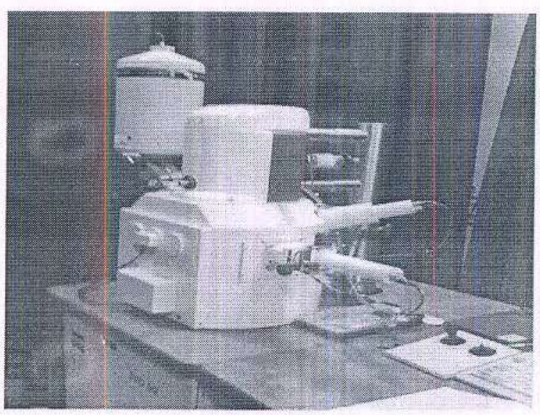

Figure 4.1 Scanning Electron Microscope/Energy Dispersive X-ray equipment

4.4 Thermoanalysis of cement

Thermoanalysis tests are performed to analysebehaviour of materials under heat treatment. Thermogravimetric analysis (TG) is performed on samples to determine changes in weight in relation to change in temperature. Such analysis relies on a high degree of precision in three measurements: weight, temperature, and temperature change. In this study, the analysis was done to determine specifically the quantity of calcium hydroxide in the various cement samples.

Differential thermal analysis (DTA) is a thermoanalytic method where the material under study and an inert reference are heated (or cooled) under identical conditions, while recording any temperature difference between sample and reference. This differential temperature is then plotted against time, or against temperature (DTA curve or thermogram). Changes in the sample, either exothermic or endothermic, can be detected relative to the inert reference. Thus, a DTA curve provides data on the transformations that have occurred, such as glass transitions, crystallization, melting and sublimation (Lea, 1970; Taylor, 1997).

Simultaneous TGA-DTA analysis measures both heat flow and weight changes (TGA) in a material as a function of temperature or time in a controlled atmosphere. Simultaneous measurement of these two material properties not only improves productivity but also simplifies interpretation of the results. The complementary information obtained allows differentiation between endothermic and exothermic events which have no associated weight loss (e.g., melting and crystallization) and those which involve a weight loss (e.g., degradation). The sample preparation and TGA/DTA tests and analysis were performed using a Seiko SSC5200 and

MettlerToledo TGA/DSC1 equipment at the Physical and Micro Analytical Laboratories, School of Chemistry, of the University of Manchester, UK.

The samples were ground in an unglazed porcelain mortar and pestle. The powders were stored in small screw-cap glass vials and labelled. The size range of the powder was such that 70-80% of it was between 149μm to 74μm. The remaining 30-20% was finer. The tests were done one after the other. Approximately 9.7 mg of a ground sample was placed in the quartz bucket and weighed accurately to the nearest 0.1 mg. Dry nitrogen at a flow rate of 100ml/min passed over the sample and heat applied from 25°C to 1000°C at 20°C/min for 10 minutes. The electromotive force (e.m.f.) equivalent to the weight change, and the e.m.f. equivalent to the temperature which was measured was displayed and the TGA/DTA/DTG graphs plotted simultaneously. During calcinations the sample lost weight because of the thermal decomposition of inherent compounds. After calcination, the sample of oxide was cooled to room temperature and evacuated

4.5 Mechanical Properties

4.5.1 Compressive, tensile strength and water absorption

The compressive strength of mortar is mostly used as a principal criterion for selecting mortar type, since compressive strength is relatively easy to measure, and it commonly relates to some other properties, such as tensile strength of the mortar. The tensile strength is a measure of an unreinforced concrete beam or slab to resist failure in tension. This strength is expressed as *modulus of rupture* and is usually between 10 and 20% of compressive strength (Dayaratnam, 1999). Other property determined was the water absorption when the mortar samples were immersed in seawater and 5% Na_2SO_4 solution.

4.5.1.1 Batching, mixing and casting

Sufficient quantities of Class 42.5N Portland cement, clay pozzolana, limestone, clam shells, steel slag, aggregates and water for batches to produce five (5) cubes and prism specimens were measured by mass as per the mix proportions. The fine and coarse aggregates were sampled from large lots by quartering before batching.

Blended cement (given in Table 4.1) to sand ratio of 1:3, and water to cement ratio of 0.5 were used to prepare all mortar samples. The materials for each mortar sample were mixed separately. The blended cement was mixed with the measured quantity of sand. Afterwards, the quantity of water needed was added and mixed for about 4 minutes. The mortar was tamped in the moulds and then vibrated for 2 minutes. After gauging, the mould was covered with a metal plate and a damp hessian sack. For the concrete test, 1:2:4 cement, fine and coarse aggregate ratio, and water to cement ratio of 0.6 were used to produce the concrete samples. In all, the test samples included 75mm cement mortar cubes, 100mm concrete cubes and 150mm x 310mm concrete cylindrical specimens were prepared for the compressive tests. 50mm x 50mm x 150mm concrete prisms were prepared for flexural tensile tests using BS and EN specifications. All the experiments were done at a room temperature of approximately 27°C $\pm$ 2°C and 70% $\pm$ 2% relative humidity.The mortar cubes, concrete cubes and prisms were removed from their moulds 24 hours after gauging and weighed. The weighed cubes were then immersed in a pond of water of average temperature of 22°C $\pm$ 1°C and kept for the specified testing periods.

In all, 1075 mortar and 620 samples were prepared for the compressive tests, and 510 mortar samples for the durability. Five samples were tested for each age date.

In all, 1075 mortar and 620 samples were prepared for the compressive tests, and 510 mortar samples for the durability. Five samples were tested for each age date.

4.5.1.2 Slump Test

This test was used to determine the workability of the fresh concrete. The steel mouldfor the slump test was a frustum of a cone, 300mm high. The mould was thoroughly cleaned and placed on a smooth levelled surface with an opening of diameter 100mm at the top and 200mm at the bottom. It was firmly held against its base and filled with concrete in three layers. Each layer was tamped 25 times with a standard 16mm diameter steel rod that was rounded at the end. The excess concrete was struck off the top and the base was cleared of all droppings. The cone was steadily lifted vertically. A straight edge was placed on top of the inverted empty cone placed alongside the slumped concrete. The slump was measured as the difference between the highest point of the slumped concrete and the underside of the straight edge.

4.5.1.3 Strength tests

The cement mortar and concrete cube and cylindrical specimens were tested for their compressive strengths at 2, 7, 28, 90 and 365 days using a universal testing machine in accordance with EN 197-2 (2000). The flexural tensile strengths of the concretes from the cement blends were determined from the prisms prepared. The modulus of rupture was calculated based on the of elastic theory using the formula:

$$F_{pc} = \frac{PL}{bd^2} \qquad 4.5$$

Where F_{pc} = modulus of rupture in N/mm^2; P= load (force); L = effective span; b= width of the beam; and d = thickness

4.5.1.4 Water Absorption

The water absorption of the cement mortar cubes, concrete cubes and prisms was determined by weighing the cubes immediately after removing them from their moulds to give the initial mass, m_1. The cubes were then immersed in water for 28 days. The mass of the wet cubes, m_2, were then taken before their compressive strengths were tested. The water absorption, w, of the cubes was calculated as;

$$w = \frac{m_2 - m_1}{m_1} \times 100\% \qquad 4.7$$

4.6 Durability Tests

Durability of cements and their products refers to their ability to withstand extreme or excessive deleterious conditions which otherwise will affect their required structural performance and resilience. The long-term durability of cementitious materials is mostly dependent upon their physical and chemical properties. It is recognized that the more important prerequisite is reducing the permeability of material to the ionic species. C_3A-related compounds are given much attention when it comes to cement durability because sulfate resistance and the chloride binding capacity of cement products depend on the stability of C_3A hydrates formed before the attack (Bonavetti*et al*, 2001). In sulfate attack, ettringite formed prior to the immersion in sulfate solution will be a stable phase while the monosulfoaluminate and the monocarboaluminate will be unstable phases.

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4.6.1 Sulphate and Chloride Resisting Tests

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Cement products, especially concretes and mortars, are attacked by acidic media, and are severely affected by sulphates and chlorides which are found in the soil and/or groundwater. These acids affect the cement structures negatively through chemical actions leading to expansion and corrosion of reinforced steel that eventually result in loss of strength and durability. It is therefore essential to determine the performance of cements in these acidic media so as to determine their durability (O"Farrel, *et al,* 1999, Osborne, 1999).

Cement mortar cubes produced as in 4.51.1 – 4.51.3were immersed in 5% Na_2SO_4 solutions and sea water for 28, 90 and 365 days. The cubes were examined visually, photographed and their compressive strengths determined.

4.6.2 Strength Deterioration Factor (SDF)

The deterioration of the mortar cubes was investigated by determining the strength deterioration factor due to the sulphate and chloride attack was determined using the formula by Murthi and Sivakumar (2008):

$$SDF = \frac{(f_{cw} - f_{ca})}{f_{cw}} \qquad 4.7$$

wheref_{cw} = the average compressive strength of cubes in water

f_{ca} = the average compressive strength of cubes in acidic solution

The cubes were tested for compressive strength at 28, 180 and 365 days according to EN 196-2 (2000).

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CHAPTER FOUR

METHODS

4.0 Introduction

This section describes the various experimental methods adopted to determine and analyse the physical, chemical, mineralogical, mechanical and engineering properties of blended cements and very essential ones of the materials used for this study. It is important to obtain these properties in order to ascertain the suitability of the materials for the specific objectives of this study.

The test methods and analysis adopted conformed to those specified by International Standards Organisation (ISO), European Standards (CEN), British Standards (BS), Indian Standards (IS), Ghana Standards (GS) and other conventional standard methods.

4.1 Physical Properties

4.1.1 Moisture Content

The moisture contents of the clay sample were determined in accordance with BS 1377 (1990). About 30g of the natural clay from the site was placed in a covered container of known weight (m_1) and weighed (m_2). The container containing the clay was uncovered, and together with the cover was placed in an electric oven and dried at 105°C for 4 hours. The container with the clay was taken out, covered and placed in a dessicator to cool, after which it was weighed again (m_3). The moisture content, MC, of the sample was calculated as:

$$MC = \frac{m_2 - m_3}{m_3 - m_1} \times 100\% \qquad 4.1$$

4.1.2 Particle Size Distribution

The particle size distribution for each of all four materials under investigations was determined by the hydrometer method of sedimentation as specified by BS 1377. About 500g of the samples were air-dried for 48 hours. After that about 200g of air-dried sample was passed through a 2.36mm standard sieve and the undersize dried in an oven at 105°C for 4 hours. The dry sample was then quartered and 50g of it was transferred into a 600-ml brass container. 100 ml of a dispersant solution, made from 7g of sodium metahexaphosphate and 33g of sodium oxalate in 1000 ml of distilled water, was added to the clay and made up to 250 ml with distilled water.

The suspension was agitated with a vibrating stirrer for 15 minutes and later transferred to a 1000-ml measuring cylinder. The contents were made up to 1000 ml with distilled water and left to stand for 24 hours to effect the decoagulation of the various soil particles. The cylinder was agitated manually for a minute to disperse the particles and placed on a bench. The timer was immediately switched on. The hydrometer was then immersed in the suspension and allowed to float upright. The hydrometer readings were first taken at 30 seconds and then at 1 minute, 2 minutes, 4 minutes and specific intervals for 8 hours and at 24 hours. Afterwards, the sample was washed through a 75 m sieve and the retained was dried at 105°C for 24 hours. The dry sample was passed through 2.4, 1.2, 0.6, 0.4, 0.2, 0.15 and 0.075mm standard sieves and the mass of fractions retained on each sieve were recorded.

4.1.3 Materials Preparation

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In order to carry out the remaining tests of the study the raw materials were prepared and blended as described subsequently. The clam shells, steel slag and limestone were separately crushed and milled in a hammer mill for one hour and then passed through a 75µm BS standard sieve. The under-size were bagged, labelled and used for the study. The clam shells were thoroughly washed, to get rid of the dirt, before grinding. The clay samples were milled, nodulised and fired in a kiln at the optimum temperature of 800°C according to the works of Atiemo (2005) to produce a pozzolanic material. The calcined clay nodules were milled in a pulveriser and bagged for subsequent test preparation.

4.1.3.1 Mix Design of blended cement

The milled and sieved mineral admixtures (limestone, clam shells, clay pozzolana and steel slag) were blended with the Class 42.5N Portland cement using various mix designs given in Table 4.1. 5% of reference cement was first replaced by the four admixtures in turn to form the binary mix. Secondly, 10% cement was replaced by 5% by mass each of the two admixtures (ternary mix); for example, 5% by mass of cement was replaced by slag and 5% by mass of limestone constituting 10% cement replacement. Then, a cement replacement of 15% by either 5% each of the three admixtures was made constituting a quaternary mix or 10% replacement by one material and 5% by another admixture. A quinternary blend was obtained by replacing reference cement by 2.5% or 5% each of the admixtures. The blended cement samples, as presented in Table 4.1, were used to produce cement paste, mortar and concrete samples respectively for the study.

Table 4.1: Mix designs of blended cements for tests

Sample/	Material, %

Type	Cement	Slag	Pozzolana	Shells	Limestone
Reference	100	-	-	-	-
	95	5	-	-	-
Binary	95	-	-	5	-
	95	-	-	-	5
	95	-	5	-	-
	90	5	-	5	-
	90	5	5	-	-
	90	-	5	5	-
	90	5	-	-	5
	90	-	5	-	5
-	90	-	-	5	5
Ternary	85	10	-	5	-
	85	5	-	10	-
	85	-	10	5	-
	85	-	5	10	-
	85	10	5	-	-
	85	5	10	-	-
	85	-	10	-	5
	85	-	5	-	10
	85	-	-	5	10
	85	-	-	10	5
	85	10	-	-	5
	85	5	-	-	10
	80	10	-	10	-
	80	-	10	10	-
	80	10	10	-	-
	80	10	-	-	10
	80	-	10	-	10
	80	-	-	10	10
	92.5	2.5	2.5	2.5	-
	92.5	2.5	2.5	-	2.5
	92.5	2.5	-	2.5	2.5
	92.5	-	2.5	2.5	2.5
Quaternary	85	5	5	5	-
	85	5	5	-	5
	85	5	-	5	5
	85	-	5	5	5
Quinternary	90	2.5	2.5	2.5	2.5
	80	5	5	5	5

4.1.4 Specific Gravity

Determination of the specific gravity of materials in cement concrete is necessary in calculating thepercentage of voids and the solid volume of aggregates in computations of yield. The determination of specific gravity of the raw and all cement samples were carried out as specified by BS 1377 (1990). A 50-ml density bottle with the stopper was dried at 105°C in an oven for 24 hrs and weighed (m_1).

25g of ground, oven-dried sample, which had been passed through 75µm sieve, was transferred into the density bottle. The bottle and its contents with the stopper were weighed again (m_2). The bottle was then half-filled with kerosene. The container was afterwards placed in a vacuum dessicator, with the stopper removed, and the air in the container gradually evacuated. When no air was seen to be released, the bottle was removed and weighed (m_3). The bottle was afterwards emptied of its contents, cleaned and completely filled with kerosene, stoppered and reweighed (m_4). The specific gravity (G_S) of the sample was calculated as:

$$Gs = \frac{G_l\,(m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_1)} \times 100\% \qquad 4.2$$

where G_L = specific gravity of kerosene.

4.1.5 Soundness Test

After cement has set it must not undergo any appreciable expansion beyond 10mm, which could disrupt a mortar or concrete. It is a measure of durability of cement. The soundness test was done in accordance with the EN 196-3 (2000) specified method. Cement paste of standard consistency was prepared. A lightly-oiled Le Chateliermould was placed on a lightly-oiled glass plate and filled immediately with the blended cement paste to the top surface. The mould was covered with the lightly oiled glass plate, a standard small weight placed on it and then the complete apparatus was immediately placed in the humidity cabinet. The cabinet environment was maintained at 20 ^{0}C$\pm$ 1^{0}C and not less than 98% relative humidity for 24 h $\pm$ 0.5 h.

At the end of the period, the distance (A) between the indicator points was measured to the nearest 0.5mm. The mould was gradually heated to boiling during (30±5) min and the water-bath was maintained at boiling temperature for 3 h ± 5min. At the end of the boiling period the distance (B) between the indicator points was measured to the nearest 0.5mm. The method was repeated. The difference between B and A was recorded and the mean of the 2 values of the difference calculated.

The percentage expansion (E) was calculated as:

$$E = \frac{B-A}{A} \times 100\% \qquad 4.3$$

4.1.6 Water permeability

Water permeability is a measure of the porosity of cement products and gives indication of ease of attack of such products by aggressive fluids. In the present study, the overall porosity is determined by water absorption which measures the pore space indirectly by the procedure given in ASTM C 642-90 by oven-drying.For this test, 100mm x 100mm x 100mm size concrete cubes were cast in duplicate. After demoulding, the specimens were kept immersed in water. The experiment was conducted at the end of28 days evaluate the effect of curing on overall porosity. At the end of curing period, the specimens were taken from the curing tank and air-dried to remove surface moisture. After this, the specimens were dried in an oven at a temperature of 100±10^{0}C for 48h, allowed to cool to room temperature, and the weight of the specimens measured to an accuracy of 1g using a digital balance. Then the specimens were kept immersed in water for one hour and the increase in weight was measured. From this the co-efficient of water absorption was calculated using the following formula.

$$Ka = \frac{(Q / A)^2}{t} \qquad 4.4$$

Where K_a is the co-efficient of water absorption, Q the quantity of water absorbed by the oven-dry specimen in time, t, and A the total surface area of concrete specimen through which water penetrates, t=60 min. The co-efficient of water absorption was calculated for each curing period.

4.1.7 Water Demand

The Vicat method, specified by EN 197-3 (2000), was used to determine the water demand and setting times of the various reference and blended cement pastes. This method gives the quantity of water needed to produce a cement paste of standard consistency and also for the setting times of the cements.

The Vicatmould, resting on a non-porous plate, was filled completely with the blended cement paste in one layer and the surface smoothened off level with the top of the mould as quickly as possible. The test block, confined in the mould and resting on the plate was placed under the rod bearing the plunger. The plunger was lowered gently into contact with the surface of the test block and quickly released and allowed to sink in. Trial blended cement pastes, made with varying amounts of water, were used until the plunger settled at 6mm from the bottom of the mould. The amount of water used was recorded as standard consistency (water demand) and expressed as a percentage by mass of the dry cement.

4.1.8 Setting Time

The setting of cement is used to describe the stiffening of cement paste which is mainly caused by the hydration of C_3A compounds in cement. The initial setting time is the interval between the mixing of the cement with H_2O and the time when the mix loses its plasticity, stiffening to a certain degree. It marks the end of the period when the wet mix can be moulded into shape. The final setting time is the point at which the set cement has acquired a sufficient firmness to resist a certain defined pressure. The amount of water, in percentage, to reach the normal stiffness is the water demand of the cement.

4.1.8.1 Initial Setting Time

The Vicat method was used for the determination of the initial setting time of the blended cement. Here, the cement paste, using the percentage of water recorded for the standard consistence, was gauged into the Vicatmould. The test block, confined in the mould and resting on the plate, was placed under the rod bearing the needle. The needle was then lowered gently into contact with the surface of the test block and quickly released and allowed to sink in. This process was repeated until the needle, when brought into contact with the test block and released as described above, did not penetrate beyond a point approximately 5mm from the bottom of the mould. The period elapsed between the time when the water was added to the cement and the time at which the needle ceased to pierce the test block beyond the prescribed depth was noted as the initial setting time.

4.1.8.2 Final Setting Time

For the determination of the final setting time, the needle used for the initial setting time was replaced by the needle with an annular attachment in the Vicat apparatus. The cement was considered as finally set when, upon applying the needle gently to the surface of the test block, only the needle made an impression, while the attachment failed to do so. The time lapse at which the needle ceased to pierce the test block, as described above, was noted as the final setting time.

4.2 Chemical Properties

The chemical compositions of the mineral admixtures and cement were determined by X-ray Fluorescence analysis using Spectro X-LAB 2000 equipment at the Ghana Geological Survey Department in Accra. The admixtures and ordinary Portland cement were blended separately at specific proportions and packaged. 4g of the blended sample presented was measured and placed in a special vessel purposely made for this kind of analysis. About 0.9g of Hoechst Micro powder was then added to blend, and the resulting mixture put in a mill. Two small round balls were added to the resulting mixture before placing it in the mill. The purpose of the milling phase was to reduce particles size further to about 100 microns and preferably less. The action of the mill also helped to achieve a homogeneous mixture.

The balls which assisted to reduce the particle size were then removed, and the remaining mixture placed in a die. The die was placed in a press, and a force of between 5 to 8 tonnes applied to produce the pellet for the chemical analysis.

4.3 Mineralogical Properties

The various minerals present in the test materials and the hydrated products of reference and blended cements were determined and analysed using infrared spectrometry (IR), X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive x-ray (EDX) and thermoanalysis methods (TG/DTA).

4.3.1 Infrared Spectrometry Analysis

Infrared spectroscopy is used to identify compounds or investigate sample composition. It exploits the fact that molecules have specific frequencies at which they rotate or vibrate corresponding to discrete energy level (vibrational modes). The infrared spectrum of a sample is collected by passing a beam of infrared light through the sample. From this, an absorbance can be produced, showing at which IR wavelengths the sample absorbs. Analysis of these absorption characteristics reveals details about the molecular structure of the sample. This technique works almost exclusively on samples with covalent bonds (Demirdöven*et al*, 2004).

IR analysis was used for the study to determine the effect of admixtures during cement hydration. The infrared analysis was recorded with hydrated blended cements at 7 and 28 days respectively. 2mg of the solid sample (blended cement) that was obtained was mixed with 400mg of potassium bromide powder in an agate mortar. 200mg of the mixture was then pressed for about 5 minutes into a pellet (disc) using a special mould and a hydraulic press with an estimated force of about 8 tonnes. The pellet was then passed through a FTIR-8201A single beam laser Shimadzu Infrared Spectrophotometer, where the specific functional groups were determined. The samples were analysed at the Physical Science Department of the University of Cape Coast.

4.3.2 X-Ray Diffraction Analysis

X-ray Diffraction (XRD) analysis is a non-destructive analytical method by which X-rays of a known wavelength are passed through a sample in order to identify the crystal structure, chemical composition, and physical properties of the sample. The wave nature of the X-rays means that they are diffracted by the lattice of the crystal to give a unique pattern of peaks of 'reflections' at differing angles and of different intensity, just as light can be diffracted by a grating of suitably spaced lines.

For this study, the hydrated cement blend was removed from water at the test date and immersed in acetone to stop hydration. About 0.5g of the cement specimen was then ground to a mesh size of below 75μm and pressed into the holder with a 10mm x 30mm thin glass plate using the thumb. The holder was then placed in a PHILIPS PW 1830 X-ray diffractometer for the determination. The tests were performed at the Materials Science Dept. Laboratory of the University of Manchester, in the United Kingdom.

4.3.3 Scanning Electron Microscopic (SEM) analysis

Scanning electron microscopy (SEM) is a technology used in studying the microstructure of cement paste. The electron microscope images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity (Stultzman, 2004).

The cement specimens were removed from water and acetone was added to them to inhibit hydration. The specimens were broken and ground to powder (about 50μm). A few of the powder was spread thinly on the adhesive surface of the holder and placed in the ZEISS SEM analyser equipment for analysis.

4.3.4 Energy Dispersive X-ray Analysis (EDX)

Energy Dispersive X-ray (EDX) analysis is a modern technique used for identifying the elemental composition of the specimen, or an area of interest thereof. The EDX analysis system works as an integrated feature of a scanning electron microscope (SEM), and cannot operate on its own without the latter. During EDX Analysis, the specimen is bombarded with an electron beam inside the scanning electron microscope. The bombarding electrons collide with the specimen atoms' own electrons, knocking some of them off in the process. A position vacated by an ejected inner shell electron is eventually occupied by a higher-energy electron from an outer shell. To be able to do so, however, the transferring outer electron must give up some of its energy by emitting an X-ray.

The amount of energy released by the transferring electron depends on which shell it is transferring from, as well as which shell it is transferring to. Furthermore, the atom of every element releases X-rays with unique amounts of energy during the transferring process. Thus, by measuring the amounts of energy present in the X-rays being released by a specimen during electron beam bombardment, the identity of the atom from which the X-ray was emitted can be established. The output of an EDX analysis is an EDX spectrum. EDX spectrum plots how frequently an X-ray is received for each energy level. An EDX spectrum normally displays peaks corresponding to the energy levels for which the most X-rays had been received. Each of these peaks is unique to an atom, and therefore corresponds to a single element. The higher a peak in a spectrum, the more concentrated the element is in the specimen. An EDX spectrum plot not only identifies the element corresponding to each of its peaks, but the type of X-ray to which it corresponds as well.

The samples were treated with acetone to halt hydration after 28 days and ground in an unglazed porcelain mortar and pestle to a particle size of less than 75μm . The powders were applied smoothly and thinly on 5mm diameter magnetic holders, labelled and stored in sealed containers to prevent moisture exchange and carbonation. The SEM/EDX tests were performed at the Materials Science Laboratory of the University of Manchester, using a ZEIS SEM/EDX equipment (Fig. 4.1).The EDX analysis of the samples was performed simultaneously as the SEM analysis.

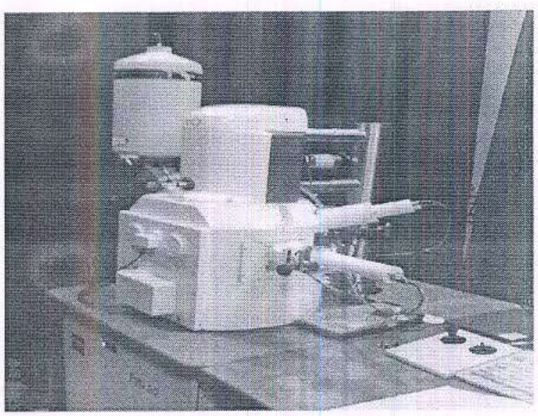

Figure 4.1 Scanning Electron Microscope/Energy Dispersive X-ray equipment

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4.4 Thermoanalysis of cement

Thermoanalysis tests are performed to analysebehaviour of materials under heat treatment. Thermogravimetric analysis (TG) is performed on samples to determine

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changes in weight in relation to change in temperature. Such analysis relies on a high degree of precision in three measurements: weight, temperature, and temperature change. In this study, the analysis was done to determine specifically the quantity of calcium hydroxide in the various cement samples.

Differential thermal analysis (DTA) is a thermoanalytic method where the material under study and an inert reference are heated (or cooled) under identical conditions, while recording any temperature difference between sample and reference. This differential temperature is then plotted against time, or against temperature (DTA curve or thermogram). Changes in the sample, either exothermic or endothermic, can be detected relative to the inert reference. Thus, a DTA curve provides data on the transformations that have occurred, such as glass transitions, crystallization, melting and sublimation (Lea, 1970; Taylor, 1997).

Simultaneous TGA-DTA analysis measures both heat flow and weight changes (TGA) in a material as a function of temperature or time in a controlled atmosphere. Simultaneous measurement of these two material properties not only improves productivity but also simplifies interpretation of the results. The complementary information obtained allows differentiation between endothermic and exothermic events which have no associated weight loss (e.g., melting and crystallization) and those which involve a weight loss (e.g., degradation). The sample preparation and TGA/DTA tests and analysis were performed using a Seiko SSC5200 and MettlerToledo TGA/DSC1 equipment at the Physical and Micro Analytical Laboratories, School of Chemistry, of the University of Manchester, UK.

The samples were ground in an unglazed porcelain mortar and pestle. The powders were stored in small screw-cap glass vials and labelled. The size range of the powder was such that 70-80% of it was between 149μm to 74μm. The remaining 30-20% was finer. The tests were done one after the other. Approximately 9.7 mg of a ground sample was placed in the quartz bucket and weighed accurately to the nearest 0.1 mg. Dry nitrogen at a flow rate of 100ml/min passed over the sample and heat applied from 25°C to 1000°C at 20°C/min for 10 minutes. The electromotive force (e.m.f.) equivalent to the weight change, and the e.m.f. equivalent to the temperature which was measured was displayed and the TGA/DTA/DTG graphs plotted simultaneously. During calcinations the sample lost weight because of the thermal decomposition of inherent compounds. After calcination, the sample of oxide was cooled to room temperature and evacuated

4.5 Mechanical Properties

4.5.1 Compressive, tensile strength and water absorption

The compressive strength of mortar is mostly used as a principal criterion for selecting mortar type, since compressive strength is relatively easy to measure, and it commonly relates to some other properties, such as tensile strength of the mortar. The tensile strength is a measure of an unreinforced concrete beam or slab to resist failure in tension. This strength is expressed as *modulus of rupture* and is usually between 10 and 20% of compressive strength (Dayaratnam, 1999). Other property determined was the water absorption when the mortar samples were immersed in seawater and 5% Na_2SO_4 solution.

4.5.1.1 Batching, mixing and casting

Sufficient quantities of Class 42.5N Portland cement, clay pozzolana, limestone, clam shells, steel slag, aggregates and water for batches to produce five (5) cubes and prism specimens were measured by mass as per the mix proportions. The fine and coarse aggregates were sampled from large lots by quartering before batching.

Blended cement (given in Table 4.1) to sand ratio of 1:3, and water to cement ratio of 0.5 were used to prepare all mortar samples. The materials for each mortar sample were mixed separately. The blended cement was mixed with the measured quantity of sand. Afterwards, the quantity of water needed was added and mixed for about 4 minutes. The mortar was tamped in the moulds and then vibrated for 2 minutes. After gauging, the mould was covered with a metal plate and a damp hessian sack. For the concrete test, 1:2:4 cement, fine and coarse aggregate ratio, and water to cement ratio of 0.6 were used to produce the concrete samples. In all, the test samples included 75mm cement mortar cubes, 100mm concrete cubes and 150mm x 310mm concrete cylindrical specimens were prepared for the compressive tests. 50mm x 50mm x 150mm concrete prisms were prepared for flexural tensile tests using BS and EN specifications. All the experiments were done at a room temperature of approximately 27°C $\pm$ 2°C and 70% $\pm$ 2% relative humidity.The mortar cubes, concrete cubes and prisms were removed from their moulds 24 hours after gauging and weighed. The weighed cubes were then immersed in a pond of water of average temperature of 22°C $\pm$ 1°C and kept for the specified testing periods.

In all, 1075 mortar and 620 samples were prepared for the compressive tests, and 510 mortar samples for the durability. Five samples were tested for each age date.

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In all, 1075 mortar and 620 samples were prepared for the compressive tests, and 510 mortar samples for the durability. Five samples were tested for each age date.

4.5.1.2 Slump Test

This test was used to determine the workability of the fresh concrete. The steel mouldfor the slump test was a frustum of a cone, 300mm high. The mould was thoroughly cleaned and placed on a smooth levelled surface with an opening of diameter 100mm at the top and 200mm at the bottom. It was firmly held against its base and filled with concrete in three layers. Each layer was tamped 25 times with a standard 16mm diameter steel rod that was rounded at the end. The excess concrete was struck off the top and the base was cleared of all droppings. The cone was steadily lifted vertically. A straight edge was placed on top of the inverted empty cone placed alongside the slumped concrete. The slump was measured as the difference between the highest point of the slumped concrete and the underside of the straight edge.

4.5.1.3 Strength tests

The cement mortar and concrete cube and cylindrical specimens were tested for their compressive strengths at 2, 7, 28, 90 and 365 days using a universal testing machine in accordance with EN 197-2 (2000). The flexural tensile strengths of the concretes from the cement blends were determined from the prisms prepared. The modulus of rupture was calculated based on the of elastic theory using the formula:

$$F_{pc} = \frac{PL}{bd^2} \qquad 4.5$$

Where F_{pc} = modulus of rupture in N/mm²; P= load (force); L = effective span; b= width of the beam; and d = thickness

4.5.1.4 Water Absorption

The water absorption of the cement mortar cubes, concrete cubes and prisms was determined by weighing the cubes immediately after removing them from their

Table 5.19:Analysis of strength of blended cement to reference cement concretes

Material	water/ cement	Slump, Mm	Compressive strength, MPa Days					% of control strength at 28 days	% of control strength at 365 days	% increase of strength from 28 to 365 days
			2	7	28	90	365			
Rh	0.6	72	13.3	17.3	22.5	23.9	31.1	100.0	100.0	38.2
5S	0.6	74	12.9	16.0	21.0	21.6	28.7	93.3	92.3	36.7
5Sh	0.6	78	12.8	15.3	21.8	22.7	29.0	96.9	93.2	33.0
5L	0.6	73	13.4	15.7	21.6	22.5	27.7	96.0	89.1	28.2
5P	0.6	65	12.4	15.8	21.7	21.8	25.0	96.4	80.4	15.2
5S5Sh	0.6	73	11.1	15.0	19.5	22.3	28.4	86.7	91.3	45.6
5L5S	0.6	70	11.4	14.7	19.1	22.4	30.1	84.9	96.8	57.6
5L5Sh	0.6	78	10.8	14.1	18.4	22.0	27.2	81.8	87.5	47.8
5P5S	0.6	65	10.9	15.0	20.0	22.9	26.9	88.9	86.5	34.5
5P5Sh	0.6	68	10.9	14.8	19.3	22.7	29.0	85.8	93.2	50.3
5P5L	0.6	70	10.8	14.4	18.6	21.5	27.3	82.7	87.8	46.8
5L 5Sh 5S	0.6	76	10.3	15.8	17.2	21.1	25.4	76.4	81.7	47.7
5P 5Sh5S	0.6	70	10.6	14.2	19.1	21.7	27.8	84.9	89.4	45.5
5P5L5S	0.6	71	10.4	14.3	18.1	20.1	26.5	80.4	85.2	31.8
5P5L5Sh	0.6	66	10.2	13.7	18.4	21.0	26.0	81.8	83.6	41.3
2.5L 2.5Sh 2.5S	0.6	72	11.7	12.5	20.6	21.3	29.6	91.6	95.2	43.7
2.5P 2.5Sh2.5S	0.6	70	11.7	12.8	20.8	21.9	26.6	92.4	85.5	27.9
2.5P2.5L2.5S	0.6	68	12.2	12.2	21.4	22.0	27.7	95.1	89.1	29.4
2.5P2.5L 2.5Sh	0.6	70	11.7	12.2	21.0	20.8	28.0	93.3	90.0	33.3
2.5P2.5L2.5Sh2.5S	0.6	71	10.9	12.1	19.8	21.8	28.0	88.0	90.0	41.4
5P5L 5Sh5S	0.6	78	10.5	10.7	17.2	19.5	24.6	76.4	79.1	43.0

Table 5.20: Comparative compressive strengths of 1:2:4 cement concrete using different water - cement ratios

Sample	Slump, mm		28-day Compressive strength	
	w/c=0.55	w/c=0.6	w/c=0.55	w/c=0.6
Rh	75	72	25.47	22.5
5S	76	74	24.1	21.0
5Sh	74	78	24.0	21.8
5L	76	73	24.3	21.6
5P	78	65	24.6	21.7
5L5S	77	70	24.3	19.1
5P5S	74	65	22.5	20.0
5P5L	78	70	22.9	18.6
5Sh5L	79	78	22.8	18.4
5S5Sh	74	73	24.0	19.5
5P5Sh	75	68	22.3	19.3
5P5L5S	72	71	19.4	18.1
5L5Sh5S	77	76	20.4	17.2
5P5Sh5S	73	70	19.7	19.1
5P5L5Sh	73	66	19.1	18.4
2.5P2.5L2.5S	73	68	21.7	21.4
2.5L2.5Sh2.5S	75	72	22.3	20.6
2.5P2.5Sh2.5S	70	70	21.4	20.8
2.5P2.5L2.5Sh	70	70	22.1	21.0
2.5L2.5S2.5Sh	74	71	21.2	19.8
5P5L5S5Sh	72	78	19.1	17.2

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Table 5.21:Tensile strengths of 1:2:4 cement concrete using different water to cement ratios

	28 – day Strength, MPa			% of Tensile to compressive strength	
		Tensile			
Sample	Compressive	w/c = 0.60	w/c = 0.55	w/c = 0.60	w/c = 0.55
Rh	43.2	4.5	6.0	10.42	13.89
5S	42.3	4.5	5.4	10.64	12.77
5Sh	43.0	4.5	5.2	10.47	12.09
5L	42.1	4.5	5.4	10.69	12.83
5P	42.8	4.5	5.4	10.51	12.62
5L5S	40.9	3.7	4.6	9.05	11.25
5P5S	41.8	3.6	4.4	8.61	10.53
5P5L	41.1	4.5	5.0	10.95	12.17
5Sh5L	40.1	3.6	4.8	8.98	11.97
5S5Sh	41.0	3.6	4.8	8.78	11.71
5P5Sh	40.4	4.1	5.2	10.15	12.87
5P5L5S	42.7	4.0	4.4	9.37	10.30
5L5Sh5S	41.1	3.6	4.3	8.76	10.46
5P5Sh5S	40.6	3.8	5.3	9.36	13.05
5P5L5Sh	42.5	3.6	5.4	8.47	12.71
2.5L2.5Sh2.5S	43.8	4.5	5.2	10.27	11.87
2.5P2.5Sh2.5S	43.5	4.0	4.8	9.20	11.03
2.5P2.5L2.5S	44.1	4.3	4.8	9.75	10.88
2.5P2.5L2.5Sh	43.0	4.5	5.0	10.47	11.63
2.5L2.5S2.5Sh	43.2	4.8	6.2	11.11	14.35
5P5L5S5Sh	41.7	3.6	4.8	8.63	11.51

5.7 Durability Test

5.7.1 Sulphate and Chloride resistance

Table 5.22 presents the compressive strengths of the mortar cubes in both solutions at 28 days. The decrease in strength compared to that immersed in water as well as their water absorption values in the solutions are also provided. The compressive strengths of the various blended cement mortars in sodium sulphate solution and seawater and the reduction in strength at from 28 to 365 days are presented in Tables 5.23 and 5.24 respectively.

Table 5.22: Compressive strength of mortar cubes immersed in Na_2SO4 solution and seawater (NaCl) at 28 days

Sample	Compressive strength, MPa			% decrease in strength		Water Absorption, %	
	Water	Seawater	Na_2SO_4	Seawater	Na_2SO_4	Na_2SO_4	Sea water
Rh	43.2	32.2	33.1	**25.5**	23.38	1.44	1.15
5Sh	43.0	27.3	28.2	**36.5**	34.42	1.62	1.37
5P	42.8	29.4	35.1	**31.3**	17.99	1.33	1.22
5L	42.1	28.4	33.5	**32.5**	20.43	1.38	1.09
5S	42.3	35.6	24.5	**15.8**	42.08	1.32	1.02
5P5Sh	41.1	29.2	38.8	**29.0**	5.60	1.26	1.14
5L5Sh	40.1	29.4	39.1	**26.7**	27.4	1.28	1.10
5L5S	40.9	30.2	35.7	**26.2**	12.71	1.17	1.11
5P5Sh	40.4	31.2	35.6	**22.8**	11.88	1.17	1.10
5Sh5S	41.0	32.0	32.1	**22.0**	21.71	1.17	1.19
5P5S	41.8	33.4	34.1	**20.1**	18.42	1.28	1.11
5P5S5Sh	39.1	29.8	30.9	**23.8**	20.97	1.28	1.14
5P5L5Sh	39.7	30.6	38.8	**22.9**	2.27	1.28	1.11
5P5L5S	39.6	30.6	30.6	**22.7**	22.73	1.17	1.40
5L5Sh5S	37.8	34.7	33.1	**8.2**	12.43	1.13	1.07
2.2P2.5L2.5Sh2.5s	41.7	33.7	39.1	**19.2**	6.24	1.04	1.23
5P5L5Sh5S	38.7	29.0	35.6	**25.1**	8.01	1.06	1.19

Table 5.23: Compressive strength of blended cement mortar cubes immersed in seawater (NaCl)

Sample	Compressive strength, MPa			% reduction	Water absorption, %			%
	Days			of strength	Days			
	28	90	365	28-365days	28	90	365	change
Rh	32.2	32.6	27.4	14.91	1.15	1.24	1.28	10.16
5S	35.6	27.6	27.6	22.47	1.02	1.12	1.25	18.40
5Sh	27.3	26.0	25.5	6.59	1.37	1.23	1.18	-16.10
5P	29.4	27.8	25.8	12.24	1.22	1.30	1.25	2.40
5L	28.4	26.4	24.9	12.32	1.09	1.16	1.33	18.05
5Sh5S	32.0	25.8	26.7	16.56	1.19	1.24	1.33	10.53
5L5S	30.2	27.7	28.0	7.28	1.11	1.20	1.09	-1.83
5P5S	33.4	29.0	27.7	17.07	1.11	1.08	1.29	13.95
5P5Sh	31.2	28.3	27.1	13.14	1.10	1.13	1.31	16.03
5L5Sh	39.4	28.8	25.6	35.03	1.10	1.25	1.23	10.57
5P5L	29.2	26.7	28.5	2.40	1.14	1.30	1.31	12.98
5L5Sh5S	34.7	28.8	26.8	22.77	1.11	1.08	1.20	7.50
5P5Sh5S	29.8	26.8	23.8	20.13	1.40	1.32	1.33	-5.26
5P5L5S	30.6	28.7	28.0	8.50	1.23	1.29	1.27	3.15
5P5L5Sh	30.8	29.0	24.7	19.81	1.23	1.32	1.36	9.56
5P5L5Sh5S	29.0	29.0	23.8	17.93	1.14	1.03	1.17	2.56
2.5P2.5L2.5Sh2.5S	33.7	27.0	28.4	15.73	1.07	1.15	1.29	17.05

Table 5.24: Compressive strength of blended cement mortar cubes immersed in Na_2SO4 solution

	Compressive strength, MPa			% reduction from 28-365 days	Solution absorption, %			% Change
	Days				Days			
Sample	28	90	365		28	90	365	
Rh	33.1	27.2	25.2	23.87	1.44	1.41	1.47	2.04
5S	24.5	23.1	22.6	7.76	1.32	1.38	1.36	2.94
5Sh	28.2	24.6	25.3	10.28	1.62	1.37	1.42	-14.08
5P	35.1	27.1	26.8	23.65	1.33	1.38	1.45	8.28
5L	33.5	25.3	24.1	28.06	1.38	1.34	1.43	3.50
5Sh5S	32.1	28.5	25.1	21.81	1.17	1.30	1.41	17.02
5L5S	35.7	27.0	26.2	26.61	1.17	1.30	1.34	12.69
5P5S	34.1	27.3	25.6	24.92	1.28	1.30	1.37	6.57
5P5Sh	35.6	28.1	23.7	33.43	1.17	1.28	1.39	15.83
5L5Sh	39.1	27.5	23.9	38.87	1.28	1.35	1.35	5.19
5P5L	38.8	26.6	24.5	36.86	1.26	1.35	1.41	10.64
5L5Sh5S	33.1	23.5	26.2	20.85	1.13	1.19	1.26	10.32
5P5Sh5S	30.9	25.6	23.3	24.60	1.28	1.31	1.28	0.00
5P5L5S	30.6	27.2	24.1	21.24	1.17	1.25	1.31	10.69
5P5L5Sh	38.8	26.5	25.1	35.31	1.28	1.34	1.35	5.19
5P5L5Sh5S	35.6	25.9	22.3	37.36	1.06	1.26	1.32	19.70
2.5P2.5L2.5Sh2.5S	39.1	28.4	27.1	30.69	1.04	1.23	1.41	26.24

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CHAPTER SIX

DISCUSSIONS

6.0 Introduction

This chapter analyses all the test results obtained and presented in Chapter Five. It also discusses the significance of the results with respect to the suitability of the blended cements for concrete and general construction using the standard specifications of British, European, Ghanaian and Indian Standards. The results are compared to that of the reference cement and similar works of other researchers. Finally, the effect on the hydration products by the admixtures and the positive resistance of the blended cements to the acidic waters are discussed.

6.1 Physical properties

6.1.1 The particle size distribution and sieve analysis of aggregates and admixtures

The particle size distribution curves of the sieved sand (Fig. 5.2) show that the sand was mostly coarse, 95% of it within the 0.5mm and 2mm range. In addition, it did not contain any fines (< 75μm). The silt content of sand was however 4.5%, greater than the required content of 2%.

Between 75% and 98% of the admixtures were below 50μm size (Fig. 5.3), except slag that gave a low figure of 30%. This gives an indication that blended cements may produce appreciable strengths since fineness plays an important role in strength development. A detailed sieve analysis of the aggregates, given in Table 5.2, shows that the fine and coarse aggregates satisfy BS 882 (1992).

The grading of the aggregates, complied with the BS 882:1990 for a 20-5mm graded coarse aggregates and the fine aggregates close to the medium sand. The mineral grains of the crushed aggregates were large enough to be seen exhibited and possessed colour that range from white to grey. The granitic aggregates are thus of good quality and therefore suitable for concrete works as per the standard specifications.

6.1.2 Specific gravity, soundness and fineness

The specific gravity of the admixtures ranged between 2.59 and 2.85 (Table 5.1), and that of the blended cements between 2.7 and 3.1, lower than that of reference value of 3.16 (Table 5.4). This is so since all the admixtures were less dense than the reference cement (Table 5.1). The specific gravity of the blended cements gave indication that they would provide dense concretes. It is evident from Table 5.3 that Blaine surface area of the cements was increased by addition of admixtures for the same residue on the 45-µm sieve. On the average, surface area increased approximately by at least $70m^2/kg$. Pozzolana blended cements gave the highest surface area with 5%Pozzolana5%shell cement of 525 m^2/kg. The high Blaine values obtained give indication of high early strengths and comparable strengths of Class 32.5N and 42.5N Portland cement.The soundness tests on the blended cements showed that they expanded less than the reference cement (Table 5.4).

6.1.3 Water Permeability

Permeability is an important property related to the durability of cementitious materials. It is defined as that property which characterizes the ease with which a fluid passes into and through the body of the concrete under a pressure gradient (Basheer, 2001).Concrete

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with low permeability exhibits good resistance to sulphate attack, chloride attack and alkali-silica reaction, since water carrying aggressive ions are difficult to penetrate into concrete pore structure (Bakker, 1983; Feldman, 1986).

From Table 5.5, the results of the permeability tests showed clearly that addition of the admixtures, except slag, reduced the porosity of the cement by at least 4% and as much as 20%. This agrees with the assertion that admixtures fill the pores of cement products making it less porous (Hawkins *et* al, 2003; Bonavetti*et al*, 2001; Péra*et al*, 1999; Soroka and Setter, 1977). Pozzolana cement gave the least permeability of 3.39 $x10^{-4}$ as compared to 4.42 $x10^{-4}$ of reference cement. Slag cement was more porous than the reference and this could be attributed to the relatively larger particle size as compared to the other admixtures (Fig. 5.3).

6.1.4 Water demand and setting times

The water demand and setting times of the reference and blended cements, as presented in Table 5.4, showed that the water demand of the blended cements ranged from 24.5% to 34.2% and that it increased as the percentage replacements of cement are increased. However, replacing cement with up to 10% of admixtures did not change the demand significantly except 5%pozzolana5%limestone cement. Cement pastes containing admixtures over 10% recorded values above 30% and this is due to the fact that increase in the amount of admixtures involves a decrease in the amount of cement (dilution effect) and consequently, an increase in the effective water cement ratio resulting in higher water demand (Adesanyaand Raheem,2009; Alam*et al*, 2006; Mehta, 1981). The addition of limestone/shell ($CaCO_3$) and clay pozzolana increased the plasticity of the mix, which needed more water for workability. In addition, $CaCO_3$ and clay pozzolana increase the effective reactive surface area, increases capacity to absorb water, and the reaction of $CaCO_3$ with C_3A to form carboaluminate hydrates leads to the higher need of water than calcium silicate hydrates (Heikal*et al*, 2000, Soroka, and Setter1977).

The initial setting times (<95min) of 5%x and 5%x5%y blended cements were lower than reference cement. This is so because there is always an interaction between tricalcium silicate (C_3S) and the admixtures, with the latter accelerating the hydration of C_3S and modifying the Ca/Si ratio of calcium silicate hydrates. Also, admixtures provide additional surface area which accelerates hydration (Heikal*et al*, 2003, Sorokaand Setter, 1977). Increasing the amount of admixtures prolongs the initial setting times of the blended cements and thus is attributed to the decrease of C_3A content of cement. Nevertheless, the initial and final setting times obtained for all cement blends were more than 75 minutes and less than 10 hours respectively for the final as stipulated by EN 197-1 (2000) and GS:22 (2004). The slag containing cements normally demanded less water than the rest which can be attributed to the delayed hydration of the slag, due to its mineralogical composition and the relatively high MgO andMnO content (Table 3.2) as stated byKourounis*et al* (2007).

6.2 Chemical properties of cement samples

The chemical compositions of the mineral admixtures are very essential in determining their suitability as appropriate minerals for blending cement. Studies have shown that chemical activity of admixtures in cement is dependent essentially on their lime, silica and alumina contents (Lea, 1970). The XRF determination, converted to its oxide composition, are provided in Tables 5.6 – 5.8. The CaO, SiO_2, Fe_2O_3 and

Al_2O_3determined are mainly constituents of hydrated calcium silicate (C_3S and C_2S), calcium aluminates (C_3A) and calcium aluminoferrite (C_4AF), the main essential compounds needed for cement hydration for strength development. The CaO- and silica-containing phases of cement are very important because the strength development and stability of cement products depend mostly on the two compounds as described in Section 2.1.1 in Chapter 2.3 and 2.4Compared with reference cement, the lime contents of the blended cements were reduced, except 5% shell cement because of its relatively higher CaO content. However, the silica contents of the 5%slag and 5%pozzolana cement blends were higher than the reference cement as a result of the higher silica content of Pozzolana and slag . This gives an indication that the binary cements would produce satisfactory results in terms of strength as explained in Chapter 2..

The iron oxide content of the binary cements ranged between 3.1% and 5.25% as compared to 4.36% of reference cement because of the high silica content of the admixtures, particularly pozzolana and steel slag. (Table 5.6). However, the alumina content was very low (3.2%) for 5%shell cement because of shell"s low alumina content and quite high (5.5% and 6.1%) for 5%pozzolana and 5%limestone cements. Alumina makes little direct contribution to the strength of Portland cement but accelerates the hydration of cement. Iron oxide in cement has no effect on cement but acts as flux to aid cement and gives the grey colour of cement (Lea, 1970). All the binary compounds contained less than 3% MgO.

The alkali content of the blended cements was quite significant, between 4.35 and 8.6%. Effects of alkalis in strength development are not fully understood but studies of 39.4MPa while slag limestone produced the minimum of 37.5 N/mm^2. The results obtained by replacing 20% cement by 5% each of the four admixtures show that the compressive strengths at 2days were higher (15.1 N/mm^2) than that obtained from 10%x10%y and 5%x5%y5%z cements (Table 4.13). The strength of 38.7 MPa obtained at 28 days (almost the same as for 10%x5%y and 5%x5%y5%z replacements) makes the blended cement (using all the four admixtures) suitable for medium strength concrete and general construction.

The results also show that integrating 7.5% of the admixtures by using 2.5% each of three of the admixtures gave almost the same strength as replacement of cement by 5% admixture at 28 days (average 42.0MPa) and about 97.3% of that of reference cement. However, the 2-day strengths of 5% binary cements averaged higher than 20N/mm^2 whereas those of 2.5%*x*2.5%*y*2.5%*z* averaged below 19N/mm^2. Increasing the admixture content to 20% with 5% each of the four admixtures produced relatively low early strength of 15.1MPa at 2ays and 28-day strength of 38.1MPa (Fig. 6.8).

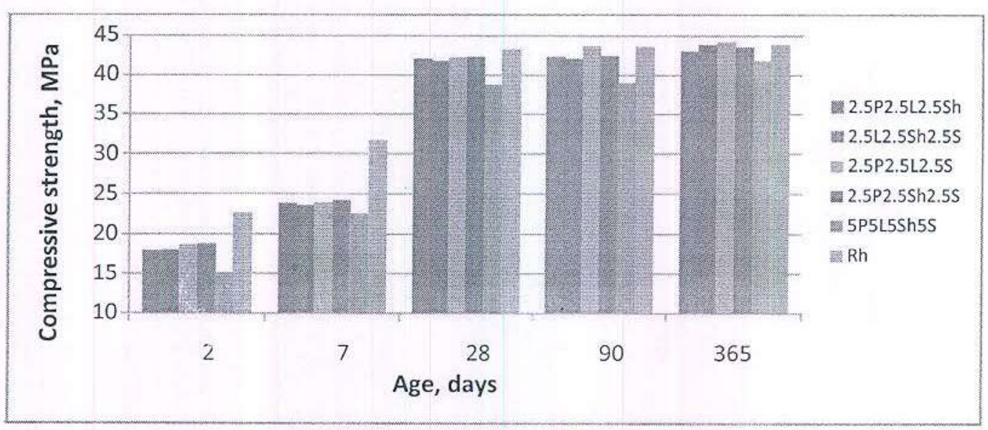

Figure 6.8: Compressive strengths of quaternary and quinternary blended cements

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6.4.2 Concrete Tests

The effect of blended cements on the fluidity of concrete was determined by slump test. The results are presented in Table 5.20. Concretes made with partial replacement of ordinary Portland cement by 5% admixtures exhibited enhanced workability compared of the reference mix, except pozzolana cement using w/c ratio of 0.6. The highest slump was recorded with mixtures containing shell cement. On the other hand, concretes made with pozzolana showed decrease in workability. The decrease in slump of pozzolana concrete could be attributed to the greater surface area due to relatively lower specific gravity of 2.59 of pozzolana. Binary blends with ordinary Portland cement with 5% each demonstrated lower slump in all the fresh concrete mixes with pozzolana. Similar results were observed with ternary and higher blends. It was generally noticed that fresh properties of blended concretes without pozzolana showed an equal or improved workability in relation to reference mix. This was in agreement with results obtained by Abdullahi (2009), Adesanya*et al* (2009) and Lea (1970) that incorporating pozzolana in concrete usually has a rather lower slump at the same water content. All concrete mixtures were found to be cohesive, relatively workable and showed no tendency of segregation.

The mechanical properties as compressive strength of blended concretes were evaluated at 2, 7, 28, 90 and 365 days of curing. Table 5.20 show the compressive strength result obtained from cylindrical specimens using a water cement ratio of 0.6 and these are presented graphically in Figs. 6.9 – 6.13. The strengths obtained for *5%x* and *2.5%x2.5%y2.5%z* were higher than the standard value of 20 MPa and at least 91.6% of the reference cement. 5%shell cement gave the highest strength of 21.5MPa compared to a value of 22.5MPa for the reference cement whereas*5%x5%y5%z5%p* cement provided the least strength of 17.2MPa (about 76.4% of control). These results comparedfavourably with the ASTM C 618 (2008) specification which stipulates minimum 28-day strength of 75% of the reference.

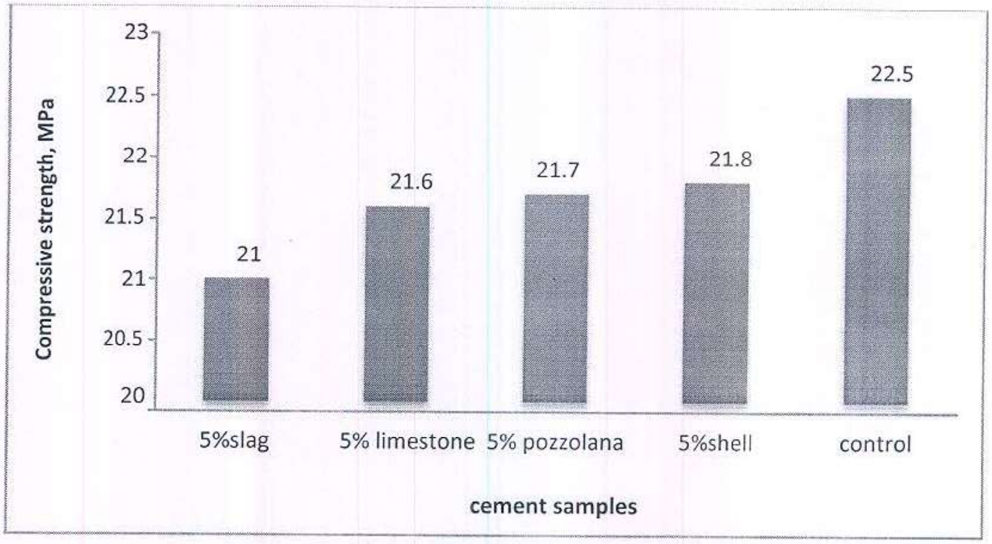

Figure 6.9: 28-day Compressive strengths of *5%x*binary blended cement 1:2:4 concrete cylinders

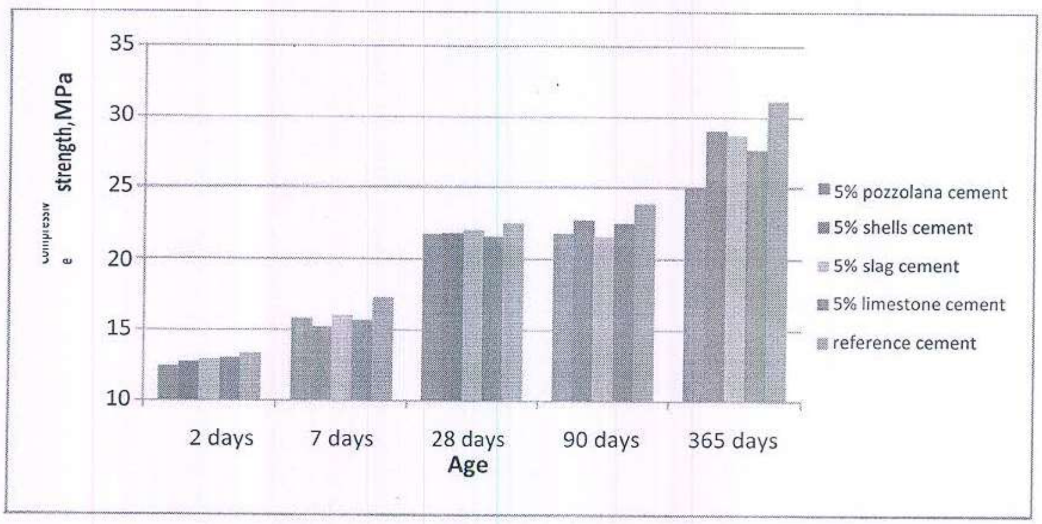

Figure 6.10: Compressive strengths of *5%x*binary blended cement 1:2:4 concrete cylinders

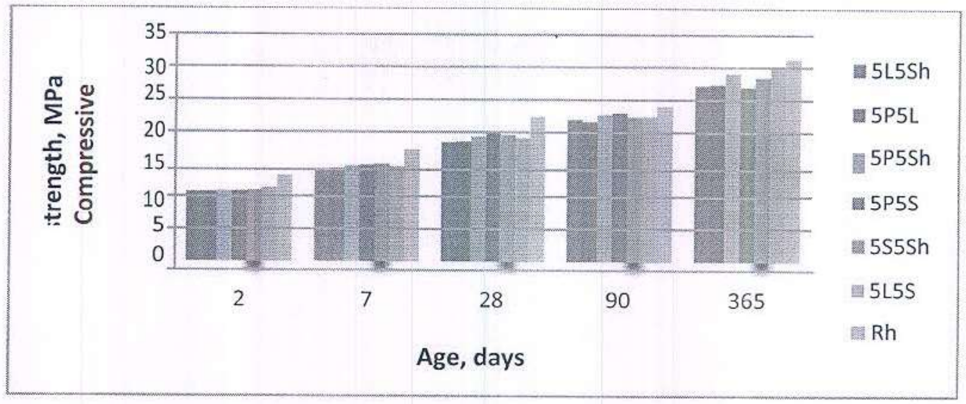

Figure 6.11: Compressive strengths of *5%x5%y*ternary blended cement 1:2:4 concrete cylinder

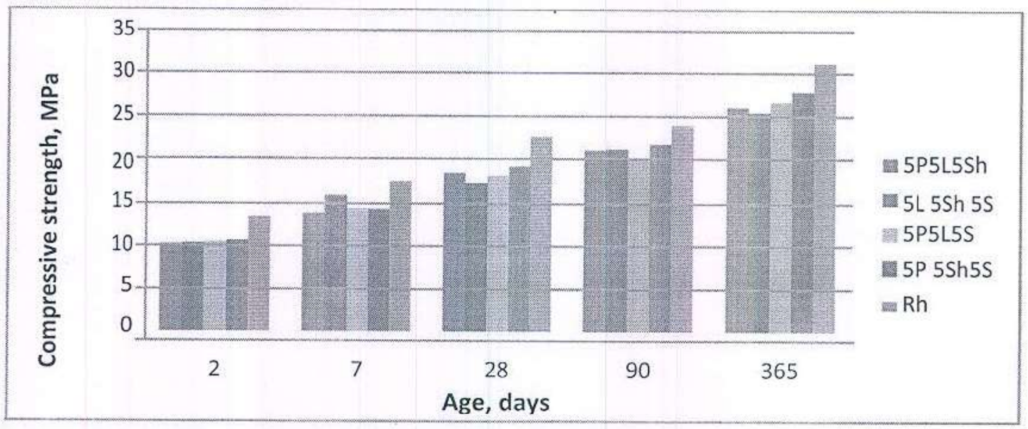

Figure 6.12: Compressive strengths of quaternary *(5%x5%y5z)* blended 1:2:4concrete cylinder

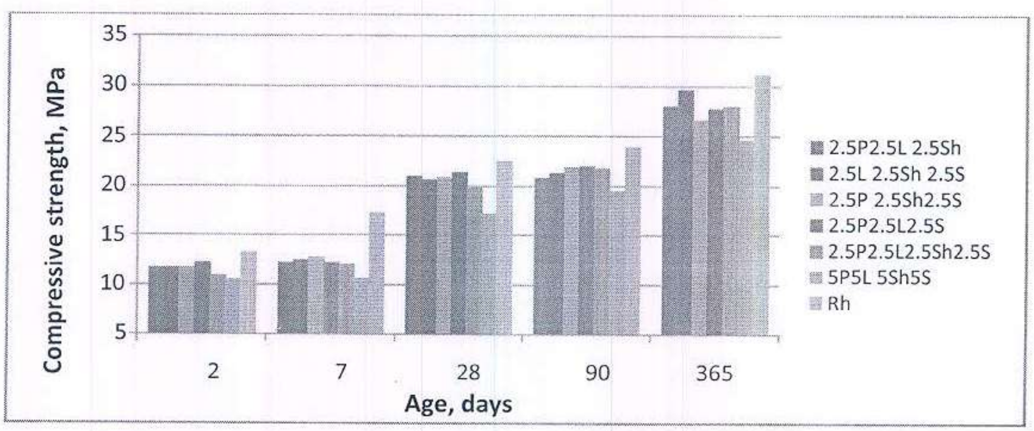

Figure 6.13: Compressive strengths of quinternary blended 1:2:4 concrete samples

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The strength of the concrete increased between 1% and 19% when the water cement ratio was reduced to 0.55. However, working with the concrete was more difficult even though the slump values also improved. Strengths ranging from 19.1MPa to 24.6MPa were obtained and the highest strength came from 5%pozzolana cement.

6.5 Flexural Tensile strength

The flexural strength is a measure of an unreinforced concrete beam or slab to resist failure in bending. It may also be referred to as modulus of rupture (Dayaratnam, 2006). The tensile strength of the concrete is usually between 10 and 20% of its compressive strength (Neville, 2000). The results obtained from the tests on the blended and reference cements indicated that replacing cement with 5% of the admixture did not affect the flexural strength of the concrete. For concretes with water-cement ratio of 0.5%, the flexural tensile strengths were between 18.0% and 24.29% of the 28-day compressive strengths of the concrete (Table 5.21).

Replacing cement with 5% admixtures using both water-cement ratio of 0.55 and 0.6 did not reduce the tensile strength significantly. The trend however shows that increasing the admixture content to 15% reduced the flexural strength by between 11% and 20%, with the exception of 5%pozzolana5%limestone, 2.5%limestone2.5%shell2.5%Slag and 2.5%pozzolana2.5%limestone2.5%shell cements that gave the same strength as the control (Figs 6.14 and 6.15) as reported by Carrasco *et al* (2004) using limestone and blast furnace slag admixtures. Significantly, replacing cement with 2.5% of each of four admixtures produced high flexural tensile that was higher than for CEM I Class 42.5N cement. The tensile strengths obtained for the blended cement ranged between 21% and 53% of compressive strengths compared to 10% - 20% stipulated by standards (Neville, 1996).Compared to results of w/c = 0.55, the results were always higher than that of 0.6. This is attributed to effect of dilution by water which reduces the strength of concrete.

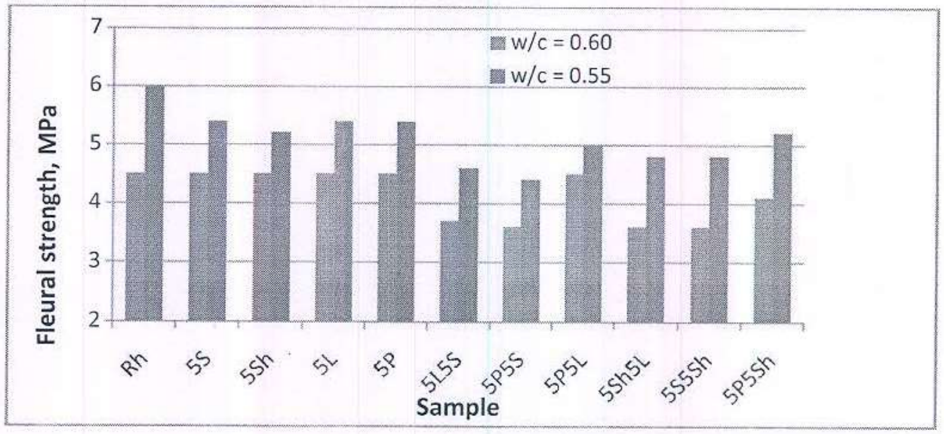


Figure 6.14: Flexural strength of binary and ternary concrete at 28 days

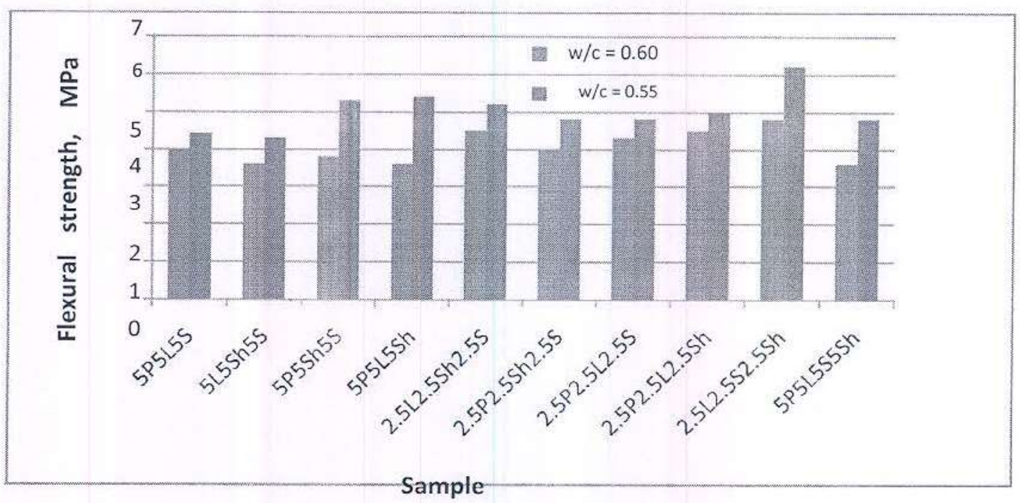
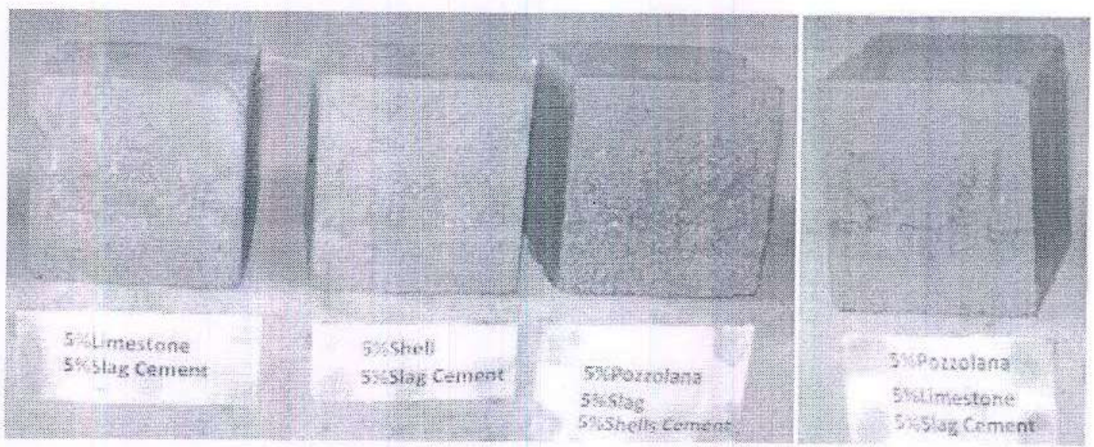


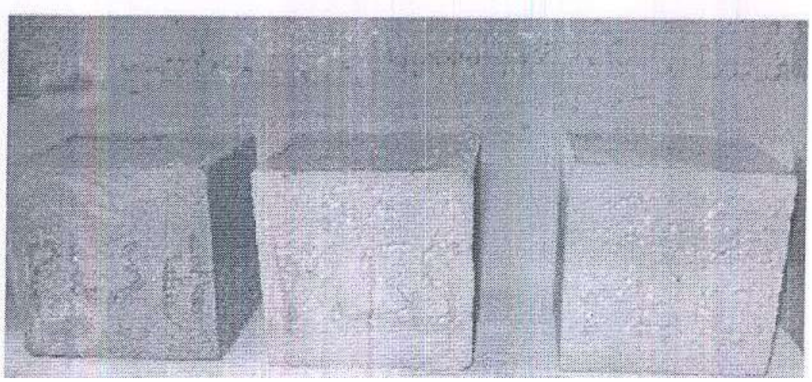
Figure 6.15: Flexural strength of quaternary and quinternary concrete at 28 days

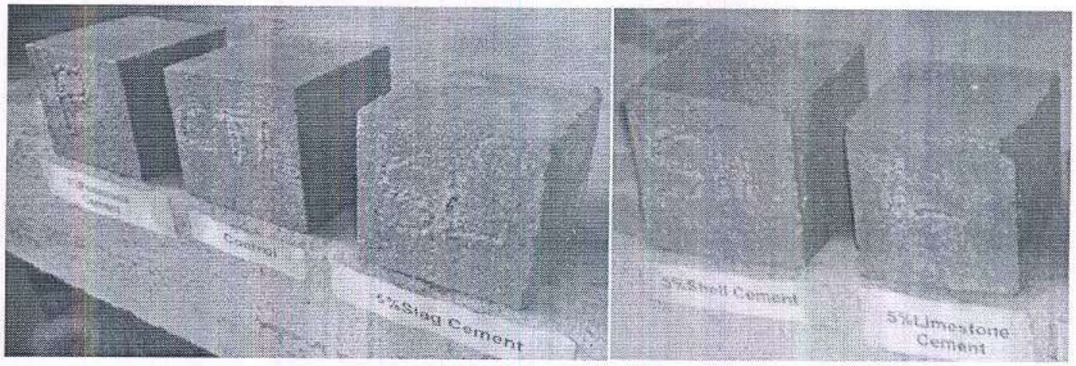
6.6 Durability tests

6.6.1 Sulphate and chloride resisting test

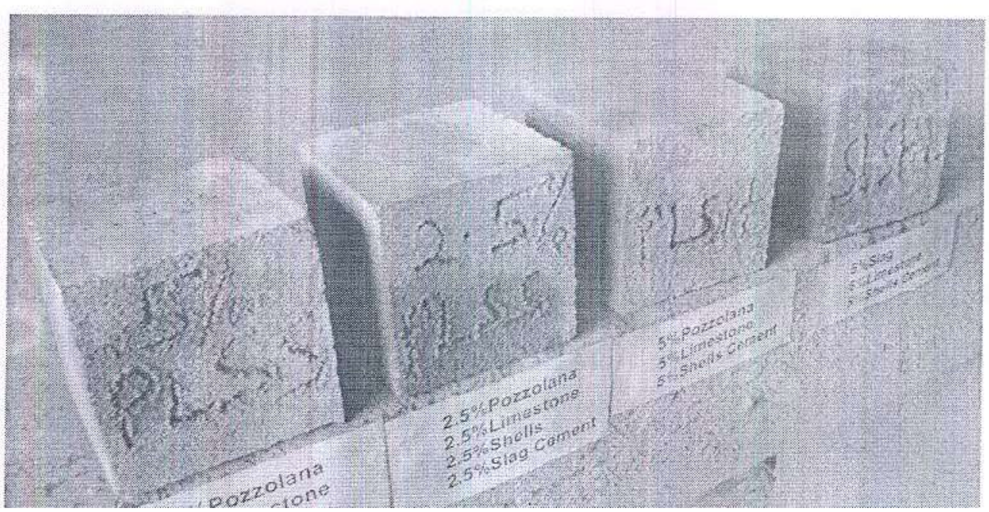
Mortar cubes, produced according to EN 196-1, were immersed in 5% Na_2SO_4 solutions and sea water (NaCl). The cubes were examined visually, photographed and tested for compressive strength at 28, 180 and 365 days. Figs. 6.16–6.19 show the physical appearance of the mortar cubes in sodium sulphate solution and seawater after 28 and 365 days. The samples seemed not physically affected, as there were no visible signs of deterioration.





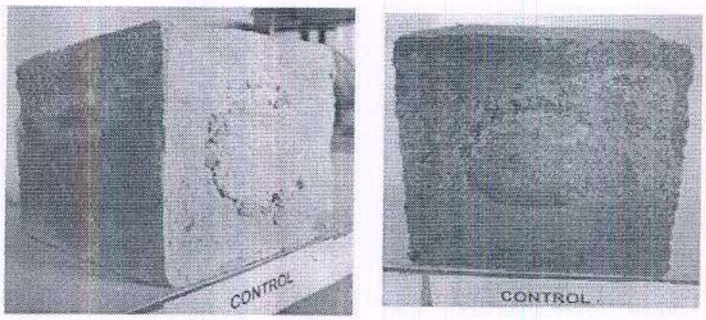


Control and 5%x blended cement cubes

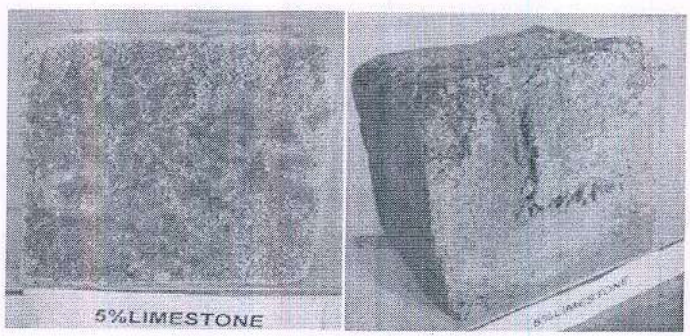


SEA WATER

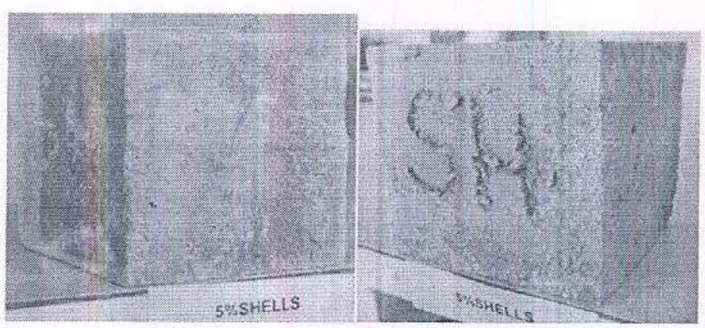
5% Na_2SO_4



Portland cement



5% limestone cement



5% shell cement

Figure 6.18: The state of control and 5%x cement cubes after a year in seawater (left) and Na_2SO4 solution (right)

SEA WATER

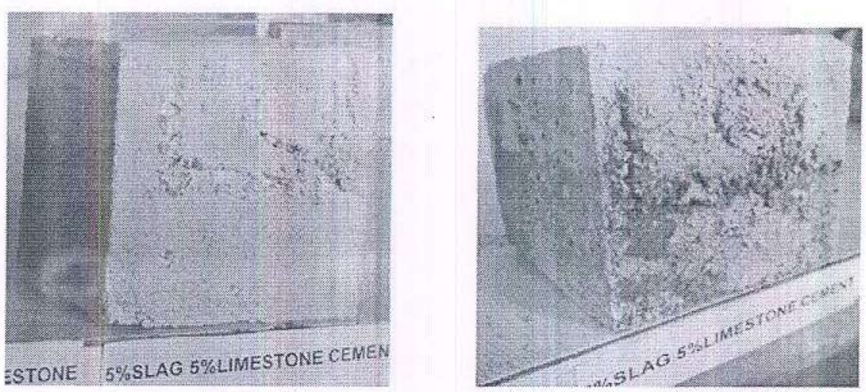


Figure 6.19: The state of the cubes after a year in seawater (left) and NaSO4 solution (right)

Analysis of their compressive strengths at 28 days presented a decrease of 8% to 36% in most affected. 5%pozzolana5%shell cement gave the best result of 38.8MPa compared to 33.1MPa from oPc(Figs. 6.20).

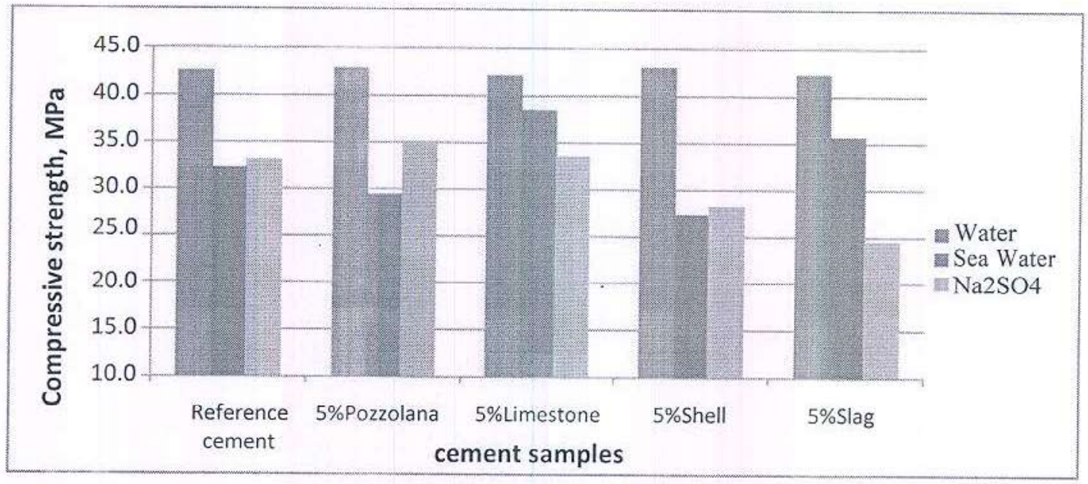


Figure 6.20: Compressive strengths of 5% cement mortars in water, seawater and 5%Na_2SO_4solution at 28 days

Generally, slag blended cements exhibited better resistance to chloride attacks and this is because slag increased the alkalinity of the pore solution of cement solution as the hydration reaction proceeded. This prevented the diffusion of chloride ions thus providing good protection (Benjamin, 2000). Also, the effect of seawater (NaCl)was reduced as the number of admixtures in the cement wereincreased (Fig. 6.21).

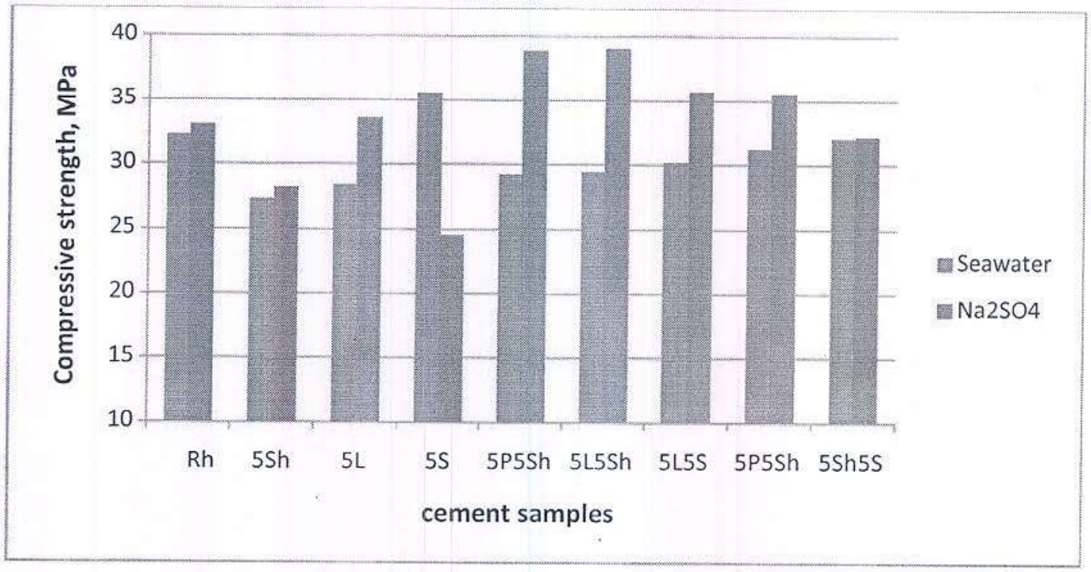


Fig. 6.21: Compressive strength of blended cement mortars in water, seawater 5% Na_2SO_4 solution at 28 days.

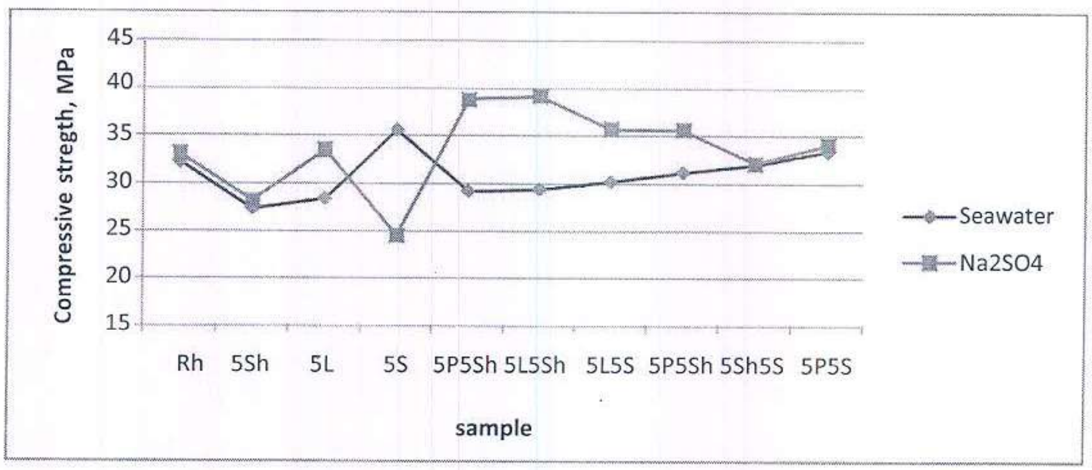


Figure 6.22: Comparative compressive strengths of binary and ternary blended cement mortars in seawater and 5%Na_2SO_4solution at 28 days

The effect of 5%Na_2SO_4 solution was more pronounced than seawater. This deleterious effect was due to the attack of sulphate on $Ca(OH)_2$ and alumina producing ettringite and other sulphonate compounds which lead to expansion of concrete/mortar and disruption. The results (Table 5.18) show that pozzolana-based cement produced the 142 highest resistance to sulphate attack with 5%slag cement giving the lowest strength value of 24.5MPa. The low CaO/SiO_2 ratio of the clay pozzolana accounted for its effective sulphate resistance (Farrel*et al*, 2000). Significantly, increasing the admixture content from binary to quinternary improved the resistance to sulphate attack. This could be attributed to the combined effect of admixture filling pores, pozzolanic action and reduction of $Ca(OH)_2$, and reduction of alkalinity needed for sulphate action. In all, 2.5%*x*2.5%*y*2.5%*z*2.5%*p* cement provided the best blend that could resist both seawater and sulphate solution negative action. This further confirms the assertion that a combination of four of the admixtures at 2.5% each reduces the portlandite content from the X-ray analysis (Table 5.11) and TG analysis (Table 5. 13) of the cement and such will provide high resistance to acidic attack.

Figure 6.18 and 6.19 show that the physical appearance of the mortar cubes in both solutions deteriorated and the strengths also decreased(Fig. 6.22) after 365 days.In both NaCl and 5% Na_2SO_4solutions, 5%limestone5%shell cement was most affected by as much as 35% and 39% respectively. As usual, blending three or more admixtures produced cements which performed better than the reference cement (Figs. 6.22 – 6.23). Finally, slag blended cements performed better than the rest in both solutions as stated by Wu *et al*,(1999) and Dongxue*et al*,(1997) in their work on resistance of slag cement in sulphate solution.

Figure 6.23: Compressive strengths of cement mortars in various solutions at 365 days

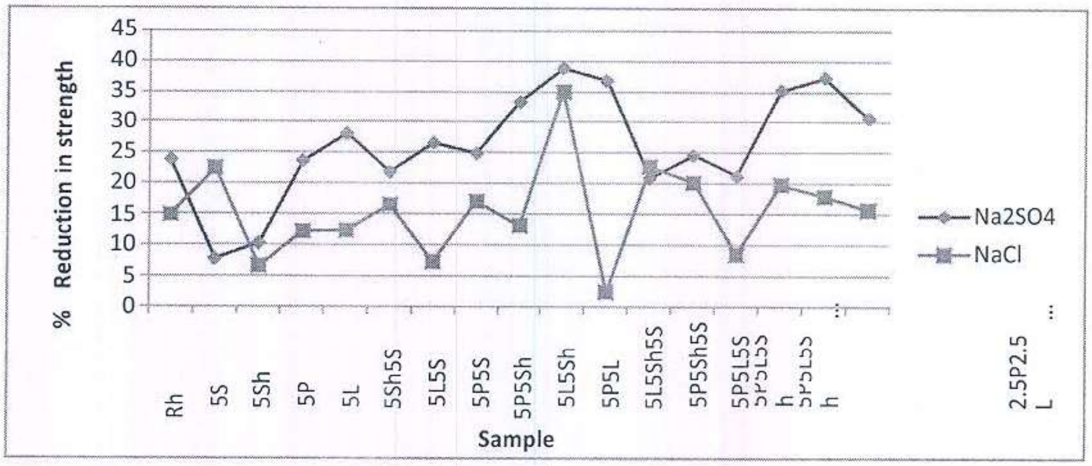


Figure 6.24: Percentage reduction of strength of blended cement mortars in seawater and Na_2SO_4 solution in 365 days

6.8 Economic benefits on using admixtures

Cement consumption in Ghana has been increasing steadily from 1.81 million tonnes in 2000 to about 3.4 million tonnes in 2010. Concurrently, the price of cement has increased from GH¢3.2 to GH¢10 - 12.00 during the same period. The current cement price ranges from to GH¢12.00 to GH¢16 (the year 2011) depending on the geographic location and the reasons for such trend have been enumerated in Chapter One. In addition, about 85% cement ingredients are imported into Ghana.

Assuming an FOB price	=	\$62.00/tonne
Total cost of clinker	=	\$210.27 million
Handling cost	=	1% of FOB
	=	\$2.10 million
Import Duty, VAT etc	=	5%
	=	\$10.51 million
Total cost (excluding insurance)	=	\$222.89 million

Replacing at least 15% of total clinker imports by these admixtures would amount to a

capital saving of	=	\$222.89 x 0.15 million
	=	\$33.43 million

This will be the least capital savings to Ghana per annum.In addition, the use of suitable local admixtures in cement production in Ghana will provide the following benefits:

- Increase utilization of local materials in cement production;
- Provide cheaper but durable cement for the construction industry;

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Director,

Reduce global environmental pollution; especially in the area of carbon credit;

Increase housing delivery in terms of cost, and

Provide revenue to the state and local authorities.

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Director

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.0 Conclusions

Locally available limestone, clam shell, clay and steel slag were used as admixtures and studied to ascertain their influence on cement hydration and properties. Physcial and chemical tests were performed on the four admixtures as well as cement blended with these admixtures. Binary, ternary, quaternary and quinternary cement blends were prepared for physical, chemical, mineralogical and mechanical properties. Also, durability tests were performed to determine their resistance to acidic water.

The soundness of the blended cement samples were less than 2.0mm. The water demand of the blended cements ranged from 24.5% to 34.5% and that it increased as the percentage admixture replacements of cement increased. However, 5% slag cement was lower than that of reference cement. The initial setting times of 5% and 5%x5%y blended binary and ternary cements were lower than reference cement but increasing admixture content increased the setting times. The initial and final setting times of all cement blends were within the standard minimum limits (GS 22). The slag containing cements normally demanded less water than the rest.

Infrared spectrometry, X-ray diffraction, SEM/EDX and TG/DTA analysis showed clearly that the presence of the four admixtures in concrete provided unique cement qualities such as low $Ca(OH)_2$ content and improved impermeability of the concrete.

The Infrared analysis showed a shifting of the characteristic v_3SiO_4; C-S-H from $970cm^{-1}$ to between $960cm^{-1}$ and $980cm^{-1}$ when the admixture content was increased from binary to ternaryindicating the accelerating effect of admixtures on hydration. This effect manifested in high early strength of the blended cement, especially the $CaCO_3$-based blended cement samples. The ettringite and monosulphonate of $CaCO_3$-based admixtures (that is, limestone and shell cement) bands were almost flat or disappeared compared to others, indicating increased reactivity between CO_3^{2-} and SiO_4^{4-} ions.

One significant and new finding from the study is that a combination of three admixtures (5% each) or all four admixtures (2.5% each) in the cement almost eliminated portlandite content as compared to 36.9% in the reference cement as a result of admixture hydration reactions as shown clearly from the XRD analysis. This is a novel revelation and it was sufficiently corroborated by the EDX and TG/DTA analysis. It is also very significant because the near absence of $Ca(OH)_2$ will make concretes made from these blended cements less susceptible to severe acidic attack and structural deterioration. The EDX and X-ray analysis also showed increased silica and oxygen composition of the blended cement compared to the control indicating increasing amounts of calcium silicate components.

All the 5%x blended cements produced high 2- and 28-day strengths which classified them as CEM I Class 42.5N cement whilst *5%x5%y* and *2.5%x2.5%y2.5%z* and *2.5%x2.5%y2.5%z2.5p* cement yielded CEM II/A Class 42.5N cements according to EN 197-1 standards, suitable for high strength concrete construction. All the other blended cements are classified as CEM II/A Class 32.5R cement, except *5%x5%y%5z5%p* cement. The concrete tests revealed that *5%x* blended cement concretes exhibited better workability than the reference cement and

also the compressive strengths of all the 1:2:4 blended cement concretes were higher than the targeted value of 20MPa. It is expected that 1:1.5:3 mixes will provide higher strengths. The mechanical properties of the blended cement could be improved when more efficient milling equipment and grinding aids are used, to better inter-grind the cement or clinker with admixtures instead of just blending them.

The durability tests using sea water and 5%Na_2SO_4, showed that the compressive strengths of all the cement samples were affected up to 365 days; the effect of 5%$NaSO_4$ solution was more pronounced than seawater. Generally, slag blended cements exhibited better resistance to chloride attacks whilst pozzolana-based cements produced the highest resistance to sulphate attack. The study showed that the effect of seawater (NaCl) and Na_2SO_4 on strength was reduced as the number of admixtures in the cement were increased. In all, the quinternary *(2.5%x2.5%y2.5%z2.5%p)* cement provided the best blend that could resist both seawater and sulphate solution negative action. This confirmed the assertion that reduction of the portlandite content as a result of a combination of four admixtures in cement (from the X-ray analysis and TG analysis) will provide high resistance to acidic attack.

Economically, incorporating local admixtures up to 15% of cement content will save the nation at least $33.43 million annually from clinker imports. In addition, it would 149 provide increased utilization of local materials in cement production, cheaper but durable cement for the construction industry, reduce global environmental pollution, increase housing delivery in terms of cost, and provide revenue to the state and local authorities.

7.1 RECOMMENDATIONS

From the results and conclusions drawn from the analysis made it is recommended that the limestone, clam shells, clay deposits and the steel slag produced as waste from the steel industries in Ghana be exploited and used as admixtures in cement production in order to improve the mechanical properties of cement products. However, further works need to be done on utilisation of blended cements using a combination of three and four admixtures, for the construction of both ordinary and reinforced concrete structures for observation and evaluation. This will include, among others:

- Pilot production with the ultimate aim of utilising local admixtures in cement must be encouraged.
- Further studies on long-term (5yrs) strength and other properties of blended cements must be carried out.
- Construction of test walls in the three climatic (coastal, tropical and savannah) for field and related studies related to environmental effects must be conducted.

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APPENDICES

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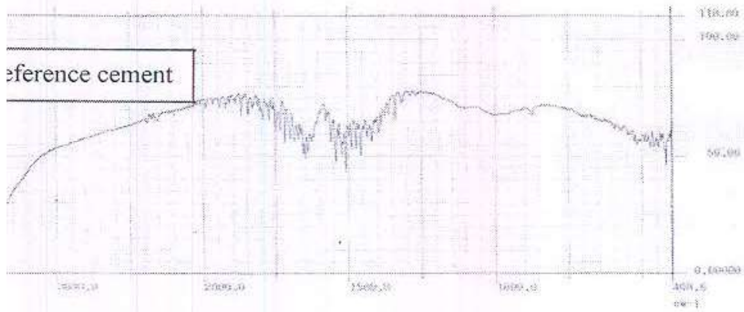
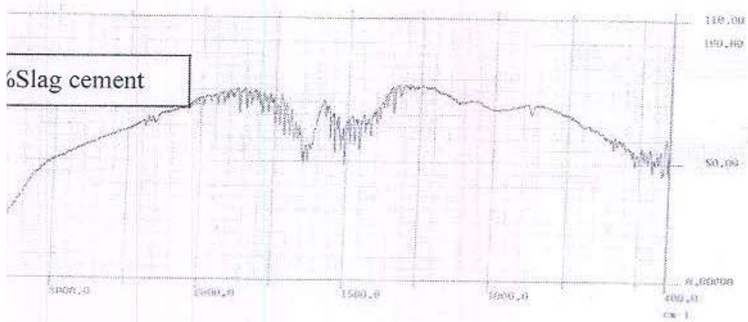
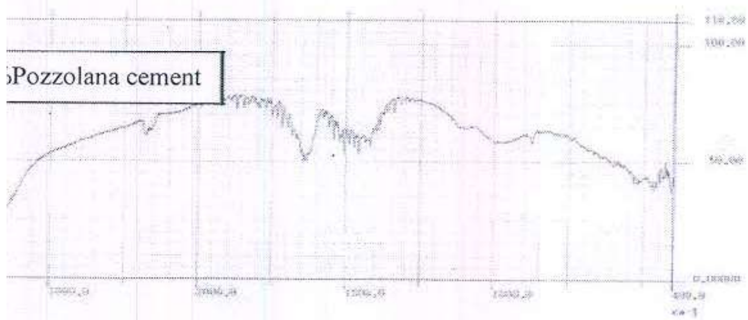
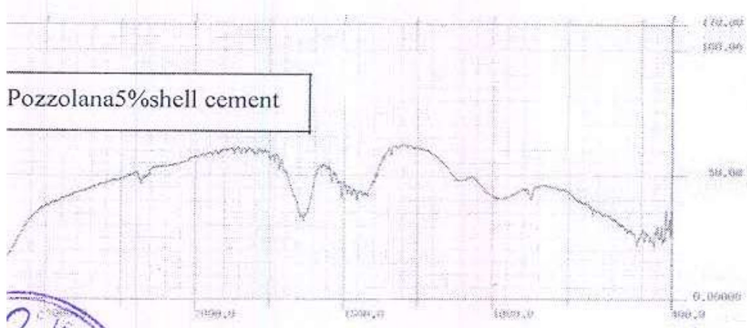
APPENDIX I

Infrared Spectra of Some Blended Cements









APPENDIX II

XRD Measurement Conditions:

File name	C:\Data 2010\June 2010\Eugene_5L.xrdml
Sample Identification	5L
Comment	5 to 85 deg
Measurement Date / Time	20/06/2010 08:46:10
Operator	Administrator
Raw Data Origin	XRD measurement (*.XRDML)
Scan Axis	Gonio
Start Position [°2Th.]	5.0300
End Position [°2Th.]	84.9500
Step Size [°2Th.]	0.0800
Scan Step Time [s]	10.0000
Scan Type	Continuous
Offset [°2Th.]	0.0000
Divergence Slit Type	Automatic
Irradiated Length [mm]	12.00
Specimen Length [mm]	10.00
Receiving Slit Size [mm]	0.2000
Measurement Temperature [°C]	25.00
Anode Material	Cu
K-Alpha1 [Å]	1.54060
K-Alpha2 [Å]	1.54443
K-Beta [Å]	1.39225
K-A2 / K-A1 Ratio	0.50000
Generator Settings	40 mA, 50 kV
Diffractometer Type	0000000000000000
Diffractometer Number	0
Goniometer Radius [mm]	173.00
Dist. Focus-Diverg. Slit [mm]	100.00
Incident Beam Monochromator	No
Spinning	No

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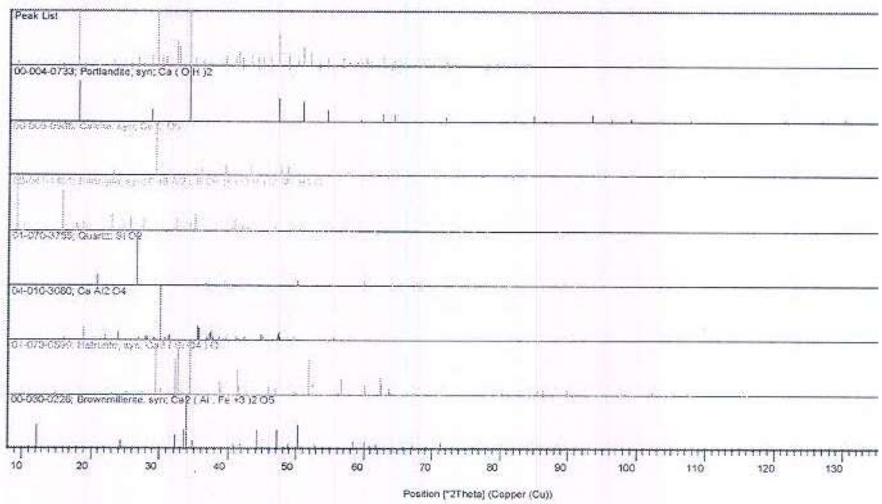
Peak List:



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Pattern List:

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	00-004-0733	55	Portlandite, syn	0.000	1.044	Ca (O H)2
*	00-005-0586	42	Calcite, syn	0.000	0.550	Ca C O3
*	00-041-1451	31	Ettringite, syn	0.000	0.202	Ca6 Al2 (S O4)3 (O H)12 ·26 H2 O
*	01-070-3755	28	Quartz	0.000	0.154	Si O2
*	04-010-3080	13	calcium dialuminium oxide	0.000	0.268	Ca Al2 O4
*	01-073-0599	41	tricalcium silicate oxide	0.000	0.588	Ca3 (Si O4) O
*	00-030-0226	19	Brownmillerite, syn	0.000	0.344	Ca2 (Al , Fe +3)2 O5

Document History:

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]
9.0798	668.15	0.2362	9.73977	7.79
12.1076	253.30	0.2362	7.31009	2.95
13.1908	63.90	0.1574	6.71214	0.75
15.7702	592.38	0.2362	5.61962	6.91
18.0290	8308.53	0.2362	4.92031	96.92
18.9090	359.53	0.2362	4.69327	4.19
20.9076	117.50	0.1574	4.24892	1.37
22.9608	892.86	0.3149	3.87342	10.42
24.3136	266.36	0.1574	3.66088	3.11
25.6265	448.51	0.2362	3.47623	5.23
26.6447	1475.01	0.2362	3.34566	17.21
27.5015	599.78	0.2362	3.24333	7.00
28.6919	1793.44	0.2362	3.11143	20.92
29.4340	8572.72	0.2362	3.03465	100.00
30.0691	1568.87	0.2362	2.97199	18.30
30.8043	1444.61	0.2362	2.90271	16.85
32.2330	3745.17	0.2362	2.77724	43.69
32.6300	3055.78	0.1574	2.74435	35.65
34.0857	8546.21	0.2362	2.63040	99.69
34.9519	1210.81	0.2362	2.56718	14.12
36.0092	892.96	0.2362	2.49419	10.42
36.6670	582.20	0.2362	2.45094	6.79
37.2757	545.88	0.2362	2.41230	6.37
38.8375	688.11	0.2362	2.31882	8.03
39.4565	1399.72	0.2362	2.28386	16.33
40.8349	1344.38	0.2362	2.20989	15.68
41.2989	2360.04	0.2362	2.18613	27.53
41.8453	1165.98	0.2362	2.15884	13.60
43.2159	1914.70	0.3149	2.09350	22.33

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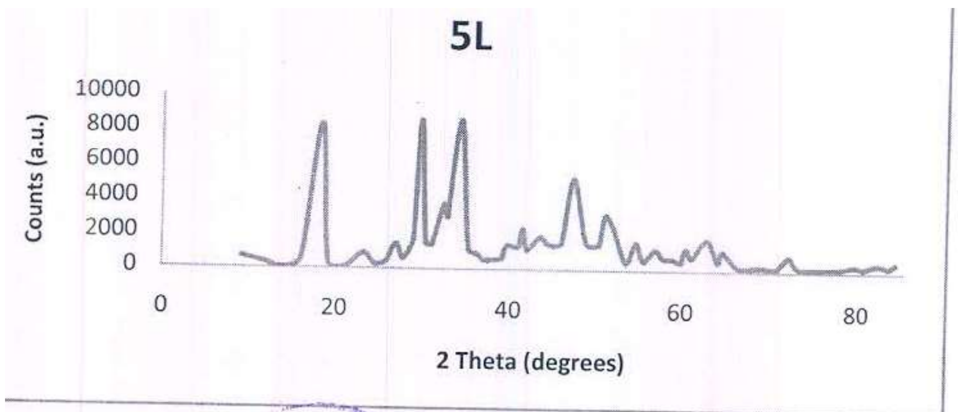

esolved XRD graph of 5% Limestone cement used to calculate % composition

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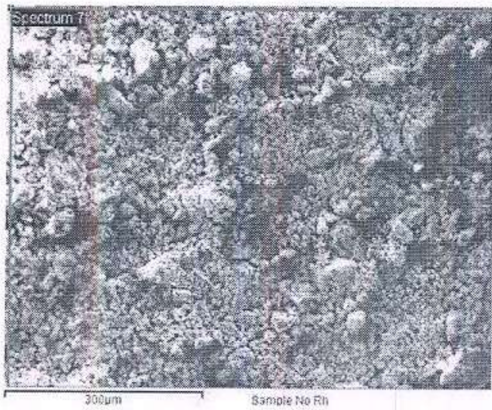
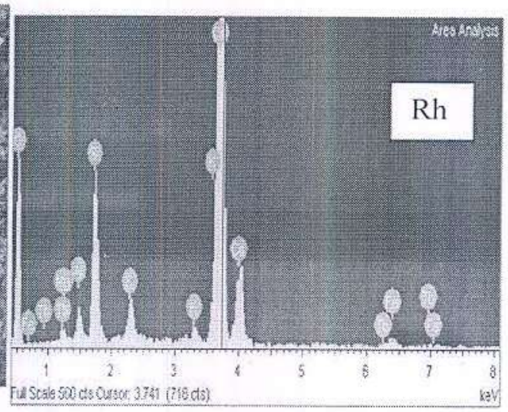
APPENDIX III

SEM/EDX graphs and computer generated values



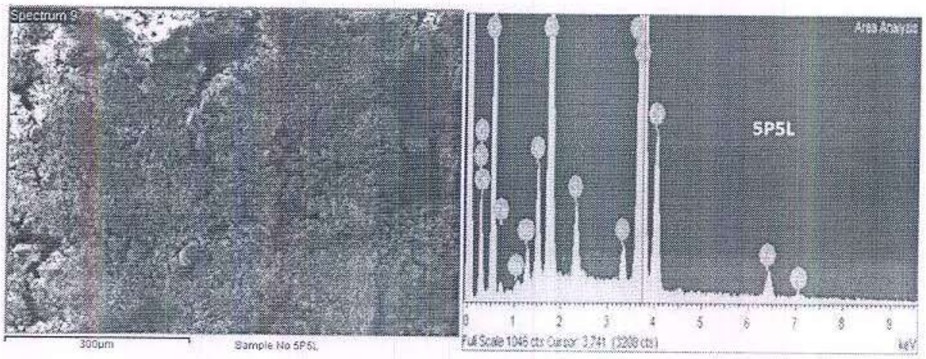


Spectrum processing : No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 5
Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Mg MgO 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
S FeS2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
CaWollastonite 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM
Tb TbF3 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	8.67	14.79
O K	48.21	61.77
Mg K	0.24	0.20
Al K	1.06	0.81
Si K	5.52	4.03
S K	1.39	0.89
K K	0.70	0.37
Ca K	32.63	16.69
Fe K	1.07	0.39
Tb L	0.51	0.07
Totals	100.00	

Sample 5P5L



Spectrum processing : No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 5
Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM Na
Albite 1-Jun-1999 12:00 AM Mg
MgO 1-Jun-1999 12:00 AM Al
Al2O3 1-Jun-1999 12:00 AM Si
SiO2 1-Jun-1999 12:00 AM S
FeS2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00
AM CaWollastonite 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	9.80	16.12
O K	50.57	62.43
Na K	0.15	0.12
Mg K	0.62	0.50
Al K	1.55	1.13
Si K	6.45	4.54
S K	1.15	0.71
K K	0.70	0.35
Ca K	27.52	13.56
Fe K	1.50	0.53
Totals	100.00	

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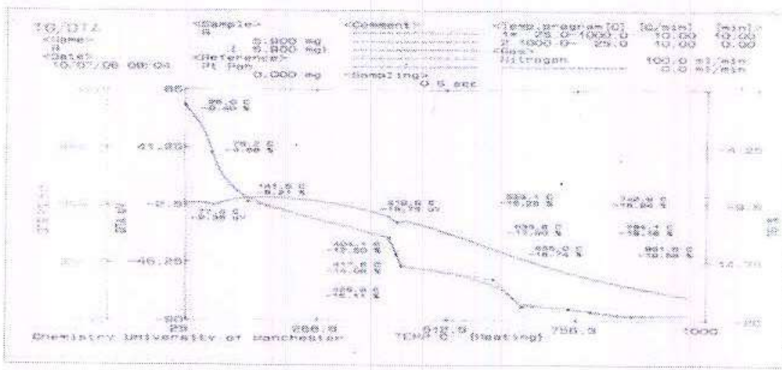
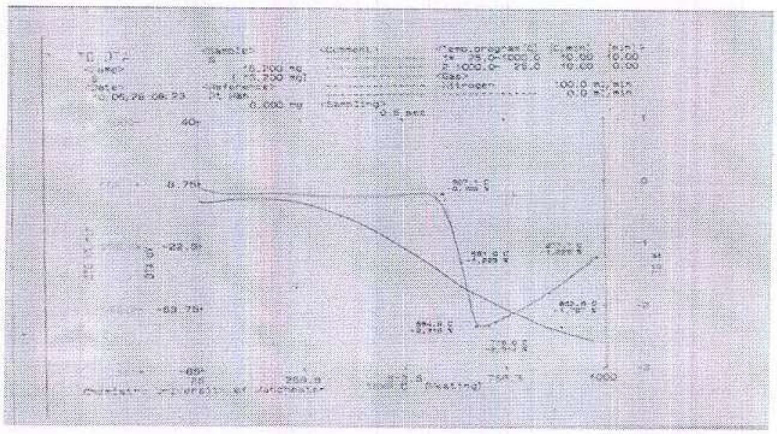
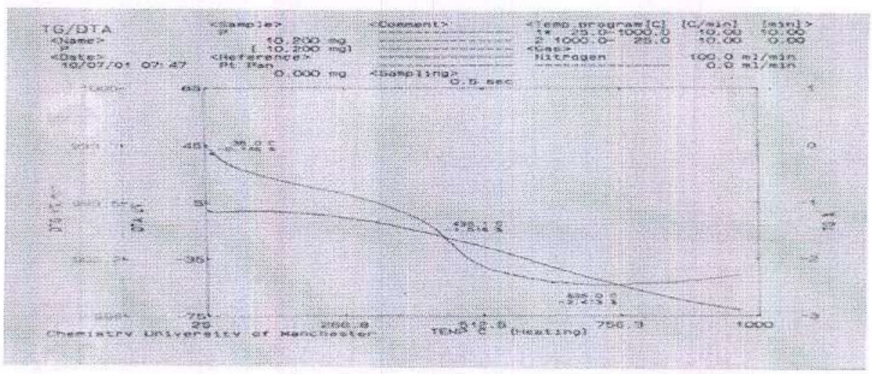
APPENDIX IV

TG/DTA THERMOGRAPHS OF BLENDED CEMENTS







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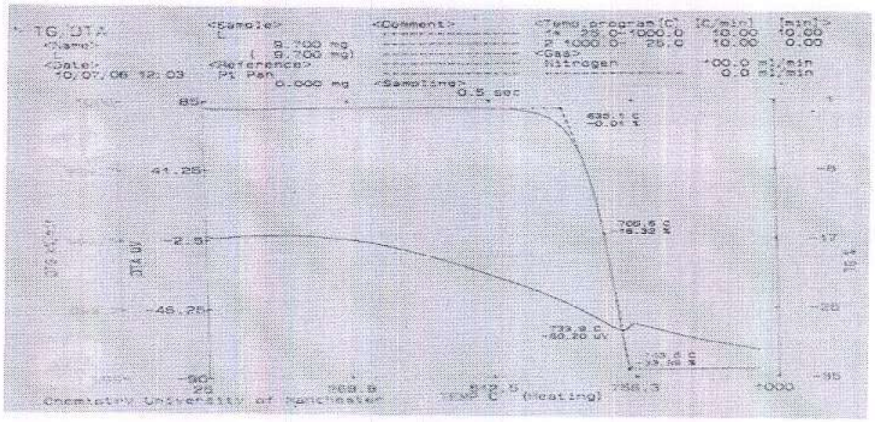

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have shown that higher levels of alkalis lower strength gain of cement beyond 28 days. However, the total absence of alkalis results in abnormally low early strength [Lea, 1970; Neville, 2000). The sulphate and chloride contents of the binary cements were lower than the standard limit of 3.5% and 0.10% respectively (EN 197-1). This is quite positive because excess SO_3 leads to formation of sulphonates that cause expansion in cement concretes which are detrimental to cement strength and durability (Odler and Gasser, M, 1988). The other minor constituents like TiO_2, MnO_2 and P_2O_3 were less than 0.5% and have no effect on strength and properties of cement products.

The CaO contents of the 5%*x*5%*y* ternary cement blends were above 52% except 5%pozzolana5%slag cement which gave a value of 50.41% (Table 5.6). Even though the CaO values are lower than the reference cement (Table 3.2) by at least 2.1% the chemical compositions of the *5%x5%y* cement blends (Table 5.6) meet the minimum percentage requirement needed to give expected reactivity during hydration to produce the strengths and soundness expected to meet minimum values specified by EN 197-1(2000). The silicon dioxide contents of between of 18.5% and 24.5% also give a positive indication of their reactivity during hydration. The MgO content was less than 5% and that of TiO_2, MnO_2 and P_2O_3 were below 0.5%. The SO_3 and chloride contents were lower than the standard limit of 3.5% and 0.1% respectively (EN 197-1)

Tables 5.7 presents the chemical compositions of *10%x5%y* ternary and *5%x5%y5%z* quaternary blended cements with a cement replacement of 15% whilst that of *10%x10%y* ternary, *2.5%x2.5%y2.5%z2.5%p* and *5%x5%y5%z5%p* quinternary blended cements are shown in Table 5.8. The lime contents of these cements ranged from 43.67% to 54.78%. Obviously, samples with less than 50% CaO will record relatively lower strength. The silica content was between 13.95% and 25.61%. The iron oxide and alumina contents of these blends ranged from 2.39% to 6.44% and 1.86 to 5.95% respectively, with slag blended samples giving appreciable values.

6.3 Mineralogy of hydrated blended cements

6.3.1 Infrared Spectrometry

The IR spectra of hydrated 5% binary and 5%*x*5%*y*blended cements at 7 days and 28 days are shown in Figs. 5.4 -5.6, and also summarized in Tables 5.9 - 5.10. In the high zone the peak at 3645cm^{-1} is assigned to the O-H stretching of $Ca(OH)_2$ formed whilst the peaks at 970 cm^{-1} is attributed to calcium silicate hydrate (C-S-H). The broad band at 3600-3000 cm^{-1} is due to symmetric and asymmetric stretching (v_1 and v_3) of the O-H vibration of the water molecule which is more intense in 28 days hydration spectrum. Deformation of water band at 1645 cm^{-1} is present in both spectra. The CO_3^{2-} bands (v_3, v_2) at 1480 cm^{-1}and 875 cm^{-1} are diminished for both spectra of 5%shell and 5% limestone cement blends compared to other admixtures indicating the significant influence of $CaCO_3$in the hydration process. Also, some SiO_4 and CO_3 bands were shifted after 7 days due to admixture reactions. The 1120 cm^{-1} and at $v_3SO_4^{2-}$1100 cm^{-1} bands are attributed to ettringite *(Aft)* and monosulphonate *(Afm)* phases respectively and were present in both spectra. The main characteristic of the hydrated samples at 970 cm^{-1} accounts for the polymerization of the units SiO_4^{4-} present in C_3S and C_2S. The peaks at 450 - 460 cm^{-1} signifies the presence of calcium aluminate and aluminosilicate hydrates which

The CO_3 and SiO_4 ion bands decreased as the hydration days increased for all the samples. The ettringite bands increased as the hydration days increased whilst SO_4 bands decreased and this could be due to replacement of SO_4 ions in ettringite by CO_3 ions. On the contrary, 5%pozzolana5%slag cement and 5%shell5%limestone cement spectra have their v_3SO_4 bands and v_3SiO_4 bands increasing as the hydration days increased therefore their bands in the 7 days hydrated samples have weak intensities unlike their 28 days spectra which have strong intensities. It could be deduced that the chemical reactions that led to their formation was slow as compared to that of the control and the other spectra which seem to be rapid.

Ettringite band at 1100 cm^{-1} is present in all the samples. The band at 3450 cm^{-1} in the samples is the symmetric and asymmetric stretching (v_1 and v_3) of O-H of the water molecules, although, there are some slight differences in the intensities of the bands; they all have the same wave number. The v_3SO_4 bands are present at 1000 cm^{-1} although the band is indistinguishable from that of v_3SiO_4.

6.3.2 X-Ray diffraction analysis

The X-Ray diffraction graphs show ettringite formation and all clinker minerals, namelyalite (C_3S), belite(C_2S) calcium alumunate (C_3A), and ferrite (C_4AF) as well as portlandite ($CaOH_2$). From Table 5.11 the portlandite [$Ca(OH)_2$] content is considerably reduced from 36.9% of reference cement to between 9.1% and 13.4% as a result of admixture reactions. Reduction of $Ca(OH)_2$ in cement product reduces the susceptibility of the blended cement to acidic attack. However, the formation of ettringite was enhanced considerably from 9.1% in reference cement to 15.5% in 5%shell cement, 33.2% in 5%pozzolana cement and 35.3% in 5%limestone cement and 21.7% in 5%pozzolana5%slag cement. However, the percentage was reduced to 6.5% in 5%pozzolana5%limestone cement.The increase in ettringite will lead to reduction in its tendency to transform to the calcium aluminate monosulphatethat affects the stability of cement products and makes it more susceptible to sulphate attack.

6.3.3 Microstructure and EDX analysis of cement samples

The micrographs (Figs. 5.13 – 5.21) from the SEM graphs indicated clearly that the pores of the blended cement were reduced as a result of addition of admixtures, except 5% limestone cement. The elemental composition (Table 5.12) from the Electron Dispersive X-ray (EDX) analysis showed that the Ca element reduced from 32.6% to between 25% and 31.7% in the blended cements. However, the mass percentage of oxygen (O) and silicon (Si), increased by at least 6.5% and 5% (except 5%shell5%slag cement) respectively in the blended cements. Since $Ca(OH)_2$ had been observed to have reduced in the blended compared to the reference cement from the Infrared (IR) and XRD analysis, it can be concluded that the increase in these elements will lead to increase amounts of calcium silicate compounds (C_3S and C_2S) which are essential to mechanical properties of cement. That is actually confirmed by the higher peaks of C_3S of the blended cements from the XRD graphs of Figs. 5.7 and 5.8, which give an indication of high early compressive strength. Also, reduction in $Ca(OH)_2$ is an additional advantage as it is a potential source of acidic attack which weakens and deteriorates concrete.

6.3.4 Thermoanalysis of raw samples and hydrated blended cements

Chemically, the steel slag contains iron oxide, silica, lime, aluminium oxide and MgO (Table 4.4). Heating of lime in the presence of silica to $1000^{o}C$ yields calcium silicate products. Formation of the compound $CaO.SiO_2$ started at an endothermic peak of $607^{o}C$ (check Appendix IV). The endothermic peak at 651°C was the conversion of the product formed to the metastable β-$CaO.SiO_2$. The formation of the α-$CaO.SiO_2$ phase began at $684.9^{o}C$ which was due to the conversion of the metastable state. Crystallization of the final product of stable hydrated calcium silicate occurred by an endothermic reaction at $977.7^{o}C$. Total loss of mass was about 1.8% (Fig. 5.22).

The main chemical component of limestone is $CaCO_3$. The endothermic peaks between 600°C and 690°C were due to decomposition of $CaCO_3$ leading to the evolution of carbon dioxide. The DTA endothermic peak at 733°C signifies the phase change (decomposition) of calcite to CaO (Appendix IV). There was a total mass change of about 34%. This is less than the expected 44% because of presence of impurities like sand(SiO_2) in the limestone used (Table 4.) The thermal effect and phases changes for clam shells are similar to that of limestone since both contain mainly $CaCO_3$. Evolution of CO_2 occurred between 666°C and 754°C whilst the phase change occurred at 740°C. The total loss of mass for the shells was about 35%.

When the clay sample was heated, a number of reactions took place which caused a series of mineralogical and crystallographic changes. An endothermic reaction, which resulted in the removal of nearly all the physically bound water occurred from 30°C to 176°C. The endothermic peaks at 435°C showed the expulsion of structural water principally from the crystal lattice of kaolinite with a mass loss of about 0.15%.As the temperature increased, dehydroxylation of the clay and formation of quasi-amorphous material, metakaolin, which is reactive with lime occurred around 635°C. Endothermic reactions which result from the removal of crystal lattice water are the most critical ones from the pozzolanic activity point of view. Each clay has an optimum calcination temperature which produces high pozzolanic activity. This temperature is just above the completion of the dehydroxylation peak and below the onset of the re-crystallization peak.

Figure 5.18 presents the thermogram of reference cement sample. The endothermic peak between 26°C and 142°C represented the evaporation of water molecules and dehydration of calcium silicate hydrate (C-S-H), formation of ettringite, decomposition of gypsum (Lea, 1970). Dehydroxylation of $Ca(OH)_2$ (portlandite) occurred from 404°C to 426°C and the TG curve gave an estimated $Ca(OH)_2$ content of 15.11% (0.76g). Since in cement burning, more than one reaction can occur at a time, the release of combined water from the clay and reaction between $CaCO_3$and finely divided quartz may have occurred at 599°C. The endothermic peaks at

636.8^{o}C and 655°C represented the dissociation of$MgCO_3$ and $CaCO_3$. The temperature range of 742.9°C - 862°C and beyond mark the beginning of the formation of calcium silicateand the final product of hydrated CaO. SiO_2. H_2O (Lea, 1970). The total loss in weight was about 19.6%.

$$CaO + SiO_2 \rightarrow CaO.SiO_2 \qquad 6.1$$

Heating 5%limestone cement, 5%shell cement, 5%pozzolana cement and 5%slag cement revealed dehydration of hydrated calcium silicate, calcium sulphate and ettringite which began at 32°C and ended at 180°C except for 5%slag cement which ended at 202°C. Dehydroxylation of portlandite occurred between 376°C and 488°C whilst $CO_2$was released due to decomposition of CaCO3 at the range of 595°C to 936°C (Taylor, 1997; Dweck*et al*, 2000; Kourounis*et al*, 2007) as given by the equation:

$$Ca(OH)_2 = CaO + H_2O \qquad 6.2$$

The loss of weight of 5% blended cements due to decomposition of $Ca(OH)_2$ was between 1.0% and 3.0% compared to 5.9% for the reference cement (Table 5.13). This gives a positive indication that the presence of the four admixtures reduced amount$Ca(OH)_2$ precipitated as compared to the reference cement and a further proof that addition of the admixtures lowered the portlandite [$Ca(OH)_2$] content as a result of the dilution of clinker and the pozzolanic reactions that ensued (Voglis*et al* (2005). The total mass loss for heating 5L, 5Sh, 5P and 5S cement mixtures was estimated at 17.73%, 17.25, 15.79 and 16.82% respectively. Further analysis of 5%limestone5%pozzolana cement (ternary blend);
2.5%pozzolana2.5%limestone2.5slag cement and 5%limestone5%pozzolana5%slag

cement (quaternary blend) and 2.5%pozzolana5%limestone2.5%shell2.5%slag cement revealed a further decrease of portlandite to 2.63%, 1.20%, 1.52% and 1.55% respectively. Figure 6.1 clearly shows that the presence of the admixtures significantly reduced the portlandite content from 24.58% in Portland cement to 5.02% in quaternary blend *(2.5x2.5y2.5z)* and 6.31%-6.46% in quinternary blended cement samples.

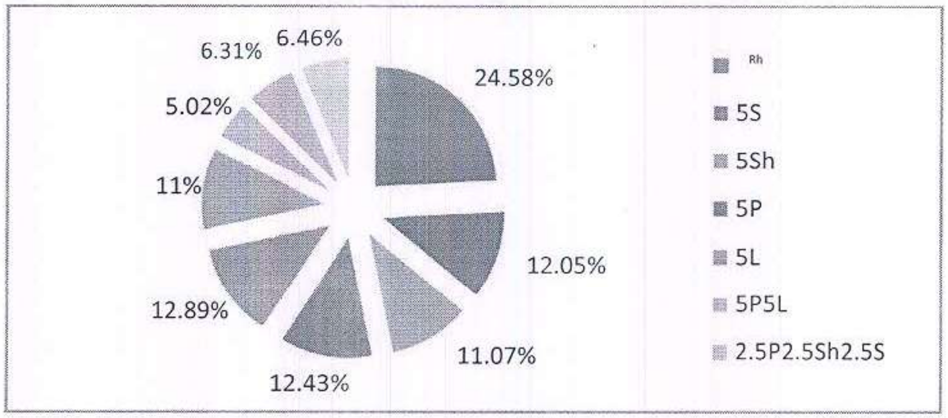

Figure 6.1: Estimated portlandite content in cement samples from TG analysis

6.3.5 Significant results from the mineralogical analysis

Several studies by prominent researchers such Tsakiridis*et al* (2008), Kumar *et al* (2008), Kourounis*et al* (2007), AmitRai*et al* (2002), Monshi and Asgarani (1999), Dongxue (1997), Conjeaud*et al* (1981) among others have used steel slag either alone or in combination with limestone or fly ash as ingredients in cement production. Most slag used was of high CaO composition ranging from 35% to 42% and high C_3S that are very essential for cement hydration and strength development. In this study however, steel slag with low Ca-containing mineral phases content of 12.44% and highwustite (Fe_2O_3) content of 31.52% was used in combination with limestone/clam shells ($CaCO_3$-based) and clay pozzolana, and analysedmineralogically to indicate their effect on cement hydration and formation of ettringite and portlandite.

The study has shown that the presence of these admixtures provided unique cement qualities such as low $Ca(OH)_2$ content and improved impermeability of concrete. The Infrared Analysis showed a shifting of the characteristic v_3SiO_4; C-S-H from $970cm^{-1}$ to between $960cm^{-1}$ and $980cm^{-1}$ (Tables 5. 10 and 5.11) when the admixture content was increased from binary to ternaryindicating the accelerating effect of admixtures on hydration. This effect is expected to manifest in high early strength of the blended cement, especially the $CaCO_3$-based blended cement samples. The ettringite and monosulphonate of $CaCO_3$-based admixtures (that is, limestone and shell cement) bands were almost flat or disappeared compared to others, indicating increased reactivity between CO_3^{2-} and SiO_4^{4-} ions.

One important and new finding from the study is that a combination of three (5% each) or all the four admixtures (2.5% each) in the cement almost eliminated portlandite as a result of admixture hydration reactions as obtained from the XRD analysis as presented in Table 5.11. This is a novel revelation and it was sufficiently corroborated by the EDX and TG/DTA analysis. It is also very significant because the near absence of $Ca(OH)_2$ makes concrete very less susceptible to acidic attack and structural deterioration.

6.4. Compressive Strength

6.4.1 Mortar tests

The results of the mortar compressive strengths of the reference and blended cements with different admixture contents are given in Table 5.15 and 5.16.

Generally, the 2- and 7-day compressive strengths of all the blended cement mortars were higher than the standard minimum value of 10MPa and 16MPa respectively stipulated by EN 197-1 (2000). For the 5% binary blended cements, the 2-day strengths were higher than 19 MPa in all cases, with limestone cement recording the highest value of about 23MPa. The high 2-days and 7-days strengths of the 5% and 10% cement replacement were due to the filler effect of admixtures as a result of the increased surface area that leads to an initial accelerating effect on cement hydration. (Péra *et al*, 1999, Soroka and Setter, 1977). At 28 days, they recorded strengths between 42MPa and 43MPa.

Thus, the cements containing 5% of any of the admixture can be classified as Class 32.5R and 42.5N (EN 197-1). The 28-day strengths of the blended cements ranged between 86.5% and 99.5% of the reference cement, more than 75% stipulated by ASTM C 618 (2008). This means that all the admixtures are very good materials for blending and/or integration in cement for all types of housing construction and are, therefore, suitable for early high-strength cement products as stiplated by EN 197-1 (2000).

The strength development of the various cement mortars from 2 days to 365 days, are presented in Figs. 6.2 whilst the 28-day compressive strengths are given in Fig. 6.3.

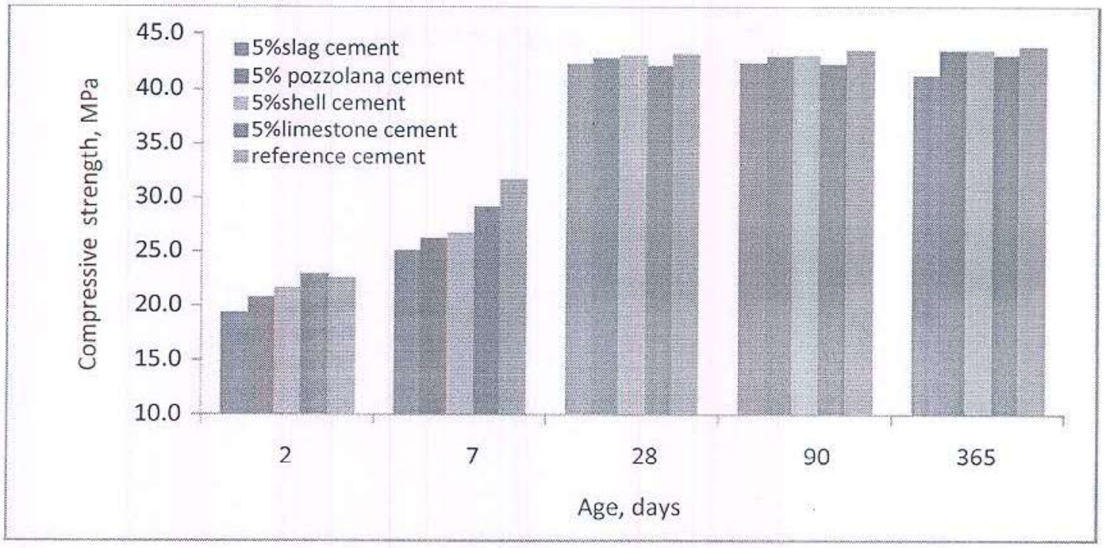

Figure 6.2: Compressive strengths of binary blended cement mortars containing 5% of one admixture.

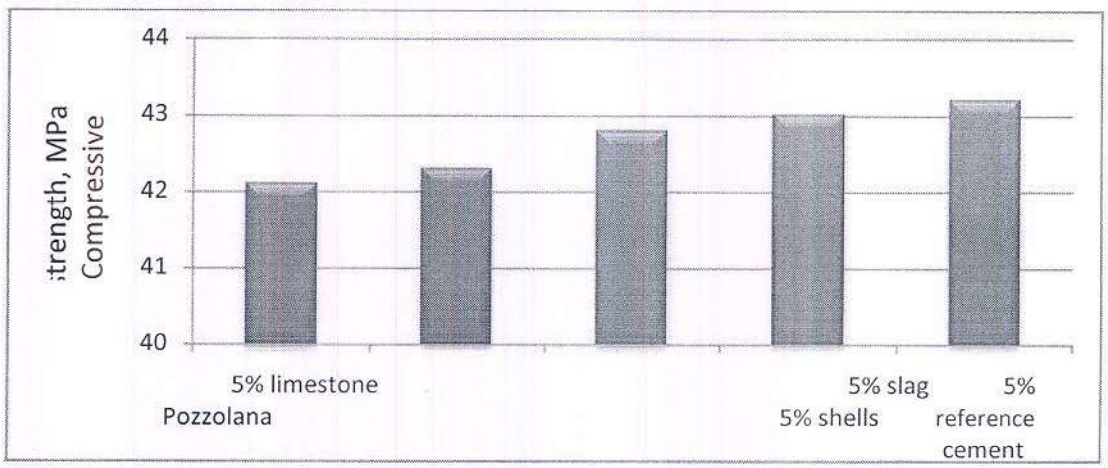

Figure 6.3: 28-day compressive strengths of binary blended cement mortars containing 5%of one admixture

The graphs show that the strengths of the blended samples increased at all times up to 365 days. However, the strengths of the 5% blended cements were always lower than that of reference cement. This is attributed partly to the fact that admixtures normally reduce the rate of reaction thus reducing the heat of hydration. The advantage however is that expansion and shrinkage are reduced resulting in less thermal cracks in cement concrete products (Lea, 1970).

Replacing 10% of the reference cement with 5% each of any two of the admixtures (for example, *5%slag5%shell* cement) produced 2-day strengths lower than the 5%cements but higher than 10MPa, ranging between 16.5MPa and 21.5MPa. Fig. 6.4 gives a graphical presentation of strength development of 5%*x*5%*y* cements from 2 to 365 days. Pozzolana slag cement produced the highest 28-day compressive strength of 41.83MPa. This could be attributed to the additional silica, CaO, C_2S provided by the two admixtures. The lowest strength of 40.1MPa was produced by limestone shell cement.

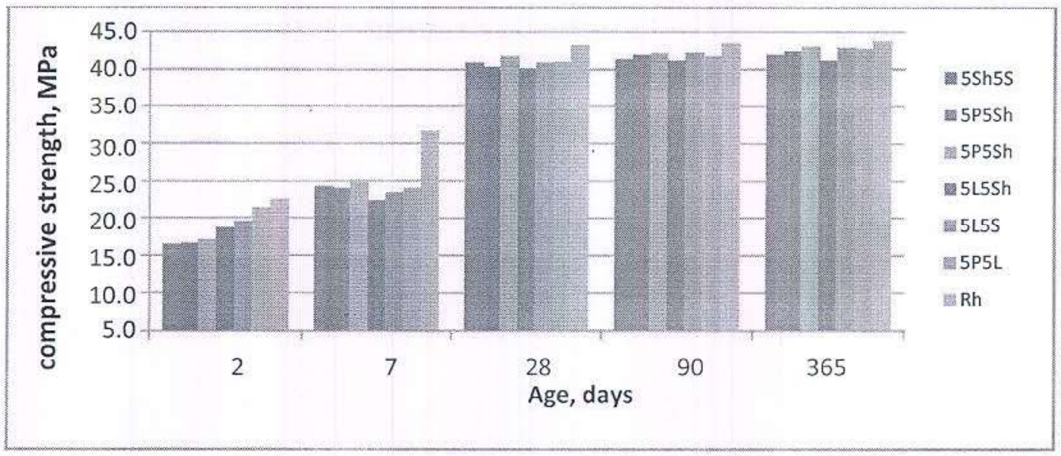

Figure 6.4: Compressive strengths of ternary blended cements containing 5% each of two admixtures.

Fig. 6.5 illustrates the compressive strengths development of 10%x5%y and 5%x10%y (e.g. *10%pozzolana5%limestone*) blended cements at 2, 7, 28, 90 and 365 days. The 2-day values were above 14 MPa whilst the 28-day strengths were between 38.5MPa and 40.5MPa (also presented in Table 5.14). These cements are classified as CEM II Class 32N (EN 197-1) and can be improved to Class 32.5R and 42.5N when the mineral admixtures are milled finer to increase their surface area. Class 32N type can be used for plain and reinforced concrete works, block making, bonding and rendering. The results, however, show that ordinary Portland cement can be replaced with 15% of admixtures (*10%x5%y; 5%x10%y*) for both concrete and general construction. For the strength characteristics of 15% replacement of ordinary Portland cement, it is observed that even though the 2-day strength of 10%*x*5%*y* cements (ternary blend) were higher than 5%*x*5%*y*5%*z* cements (quaternary blend) the 28-day and 365-day compressive strengths were almost the same (Fig. 6.5; Fig. 6.6).

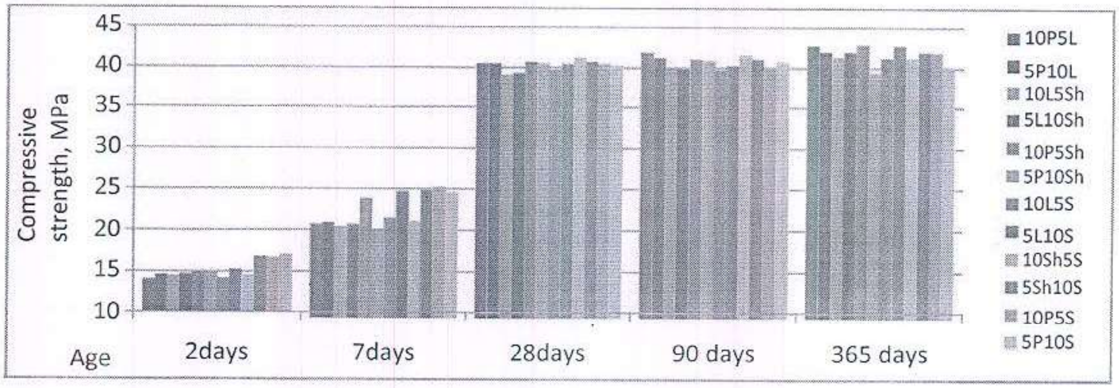

Figure 6.5: Compressive strengths of ternary blended cements containing *10%x5%y or 5%x10%y* admixtures

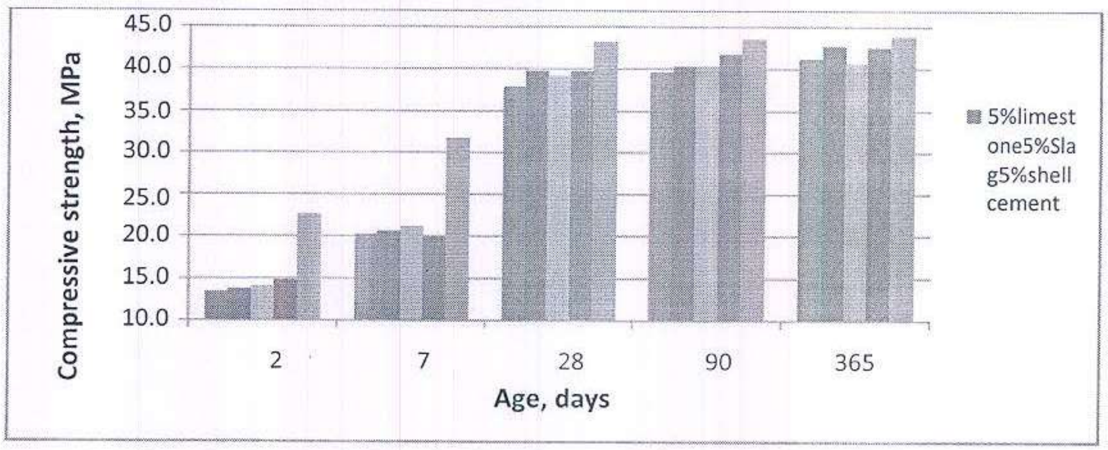

Figure 6.6: Compressive strengths of quaternary blended cements containing 5% each of three admixtures

At 15% to 20% replacement, the filler effect is surpassed by the dilution effect and this leads to lower relative strength as compared to up to 10% replacement.The compressive strength development of 20% blended cement that had been replaced with 10% each of two admixtures (10%*x*10%*y*) is illustrated in Fig. 6.7. The strengths at 2 days averaged 13.8MPa whilst the 28-day strengths were above 38MPa but below 40MPa. The strengths with 20% replacement were always lower than that of 5% and 10% *(5%x5%y*) and this should be attributed to reduction of active clinker minerals needed to obtain early high strength and slow pozzolanic action as stated by Wild *et al* (2001). The 10%pozzolana10%limestone 2- and 28-day strengths of 13.9MPa and 38.0MPa respectively compared with 12.9MPa and 41.4MPa obtained by Ghrici *et al* (2010). Also, the strengths obtained from 10% slag content with additional 10% content from any of the admixtures ranged between 87% and 91.5% as compared to 75% and 80% obtained by Altun and Yilmaz (2002) and Kourounis *et at* (2007).

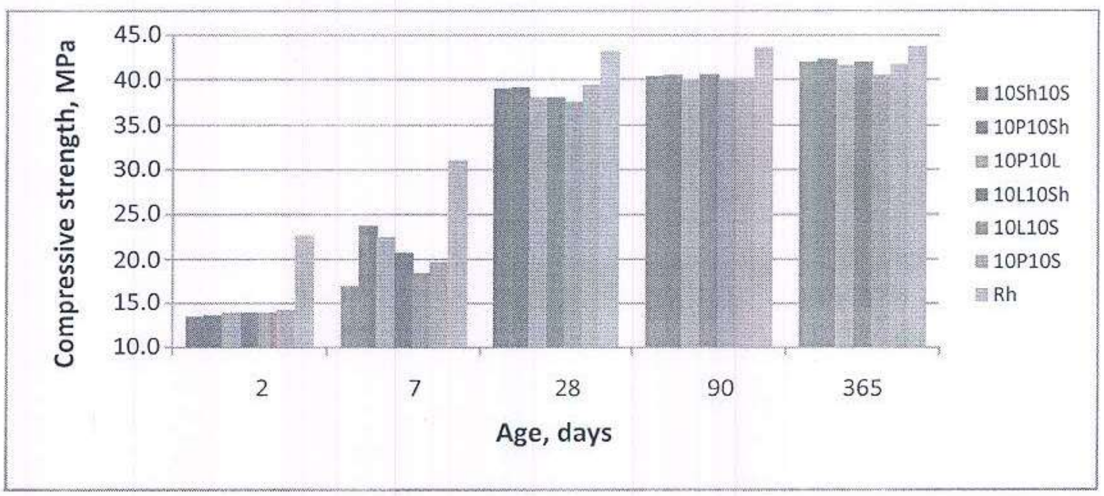

Figure 6.7: Compressive strengths of ternary blended cements containing 10% each of two admixtures

This means that these blends could not be considered as early high strength cements for high strength concrete structures but are suitable for low to medium strength concrete and general construction. Pozzolana slag cement gave the highest strength

PROJECT REPORT

on

Quality Improvement in Cement Manufacturing

Compiled and submitted

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Table of contents

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1 Introduction

Grinding aids are mostly organic compounds that are added to the clinker in the cement mill. Their main purposes are to reduce the energy required to grind the clinker into a given fineness and therefore increase the efficiency of the cement mill. Grinding aids have been used for more than 50 years and the most common additives can consist of glycols, alkanolamines and phenol-type compounds. In addition to increase the efficiency of the mill, some grinding aids also provide important positive effects on the final cement such as, rheology of the fresh cement paste or concrete and improved strength development. Grinding aids that provides these "extra" properties are called *quality improvers* or the name *performance enhancer* as we also may like to use.

The grinding technology of clinker in cement production is indeed important for several reasons. Firstly, the fineness (Blaine specific surface) of the finished cement is one of the main factors that are affecting the early strength development. Norcem produces rapid hardening cement (Norcem Industrisement) with a Blaine of 520 m^2/kg; commercially available in Norway. In order to achieve such high fineness grinding aids are used and in this particular case triethanolamine is used. In general, the energy consumption is linear up to a fineness of approximately 300 m^2/kg (Hewlett 1998). Above this level, the energy consumption increases progressively due to agglomeration in the cement mill and a higher amount of energy is lost in heat. This is usually taken care of by the use of grinding aids and also by optimizing the cement mill technology. The latter will not be considered in detail in this state of the art report.

Reducing energy consumption is therefore another main driving force in the field of cement mill technology. Approximately 35-40 kWh/t is required to produce Portland cement with a Blaine in the area of 300-340 m^2/kg (Hewlett 1998). For higher surface areas (e.g. Norcem Industrisement) the energy required is > 50 kWh/t. By the use of grinding agents the energy is reduced or the production rate is increased at the same energy consumption level. Moreover, energy saving is indeed important when producing blended cements. In the production of blast furnace slag cements the pure cement clinker is far more easy to size reduce compared to the slag. In Trenkwalder and Ludwig (2001) they estimated the power consumption to be 43 and 68 kWh/t for producing cement and slag meal (separate processes) with a Blaine of 300 and 400 m^2/kg respectively. Together with optimized mill technology they achieved reduction in the electric power consumption of 7% without the use of grinding aid. Including a suitable additive in such processes, the possibilities for further increase in the grinding efficiency are most likely present.

In summary, *conventional* grinding aids are used to increase the production rate in the cement mill. If such additions give beneficial chemical effects during hydration of the final cement (e.g. increased strength, improved workability etc.) the grinding aid is regarded as quality improver or performance enhancer. It is emphasised that several *conventional* grinding aids today are also claimed to give beneficial chemical effects to a certain extent.

2 Principle mechanisms and desirable effects of quality improvers

2.1 Mechanisms during grinding in the cement mill

The mechanisms in charge when improving the grindability of a clinker must be explained from a physico-chemical point of view. In general, the surfaces of the clinker particles are not in thermodynamic equilibrium due to the incomplete surface bonds, which lead to a free surface charge. As in all systems, the particles will try to approach equilibrium by lowering the free energy, which in turn is done by aggregation and adhesion to surfaces. When the clinker is entering the cement mill the particles are coarse and the energy considerations are not significant. As the clinker is size reduced during grinding, the free energy of the surface increases and the non equilibrium become significant. The aggregation and agglomeration will therefore become increasingly significant and the efficiency of the mill is reduced. This is shown in Figure 1b.

By using grinding aids the organic additives are adsorbed to the surface of the clinker/cement particles. This reduces the energy needed to break down the particles and reduces the surface charge. The latter is thus preventing the cohesion of cement particles. The organic additives also change the electrostatic forces between the cement particles by reducing the attraction forces (Van der Waal) and increasing the repulsion forces. The effect of using a grinding aid is shown in Figure 1a. The additives are thus behaving as surfactants.

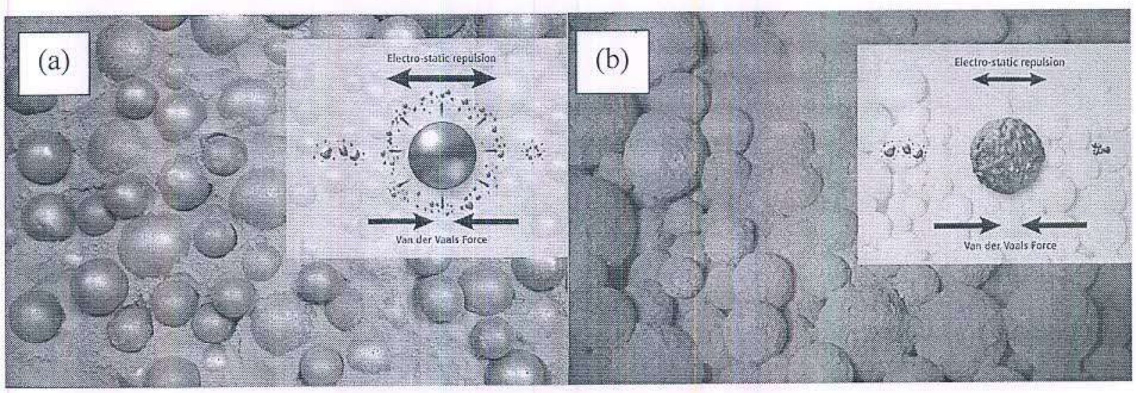

Figure 1 Principle of grinding cement clinker with (a) and without (b) grinding aid
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The energy supplied (grinding time) versus the surface area generated is usually linear up to a surface Blaine of 300 m^2/kg before the agglomeration starts. With grinding aids this linear relationship is prolonged. The maximum surface Blaine achieved, i.e. optimum grinding time, is at the point where significant deviation from linearity is seen. This is showed in Figure 2a where 3 different glycols were tested as grinding aids (Teoreanu and Guslicov 1999). It can be seen that the linear area is significantly prolonged for a given dosage of additive and that serious non-linearities start when the Blaine specific surfaces were approaching 600 m^2/kg. The reduction in evolved surface area is due to reduced activity of the surfactants as the surface area becomes too high. This is the stage where agglomeration and adherence to grinding media and walls of the cement mill starts. With respect to the dosage, an optimum dosage of additive exists for a given grinding time. The optimum dosage is achieved when a continuous monolayer is formed onto the particle surfaces (Teoreanu and Guslicov 1999). Higher additions will lead to lubrication effects that will decrease the breakdown of the particles and the efficiency of the mill decreases. In

Figure 2b large reduction in power consumptions can be seen due to increased grindability relative to the reference cement.

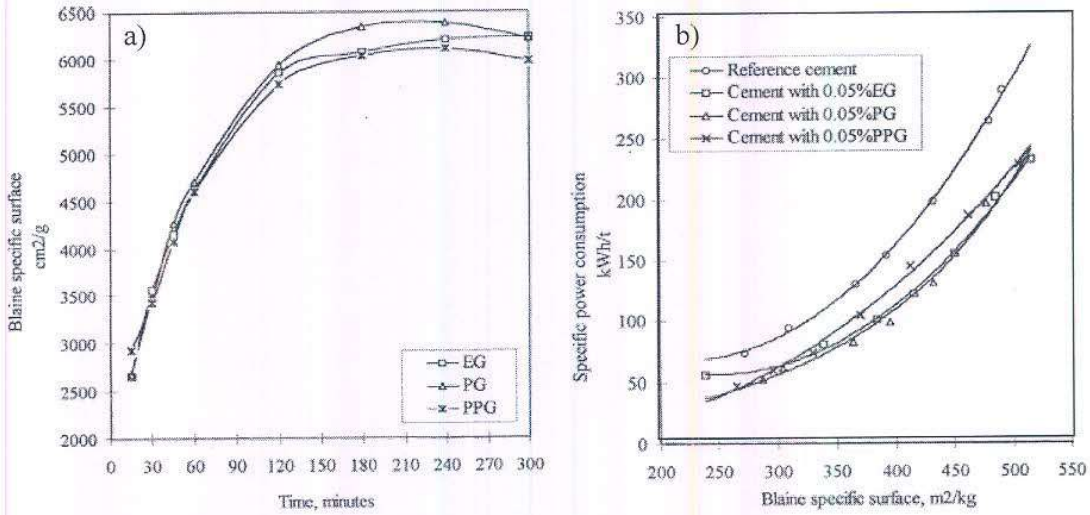

Figure 2 Evolution of specific surface as function of grinding time (a) and the specific power consumption with increasing Blaine (b). Results achieved for cement clinker ground with ethylene glycol (EG), propylene glycol (PG) and polypropylene glycol (PPG). (Teoreanu and Guslicov 1999).

Other considerations that can be taken into account regarding the grindability are the mineral composition of the clinker. Alite crystals are more elongated than belite. The more alite present in the clinker the easier it is to grind. The grindability of a clinker is determined by the fracture energy and the size of the micro cracks present (Hewlett 1998) which in turn are dependent of the cooling regime applied to the clinker. Brittleness index values have been calculated for principle clinker phases to be 4.7 (C_3S), 2.9 (C_3A), 2.0 (C_2S and C_4AF). From this we also can deduce that C_3A is easier to grind than C_4AF. In addition, mineralising effects that influence the molten phase and are forming solid solutions with C_3S and C_2S will increase the grindability by reduced hardness of these phases (Opoczky and Gavel 2004).

2.2 Mechanisms during hydration

Many grinding additives are reported to give beneficial effects during hydration. The mechanisms can in general be explained as for the admixture used in concrete. The surface of the cement has a residual positive charge whereas sand and aggregates has a net negative charge. In addition water molecules are dipoles. The overall action of charged surfactants are that they arrange in such a way that opposite charges are cancelled out, i.e. decreasing the free energy (electric potential) of the system (Hewlett 1998). The additives used during grinding are, as explained in previous section, adsorbed to the surface of the cement particles. This means that the additives will have some action on the rheology of the concrete mixture and during hydration depending of the molecule structure. Triethanolamine (TEA), for example, is widely used as grinding additive and will in fact influence the hydration properties. In Figure 3 the differential heat of hydration is shown for cement ground with different concentration of TEA, i.e. the hydration heat for pure cement is subtracted. At the lowest dosage (0.015%) it behaves as an accelerator whereas retardation properties were found at higher dosages. From the appearance of the change in hydration heat, it is the hydration rate of C_3S that is altered. In the same figure we also can see that

TEA changes the hydration of C_3A (AFt formation). At a dosage of 0.015%, TEA is accelerating both the hydration of C_3S and C_3A.

Accelerators are generally divided into two subgroups. The first group comprise admixtures that increase the hydration of C_3A by interfering with the first ettringite formation and increase the dissolution of silica (e.g. alkali metal hydroxides). The other main group include admixtures that increase the hydration of C_3S by increasing the dissolution of lime (e.g. halide, nitrate, nitrite etc.). According to Hewlett (1998) the TEA additive increases the formation of C_2AH_8 and C_4AH_{19} (and therefore promoting conversion to thermodynamic stable hydrogarnet phase) and also increases the formation of ettringite.

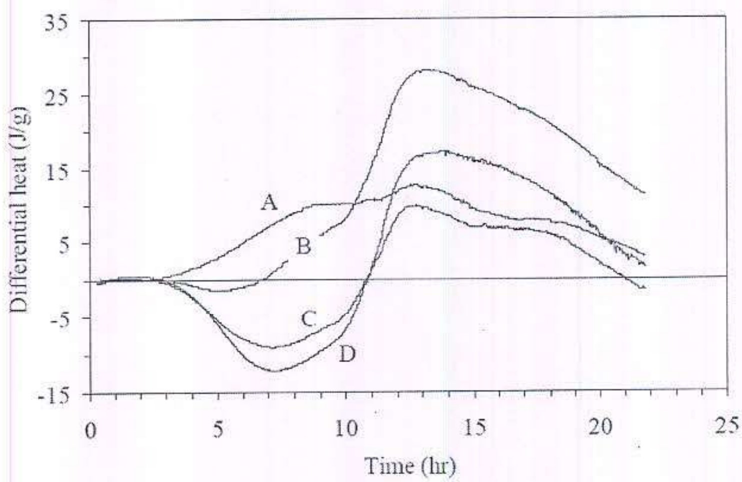

Figure 3 Hydration heat evolution for cement ground with various concentration of triethanolamine (TEA): 0.015% (A), 0.075% (B), 0.1% (C) and 0.15% (D). The hydration heat for pure cement is subtracted (Jolicoeur et al 2007).

2.3 Desirable effects

Using quality improvers in cement making affects various parameters as discussed above. The desirable effects can be summarised as follows:

- Increased grindability
- Increased or maintaining sufficient powder fluidity
- Workability/rheological effects
- Hydration effects: retarding/accelerating effects
- Increased strength

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Increasing the grindability and powder fluidity are typical effects that are determined by grinding aids whereas rheology, hydration and strength development are affected by conventional admixtures (added to the fresh concrete mix). These effects, all together, recognise the quality improver or a performance enhancer added in the cement clinker mill.

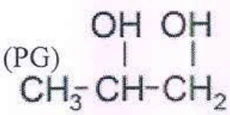
3 Quality improvers tested for Portland cement

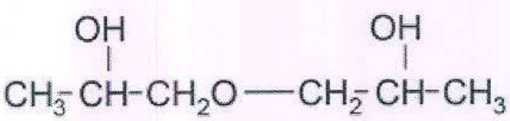
3.1 Polyol type additives

In a recent study, Jolicoeur et al (2007) investigated effects of glycols and compared the results with triethanolamine (TEA). The grinding aids tested are shown in Table 1. The ethylene glycol series have the structural formula of $HO\text{-}CH_2\text{-}CH_2[\text{-}O\text{-}CH_2\text{-}CH_2]_n\text{-}OH$ (n = 0, 1, 2 etc., gives EG, DEG, TEG etc.). Improved powder fluidity relative to TEA was not observed with the ethylene glycol series at a dosage of 0.1% as can be seen in Figure 4a.

The propylene glycol series have the structural formula of $HO\text{-}CH(CH_3)\text{-}CH_2\text{-}[O\text{-}CH_2\text{-}CH(CH_3)\ ]_n\text{-}OH$ (n = 0, 1, 2 etc., gives PG, DPG, TPG etc.) or illustrated as:

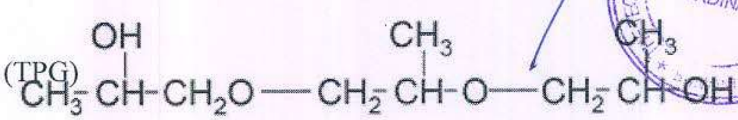
(PG)





(DPG)

(TPG)



For the propylene glycol (PG) series in Figure 4b, only the monomer (PG) achieved improved fluidity relative to TEA. In addition the effect of molecular weight can be seen as the fluidity decreases in the sequence of monomer (PG), dimer (DPG) and trimer (TPG).

In Figure 4c the effect of aliphatic tail is shown for the diols at a dosage of 0.075%. Maximum fluidity was obtained with PG (1,2-propanediol) and 12HD (1,2-hexanediol). The effect is most likely caused by repulsion between particles and that the optimum is achieved with a certain size of the tail. PPT (polypropylene glycol triol) is also included in Figure 4c and the achieved high fluidity was not expected as Figure 4b showed fluidity decrease with increasing polymerisation.

In Figure 4d the effect of molecular structure is shown. The positions of the hydroxyl groups in butanediol seemed to be decisive as the fluidity index of the cement was 16 times higher when 2,3-butanediol (23BD) was used compared to the 1,4-butanediol (14BD). The effect of adding a methyl group to 2-methyl-1,3-propanediol (MPdiol) yielding 2,2-dimethyl-1,3-propanediol (DMPD) was found to largely increase the fluidity.

Table 1 List of different polyols given by Jolicoeur et al (2007)

Abbreviation	Name	Abbreviation	Name
TEA	Triethanolamine		
EG	Ethylene glycol	PG	Propylene glycol
DEG	Diethylene glycol	DPG	Dipropylene glycol
TEG	Triethylene glycol	TPG	Tripropylene glycol
PEG	Poly(ethylene glycol)	PPG	Poly(propylene glycol)
12HD	1,2-Hexanediol	12OD	1,2-0ctanediol
12BD	1,2-Butanediol	23BD	2,3-Butanediol
GLY	Glycerol	PPT	Polypropylene glycol triol
MPdiol	2-methyl-1,3-propanediol	DMPD	2,2-dimethyl-1,3-propanediol
LF2	Mixed EG-PG copolymer	LG650	Polypropylene glycol triol

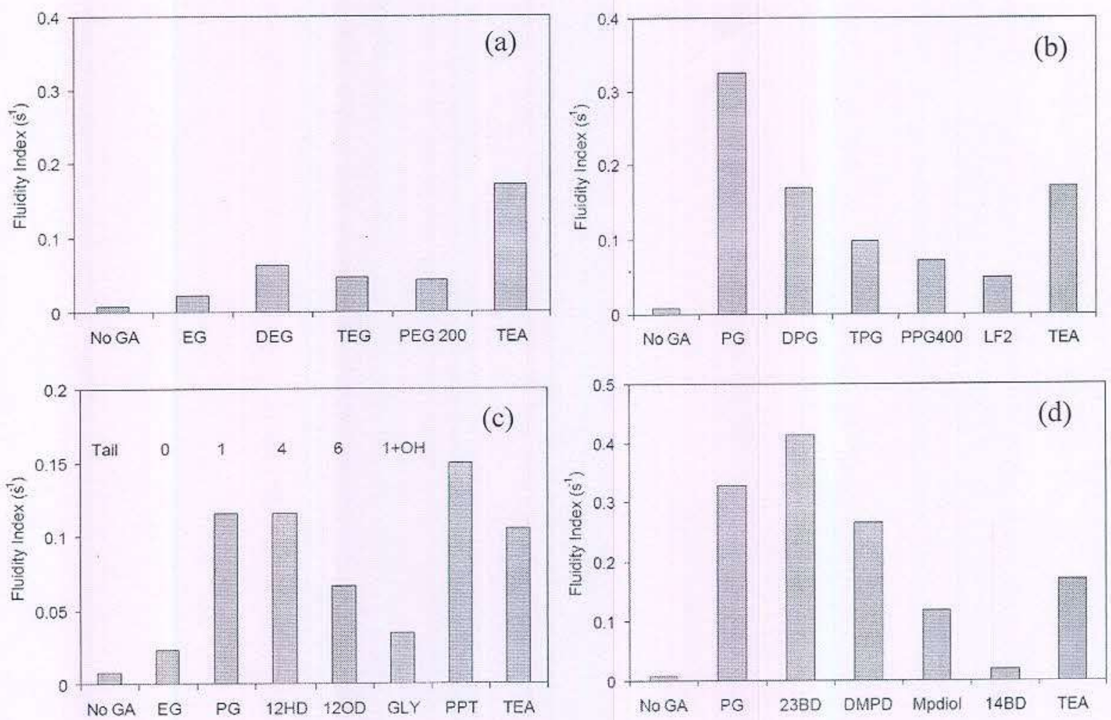


Figure 4 Fluidity of the cement ground with different glycol additives and its oligomers at dosages of 0.1%. No GA means cement ground with no grinding aid and serves as a reference: (a) ethylene glycol series, (b) propylene glycol series in addition to the EG-PG block co-polymer LF2, (c) effect of tail length for additives (0.075%) with adjacent hydroxyl groups, the triol additive PPT is also included, (d) effect of hydroxyl position in butanediol (BD) and addition of a methyl group to MPdiol yielding DMPD (Jolicoeur et al 2007).

In section 2.2 we examined the triethanolamine (TEA) effect on hydration, see Figure 3. In regard to the fluidity of dry cement, PG and PPT (as the additive LG 650) were the most promising additives. The effect on hydration was therefore also tested for these additives by Jolicoeur et al (2007) in addition to glycerol (GLY) and glucose shown in Figure 5. The latter was included only for visualising a known retarder. It was demonstrated that these additives behaved as accelerators for both the silicate and aluminate phases. The accelerating effect of the PG additive lasted for almost 24 hours as can be seen in the thermogram in Figure 5.

From the mentioned study above it is quite clear that PPT and PG behaves as significant quality improvers as the fluidity was improved relative to TEA and accelerating hydration properties were demonstrated. (Teoreanu and Guslicov 1999) examined the grindability effects of EG, PG and PPG and found significant improvement in terms of Blaine specific surface and thus reduced power consumption, see Figure 2.

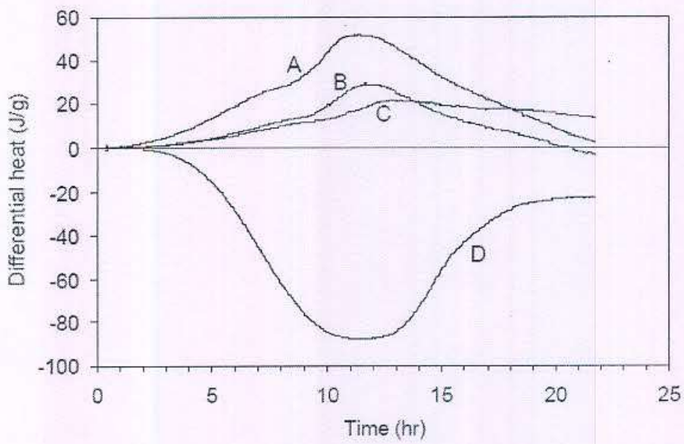
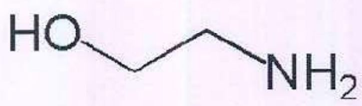


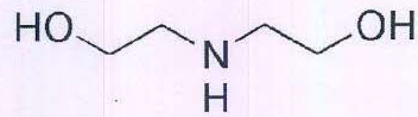
Figure 5 Differential heat of cement hydration. GLY (A), LG650 (B), PG(C) and Glucose (D). The dosage for PG was 0.1%; the dosages for the other additives were 0.075% (Jolicoeur et al 2007).

3.2 Alkanolamines

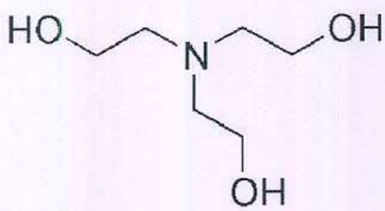
Alkanolamines are widely used as admixtures to concrete. Some of them (e.g. TEA) have also been used as grinding aids in the cement mill as discussed in previous sections. It is therefore important to explore their mechanisms during hydration in addition to their grinding aid effects. Structures of monoethanolamine (MEA), diethanolamine (DEA), triethanolamine (TEA) and triisopropanolamine (TIPA) are shown below:



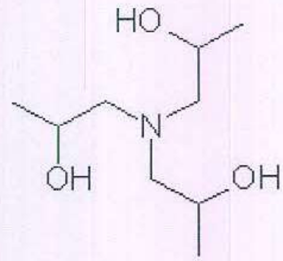
MEA



DEA



TEA



TIPA

TEA is a common grinding additive and its effects on the cement powder fluidity and the hydration are discussed in previous sections. The influence of cement hydration, however, is not straight forward as it acts as both retarder and set accelerator depending on the dosage. In Jolicoeur et al (2007) dosages in the range of 0.02-0.15% were used. At 1% TEA, strong accelerating effects are observed on cement hydration due to rapidC_3A hydration (flash setting) (Dodson 1990). Heren and Olmez (1996) studied the hydration and mechanical effects of the ethanolamines oligomers at dosages in the range of 0.1-1% added directly in the mixing water. They found the retarding effects of the ethanolamines decreasing in the sequence of TEA > DEA > MEA at all dosages (0.1-1%). Note that flash setting was not observed in these cases at 1% dosages, but keep in mind that white Portland cement was tested (low C_4AF). The effect on C_4AF will be discussed later. Lower strength was measured at early and late hydration for TEA whereas only slight reduction in early strength (3days) was observed for MEA. Note that the early strength of cement pastes with DEA was as high as the reference sample. In the same study published the following year (Heren and Olmez 1997), they also found that DEA and TEA did produce more porous pastes (larger size pores) although the general shape of the pore size distributions were the same. The pore structure of pastes containing MEA seemed to be close to the control sample.

Aiad et al (2003) tested the rheological properties of PC (Portland Cement) and SRC (Sulphate Resistant Cement) pastes separately spiked with of MEA, TEA and PTEA (polymer) in the concentration range 0-2%. The study more or less confirmed the accelerating and retarding effects of the ethanolamines in terms of changes in the shear stress and viscosity. If we recall the retarding and accelerating effects on cement in Figure 3, Aiad et al (2003) demonstrated the importance of the phase composition of the cement. This is shown in Figure 6 where the shear stress in almost every cases decreases with increasing dose of admixture, which in turn show the retarding effects. Moreover, the decrease in shear stress is more significant in the SRC pastes. This is most likely due to the low C_3A content (2.6%) in the SRC used and therefore no accelerating effects, although not pointed clearly out by Aaid et al (2003). They conclude that ethanolamines influence the rheological properties of SRC pastes in the sequence of TEA > PTEA > MEA.

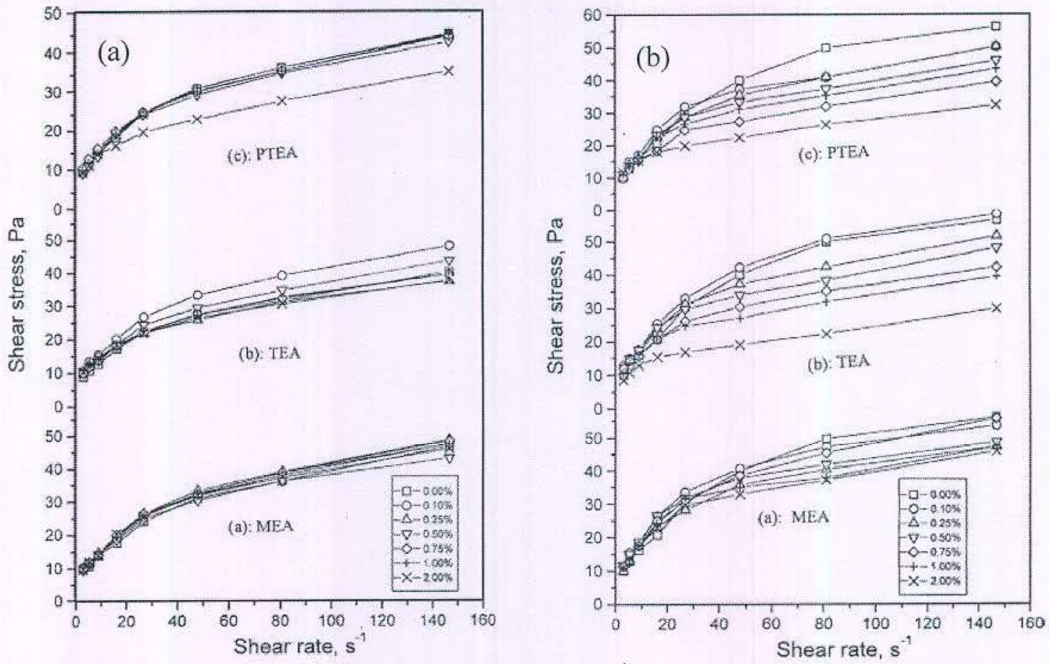


Figure 6 Shear stress as function of shear rate for OPC (a) and SRC (b) pastes admixed with MEA, TEA and PTEA (Aiad et al 2003).

TriIsoPropanolAmine (TIPA) is an additive that can be regarded as a quality improver. Gartner and Myers (1993) studied the effects of TEA and TIPA on hydration of cement mortar. They found in some cases increased 1 day strength of the mortar admixed with TIPA due to increased hydration of C_4AF. The mechanism was proposed to be that TIPA remained in solution (not adsorbed to surfaces as TEA) also after all the sulphates have reacted and that TIPA formed iron complexes that enhanced the transport of the ferric ions. Ichikawa et al (1997) confirmed the accelerated hydration of C_4AF by TIPA. They also showed that the amount of C_3S is important. The grindability of C_3S is higher relative to C_2S and fractures of the former grains are therefore expected to penetrate into the crystal. This causes interstitial phases (C_4AF) to coexist in the C_3S grains. This polymineralic C_3S favours both hydration of C_4AF and the C_3S in the presence of TIPA. In the same study it was also indicated that TIPA increased the limestone reaction in the formation of carboaluminates. Perez et al (2003) argued that the strength gain with TIPA was not caused by an increase in the hydration but rather by a modification of the cement paste - aggregate interface. Sandberg and Doncaster (2004), however, largely disagreed in this explanation and showed in their experiments results that supported increased hydration rate. In the very recent study of Aggoun et al (2008) TEA and TIPA was tested separately and also in combination with the set accelerator $Ca(NO_3)_2$ (calcium nitrate) in regard to setting time and strength development of two types of cement pastes.

The strength development results are shown in Figure 7 and significant increase in the strength at all ages was determined for both TEA and TIPA. The best results, however, were achieved with TIPA as emphasised by Aggoun et al (2008). Studying the results (Figure 7) in more detail it is apparent that TIPA is far more efficient at early age (185% strength increase after day 1 relative to control sample) for the cement sample rich in C_4AF (16%), not specifically pointed out by the authors (Figure 7b). In relation to the above discussions, this is a strong indication of accelerating the hydration of C_4AF keeping in mind that the *normal* cement consisted of ~9% C_4AF and thus achieved 90% strength increase relative to the control sample (Figure 7a). In regard to the dosage used (0.05%), TEA is expected to have accelerating features which is in reasonable agreement with Jolicoeur et al (2007), see Figure 3.

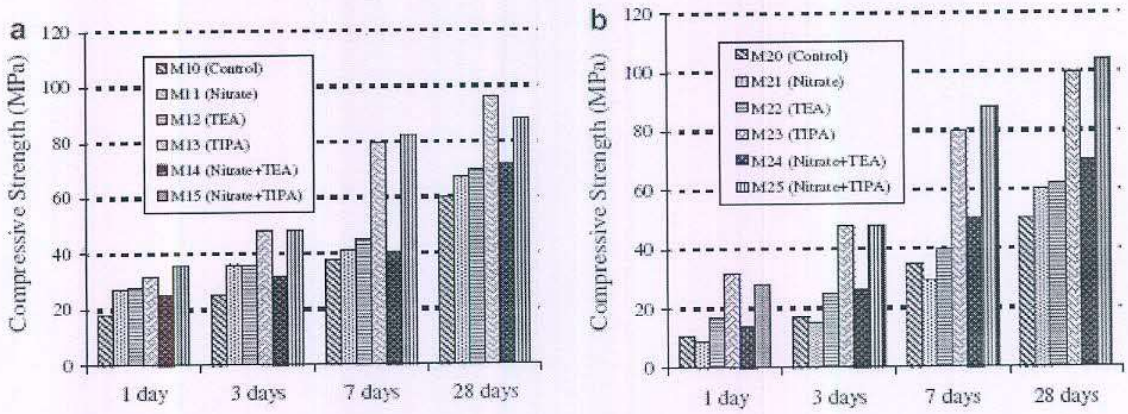


Figure 7 Strength developments for two different cement pastes with different admixtures, concentrations of 0.05% are used for TEA and TIPA and 1% are used for calcium nitrate. The principle mineral phases in the cements used were (a) C_3S (51%), C_2S (25%) C_3A (8.3%), C_4AF (8.9%) and (b) C_3S (52%), C_2S (23%), C_3A (2.8%), C_4AF (16%) (Aggoun et al 2008).

Figure 7 also show interesting combinations of calcium nitrate with TEA and TIPA. The latter combination gave strength improvement in the same range as for TIPA alone. In regard to the setting, TEA and TIPA did not reduce the initial and final setting times. In combination with calcium nitrate, however, both admixtures achieved considerable reduction in setting time (35-70%). Kuroda et al (1986) tested a combination of calcium nitrite, calcium rhodonate and TEA in total concentration of 1% at 5 and 20°C. They found accelerated initial and final setting at both temperatures in addition to increased early strength at 20°C.

From the results shown above, alkanolamines undoubtedly serve as strength enhancers. In regard to improving the grindability and preserve sufficient powder fluidity for the additives under consideration, there are not many systematic studies available in addition to those already mentioned. Bravo et al (2003), however, carried out grinding experiments with glycols (MEG, DEG, PEG, MPG and DPG), alkanolamines (DEA, TEA and TIPA) and a superplasticizer (Poly Carboxylic Acid Esters, PCAE). In regard to the BET specific surface area, considerable increase was achieved for all additives as shown in Figure 8.

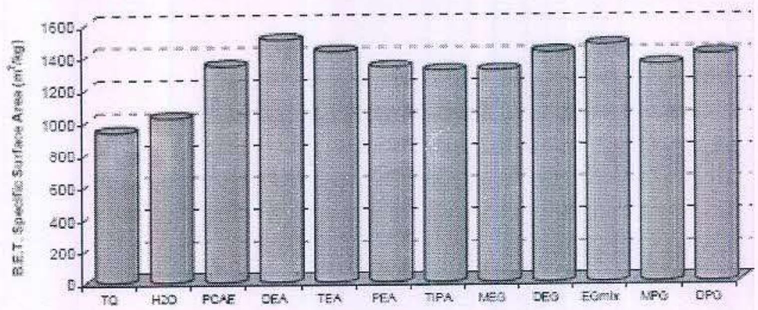


Figure 8 BET specific surface area after grinding clinker powder for 90 minutes admixed with different grinding aids (Bravo et al 2003).

Granulometric experiments carried out with mechanical sieves also showed improving results relative to the reference clinker except for PEG and PCAE in particular. The authors hypothesized that the polymers on the surface tend to make the clinker grains sticky causing agglomeration. The sieving analysis in regard to PEG (also for DEG) were in accordance to what Jolicoeur et al (2007) reported some years later in their fluidity experiments, see Figure 4a. It is therefore important to evaluate not only the particle surface evolution with grinding time, but also evaluate how the cement powder behaves in a more practical way by for example simple fluidity experiments on the dry cement.

Performance enhancers (quality improvers) are supposed to increase the efficiency of the cement mill and at the same time preserve sufficient *"workability"* of the dry cement i.e. not giving rise to problems like clogging during storage, packing or offloading from bulk transportation. In addition, the additives shall enhance the rheological and strength properties for fresh and hardened concrete respectively. In regard to the latter, a *"true"* quality improver must increase the early strength due to a chemical effect and not only due to increased fineness of the cement. There are not many studies where both the cement powder and concrete properties are studied, in particular where the additive is added in the grinding process. The results of Jolicoeur et al (2007) and to a certain extent Bravo et al (2003), however, are nice examples where the quality improvers have been added in the *"mill"* for investigation of both properties. In the latter study, only the hydration properties of TEA were determined.

From Figure 8 we also note that DEA gave interesting results. We know from Heren and Olmez (1996) that retarding effects was measured in the decreasing sequence of TEA > DEA > MEA for white Portland cement. The observed retardation was due to the high admixed content (0.1-1%) and the fact that the samples contained only 0.9% C_4AF. In lower admixed concentrations, DEA might have the same accelerating properties as TEA, and can thus be regarded as a quality improver as well.

3.3 Patents

Several patented grinding aid formulations exist which claim to improve the cement clinker grinding process. In Gartner et al (1991) the TIPA containing additive had improved grinding effects on blended cement and it was a strength enhancer at 7 and 28 days. The requirement was that the clinker should contain at least 4% C_4AF. The recommended dosages were additions to the cement in an amount up to 0.2%, preferably less than 0.1%, and most preferably between 0.005% and 0.03%, based on the weight of the cement. Moreover, Cheung and Gartner (1995) formulated a quality improver that is claimed to increase the early strength. The grinding aid was composed of a mixture of C_2 -C_3 alkylene glycol and corresponding oligomers in combination with carbon powder in weight ratios of from about 1:0.01 to 1:0.5.

Jardine (2007) combined a diamine (e.g. tetrahydroxylethylethylene diamine) with an alkanolamine (e.g. TEA, TIPA, DIPA etc.) and the grinding improvements are larger compared to these additives added separately. In regard to the mixing dosages to achieve favourable early strength, experiments showed that optimum mixture was 20-30% tetrahydroxylethylethylene diamine and 70-80% diethanolisopropanolamine (DIPA). The addition dosage was in the range 0.04% to 0.06%.

The few patents shown here describe the wide range of possibilities in quality improver formulations. Very often the key factor is to find the optimum mixture blends.

4 Quality improvers tested for blended cements

4.1 Fly ash

An interesting study has been carried out by Lee et al (2003). They studied the effects on strength by adding separately triethanolamine (TEA), Na_2SO_4 and K_2SO_4 to the mixing water of fly ash mortars. The results for TEA can be seen in Figure 9 and show that TEA contributed positively to the strength development. In the same study they measured the evolution of ettringite in the corresponding paste samples and found only a small increase at day 1 compared to the reference. The increase in early strength for mortars admixed with TEA cannot be caused by increased hydration of C_3A (ettringite formation) as were the case for mortars admixed with Na_2SO_4 and K_2SO_4. Lee at al (2003) also found that TEA (0.03%) reduced the total porosity by increasing the number of smaller pores.

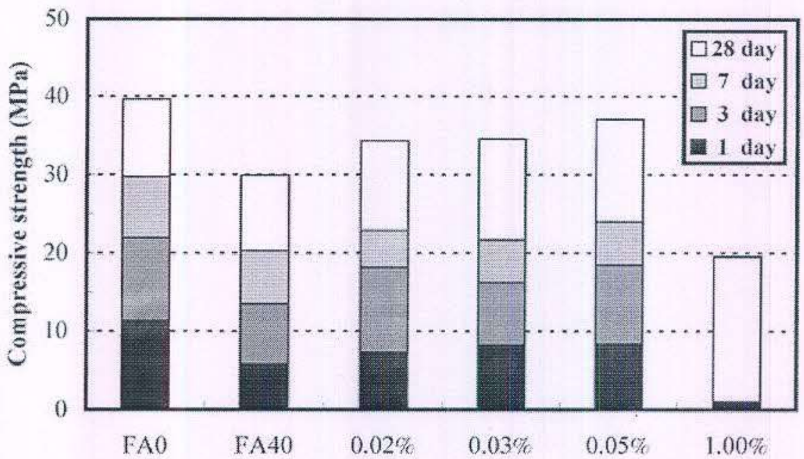


Figure 9 Compressive strength of cement (FA0) and cement with 40% fly ash replacement (FA40) mortars. The FA40 samples are admixed with 0-1% triethanolamine (Lee et al 2003).

Bouzoubaâ et al (1998) studied the high volume fly ash cements with respect to grindability and mechanical properties of the corresponding mortars. The clinker, fly ash and gypsum were interground in the portions 43.7:55:1.3. The grinding aid was a superplasticizer (sulfonated naphthalene formaldehyde condensate). Three different types of fly ash were used. In Figure 10 the grindability results in terms of Blaine surface are shown for Portland clinker and one type of fly ash blended clinker (Sundance FA) using the superplasticizer (SP). Considerable effect of SP was determined for the normal Portland clinker and more limited, but significant, effect was achieved for the blended clinker. The mechanical properties were improved with SP due to increased fineness. However, at a given Blaine (4500 cm^2/g) the strength development did not improve with SP for blended cements. For the Portland cement at the same Blaine an interesting comparison can be made as they added SP to the mixing water and to the laboratory mill. Although the conditions were not exactly the same, i.e. the cement contents were 315 and 240 kg/m^3 when the SP was added in the mixing water and the laboratory mill respectively. Moreover, the SP dosage was 0.7% compared to 0.9% in the mill. The compressive strength results achieved were not different with a slight increase at 7 and 28 days strength in the latter case. In regard to quality improvers, this study indicates that effects found when the additive is mixed with the hydration water also can be found when the additive was included in the grinding process. However, the authors emphasise that comparison is difficult and further research should be carried out. It is emphasised that when testing quality improvers, the addition should be made in the grinding mill.

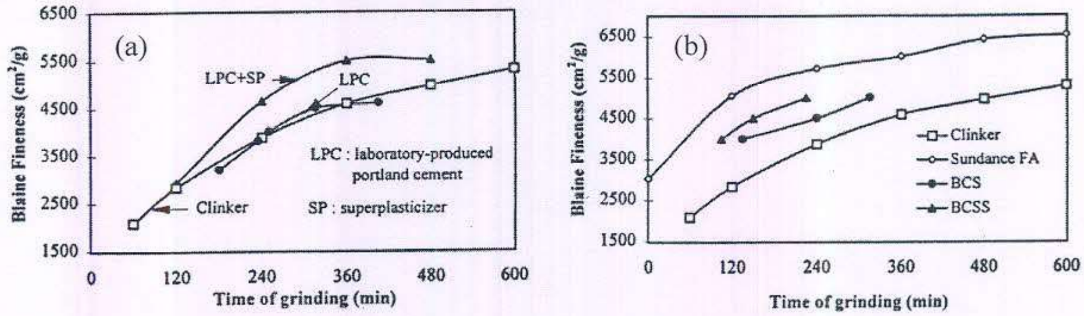


Figure 10 Blaine development as function of time. (a) Laboratory produced Portland cement with and without 0.9% superplasticizer. (b) BCS: Blended cement made with Sundance FA, BCSS: Blended cement made with Sundance FA and 0.9% superplasticizer (Bouzoubaâ et al 1998).

4.2 Slag cements

In the early study by Tachihato et al (1984) it was found a strength increase of 40% was found after 7 days for a Portland cement mortar with 70% slag and 0.5% TEA. Grinding of granulated blast furnace slag (GBS) is more energy demanding compared to grinding pure Portland clinker. In Trenkwalder and Ludwig (2001) they optimised the production of slag cements by separating the grinding of cement clinker and GBS in the Karlstadt cement works. Without any grinding aids, at least not reported, they managed to reduce the total electric energy consumption for cement grinding by 7% for all slag cements produced i.e. for the types CEM II/A-S, CEM II/B-S and CEM III/A-C. In addition, the workability and the strength development was improved. Improving the former property also reduce the use of plasticizers. In Erdogu et al (1999), grinding of cements blended with either 25% of GBS or natural pozzolan was studied in terms of intergrinding and separate grinding of the ingredients. They concluded that for producing the cement with natural pozzolan, intergrinding was less energy consuming than separate grinding for a given Blaine of 3500 cm^2/g. The interground pozzolan cements produced higher strength at all ages (1-90 days). Moreover, they also found that the intergrinding process consumed more energy than separate grinding for production of the slag cements at the given Blaine. The latter was due to coarser particles at the highest particle size range (60-90µm). These mentioned studies remind us that several factors need to be considered in order to obtain the desirable product produced at optimised conditions.

Padovani and Corcoran (2004) tested quality improvers for GBS cements. In the first part of the study, they tested the grindability and the mechanical strength of 4 different slags used in commercial production of slag cements in central Europe. Different results were obtained which also was the case when the specific slags were tested as finished slag cements (CEM III/A 32,5R) prepared in laboratory. It was also emphasised that the slags with high strength were those which contained the highest glass content. In the second part, the additives MAGA/C098, MAGA/C150 and MAPE/S500 were tested, all commercial products of Mapei. Unfortunately, the "active" ingredients were not reported and only the datasheet of the former was available. According to the safety data sheet, MAGA/C098 consisted of diethylene glycol (7-10%) and ethanediol (7-10%). Moreover, the exact additive dosage was not reported.

The quality improvers were tested on the 4 slag cements prepared in laboratory complying to CEM III/A 32,5R (50% GBS and 5% gypsum). The results are shown in Figure 11 and we note a significant effect for MAGA/C098. The improved early strength for this additive is due to the increased fineness and is therefore only considered as a grinding aid. This was also pointed out in Revuelta et al (2003). The two other additives tested, shown in Figure 11, achieved even higher strength development due to chemical interaction during hydration and are therefore considered as quality improvers. Hydration temperatures measurements of one slag cement showed, however, that MAGA/C098 had almost identical temperature profile as MAGA/C150 (GA+).

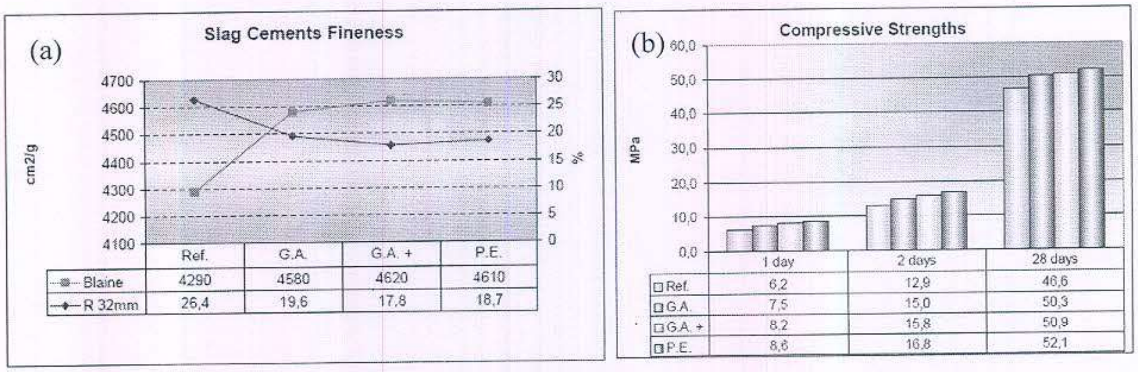


Figure 11 Fineness achieved for a given grinding time obtained (a) and compressive strength (b). Each measuring point is given as the average of a reference clinker prepared with 4 different commercial slags and with different quality improvers; Ref (without additive), GA (MAGA/C098), GA+ (MAGA/C150) and PE (MAPE/S500) (Padovani and Corcoran 2004).

Water glass (WG) has also been investigated as quality improver for GBS cements in India by Roy at al (1998). For the slag cement (50% slag and 4% gypsum) the Blaine increased from 3650 (0% WG) to around 4100 cm^2/g (1.5% WG) for the same grinding time. In terms of compressive strength 1% WG was found to be the optimum dosage. For slag substitution of 30-80% the early strength (1, 3 and 7 days) was always higher with 1% WG relative to no addition keeping in mind that the Blaine values were kept at the same level (3500-3600 cm^2/g). The authors indicated that WG activated the pozzolan reactions occurring in slag cements.

4.3 Other studies

The effect of various grinding aids on the separate grinding of limestone, quartz and Portland cement clinker were investigated by Sohoni et al (1991). In this study TEA, MEG, DEG, oleic acid (OA), sodium oleate (SO), sulphite waste liquor (SWL) and dodecylbenzene sulphonic acid (DBS) was tested. Nearly all the additives were effective as grinding aids for Portland clinker and limestone (SO, DEG and DBS not tested for limestone; OA and SO not tested for Portland clinker). Hardly any grinding effect was seen for quarts. The grinding effect of gypsum on the Portland cement clinker was also shown in this study. An addition of 4.3% (normal dosage area) showed Blaine improvement comparable to clinker ground with 0.04% TEA and no gypsum addition. Adding gypsum to the latter further increased the Blaine, but not in an additive way.

Hrazdira (1990) tested the grinding effects of TEA, Abeson-TEA (dodecylbenzenesulfonic acid-TEA), amorphous SiO_2 and Sodium Lignosulphonate (SL) in gypsum free cements. The dosages were 0.05% for the two former and 0.3% for the latter additives. In regard to grindability of the cement Abeson-TEA produced the narrowest particle size distribution. The viscosities of the corresponding pastes were decreasing in the order of TEA > Abeson-TEA > LS > $SiO_{2[am]}$. The initial set was 39 and 49 min. for pastes with TEA and Abeson-TEA respectively, and more than 100 min. for the others. The paste strength development (1-180 days) was, however, significantly higher for the Abeson-TEA paste. Again we see the accelerating effects of TEA and its derivatives at a certain dosage level (0.05%). Note that the cements used in this study were gypsum free (total SO_3 of 1.05%) and the hexagonal aluminate (C_2AH_8 and C_4AH_{19}) phases are expected to develop in stead of ettringite. In Hrazdira (1992) the properties of gypsum free cements clinker grinded with Abeson-TEA was further studied. In regard to the compressive strength, an optimum dosage was found for a given Blaine.

5 Proposals for activities

Based on the studies discussed in this report several additives are interesting. Triisopropanolamine (TIPA) is already a well known quality improver and in combination with nitrate it gave excellent early strength development. The conventional grinding aid TEA proved to be a strong quality improver also in combination with nitrate. We suggest to further investigate these combinations. In this respect it is proposed to also combine DEA with nitrate. Some studies showed that DEA had even higher grinding effects than TEA.

The testing should emphasise fluidity and grinding for the chosen additive or combination of additives. The choice must also be based on the recommendations and conclusion in the state-of-the-art report on accelerators (Myrdal 2007). It is therefore considered important to link the research on grinding aids with potential strength enhancement properties to the R&D activities on accelerating admixtures for concrete. In any case it is recommended to test the features (grindability and hydration) of a quality improver by including the additive in the milling procedure.

An interesting activity will be to look at the overall effect of mineralisers together with quality improvers. From Engelsen (2007) it is known that certain trace elements (e.g. Cu, Cr and Zn) have considerable mineralising action during clinker burning. Opoczky and Gavel (2004) showed that the certain metals also have positive effects on the grindability. Considerable increase in specific surface (Blaine) was achieved for Zn, Cr and Ti added as 0.1% oxides as shown in Figure 12.

If for example a clinker is prepared with the use of the mineraliser(s) containing Zn, Cr, Cu and Ti, an improved grindability should be the results. This mineralised clinker can be further optimised by applying the appropriate quality improver depending on the desirable properties of the final cement. The rheological properties of the corresponding cement paste should also be measured in addition to the final strength in the paste, mortar and concrete form. The documented improvements from the mineralising, grinding and final concrete stage should be calculated in order to visualize the total effect.

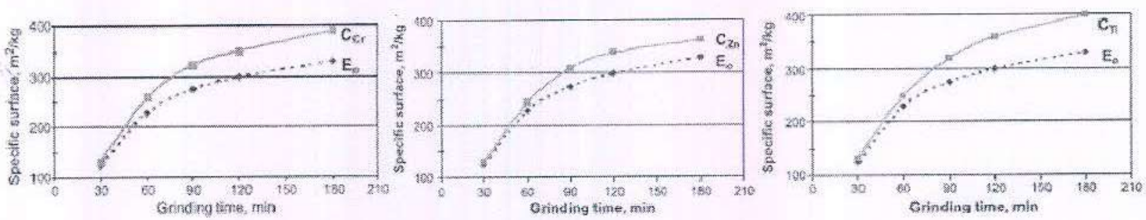


Figure 12 Blaine as function of grinding time for Portland clinker mineralised with Cr, Zn and Ti compared to a Portland clinker without mineral addition during burning (E_0). The content of mineralisers added to the raw materials was 0.1% as oxides (Opoczky and Gavel 2004).

The proposed activities are also valid for blended cements (slag, fly ash and limestone). In for example Tsivilis et al (1999), they optimised the clinker and limestone quality together with the optimum limestone content. They found that 10% limestone content in the cement gave comparable strength values as for the pure cement provided optimised conditions without the use of organic grinding aids. The potential for further substitution, maintaining the sufficient properties of the cement by applying a quality improver system, are proposed to be carried out. Most grinding aids/quality improvers also are effective for limestone.

6 Conclusion

It has been shown that the overall cement properties are interconnected and in many cases there is still potential for further production improvement by only optimising the different stages (e.g. separate grinding, mill operation etc.). This, in turn, indicates the potential for quality improvers to further optimise the production and improve the quality of the cement. It was found that the combination of certain alkanolamines (TEA and TIPA) with calcium nitrate gave considerable enhanced early strength. Probably the same effect will be found by combining nitrate with the highly efficient grinding aid DEA. If quality improvers are used for clinkers that is mineralised with relatively small amounts of for instance Zn, Ti or Cr, significant improvements can be achieved. The total improvement as decrease in clinkering temperature, increased Blaine and increased early strength can be measured and expressed in terms of decreased energy used pr. cubic metre of produced concrete.

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BALANCE SHEET AS AT 31ST MARCH 2017

31/03/2016 (Rs.)	(Rs.)		LIABILITIES		(Rs.)	31/03/2017 (Rs.)
			RESERVES & SURPLUS			
			Capital Reserve			
			(I) On Revaluation of Land			
	91,21,842		As per last account		91,21,842	
			(ii) On Sale of Fixed Assets (being net excess of Sale proceeds over depreciated book value)			
		11,67,80,639	As per last account	11,67,77,339		
		-	Add: Additions during the year	17,47,025		
	11,67,77,339	(3,300)	Less : Deletions during the year	-	11,85,24,364	
	50,52,556		(iii) On Acquisition of Land by Govt. Of Haryana		50,52,556	
			Reserve against Govt. Grants & Subsidy towards Non-recurring Expenditure (Utilised as per contra)			
		4,82,21,833	As per last account	4,92,51,402		
		10,29,569	Add: Additions during the year	-		
	4,92,51,402	-	Less : Adjustment during the year	(7,21,587)	4,85,29,815	
			Reserve against Donations towards Non-recurring Expenditure (Utilised as per Contra)			
	5,53,301				5,53,301	
			Reserve against Donations for Education Purposes			
	1,75,00,000				1,75,00,000	
			Depreciation Reserve			
		23,02,04,059	As per last account	23,62,66,415		
			Add: Depreciation on Fixed Assets			
		74,95,692	during the year	75,66,888		
43,45,22,855	23,62,66,415	(14,33,336)	Less : Deletion during the year	(42,15,245)	23,96,18,058	43,88,99,936
			Closer Compensation Payment Reserve			
		2,85,61,458	As per last account	3,90,66,509		
3,90,66,509		1,05,05,051	Add: Additions during the year	99,07,465		4,89,73,974

31/03/2016 (Rs.)	(Rs.)		ASSETS		(Rs.)	31/03/2017 (Rs.)
32,37,08,753			**FIXED ASSETS** (As per 'Schedule A' attached)			32,43,84,196
			CURRENT ASSETS, LOANS AND ADVANCES			
			Stock-in-Trade:			
		9,27,379	Stores, Spare parts etc.	9,22,277		
	7,74,500	(1,52,879)	Less : Provision for non-moving / obsolete	(1,52,879)	7,69,398	
	7,180		Goods under Process		-	
8,43,117	61,437		Waste		-	7,69,398
			Sundry Debtors			
	9,69,938		(Considered Good except where otherwise stated)		3,34,819	
7,89,678	(1,80,260)		Less: Provision for Doubtful/ Disputed Debts		(1,80,260)	1,54,559
			Cash and Bank Balances			
			With Scheduled Banks:			
	14,40,48,641		In Fixed Deposit Account (Includes Receipts deposited Rs.4,25,000/- (Previous year Rs. 4,25,000/-) with Director, Technical Education Haryana, Chandigarh in the name of Registrar M.D. Univ., Rohtak and Receipts of Rs.1,62,40,390/-(Previous Year Rs. 1,51,67,893/-) pledged with bank for current account overdraft facility.)		15,83,10,201	
	23,09,585		In Current Accounts		24,70,322	
	501		In Post Office Saving Bank Account (Pass Book deposited with Market Committee, Bhiwani)		501	
14,66,18,194	2,59,467		Cash & Stamps in hand (including cheque in hand of Rs. 63,990/-)		4,12,301	16,11,93,325

IQAC COORDINATOR
THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

KOTHARI & COMPANY
KOLKATA
FRN.301178E
CHARTERED ACCOUNTANTS

31/03/2016 (Rs.)	(Rs.)		LIABILITIES		(Rs.)	31/03/2017 (Rs.)
			SECURED LOANS -			
			From Uco Bank			
1,01,04,639			Cash Credit Account (Secured against equitable Mortgage of Land & Building at Bhiwani and Hypothecation of Stocks of Raw materials, Stores and spare parts, Stock-in-trade and in process, Book Debts & receivables)			56,03,461
1,32,55,937			**From HDFC Bank** Current Account Overdraft (Secured Against Fixed Deposits receipts)			56,67,132
1,40,976			**From TATA Motors** (Secured Against hypothication of School Bus)			-
			DEPOSITS			
	5,10,000		Security Deposit from Agents		4,10,000	
		5,11,27,934	Fixed Deposit from Employees	5,07,59,094		
	5,83,21,138	71,93,204	Add: Interest Accrued on above	66,20,784	5,73,79,878	
		98,262	Deposit from Employees	97,762		
	1,05,531	7,269	Add: Interest Accrued on above	12,839	1,10,601	
		3,11,015	Orphic Scholarship Fund	3,54,557		
		43,542	Add: Contribution during the year	46,092		
	3,54,557	-	Less: Fund Utilised	-	4,00,649	
		6,690	N.M.Jain Scholarship Fund	6,690		
		937	Add: Contribution during the year	870		
	6,690	(937)	Less: Fund Utilised	(870)	6,690	
	2,10,340		Other Fund - contribution from Employee		2,10,680	
6,00,09,467	5,01,211		From Contractors & Others		4,97,011	5,90,15,509
			CURRENT LIABILITIES AND PROVISIONS			
	5,32,46,778		Sundry Creditors for Goods, Expenses etc. (Including Provisions)		4,20,96,799	
	43,26,201		Other Liabilities		47,12,428	
	9,03,998		Provision for Income Tax		9,03,998	
	9,32,59,471		Provision for Gratuity		9,90,16,173	

31/03/2016 (Rs.)	(Rs.)	ASSETS	(Rs.)	31/03/2017 (Rs.)
		LOANS AND ADVANCES (Considered good, except where otherwise stated)		
	-	Advances against Purchase of Raw Material, Stores, Spares, Machineries etc.	18,000	
	625	Advance to Staff	625	
	31,90,144	Advance to others	31,37,268	
	3,89,883	Balances with Central Excise Authorities	95,844	
	38,38,950	Security Deposits	38,38,950	
	34,07,994	Fee & Other Amounts Receivable	43,13,616	
	96,71,595	Income-Tax Deducted at Source	92,29,081	
	47,30,916	Interest Accrued but not Due on Fixed Deposits	44,51,492	
	1,24,087	Prepaid Expenses	5,92,601	
2,71,10,277	17,56,083	Due from Government Department pertaining to College (Net of Advance)	15,77,755	2,72,55,232

IQAC COORDINATOR
THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES * BHIWANI *

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

KOTHARI & COMPANY * KOLKATA FRN.301178E * CHARTERED ACCOUNTANTS *

31/03/2016 (Rs.)	(Rs.)	LIABILITIES	(Rs.)	31/03/2017 (Rs.)	31/03/2016 (Rs.)	(Rs.)	ASSETS	(Rs.)	31/03/2017 (Rs.)
							INCOME & EXPENDITURE ACCOUNT		
	96,54,524	Provision for Leave Encashment	1,05,93,351			27,24,76,200	As per last Account	25,29,95,943	
	2,22,22,807	Sundry Credit Balances pertaining to the College and School	2,57,50,394						
19,49,65,579	1,13,51,800	Refundable Deposits & Caution Money from Students (including ex-student)	1,16,50,800	19,47,23,943	25,29,95,943	(1,94,80,257)	Less: Excess of Income over Expenses as per attached Income & Expenditure Account	(1,38,68,698)	23,91,27,245
75,20,65,962				75,28,83,955	75,20,65,962				75,28,83,955

Notes on Accounts - As per Schedule 'B' annexed
Notes & Schedules Form an Intregral part of Accounts

In the terms of our Report of even date

For KOTHARI & COMPANY
Chartered Accountants
ICAI Reg. No. 301178-E

(Manaswy Kothari)
Partner
Membership No. 64601

Place : Kolkata
Dated :

28 AUG 2017

For The Technological Institute of Textile & Sciences

Chairman

Member
Managing Committee

Hon. Secretary

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

KOTHARI & COMPANY CHARTERED ACCOUNTANTS KOLKATA FRN.301178E

THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES BHIWANI IQAC COORDINATOR

THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES

REGD. OFFICE :- 9/1 R.N. MUKHERJEE ROAD, KOLKATA -700001

Schedule 'A' of Fixed Assets attached to and forming part of the Society's Balance Sheet As on 31.03.2017

Description of Assets	Cost/Book Value as at 01/04/2016		Additions /Adjustments during the year		Deductions and/or Adjustments during the year		Balance as at 31/03/2017			Balance as at 31/3/2016		
	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Total (Rs.)	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Total (Rs.)
Land	-	91,93,334	-	-	-	-	-	91,93,334	91,93,334	-	91,93,334	91,93,334
Plant & Machinery	4,12,05,186	11,02,58,309	-	21,29,214	2,00,447	33,91,606	4,10,04,739	10,89,95,917	15,00,00,656	4,12,05,186	11,02,58,309	15,14,63,495
Buildings	13,50,284	8,04,98,187	-	15,73,352	-	1,61,206	13,50,284	8,19,10,333	8,32,60,617	13,50,284	8,04,98,187	8,18,48,471
Furniture & Fixtures	3,33,115	2,66,00,067		15,75,556	-	-	3,33,115	2,81,75,623	2,85,08,738	3,33,115	2,66,00,067	2,69,33,182
Vehicles	6,50,872	40,61,174	-	-	6,50,872	86,655	-	39,74,519	39,74,519	6,50,872	40,61,174	47,12,046
Office Equipments	9,47,122	33,74,632	-	2,83,863	-	-	9,47,122	36,58,495	46,05,617	9,47,122	33,74,632	43,21,754
Water Pipe Line	-	67,415	-	-	-	-	-	67,415	67,415	-	67,415	67,415
Tube Well	-	1,16,558	-	-	-	-	-	1,16,558	1,16,558	-	1,16,558	1,16,558
Computer	54,47,856	3,86,48,260	-	5,60,626	-	-	54,47,856	3,92,08,886	4,46,56,742	54,47,856	3,86,48,260	4,40,96,116
Capital Work- in- progress	-	9,56,382	-	-	-	9,56,382	-	-	-	-	9,56,382	9,56,382
Total	4,99,34,435	27,37,74,318	-	61,22,611	8,51,319	45,95,849	4,90,83,116	27,53,01,080	32,43,84,196	4,99,34,435	27,37,74,318	32,37,08,753
Previous Year	4,89,04,866	26,67,14,858	10,29,569	84,96,096	-	14,36,636	4,99,34,435	27,37,74,318	32,37,08,753	4,89,04,866	26,67,14,858	31,56,19,724

In the terms of our Report of even date

For KOTHARI & COMPANY
Chartered Accountants
ICAI Reg. No. 301178-E

(Manaswy Kothari)
Partner
Membership No. 64601

Place : Kolkata
Dated :

2 8 AUG 2017

For The Technological Institute of Textile & Sciences

Chairman

Member
Managing Committee

Hon. Secretary

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES
REGD. OFFICE :- 9/1 R.N. MUKHERJEE ROAD, KOLKATA -700001

INCOME & EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST MARCH 2017

31/03/2016 (Rs.)	(Rs.)		EXPENDITURE	(Rs.)	31/03/2017 (Rs.)
		To	Opening Stock		
	61,437		Waste		
68,617	7,180		Goods under process	7,180	7,180
7,51,602		To	Power, Fuel and Canal Water		5,91,041
		To	Payments to and Provisions for Employees		
	34,78,756		Salary, Wages, Bonus and Ex-gratia	19,91,140	
	3,95,209		Contribution to Provident and Family Pension Funds and Employees State Insurance	2,09,641	
	7,07,249		Gratuity	10,24,049	
46,87,364	1,06,150		Employees' Welfare Expenses	55,042	32,79,872
22,676		To	Telephone, Telegram and Postage		-
91,097		To	Rates and Taxes		81,642
1,68,473		To	Insurance		1,92,751
	19,21,090	To	Electricity	-	
60,190	(18,60,900)		Less: Realised	-	-
3,39,751		To	Traveling and Conveyance		25,783

31/03/2016 (Rs.)	(Rs.)		INCOME	(Rs.)	31/03/2017 (Rs.)
		By	Sales		
	-		Finished Goods	-	
	92,892		Sale of Waste	23,77,669	
	92,892			23,77,669	
92,892	-		Less: Excise Duty	-	23,77,669
		By	Closing Stock		
	61,437		Waste	-	
68,617	7,180		Goods under process	-	-
	3,01,928	By	Rent & Accommodation Charges	2,89,978	
2,60,488	(41,440)		Less: Paid	(41,440)	2,48,538
	-	By	Electricity Charges received	5,46,323	
-	-		Less: Paid	(5,45,674)	649
93,047		By	Unclaimed Balances and Unspent Liabilities Written Back		5,91,209
11,94,54,196		By	College Fees		12,29,00,421
75,88,992		By	Grants for School (On cash basis)		1,76,71,279
16,35,685		By	Kinder Garten Fees		17,30,775
2,73,07,261		By	Fees for Educational Activities		2,68,76,834

IQAC COORDINATOR, THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES, BHIWANI

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

KOLKATA FRN.301178E CHARTERED ACCOUNTANTS

31/03/2016 (Rs.)	(Rs.)	EXPENDITURE	(Rs.)	31/03/2017 (Rs.)
2,328		To Bank Charges		-
4,52,555		To Interest Paid		2,50,208
		To **College Expenses**		
	7,58,53,004	Salary, Wages and Leave encashment	8,30,51,419	
	1,26,26,234	Gratuity	1,15,59,965	
	95,63,318	Contribution to Provident Fund, Family Pension Funds & ESI	1,00,26,244	
	19,88,324	Employees Welfare Expenses	20,34,026	
	21,36,259	House Keeping	24,73,014	
	74,79,691	Interest Paid	64,11,476	
	19,43,507	Building Repair & Maintenance	21,34,372	
	45,34,157	Electricity & Fuel	41,91,837	
	26,320	Generator Expenses	2,70,315	
	16,258	Staff Recruitment Expenses	18,984	
	9,05,441	Traveling and Conveyance Expenses	11,17,833	
	15,67,620	Communication Expenses	11,65,090	
	2,99,201	Library Expenses	2,88,940	
	65,285	Newspaper & Journals	95,285	
	6,27,669	Car Running & maintenance Expenses	5,74,401	
	1,07,742	Computer Expenses	1,72,768	
	2,52,800	Equipment Repair	3,05,730	
	2,82,176	Electric Repair	3,98,298	
	3,48,338	Insurance	4,51,102	
	1,51,319	Printing & Stationery	1,58,079	
	2,65,195	Professional Fees	4,37,382	
	4,08,159	Training & Placement	1,67,335	
	1,36,136	College Visitors	1,34,494	
	59,460	Science Lab	1,46,136	
	93,405	Fees & Taxes	1,34,013	
	2,000	Expenditure on visiting Faculty including remuneration	67,927	
	4,98,824	Water Supply	3,13,435	
	1,91,007	Furniture Repair	2,33,326	
	10,86,667	Sewerage Treatment Plant Expenses	10,14,837	
	4,24,141	Counselling / Admission Expenses	6,04,720	
	1,44,706	Examination Expenses	1,23,676	
	90,211	Garden Maintenance	57,819	
	8,22,121	Legal Expenses	2,28,958	
	78,000	Merit Scholarship	1,33,092	
12,63,32,599	12,57,904	Other Expenses	24,47,450	13,31,43,778

31/03/2016 (Rs.)	(Rs.)	INCOME	(Rs.)	31/03/2017 (Rs.)
29,300		By Sample Development & Testing Charges		-
1,28,467		By Miscellaneous Receipts		1,064
19,83,853		By Interest Received		20,36,850
3,46,17,612		By Income from Technical & Consultancy Services (Net)		2,04,83,975
8,34,289		By Insurance Claim		2,28,800
60,280		By Income from Infrastructure Utilization		28,333

IQAC COORDINATOR

THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

KOTHARI & COMPANY
KOLKATA
FRN.301178E
CHARTERED ACCOUNTANTS

31/03/2016 (Rs.)	(Rs.)	EXPENDITURE	(Rs.)	31/03/2017 (Rs.)	31/03/2016 (Rs.)	(Rs.)	INCOME	(Rs.)	31/03/2017 (Rs.)
		To **School Expenses**							
	2,23,74,208	Salary & Wages	2,33,57,110						
	17,51,940	Gratuity	29,76,799						
	17,26,520	Contribution to Provident Fund & ESI	19,66,475						
	4,84,076	Employees Welfare Expenses	4,69,286						
	1,65,355	Building Repair & Maintenance	5,07,185						
	18,03,382	Electricity	15,23,512						
	14,835	Computer Expenses	12,401						
	2,375	Books	12,759						
	42,340	Fees & Taxes	45,590						
	1,12,022	School Fee Refund	-						
	16,33,672	Interest Paid	15,43,836						
	6,91,233	Functions	7,52,322						
	1,12,301	Insurance	1,34,441						
	1,59,216	Printing & Stationery	1,74,473						
	50,482	Travelling Expenses	1,19,194						
3,19,54,434	8,30,477	Other Expenses	11,23,480	3,47,18,863					
11,96,315		To Kinder Garten Expenses		14,23,929					
8,98,150		To Miscellaneous Expenses		25,763					
74,95,692		To Depreciation		75,66,888					
1,52,879.00		To Provision for Non-moving / obsolete store		-					
1,94,80,257		To Balance being excess of Income over Expenditure transferred to Balance Sheet		1,38,68,698					
19,41,54,979		Total		19,51,76,396	19,41,54,979		Total		19,51,76,396

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

For KOTHARI & COMPANY
Chartered Accountants
ICAI Reg. No. 301178-E

(Manaswy Kothari)
Partner
Membership No. 64601

Dated : 28 AUG 2017

For The Technological Institute of Textile & Sciences

Chairman

Member
Managing Committee

Hon. Secretary

IQAC COORDINATOR
THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES * BHIWANI *

THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES

REGD. OFFICE :- 9/1 R.N. MUKHERJEE ROAD, KOLKATA -700001

BALANCE SHEET AS AT 31ST MARCH 2018

31/03/2017 (Rs.)	(Rs.)		LIABILITIES		(Rs.)	31/03/2018 (Rs.)
			RESERVES & SURPLUS			
			Capital Reserve			
			(I) On Revaluation of Land			
	91,21,842		As per last account		91,21,842	
			(ii) On Sale of Fixed Assets (being net excess of Sale proceeds over depreciated book value)			
		11,67,77,339	As per last account	11,85,24,364		
		17,47,025	Add: Additions during the year	-		
	11,85,24,364	-	Less : Deletions during the year	-	11,85,24,364	
	50,52,556		(iii) On Acquisition of Land by Govt. Of Haryana		50,52,556	
			Reserve against Govt. Grants & Subsidy towards Non-recurring Expenditure (Utilised as per contra)			
		4,92,51,402	As per last account	4,85,29,815		
		-	Add: Additions during the year	-		
	4,85,29,815	(7,21,587)	Less : Adjustment during the year	-	4,85,29,815	
			Reserve against Donations towards Non-recurring			
	5,53,301		Expenditure (Utilised as per Contra)		5,53,301	
			Reserve against Donations for Education Purposes			
	1,75,00,000		As per last account		1,75,00,000	
			Depreciation Reserve			
		23,62,66,415	As per last account	23,96,18,058		
			Add: Depreciation on Fixed Assets			
		75,66,888	during the year	77,27,516		
43,88,99,936	23,96,18,058	(42,15,245)	Less : Deletion during the year	-	24,73,45,574	44,66,27,452

31/03/2017 (Rs.)	(Rs.)	ASSETS	(Rs.)	31/03/2018 (Rs.)
32,43,84,196		**FIXED ASSETS** (As per 'Schedule A' attached)		32,87,82,223
		CURRENT ASSETS, LOANS AND ADVANCES		
		Stock		
	9,22,277	Consumable Stores, Spare parts etc.	8,10,413	
7,69,398	(1,52,879)	Less : Provision for non-moving / obsolete	(1,52,879)	6,57,534
		Sundry Debtors		
	1,80,260	(Considered Good except where otherwise stated)	1,80,260	
-	(1,80,260)	Less: Provision for Doubtful/ Disputed Debts	(1,80,260)	-
		Cash and Bank Balances		
		With Scheduled Banks:		
	15,83,10,201	In Fixed Deposit Account (Includes Receipts deposited Rs.4,25,000/- (Previous year Rs. 4,25,000/-) with Director, Technical Education Haryana, Chandigarh in the name of Registrar M.D. Univ., Rohtak and Receipts of Rs.1,73,25,363/-(Previous Year Rs. 1,62,40,390/-) pledged with bank for current account overdraft facility.)	18,51,05,463	
	24,70,322	In Current Accounts	13,92,860	
	501	In Post Office Saving Bank Account (Pass Book deposited with Market Committee, Bhiwani)	501	
16,11,93,325	4,12,301	Cash & Stamps in hand	1,33,950	18,66,32,774

IQAC COORDINATOR
THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

LIABILITIES

31/03/2017 (Rs.)	(Rs.)		LIABILITIES		(Rs.)	31/03/2018 (Rs.)
			Closer Compensation Payment Reserve			
		3,90,66,509	As per last account	4,89,73,974		
4,89,73,974		99,07,465	Add: Additions during the year	96,47,072		5,86,21,046
			SECURED LOANS			
			From Uco Bank			
56,03,461			Cash Credit Account (Secured against equitable Mortgage of Land & Building at Bhiwani and Hypothecation of Stocks of Raw materials, Stores and spare parts, Stock-in-trade and in process, Book Debts & receivables)			48,98,424
			From HDFC Bank			
56,67,132			Current Account Overdraft (Secured Against Fixed Deposits receipts)			8,95,162
			DEPOSITS			
	4,10,000		Security Deposit from Agents		25,000	
		5,07,59,094	Fixed Deposit from Employees	4,81,03,573		
	5,73,79,878	66,20,784	Add: Interest Accrued on above	53,70,859	5,34,74,432	
		97,762	Deposit from Employees	1,09,760		
	1,10,601	12,839	Add: Interest Accrued on above	12,074	1,21,834	
		3,54,557	Orphic Scholarship Fund	4,00,649		
		46,092	Add: Contribution during the year	44,071		
	4,00,649	-	Less: Fund Utilised	-	4,44,720	
		6,690	N.M.Jain Scholarship Fund	6,690		
		870	Add: Contribution during the year	736		
	6,690	(870)	Less: Fund Utilised	(736)	6,690	
	2,10,680		Other Fund - contribution from Employee		2,07,960	
5,90,15,509	4,97,011		From Contractors & Others		5,22,811	5,48,03,447

ASSETS

31/03/2017 (Rs.)	(Rs.)	ASSETS	(Rs.)	31/03/2018 (Rs.)
		LOANS AND ADVANCES (Considered good, except where otherwise stated)		
	18,000	Advances against Purchase of Consumable Stores, Spares etc	55,357	
	625	Advance to Staff	19,775	
	31,37,268	Advance to others	8,07,460	
	95,844	Balances with Central Excise Authorities	-	
	38,38,950	Security Deposits	19,72,427	
	44,68,175	Fee & Other Amounts Receivable	89,57,945	
	92,29,081	Income-Tax Deducted at Source	1,33,90,011	
	44,51,492	Interest Accrued but not Due on Fixed Deposits	41,55,436	
	5,92,601	Prepaid Expenses	4,89,960	
2,74,09,791	15,77,755	Due from Government Department pertaining to College	4,60,060	3,03,08,431

IQAC COORDINATOR
THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES, Bhiwani

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

31/03/2017 (Rs.)	(Rs.)	LIABILITIES	(Rs.)	31/03/2018 (Rs.)	31/03/2017 (Rs.)	(Rs.)	ASSETS	(Rs.)	31/03/2018 (Rs.)
		CURRENT LIABILITIES AND PROVISIONS							
	4,20,96,799	Sundry Creditors for Goods, Expenses etc. (Including Provisions)	4,79,55,407						
	47,12,428	Other Liabilities	65,78,543						
	9,03,998	Provision for Income Tax	9,03,998						
	9,90,16,173	Provision for Gratuity	8,43,38,528				**INCOME & EXPENDITURE ACCOUNT**		
	1,05,93,351	Provision for Leave Encashment	99,58,804			25,29,95,943	As per last Account	23,91,27,245	
	2,57,50,394	Sundry Credit Balances pertaining to the College and School	2,60,36,800						
19,47,23,943	1,16,50,800	Refundable Deposits & Caution Money from Students (including ex-student)	1,07,36,800	18,65,08,880	23,91,27,245	(1,38,68,698)	Less: Excess of Income over Expenses as per attached Income & Expenditure Account	(3,31,53,796)	20,59,73,449
75,28,83,955				75,23,54,411	75,28,83,955				75,23,54,411

Notes on Accounts - As per Schedule 'B' annexed
Notes & Schedules Form an Integral part of Accounts

In the terms of our Report of even date

For KOTHARI & COMPANY
Chartered Accountants
ICAI Reg. No. 301178-E

(Manaswy Kothari)
Partner
Membership No. 64601

Place : Kolkata
Dated : 2nd August 2018

For The Technological Institute of Textile & Sciences

Chairman

Member
Managing Committee

Hon. Secretary

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

IQAC COORDINATOR

THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES

REGD. OFFICE :- 9/1 R.N. MUKHERJEE ROAD, KOLKATA -700001

Schedule 'A' of Fixed Assets attached to and forming part of the Society's Balance Sheet As on 31.03.2018

Description of Assets	Cost/Book Value as at 01/04/2017		Additions /Adjustments during the year		Deductions and/or Adjustments during the year		Balance as at 31/03/2018			Balance as at 31/3/2017		
	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Total (Rs.)	Against Govt.Grant/ Subsidies / Donations (Rs.)	Others (Rs.)	Total (Rs.)
Land	-	91,93,334	-	-	-	-	-	91,93,334	91,93,334	-	91,93,334	91,93,334
Plant & Machinery	4,10,04,739	10,89,95,917	-	5,55,536	-	-	4,10,04,739	10,95,51,453	15,05,56,192	4,10,04,739	10,89,95,917	15,00,00,656
Buildings	13,50,284	8,19,10,333	-	2,70,426	-	-	13,50,284	8,21,80,759	8,35,31,043	13,50,284	8,19,10,333	8,32,60,617
Furniture & Fixtures	3,33,115	2,81,75,623		6,42,099	-	-	3,33,115	2,88,17,722	2,91,50,637	3,33,115	2,81,75,623	2,85,08,738
Vehicles	-	39,74,519	-	-	-	-	-	39,74,519	39,74,519	-	39,74,519	39,74,519
Office Equipments	9,47,122	36,58,495	-	7,55,954	-	-	9,47,122	44,14,449	53,61,571	9,47,122	36,58,495	46,05,617
Water Pipe Line	-	67,415	-	-	-	-	-	67,415	67,415	-	67,415	67,415
Tube Well	-	1,16,558	-	-	-	-	-	1,16,558	1,16,558	-	1,16,558	1,16,558
Computer	54,47,856	3,92,08,886	-	20,00,236	-	-	54,47,856	4,12,09,122	4,66,56,978	54,47,856	3,92,08,886	4,46,56,742
Capital Work- in- progress	-	-	-	1,73,776	-	-	-	1,73,776	1,73,776	-	-	-
Total	4,90,83,116	27,53,01,080	-	43,98,027	-	-	4,90,83,116	27,96,99,107	32,87,82,223	4,90,83,116	27,53,01,080	32,43,84,196
Previous Year	4,99,34,435	27,37,74,318	-	61,22,611	8,51,319	45,95,849	4,90,83,116	27,53,01,080	32,43,84,196	4,99,34,435	27,37,74,318	32,37,08,753

In the terms of our Report of even date

For KOTHARI & COMPANY
Chartered Accountants
ICAI Reg. No. 301178-E

(Manaswy Kothari)
Partner
Membership No. 64601

Place : Kolkata
Dated : 2nd August 2018

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Director,
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OF TEXTILE & SCIENCES, BHIWANI

THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES
REGD. OFFICE :- 9/1 R.N. MUKHERJEE ROAD, KOLKATA -700001

INCOME & EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST MARCH 2018

31/03/2017 (Rs.)	(Rs.)		EXPENDITURE	(Rs.)	31/03/2018 (Rs.)
		To	Opening Stock		
	-		Waste	-	
7,180	7,180		Goods under process	-	-
5,91,041		To	Power and Fuel Expenses		5,51,747
		To	Payments to and Provisions for Employees		
	19,91,140		Salary, Wages, Bonus and Ex-gratia	20,77,769	
	2,09,641		Contribution to Provident and Family Pension Funds and Employees State Insurance	1,50,605	
	10,24,049		Gratuity	28,42,236	
32,79,872	55,042		Employees' Welfare Expenses	11,658	50,82,268
81,642		To	Rates and Taxes		1,31,190
1,92,751		To	Insurance		1,82,309
2,50,208		To	Interest Paid		2,13,722
25,783		To	Travelling and Conveyance		-

31/03/2017 (Rs.)	(Rs.)		INCOME	(Rs.)	31/03/2018 (Rs.)
		By	Sales		
	-		Finished Goods	-	
	23,77,669		Sale of Waste	6,47,306	
	23,77,669			6,47,306	
23,77,669	-		Less: Excise Duty	-	6,47,306
12,29,00,421		By	College Fees		12,61,06,092
	2,89,978	By	Rent & Accommodation Charges	3,25,313	
2,48,538	(41,440)		Less: Paid	(41,440)	2,83,873
	5,46,323	By	Electricity Charges received	1,43,258	
649	(5,45,674)		Less: Paid	(1,01,724)	41,534
1,76,71,279		By	Grants for School (On cash basis)		82,44,963
17,30,775		By	Kinder Garten Fees		20,66,030
2,68,76,834		By	Fees for Educational Activities		2,70,97,997
2,04,83,975		By	Income from Technical & Consultancy Services (Net)		3,00,00,000

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31/03/2017 (Rs.)	(Rs.)		EXPENDITURE	(Rs.)	31/03/2018 (Rs.)
		To	**College Expenses**		
	8,30,51,419		Salary, Wages and Leave encashment	8,16,07,948	
	1,15,59,965		Gratuity	64,57,916	
	1,00,26,244		Contribution to Provident Fund, Family Pension Funds & ESI	1,04,85,466	
	20,34,026		Employees Welfare Expenses	19,61,333	
	24,73,014		House Keeping	29,42,640	
	64,11,476		Interest Paid	46,99,038	
	21,34,372		Building Repair & Maintenance	21,88,411	
	41,91,837		Electricity & Fuel	33,87,530	
	2,70,315		Generator Expenses	1,76,312	
	18,984		Staff Recruitment Expenses	1,03,022	
	11,17,833		Travelling and Conveyance Expenses	12,27,876	
	11,65,090		Communication Expenses	13,47,041	
	2,88,940		Library Expenses	2,02,860	
	95,285		Newspaper & Journals	1,49,282	
	5,74,401		Car Running & maintenance Expenses	8,74,405	
	1,72,768		Computer Expenses	2,50,724	
	3,05,730		Equipment Repair	1,84,767	
	3,98,298		Electric Repair	5,69,777	
	4,51,102		Insurance	4,62,057	
	1,58,079		Printing & Stationery	1,99,550	
	4,37,382		Professional Fees	4,63,970	
	1,67,335		Training & Placement	6,09,467	
	1,34,494		College Visitors	1,30,500	
	1,46,136		Science Lab	1,57,778	
	1,34,013		Fees & Taxes	3,06,186	
	67,927		Expenditure on visiting Faculty including remuneration	49,000	
	3,13,435		Water Supply	2,55,426	
	2,33,326		Furniture Repair	1,02,853	
	10,14,837		Sewerage Treatment Plant Expenses	9,64,893	
	6,04,720		Counselling / Admission Expenses	19,20,280	
	1,23,676		Examination Expenses	1,63,703	
	57,819		Garden Maintenance	59,174	
	2,28,958		Legal Expenses	13,27,330	
	1,33,092		Merit Scholarship	95,000	
13,31,43,778	24,47,450		Other Expenses	28,19,719	12,89,03,234
75,66,888		To	Depreciation		77,27,516
-			Sundry Balances Adjusted		65,423

31/03/2017 (Rs.)	(Rs.)		INCOME	(Rs.)	31/03/2018 (Rs.)
1,064		By	Miscellaneous Receipts		47,662
20,36,850		By	Interest Received		20,04,429
5,91,209		By	Unclaimed Balances and Unspent Liabilities Written Back		3,72,839
2,28,800		By	Insurance Claim		-
28,333		By	Income from Infrastructure Utilization		-
-		By	Sample Development & Testing Charges		1,900
-		By	Financial Assistance for Educational Purposes		25,00,000
-		By	Gratuity Provision written back		1,46,77,645
-		By	Leave Provision written back		6,34,547

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31/03/2017 (Rs.)	(Rs.)	EXPENDITURE	(Rs.)	31/03/2018 (Rs.)	31/03/2017 (Rs.)	(Rs.)	INCOME	(Rs.)	31/03/2018 (Rs.)
		To **School Expenses**							
	2,33,57,110	Salary & Wages	2,58,34,416						
	29,76,799	Gratuity	27,07,406						
	19,66,475	Contribution to Provident Fund & ESI	22,76,499						
	4,69,286	Employees Welfare Expenses	4,43,775						
	5,07,185	Building Repair & Maintenance	6,74,522						
	15,23,512	Electricity & Fuel	14,14,014						
	12,401	Computer Expenses	10,677						
	12,759	Books	-						
	45,590	Fees & Taxes	45,590						
	15,43,836	Interest Paid	12,81,785						
	7,52,322	Functions	7,80,599						
	1,34,441	Insurance	1,56,980						
	1,74,473	Printing & Stationery	2,79,477						
	1,19,194	Travelling Expenses	1,53,714						
	12,864	Garden Maintenance	41,095						
	1,53,864	Examination Expenses	84,932						
	94,865	Electric Repair	78,585						
	99,475	Legal Expenses	77,880						
	6,421	Furniture Repair	48,023						
3,47,18,863	7,55,991	Other Expenses	6,79,590	3,70,69,559					
14,23,929		To Kinder Garten Expenses		16,42,965					
25,763		To Miscellaneous Expenses		3,088					
1,38,68,698		To Balance being excess of Income over Expenditure transferred to Balance Sheet		3,31,53,796					
19,51,76,396		Total		21,47,26,817	19,51,76,396		Total		21,47,26,817

For KOTHARI & COMPANY
Chartered Accountants
ICAI Reg. No. 301178-E

(Manaswy Kothari)
Partner
Membership No. 64601

Dated : 2nd August 2018

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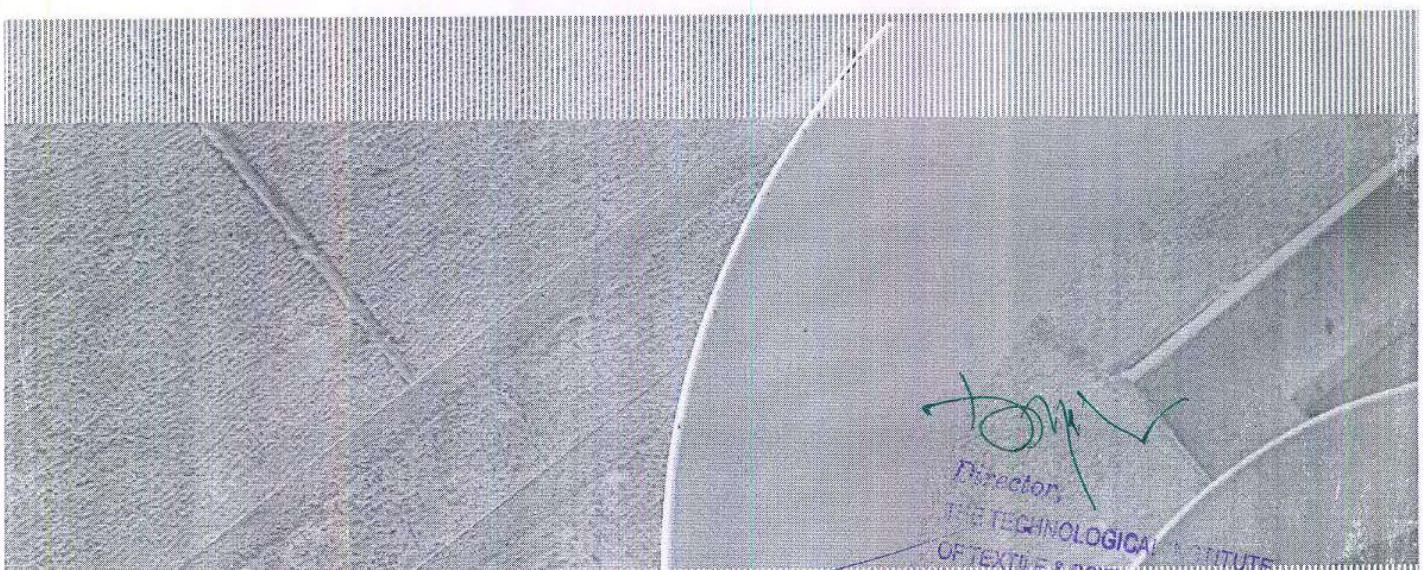

Director,
THE TECHNOLOGICAL I...TITUTE
OF TEXTILE & SCIENC... ...WANI

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PROJECT REPORT

on

Supply Chain Management in Cement Industries

Compiled and submitted

BY

PROF. (DR.) G. K. TYAGI

DEAN (ENGINEERING), TIT&S, BHIWANI

THE TECHNOLOGICAL INSTITUTE OF TEXTILES AND SCIENCES

BHIWANI, HARYANA - 127021 (INDIA)

2016-17

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES * BHIWANI *
IQAC
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ABSTRACT

Traditionally supply chain management has played an operational role within cement and mineral extraction commodity companies. Recently, cost reduction projects have brought supply chain management into the limelight. In order to clarify the reasons of the evolution of supply chain management and to demonstrate the value of efficient supply chain management within the cement industry, an analysis of the cement supply chain has been carried out using Michael Porter's five forces. In addition, a comparative analysis of the supply chain strategy of the four largest cement companies has been presented, according to Larry Lapide's excellent supply chain framework.

Also, a characterization of the current cement supply chain has been done, using the Supply Chain Council's SCOR model processes; plan, source, make, deliver and return. Five authors' various frameworks of supply chain design have been used to gain insight into the general characteristics of the cement supply chain and propose a definitive supply chain strategy. Finally, three case studies from mineral extraction commodity companies have been presented to demonstrate the potential of supply chain management. The study concludes that supply chain management has tremendous potential to add value as a strategic function for companies in these industries.

Table of Contents

THE TECHNOLOGICAL INSTITUTE OF TEXTILE & SCIENCES IQAC COORDINATOR BHIWANI

Director,
THE TECHNOLOGICAL INSTITUTE
OF TEXTILE & SCIENCES, BHIWANI

List of Figures

List of Tables

Chapter- I: Introduction

Commodity products are the starting point of manufacturing processes. They are normally tied to the extraction or exploitation of natural resources. The economies of developed and underdeveloped countries are based on commodity exploitation. Cement is produced in more than 150 countries all over the world. Cement, as the most important ingredient of concrete, is essential in the development of infrastructure and construction in general. The level of advancement in cement and concrete Supply Chain Management (SCM) can facilitate or constrain world economic development. The four research questions of this thesis are:

- What are the unique characteristics of SCM in the cement industry?
- Why SCM traditionally played an operational role in the cement industry?
- What is the right supply chain for cement?
- Can SCM generate value in the cement industry?

To gather information about the unique characteristics of SCM in the cement industry, SCM employees from three of the eight largest cement companies and one medium size cement company were interviewed. A list of the respondent companies and the interviewee position in the organizational chart are presented in Appendix A.

To enrich the analysis, three companies in the mineral extraction business; one in the oil industry, one in the coal industry and one in the steel industry were interviewed.

The reason why these companies were interviewed is because they are facing similar SCM challenges as cement companies.

A questionnaire that covers the five logistics processes defined by the SCOR Model: Plan, Source, Make, Deliver and Return, was used to conduct the interviews. The questionnaire is presented in Appendix B.

This thesis is organized as follows. In section 3.1, a competitive analysis of the cement industry using Michael Porter's framework of five forces driving industrial competition was made, using the information gathered in the interviews and the information in the literature review.

In section 3.2 a comparative analysis of the supply chain strategy of the four largest cement producers was made using the Supply Chain Excellence Framework (Lapide, 2006).

In section 3.3 an analysis of the cement supply chain operating model using two perspectives: processes and product. The process perspective analysis was made using the SCOR model, the Four Types of Supply Chain Design Framework (Reeve and Srinivasan, 2005) and the

Matching Supply Chain (SC) strategies with Products Framework (Simchi-Levi et al., 2008). These frameworks will be described in the literature review.

The product perspective analysis was made using the Demand Uncertainty Framework (Fisher, 1997), the Uncertainty framework (Lee, 2002) and the Triple A framework (Lee, 2004). These frameworks will be described in the literature review

In section 4, three cases studies were documented to confirm that SCM can add value to the strategy of the cement and the mineral extraction commodity industry. The first case is the implementation of a single 3PL (Third Party Logistics Provider) by three of the largest oil companies in Colombia. The second case is a collaboration project between concrete and cement supply chain in Cemex Colombia. The third case is collaborative port operation contract in the steel industry.

Finally, a summary is presented with the conclusions about the evolution of supply chain management in the cement industry. The majority of these concussions can be extended to the mineral extraction commodity industry.

Chapter- II: Literature Review

2.1 SCM research in the cement industry

Supply Chain Management (SCM) is a topic with limited research in the cement industry. A search made in April 6 of 2009 in Business Source Complete database from 1970 to present using the words "supply chain," yields 47,101 records. A search within these 47,101 records with the word "commodity," yields 659 records. A search within the 47,101 records with the word "cement" yields only 34 records. The same search in Compendex database within the same time period yields 4224 records for "supply chain," 175 records for "supply chain" and "commodity" and only 37 records for "supply chain" and "cement." Combining the records obtained and excluding common records and documents non-related to cement as a construction product, a total of 48 documents was classified into nine topics as shown in Table 1.

Cement supply chain management research topics reflect the major concerns of the cement industry like manufacturing, cement material management and sustainability.

Table 1. Supply Chain Research Topics in the Cement Industry

Topic	Quantity	Participation
Manufacturing	12	25.0%
Material management	10	21.0%
Sustainability	7	14.5%
Industry overview	7	14.5%
Distribution	6	12.5%
Demand management & Forecasting	4	8.3%
Transportation	2	4.2%
Total	48	100.0%

From an economic perspective, there is significant research about the cement industry by Pankaj Ghemawat from Harvard University. He is particularly interested in the history of Cemex, the third largest cement producer. 32 Harvard Business School cases are related to cement companies and ten of them are about Cemex. Research about Cemex from a Supply Chain perspective was made by Hau Lee and his research group in Stanford University.

In the sources reviewed, there was no conceptualization about the role of SCM or the right structure of the cement supply chain in the cement industry from a broad perspective, without focusing on a particular company. The focus of this project is to present an insight into the role and structure of SCM in the cement industry, and provide certain generalizations applicable to the overall extraction commodity industry.

2.2 Cement Industry Background

In general, cement is a mixture of limestone, sand, clay and iron. The most common type of hydraulic cement is the Portland cement. The term hydraulic cement is used because cement hardens when mix with water. According to the Portland Cement Association (2008), "Portland cement is a closely controlled chemical combination of calcium, silicon, aluminum, iron and small amounts of other ingredients to which gypsum is added in the final grinding process." Portland cement may be gray or white but blends can be generated based on the two products.

Cement is the major component of concrete. According to Van Oos (2005), concrete is "an artificial rock-like material made from a proportioned mix of hydraulic cement, water, fine and coarse aggregates, air, and sometimes additives." Concrete can also be made from a ready-mix formula in a concrete plant. Concrete is one of the most important and widely spread building materials in the world.

According to Cembeureau (2008), the cement industry is capital and energy intensive, but not labor intensive. According to Lafarge (2007), the cost of a new cement plant is between 50 and 160 Euros per ton of annual capacity, depending on the country. According to Ghemawat (2002), the minimum scale that is efficient for a cement plant is approximately one million tons of annual capacity. Combining this information, the average investment for an efficient plant is approximately 105 million Euros. Labor usage in the cement industry is relatively low because it is a continuous process with a high level of automation.

A description of the upstream component of the cement supply chain, including sourcing of raw materials, manufacturing and delivery from the plant is shown in Figure 1.

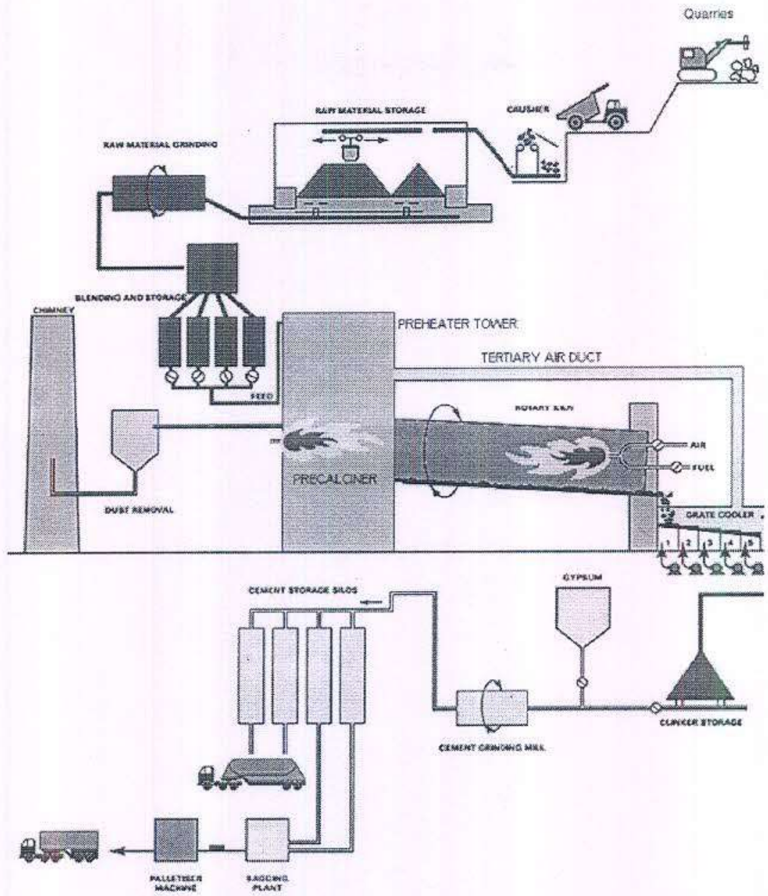

Figure 1. Upstream Cement Supply Chain. Source: Cemex (2008)

Cement plants are normally located near the quarries which are the source of their main raw materials. The main reason for their location is that **1.6** tons of main raw materials are required to produce **1** ton of cement. According to the information gathered, there are no constraints on the availability of main raw materials needed for cement.

There are two main steps in cement production. The first step is the production of clinker from raw materials. The second step is the production of cement from clinker. The first step requires raw materials to be transported to the plant and then to be crushed and homogenized to enter a big rotating pipe called a kiln. The kiln is heated to very high temperatures, and then it is inclined, allowing the raw materials to roll to the other end, where they are quickly cooled. The result is a solid grain called "clinker." The second step is the transformation of clinker into cement in a grinding mill process. Additional elements like gypsum and perhaps other minerals might be aggregated to obtain a fine powder called cement. Finally, cement is moved to storage until a customer place an order.

According to the U.S. Geological Survey (2008) in 2006, cement world production was around 2.6 billion of metric tons. The production is highly concentrated in Asia -Pacific countries as shown in Figure 2.

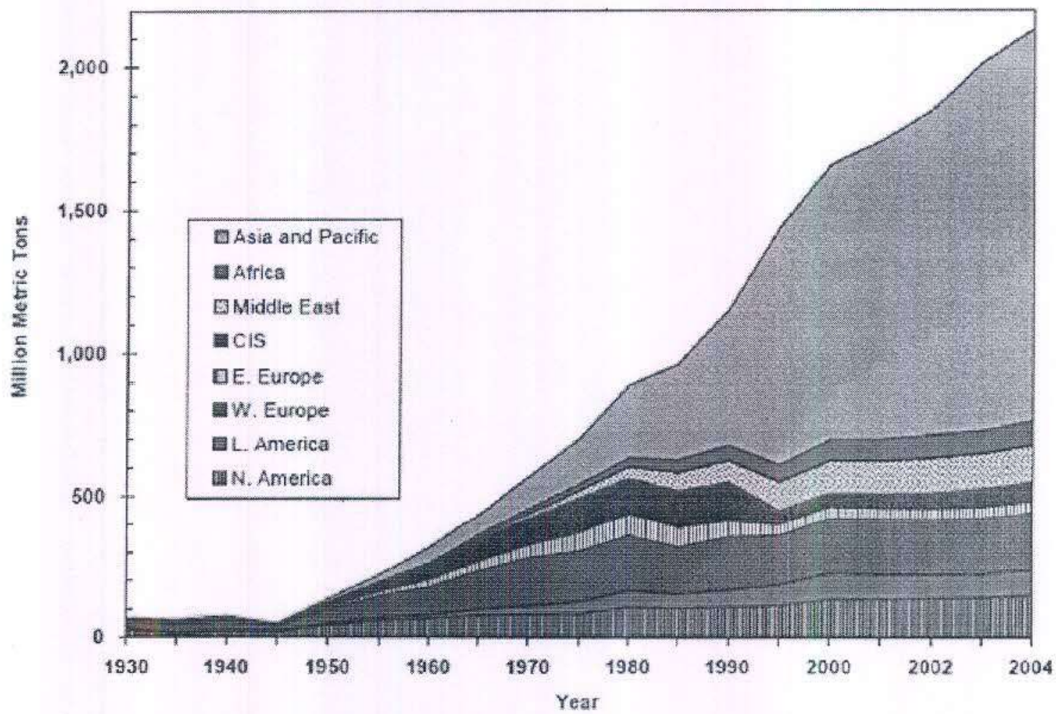

Figure 2. World Production of Hydraulic Cement by Region. Source: Van Oos, H (2005)

Cement is produced by a large number of companies all over the world, but only a few companies are global. Appendix C presents a summary of information about the largest cement producers.

The downstream component of the cement supply chain varies from country to country. Concrete (and therefore cement) demand is created in the short term by residential, non-residential and public sector construction. Cement sales are normally related to economic growth, macroeconomic factors and weather conditions. These issues have local and regional cycles.

Cement as a final product is sold in bulk or bags. Cement bulk is the normal way to distribute cement in developed economies. Bulk sales represent almost 90% of the US cement market. Concrete producers are the biggest customers. According to Cemex, bagged cement represents 80% of sales in emerging markets. Bags sales are strongly related to Do-It-Yourself (DIY) home construction.

There are two important challenges in the future of the cement industry: fuel costs and environmental regulations. Fuel concern is motivated by the high impact of fuel and energy in the cost of cement. Because of this situation, there are several research initiatives in alternative fuel sources for cement manufacturing and transportation.

Government regulations are related to carbon emissions and environmental protection.

There are three issues regarding this topic in cement production:

- Dust emissions and solid waste generated in the manufacturing process
- Air emissions generated from the kiln in the heating process
- Heavy metals in cement / concrete with the risk of leaching into drinking water

2.3 SCM in Commodity Products

The drivers that influence SCM in the commodity industry also affect SCM in the cement industry.

A commodity is a product or service that is widely available; and associated margins and product differentiation is typically low. In general, commodity prices are defined by supply and demand. According to Radetzki (2008), commodity represents "the value of output from the primary sector, comprising agriculture (including hunting, forestry and fishing), mining and utilities." These activities provide raw and unprocessed materials for other sectors in the economy.

There are three issues related to the history of commodities that are significant to understand their current supply chain. The first issue emerges when a country moves from a lower to a higher level of economic development. The common pattern is that the relative importance of primary commodities decreases as the economy develops.

Cement industry reflects this issue as shown in Figure 2.

The second issue is the impact of transportation costs in the trade of commodities. In the past, commodity price was very low compared to other products; thus the share of transportation cost in the total commodity price was high. With the entrance of technology in the rail and maritime transportation systems in the 1950s and the reduction in maritime freights, it was profitable to move commodities overseas. In some cases, it was cheaper to get commodity products from other countries than to purchase them locally. The impact of rail and water transportation development was also extended to the cement industry. Because of this development, today it is possible to have Chinese cement with competitive prices in the west coast of the US.

The third issue is government intervention in the commodity market price and raw materials availability. According to Radetzki (2008) it is "reasonable to say that state interventionism is well past its peak" but recent geopolitical trends might change the current situation. Government intervention is also an essential factor for the cement industry. Normally, government controls cement raw materials availability trough licensing and environmental regulations.

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2.4 Industry Analysis Model

In his book Competitive Strategy, Michael Porter (1980) defines a model of structural analysis for industries. Porter (1980) suggests that a company must understand its environment to formulate a successful strategy. The term environment includes social and economic forces; some are generated within the industry and some are external to the industry.

The level of competition in an industry is determined by five competitive forces: threat of entry, rivalry among competitors, pressure from substitute products, bargaining power of buyers and bargaining power of suppliers. The level of influence of these forces controls the profit in the industry and therefore the return on capital invested by a company within the industry.

- *Threat of Entry* is generated by new entrants in the industry. They normally bring desire of market share, new capacity and resources. This force is controlled by the barriers of entry and the reaction of current actors to new competitors in the industry. If barriers are high, the threat of entry is low. There are seven major barriers to entry in a new industry: economies of scale, product differentiation, capital requirements, switching costs, access to distribution channels, cost disadvantages independent from scale, and government policy (control by license requirements or access to raw materials).

- *Rivalry Among Competitors* occurs when one or more competitors detect an opportunity to increase margins or feel pressure from others companies. Tactics used are price competition, product introduction, customer service and warranties.

The level of rivalry within an industry depends on the number of equally balanced competitors, industry growth, fixed or storage cost, product differentiation, size of capacity increments, competitor's diversity, competitor's strategic stakes and exit barriers.

- *Pressure from Substitute Products* has an effect of limiting the returns of the industry by creating a ceiling for product prices. If the substitute product price is more attractive, the industry profit based on the current product is limited. A substitute is a product that performs the same function as the industry product.

- *Bargaining Power of Buyers (BPB)* has the capacity to influence prices, product quality and services. Buyers can force competition among the industry suppliers and reduce industry profitability. Each of the following drivers increases BPB: buyer purchases large volumes relative to seller sales, seller's product importance on buyer's costs or purchases, type of product (standard or differentiated), buyer's switching cost, buyer's profits, threat of backward integration from buyers, seller's product importance to the quality of buyer's product, and buyer's level of information.

- *Bargaining Power of Suppliers (BPS)* has the capacity of increasing prices or reducing product or service quality. BPS is affected by the following drivers: supplier industry concentration compare to the buyer's industry, availability of substitute products for sale to the buyer's industry, buyer's industry importance as a customer of the supplier industry, supplier's product as an input to the buyer's business, supplier's products differentiation and switching costs, and threat of forward integration from the supplier groups.

2.5 Supply Chain Strategy Framework

One framework was considered to analyze the supply chain strategy of companies within the cement industry. The framework was presented by Larry Lapide in 2006 in his article "The essence of excellence" based on the information of the MIT Center for Transportation and Logistics Supply Chain 2020 project. The article presents the results of the first phase of research proposing a definition about excellent supply chains. Lapide (2006) argues that an excellent supply chain is a competitively principled supply chain where there is an alignment between supply chain strategies, operating models and metrics within the strategic framework of the company.

The principles that guide excellent supply chains are grouped into two dimensions.

The first dimension specifies that an excellent supply chain has to be aligned with the business strategy and has to operate within the framework that is shown in Figure 3.

The second dimension is that supply chain managers should comprehend, execute, and respect the focus and purpose of the aligned supply chain.

Figure 3. Framework for an Excellent Supply Chain. Source: Lapide (2006)

The upper box in Figure 3 reinforces the idea of supply chain alignment. In excellent supply chains, the corporate strategy is understood and shared by supply chain managers. In addition, supply chain management enhances, facilitates and evolves with the corporate strategy. In other words, supply chain fits in the corporate strategy.

Supply chain execution is also an important element in excellent supply chains. Excellence is doing well in activities that affect the firm's competitive advantage. A supply chain has to exceed the company's operational objectives. The operational objectives can be classified in three groups as shown in Figure 4. A competitive strategy requires focus on one of the groups and less on the others.

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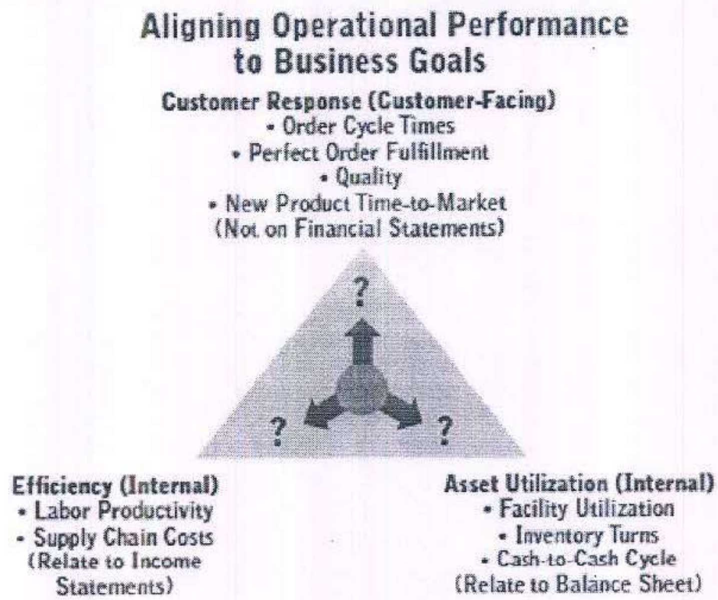

Figure 4. Operational Objectives. Source: Lapide (2006)

- The first set of operational objectives is gathered under *Customer Response.* An example of the metrics included in this group are order cycle time, perfect orders, new product time-to-market and product quality. These metrics generate results in customer-face operations. Companies in high margin and short life cycle industries such as fashion, pharmaceuticals and entertainment, are often concentrated in this objective.

- The second set of operational objectives is under the umbrella of *Efficiency.* The metrics included in this group are internal, for example, labor productivity, supply chain cost, or waste management cost. The data to calculate these metrics is obtained from the Income Statement. Companies in the food, beverage and basic retail goods industry which are focused in cost reductions are concentrated in these objectives.

- The third set of operational objectives is combined under *Asset Utilization.* The metrics in this group are also internal but they focus on how well the company is utilizing its assets. The information to calculate these metrics is in the balance sheet. Companies in the petrochemical and semiconductors industry are concentrated in these objectives. Typically, these companies want to maximize the return on the expensive capital investment made in their plants. Metrics such as cost, inventory turnover and fill rates are common. If a company concentrates in more than one metric, trade-offs between the metrics results are required.

The final aspect of this framework of excellence in supply chain is *tailoring practices.* Tailored practices are limited in number and are aligned with operational objectives. They have to be consistent, integrated and reinforcing. Finally, the concept of Operating Principles is introduced. Lapide (2006) argues that Operating Principles such as visibility, use of supply contracts and matching of supply and demand don't change over time. This is why supply chain managers have "to create an evolving set of tailored practices based on understanding the operating principles being leveraged by them."

In addition to the information in this article, Lapide (2008) expands this framework in a new article called "The operational performance triangles". In this article, Lapide (2008) introduces the concept of absolute or relative triangles as shown in Figure 5.

The absolute triangle refers to the objectives that all companies within the industry must have, to be able to play in the industry. The relative triangle refers to the objectives where companies should focus to achieve significant differentiation from its competitors.

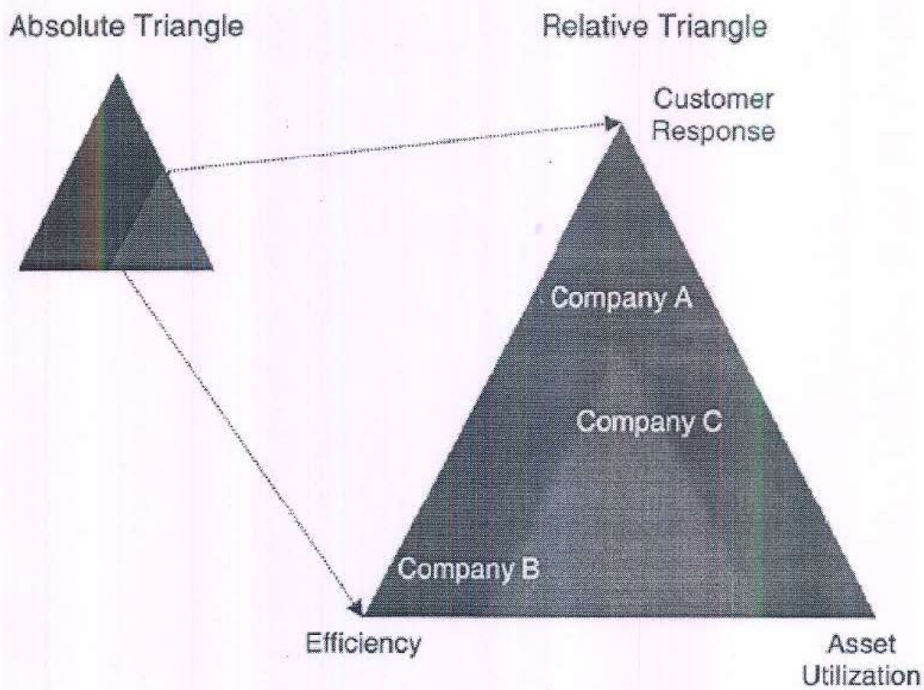

Figure 5. Absolute and Relative Triangles. Source: Lapide (2008)

2.6 Supply Chain Operating Model Characteristics

Supply Chain Operating Model characteristics are analyzed according to two perspectives: processes and products.

2.6.1 Supply Chain Processes

Two frameworks were used to analyze cement supply chain processes: the SCOR model and the Push-Pull Supply Chain frameworks.

2.6.1.1 SCOR Model

The Supply-Chain Operations Reference model (SCOR) was used to analyze the cement supply chain processes. SCOR is a cross-functional framework for evaluating and comparing supply chain activities. SCOR was developed by the Supply Chain Council as an independent global consortium of more than one thousand corporate members. SCOR covers activities from the supplier's supplier to the customer's customer as is shown in Figure 6.

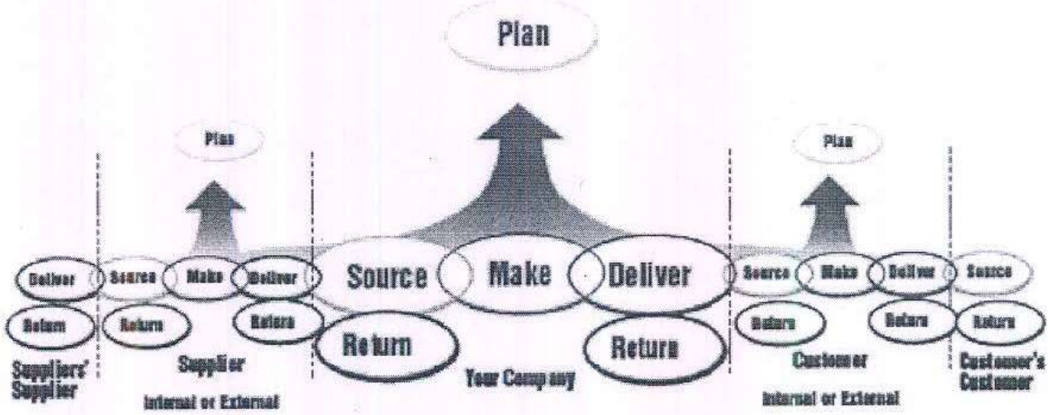

Figure 6. SCOR Model Structure. Source: Supply Chain Council (2009).

There are five processes define in the SCOR Model: Plan, Source, Make, Deliver and Return.

- *Plan* includes the management processes to coordinate aggregated supply and demand. Plan generates a course of action to satisfy source, make, deliver and return requirements.

- *Source* is an umbrella for the processes that procure goods to satisfy customer requirements, from strategic roles such as identifying and selecting supply sources, to the execution of operational and tactical activities. Source also includes risk management, contracts and negotiation.

- *Make* covers the processes of transforming a product from raw material to finished good. Make includes processes such as scheduling, work in process inventory control, testing and packaging.

- *Delivery* is an umbrella for the processes that provide finished goods to meet planned or actual demand. Delivery typically includes order management, transportation management, and distribution management.

- *Return* covers two types of processes, the return of raw materials to the supplier and the return of finished goods from the customer. Return processes effectively move defective, excess or hazardous products to the appropriate destination guaranteeing final disposal.

2.6.1.2 Push-Pull Supply Chain frameworks

Two push-pull supply chain frameworks were considered to analyze the processes of the cement supply chain: Four Types of Supply Chain Design Framework (Reeve and Srinivasan, 2005) and Matching Supply Chain (SC) strategies with Products Framework (Simchi-Levi et al., 2008)

2.6.1.2.1 Four Types of Supply Chain Design Framework

The first framework was created by Reeve and Srinivasan in 2005 in their article "Which Supply Chain Design Is Right for You?" In this article the authors suggest that supply chain design is important because currently, competition is not between companies but between supply chains. There a four major supply chain designs: Builtto-Stock (BTS), Configure-to-Order (CTO), Built-to-Order (BTO) and Engineer-to-Order (ETO).

-*Built-to-Stock (BTS):* In this design the product is manufactured before its demand appears according to a standardized bill of materials. This design offers the fastest response time to consumer because the product is normally stored in the warehouse. BTS is widely used in consumer goods and critical repair components.
Product adjustments are not possible so the final product can be either over configured or under configured according to customer needs.

- *Configure-to-Order (CTO):* In this structure, the products are assembled to order using regular components or modules. CTO is used in the computer and in the automotive industry. In CTO, customer orders are generated prior to assembly, and accordingly, replenishments orders for parts are placed as per the configuration needed by the customer. Normally, there is a trade-off in the variety of product configuration versus the time that a customer has to wait to get the final product.

The main goal in CTO design is to minimize the lead time from assembly to delivery.

- *Built-to-Order (BTO):* In this design, the product is manufactured to order according to a standard bill of materials. Two examples are the jet and the industrial machinery industry. In this option, orders are introduced at the beginning of the manufacturing process. BTO products are usually highly customized and extremely expensive to manufacture. The production process normally has to deal with expediting and exception activities.

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-*Engineer-to-Order (ETO)*: In this design, the product is manufactured to order with exclusive components and drawings. ETO supplies truly customized products. The lead time from order to final delivery is usually long. Upstream supply chain processes are more complex than downstream supply chain processes. Almost all the processes are made in units of one.

A graphical summary of the four supply chain structures is presented in Figure 7. Also, a summary of the trade-offs of each of the designs is presented in Figure 8.

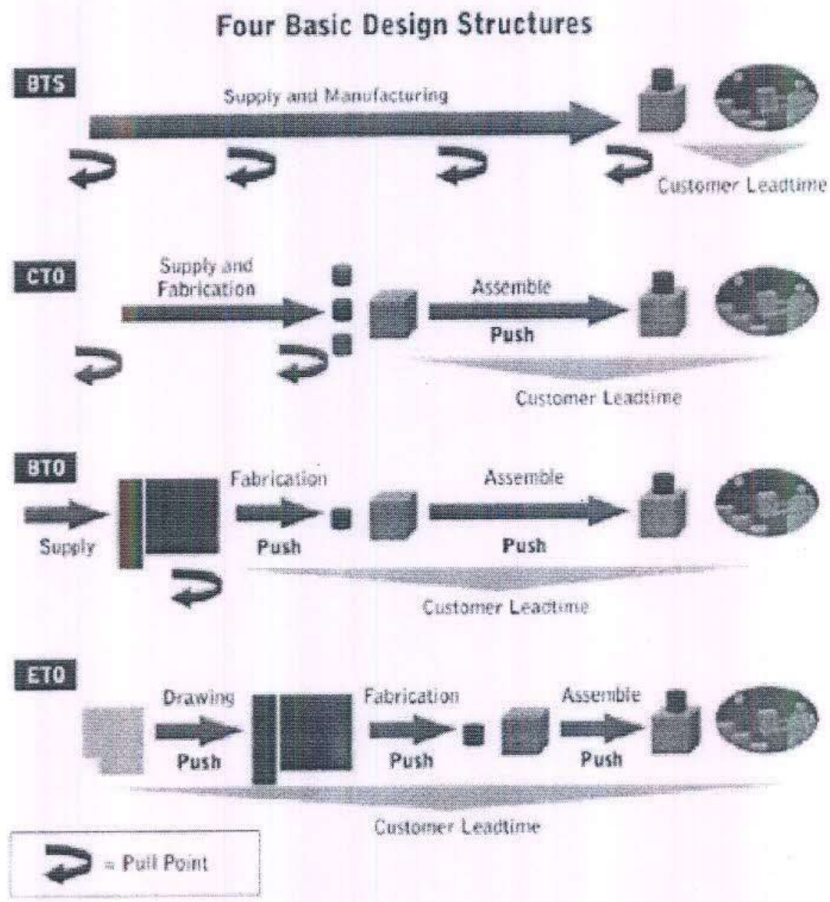

Figure 7. Four Basic Supply Chain Structures. Source: Reeve et al. (2005)

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Supply Chain Design and Value Trade-off

	BTS	CTO	BTO	ETO
Point of order entry	At point of stock	Prior to Assembly	Prior to Fabrication	Prior to Drawing
Pull point	Point of stock to upstream	Point of assembly to upstream	Point of fabrication to supply base	No pull
Inventory speculation	End-item speculation	Module speculation	Component speculation	None
Leadtime to customer	Minimal	Short	Long	Longest
Degrees of customer choice	Limited	Modularized	Semi-customized	Customized

Figure 8. Supply Chain Design and Value Trade-Off. Source: Reeve et al. (2005)

According to Reeve and Srinivasan (2005), the ideal supply chain design "is one in which a small number of components are used to configure a large variety of end products." They introduced the concept of Raw-As-Possible (RAP), suggesting that inventories should be kept as raw as possible in the supply chain. The perfect structure according to this principle is CTO.

The application of the RAP concept is constrain by product configuration and customer lead time requirements. Product configuration is presented in the product Bill of Materials (BOM). The first step to design a supply chain is to evaluate the product BOM to identify opportunities to apply the RAP concept. Risk pooling and aggregation opportunities are also worth evaluating in the product BOM.

Supply chain should reply to consumer requirements rather than to product configurations. This is why in recent years; it is common for companies to move from BTS to CTO or from BTO to CTO. Finally, the authors argue that there is no one-size fits-all supply chain design. Supply chain managers have to be able to assess the current design of their supply chains and adjust it to the market requirements, as needed.

2.6.1.2.2 Matching SC strategies with Products Framework

The second framework by David Simchi-Levi, Phillip Kaminsky and Edith Simchi-Levi in 2008 was presented in their book "Designing and Managing the Supply Chain." Simchi-Levi et al. (2008) argues that traditionally, supply chain strategies have been characterized as either push or pull. A new trend has emerged in the last few years with the implementation of a hybrid system, the push-pull supply chain.

Push-based supply chains are characterized by the use of long-term forecasts for production and distribution decisions. Push-based supply chains are slow to react to market changes, therefore stock outs or excess in inventory are common. Typically, push-based demands have high transportation costs, high inventory levels and / or high manufacturing costs.

Pull-based supply chains are demand driven, therefore production and distribution decisions are based on true customer demand, not on forecasts. In a pure pull system, the company doesn't need inventory because the supply process is triggered by the customer order. Typically, pull-based supply chains have lower inventory, lower variability and lower cost in the system than push-based supply chains. Pull-based supply chains have challenges such as low economies of scale in manufacturing or transportation. This is why the idea of a hybrid system is popular.

In a *push-pull strategy,* some components of the supply chain are operated in a push-based mode and other components are operated in a pull-based mode. The limit between the pull and pull mode is known as the push-pull boundary.

To answer the question about the most appropriate supply chain for a particular product, Simchi-Levi et al. **(2008)** provide a framework for matching supply chain strategies with products as shown in Figure 9.

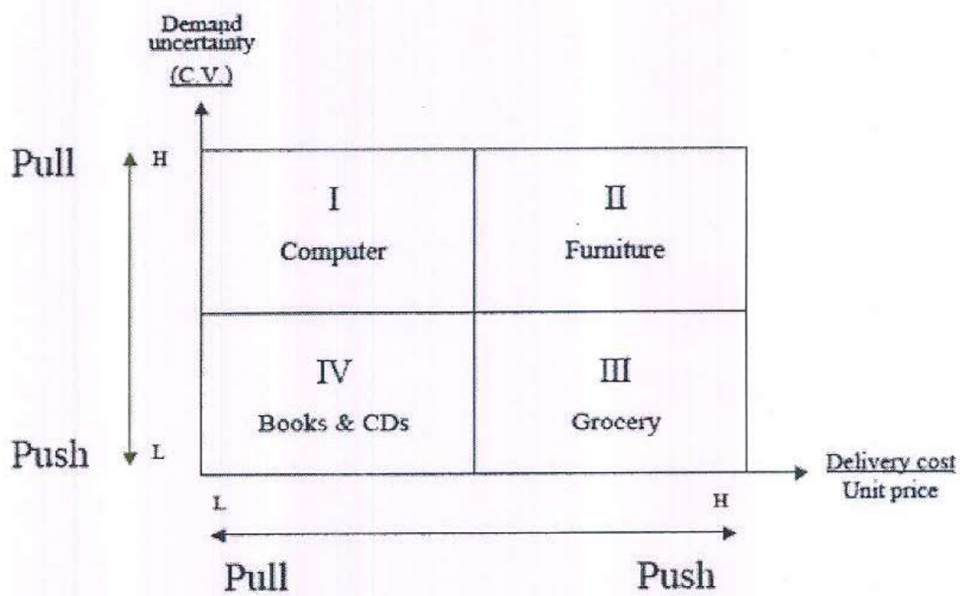

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Figure 9. Matching Supply Chain Strategies with Products Framework.
Source: Simchi-Levi et al. (2008)

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The vertical axis gives information about product demand uncertainty. The metric for demand uncertainty is the coefficient of variation that is defined as the standard deviation of the product demand divided by the product average demand.

Higher demand uncertainty leads to a preference for a pull strategy. Smaller demand uncertainty leads to a more accurate forecast resulting in a preference for a push strategy.

The horizontal axis gives information about the importance of manufacturing or distribution economies of scale. The metric for economies of scale is the result of dividing the delivery cost by the price per unit of a product.

The level of importance of economies of scale dictates the benefits obtained from demand aggregation and long term forecasts. As the importance of economies of scale increases, value addition from demand aggregation increases, and more preference is given to long term forecasts. This effect is generated by push-based supply chains. On the other hand, if economies of scale are low, there is no value in aggregation, so a pull-based supply chain is preferable.

In Figure 9, a 2x2 matrix is presented. *Box I* represents industries or products with high demand uncertainty and low economies of scale. One example is the computer industry. A pull-based supply chain is appropriate for products in Box I.

Box III represents industries or products, such as beer and pasta, with low demand uncertainty and high economies of scale. A push-based supply chain is appropriate for products in Box I. In this case, holding costs are minimized with the use of long-term forecast while distribution costs are minimized with the advantages from economies of scale.

Box IV represents products or industries with low demand uncertainty where a push-base supply chain is better, and low economies of scale where a pull-based supply chain is better.

As a result, a push-pull strategy is more appropriate for this case. *Box II* represents products or industries with high demand uncertainty and high economies of scale. One example is the automotive industry and the furniture industry. In this case as well, a push-pull strategy is the best option.

There are many alternatives to implement a push-pull strategy. The implementation depends on the position of the push-pull boundary. Normally, the push strategy is used in the part of the supply chain where demand is stable and the use of long-term forecast is appropriate. On the other hand, the pull strategy is normally used in the part of the supply chain where demand is unpredictable and therefore the use of real demand is recommended.

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The objective on the push part of the supply chain should be minimizing cost with a focus on resource allocation, using supply chain planning processes. The objective of the pull part of the supply chain should be maximizing service level with a focus on responsiveness using order fulfilment processes.

2.6.2 Supply Chain Structure According to Product Characteristics

Three authors' various frameworks of supply chain design were used to describe the way cement supply chain structure should be.

2.6.2.1 Demand Uncertainty Framework

In his article "What is the right supply chain for your product?" Marshall Fisher (1997) proposed a framework to understand the nature of product demand and the supply chain design that is appropriate to satisfy it. Fisher proposes that products are typed, according to their demand, as functional and innovative.

Functional products normally satisfy basic needs which don't change over time.

They have long life cycles. Because their demand is stable and predictable, competition is attracted and margins are low. To avoid this situation, some companies switch from functional to innovative products gaining customer loyalty.

Innovative products have high margins; short life cycles and because they are new, their demand is unpredictable. A challenge is that suppliers of innovative products have to release new products faster than their competitors to survive in the market.

Figure 10 presents Fisher's summary of demand aspects of functional and innovative products.

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	Functional (Predictable Demand)	Innovative (Unpredictable Demand)
Aspects of Demand		
Product life cycle	more than 2 years	3 months to 1 year
Contribution margin*	5% to 20%	20% to 60%
Product variety	low (10 to 20 variants per category)	high (often millions of variants per category)
Average margin of error in the forecast at the time production is committed	10%	40% to 100%
Average stockout rate	1% to 2%	10% to 40%
Average forced end-of-season markdown as percentage of full price	0%	10% to 25%
Lead time required for made-to-order products	6 months to 1 year	1 day to 2 weeks

Figure 10. Functional Versus Innovative Products. Source: Fisher (1997)

Fisher (1997) defines supply chain as two functions: the physical function and the market mediation function. The *physical function* extends from the transformation of raw material to the transportation to final consumers. The *market mediation function* matches the company's offer with the customer requirements.

A physically efficient process is concentrated in the physical function. A market responsive process is concentrated in the market mediation function. Figure 11 presents Fisher's summary of differences between a physically efficient process and a market-responsive process.

	Physically Efficient Process	Market-Responsive Process
Primary purpose	supply predictable demand efficiently at the lowest possible cost	respond quickly to unpredictable demand in order to minimize stockouts, forced markdowns, and obsolete inventory
Manufacturing focus	maintain high average utilization rate	deploy excess buffer capacity
Inventory strategy	generate high turns and minimize inventory throughout the chain	deploy significant buffer stocks of parts or finished goods
Lead-time focus	shorten lead time as long as it doesn't increase cost	invest aggressively in ways to reduce lead time
Approach to choosing suppliers	select primarily for cost and quality	select primarily for speed, flexibility, and quality
Product-design strategy	maximize performance and minimize cost	use modular design in order to postpone product differentiation for as long as possible

Figure 11. Physically Efficient versus Market-Responsive Supply Chains. Source: Fisher(1997)

Supply chain for functional products has to be physically efficient. Providers of functional products have to concentrate on the physical function by minimizing costs with the use of planning tools and the proper information flow between supply chain echelons.

Supply chain for innovative products has to be market-responsive. Decisions about inventory and capacity should be made to hedge against demand uncertainty. Early information about customer trends and continuous analysis of market signals are important.

2.6.2.2 Uncertainty Framework

Hau Lee (2002) in his article "Aligning supply chain strategies with product uncertainties?" proposed that the right supply chain strategy has to be tailored to meet customer requirements. Lee proposes that a product with stable demand has to be managed differently from a product with variable demand and supply uncertainty.

One-size-fits-all supply chain strategies are destined for failure. Lee proposes an uncertainty framework with two components: demand and supply. The *demand component* is covered by Fisher in his classification of innovative and functional products. The *supply component* classifies supply processes into two types: stable and evolving.

A stable supply process occurs when manufacturing processes and their technology are mature and the supply base is well established. Manufacturing complexity in a stable supply process tends to be low or manageable. Manufacturing processes are typically highly automated and long term supply contracts are commonly used.

An evolving supply process occurs when manufacturing processes and their technology are under development. Normally, the supply base is limited in size and experience. The differences between stable and evolving supply processes are summarized in Figure 12.

Stable	Evolving
Less breakdowns	Vulnerable to breakdowns
Stable and higher yields	Variable and lower yields
Less quality problems	Potential quality problems
More supply sources	Limited supply sources
Reliable suppliers	Unreliable suppliers
Less process changes	More process changes
Less capacity constraint	Potential capacity constrained
Easier to changeover	Difficult to changeover
Flexible	Inflexible
Dependable lead time	Variable lead time

Figure 12. Supply Processes. Source: Lee (2002)

The assumption that functional products always have a stable supply process or that innovative products always have an evolving supply process is incorrect.

As a result of demand and supply components, a two-by-two matrix was generated.

In this matrix, products can be classified as shown in Figure 13.

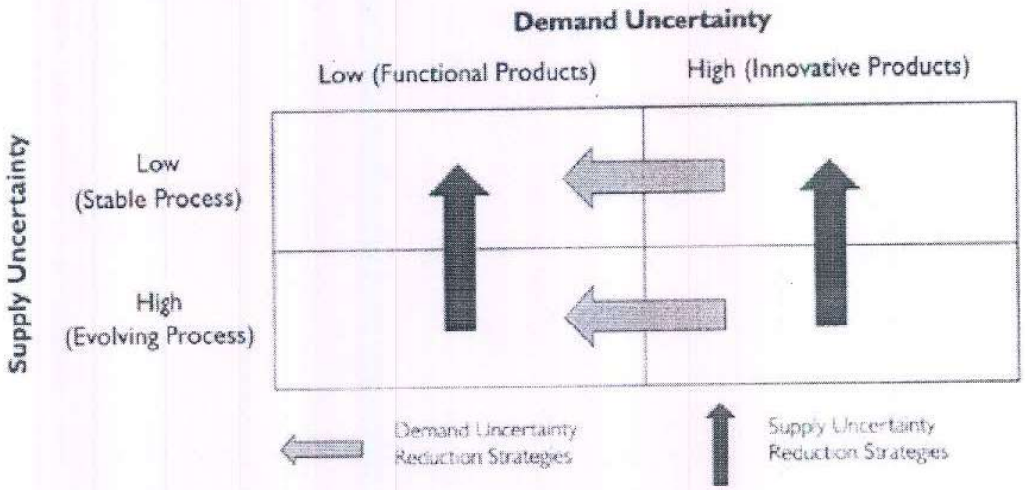

Figure 13. The Uncertainty Framework. Source: Lee (2002)

According to Lee (2002), there are four types of supply chain strategies: efficient supply chains, risk-hedging supply chains, responsive supply-chains, and agile supply chains. There is a match of these strategies with the matrix in Figure 14.

Supply Uncertainty	Demand Uncertainty: Low (Functional Products)	Demand Uncertainty: High (Innovative Products)
Low (Stable Process)	Efficient supply chains	Responsive supply chains
High (Evolving Process)	Risk-hedging supply chains	Agile supply chains

Figure 14. Supply Chain Designs in the Uncertainty Framework. Source: Lee (2002)

Lee (2002) argues "that different supply chains are need for different products."

Table 2 present supply chain strategies in each quadrant of the uncertainty framework.

Table 2. Supply chain strategies in the uncertainty framework. Source: Lee (2002)

Efficient Supply Chains – Cost efficiency is generated by just-in-time systems, automation, lean manufacturing, facility layout or workflow streamlining. – Supply chain efficiency is generated by Full-Truck-Load (FTL) deliveries, warehouses quantity reduction, replenishment software, optimization or information sharing across the supply chain.	*Responsive Supply Chains* – Responsive supply chains use strategies such as postponement, build-to-order and mass customization.
Risk-hedging Supply Chains – Risk-hedging is generated by inventory risk pooling, resource sharing, product design using the same components, multiple supply bases or market exchanges in internet.	*Agile Supply Chains* – Agile supply chains are a combination or risk-hedging and responsive supply chains, therefore a mixture of both supply chain strategies is possible.

2.6.2.3 Triple A framework

The third framework was created by Hau Lee in 2004 in his article "The triple A supply chain." In this article, Lee (2004) argues that everything else being equal, the two core concepts of supply chain management of greater speed and cost effectiveness are not enough to gain competitive advantage. The reason why efficient supply chains fail is because they are unable to respond to unexpected changes in supply or demand.

Efficient supply chains are designed to maximize economies of scale with centralized manufacturing and distribution facilities. For example, when there is an increase in demand, efficient supply chain deliveries are normally delayed because they are not big enough to fill a complete truck. This delay generates stock outs affecting the company's customer perception. Additionally, efficient supply chains are slow in making decisions to adapt to changes in market structures such as moving manufacturing facilities off-shore or outsourced manufacturing. In summary, "Supply chain efficiency is necessary, but it isn't enough to ensure that firms will do better than their rivals."

According to Lee's research in 2004, top performing supply chains have three characteristics: agility, adaptability and alignment. Lee (2004) emphasizes that there is no need to make trade-offs among these characteristics and that the implementation of the three characteristics simultaneously is required to generate competitive advantage.

- *Agility:* An agile supply chain is able to respond to rapid and unanticipated market changes. Agility is critical because changes are frequent in the present time. Agile supply chains react both swiftly and cost-effectively. The methods to reach agility are presented in Figure 15.

The ability to react and recover rapidly from disruptions such as terrorist attacks or natural disasters is a measurement of agility. This ability is particularly important in today's global supply chains.

Agility

Objectives:

Respond to short-term changes in demand or supply quickly; handle external disruptions smoothly.

Methods:

>Promote flow of information with suppliers and customers.
>Develop collaborative relationships with suppliers.
>Design for postponement.
>Build inventory buffers by maintaining a stockpile of inexpensive but key components.
>Have a dependable logistics system or partner.
>Draw up contingency plans and develop crisis management teams.

Figure 15. Agility Methods. Source: Lee (2004)

- *Adaptability:* Successful organizations continuously execute changes in their supply chains to adapt to changes in markets or business strategies. For these companies, it is important to anticipate changes by gathering and analyzing relevant data and by making decisions accordingly. Sometimes, adaptability forces companies to have more than one supply chain depending on the nature of the products. Aspects such as the product stage in the life cycle and the level of manufacturing technology influences the type of supply chain that is required. The methods to reach adaptability are presented in Figure 16.

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Adaptability

Objectives:

Adjust supply chain's design to meet structural shifts in markets; modify supply network to strategies, products, and technologies.

Methods:

- Monitor economies all over the world to spot new supply bases and markets.
- Use intermediaries to develop fresh suppliers and logistics infrastructure.
- Evaluate needs of ultimate consumers – not just immediate customers.
- Create flexible product designs.
- Determine where companies' products stand in terms of technology cycles and product life cycles.

Figure 16. Adaptability Methods. Source: Lee (2004)

- *Alignment:* Great companies align the interest of its supply chain partners. **If** this alignment is not reached, each company will maximize its own results instead of maximizing the results of the supply chain as a whole. This misalignment can also occur among the divisions of a single company. Vendor Managed Inventory (VMI), implemented in a collaborative way, is one of the logistics practices that facilitate alignment. One way to get alignment with supply chain partners is the use of contracts where risk, cost, incentives and benefits are shared. Figure **17** presents the methods to accomplish an aligned supply chain.

Alignment

Objective:

Create incentives for better performance.

Methods:

- Exchange information and knowledge freely with vendors and customers.
- Lay down roles, tasks, and responsibilities clearly for suppliers and customers.
- Equitably share risks, costs, and gains of improvement initiatives.

Figure 17. Alignment Methods. Source: Lee (2004)

Triple **A** supply chains do not require high technology investments. **A** Triple **A** supply chain is made by people with a full supply chain vision.

3 Characterization of SCM in the cement industry

This section is divided in three parts. The first part is a cement industry analysis using Michael Porter's five forces. The second part presents an analysis of the supply chain strategy of the four largest cement companies using Lapide's excellent supply chain framework. Finally, different frameworks are applied to analyze alternative supply chain operating models for the cement industry.

3.1 Cement Industry Analysis

Cement industry analysis was made using Michael Porter's **(1980)** five forces driving industrial competition. See Section 2.4 for details of Porter's model. The five competitive forces are: threat of entry, rivalry among competitors, pressure from substitute products, bargaining power of buyers and bargaining power of suppliers.

- *Threat of Entry:* Table 3 presents the analysis of the barriers to entry of the cement industry. Each barrier was qualified as high, medium or low. When barriers of entry are high, the threat of entry is low.

Table 3. Barriers of Entry of the Cement Industry.

Barriers	Barriers of Entry in the Cement Industry
Economies of scale (EoS)	Cement plants are built to get economies of scale. In general, cement plants that are owned by large companies are big, highly automated with major quality standards. This barrier of entry is **high** in mature markets; in emerging markets with presence of the large cement companies, the barrier is **high** as well.
Product differentiation	Cement is a commodity. Traditionally there were no efforts of building brand equity. Some cement companies are trying to de-commoditize cement with product innovation, branding and packaging initiatives. The barrier of entry is **low**.
Capital requirements	The cost of an efficient cement plant is approximately 105 millions Euros and it is expected to last 100 years. In some cases, cement companies are vertically integrated with transportation and logistics infrastructure. These investments are significant, especially in developed markets where bulk transportation is common. This barrier of entry is **high**, especially

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	when the large cement companies are already established in the market.
Switching costs	Cement is a commodity. The switching cost from one supplier to other is low. This barrier of entry is **low**.
Access to distribution channels	Concrete companies can be seen as a distribution channel that is normally integrated and controlled by cement companies. This is not the case in the US. Retail and wholesalers channels are usually not controlled by cement companies and are fragmented. This barrier of entry is **medium**.
Cost disadvantages independent from scale	Cement companies are mature companies with years of experience. They have the know-how, access to raw materials, established locations, and high learning experience curve. On average, the age of the top 4 cement companies is 130 years and they have been focused on cement from their origin. Some of them expanded to new construction related products and new businesses as shown in the second column of Appendix C. This barrier of entry is **high**.
Government policy	This barrier of entry depends on country's regulations about ownership of subsoil. If subsoil is owned by the government, cement companies identify raw materials sources and work closely with the government to get licenses to exploit them. If the subsoil is owned by people, cement companies acquire the land and exploit it. Normally, there are environmental controls involved in both situations. Additionally government can also control fuel prices and freights. This barrier of entry is **medium**.

We can conclude that the cement industry has **medium to low** threat of entry. This is particularly true when large cement companies are in control of the country's cement production. In recent decades, large cement companies have acquired local cement companies in countries where presence of other large cement companies was limited or inexistent. Acquisitions were promoted by the following reasons:

- Desire of increased volume, revenues and market share.
- Risk diversification among different countries with different economic cycles tied to cement demand.
- Take advantage of a company's low market value in a moment of crisis.
- Benefits from the scale in the purchase of raw materials, components and energy.
- Acquisitions were possible due to the access to larger financial capital markets for cement global corporations.
- *Rivalry Among Competitors.* Table 4 presents the analysis of the drivers for rivalry in the cement industry.

Table 4. Rivalry in the Cement Industry.

Drivers for Rivalry	Rivalry in the cement industry
Numerous or Equally Balanced Competitors	In the cement industry, there are a small number of equally balanced competitors; hence, rivalry is **high**. There are countries where there still is local competition from small or medium size firms, but their number is limited. Some of the local competitors have small cement plants with limited automation and quality standards. They offer low prices that compete with the large cement companies, especially in emerging markets where quality requirements and purchase power is low.
Industry Growth	According to the Portland Cement Association (2006), from 2002 to 2005 world cement consumption increased by 25%. China represents 45% of world consumption and is expected to grow at a steady rate of 8.5% annually. Cement consumption growth is concentrated on emerging markers; therefore the rivalry to enter these markets is **high**. Even though in mature markets the consumption growth is small, companies compete to maintain their dominant positions. The rivalry is also **high**.
Fixed or Storage Cost	According to Lafarge (2008), its production costs (before distribution and administrative cost) are distributed as 34% for energy, 29% for raw materials & consumables, 28% for labor & maintenance, and 11% for depreciation. Assuming that the last two are fixed, their relative weight is significant and hence rivalry is **high.**
Differentiation	Cement differentiation is low; hence rivalry is **high**.
Capacity Augmented in Large Increments	Cement increments in production capacity are normally high; hence rivalry is **high**. In addition, capacity increments are a fixed cost investment with penalty for underutilization. The only way to reduce production (since this is a continuous process) is by turning off the plant. According to Cemex, "the cost of stopping a cement plant is significant due to lost sales. The inventories in the distribution channel are no more than 2 days; hence there is no buffer to cover supply shortages."
Diverse Competitors	Large cement companies come from different regions and they all have many years of experience. Large cement companies have huge geographical coverage. On average, the top 4 cement companies are in 57 countries. See Appendix C for details. The rivalry is **high**.
Strategic Stakes	Cement firms normally have high stakes in the market so rivalry is **high**. The stakes are mostly related to capital investment required to open a new plant.
Exit Barriers	Cement firms normally have specialized assets, long term government licenses and significant capital investment, hence rivalry is **high**.

We can conclude that the cement industry has high level of rivalry amongst major competitors. The cement industry can be defined as an oligopoly; a market dominated by a small number of sellers. According to Ghemawat (2007), concentration in the cement industry has increased since 1980 where the top 5 companies owned 11% of the cement industry. By 2007, concentration increased to 25%.

- *Pressure from Substitute Products.* Cement has no direct substitutes. Modern cement was developed in the 1800s in the Industrial Revolution and today's product is essentially the same. Since cement is the major component of concrete, the substitutes of concrete are also a threat to cement. In this case, other building materials are substitutes of concrete e.g. asphalt, wood, clay bricks, stone, gypsum, fiber glass and steel. They don't represent a major challenge especially for large buildings and infrastructure projects. Therefore the pressure from substitute products is low.

- *Bargaining Power of Buyers (BPB):* In the case of the cement industry, there is a difference between the BPB of large construction companies and government, and the BPB of Do-It-Yourself (DIY) builders and small contractors. The relative importance of each type of buyer depends on the level of development of the country. For example, according to the U.S. Geological Survey (USGS) (2009) in 2008 about 75% of cement sales in the US went to ready-mixed concrete producers, 13% to concrete product manufacturers, 6% to contractors (mainly road paving), 3% to building materials dealers, and 3% to other users. In underdeveloped countries, cement demand from DIY builders is approximately 70% of sales. Self builders buy cement in small quantities combined with other construction materials. Normally, wholesalers and retailers are used as distribution channels to DIY builders. The drivers for BPB are represented in Table 5.

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Table 5. Bargaining Power of Buyers in the Cement Industry.

BPB Drivers	DIY Builders and Small contractors BPB	Large Construction Companies / Government BPB
Buyer purchases large volumes relative to seller sales	Market is dominated by a group of dispersed buyers; hence BPB is **low**.	One buyer or one group of buyers makes the purchasing decision; therefore BPB is **high**.
Seller's product importance on buyer's costs or purchases	Cement price is significant but the quantity that the final customer buys is small. So, BPB is **medium**.	Cement unit price is low but the quantity that the buyer needs is significant; hence BPB is **high**.
Standard of differentiated product	Cement differentiation is low; hence BPB is **high**.	Cement differentiation is low; hence is **high**.
Buyer's switching cost	Cement buyer's switching costs are low; hence BPB is **high**.	Cement buyer's switching costs are low; hence BPB is **high**.
Buyer's profits	Cement is mostly use in DIY building where profits are not an issue. Small contractor's profits are not significant. BPB is **low**.	Profits of large construction companies are low so there is pressure for low prices; hence BPB is **high**.
Buyers pose a threat of backward integration	There is no clear evidence about backward integration in the cement industry; hence BPB is **low**.	There is no clear evidence about backward integration in the cement industry; hence BPB is **low**.
Seller's product importance to the quality of buyer's product	Because of the fractioned market and the DIY building, quality is not a significant issue. This market is more price sensitive than quality sensitive; hence BPB is **low**.	In this market the quality of cement / concrete is very important. Buyer's prestige and future contracts are in stake; hence BPB is **high**.
Buyer's level of information	Because of the fractioned market and the DYI building, buyer's level of information is low; hence BPB is **low**.	Large construction buyers have a high level of information; hence BPB is **high**.

We can conclude that the bargaining power of buyers of DIY builders and small contractors is low. Instead, large construction projects and governments have high bargaining power.

Emerging markets are dominated by DIY builders and small contractors. Developed economies are dominated by large construction companies. A possible effect of the lack of BPB of the cement buyers in emerging economies might explain the difference in the current prices per ton of cement. The retail price in the US is approximately 110 dollars per ton versus 200 dollars per ton in Colombia.

- *Bargaining Power of Suppliers (BPS).* Cement companies are normally the owners of quarries where major raw materials are extracted. Exploitation of quarries varies depending on country regulations about the ownership of subsoil. For example, in the US, the owner of the land is also the owner of the subsoil. In contrast, in several countries in Latin-America the subsoil is owned by the government. In these countries, the government controls the access to raw materials through medium to long-term licensing. This situation is a challenge due to the risk of continuous changes in the licensing regulations that occur in emerging markets.

There are other cement raw materials that are acquired in the spot market and are subject to significant price fluctuations. Fuel is one of the raw materials that are most important for the cement industry. The production of a ton of cement requires about 60 to 130 kilograms of fuel or equivalent source of energy. It also consumes 150 Kwh of electricity. The drivers for BPS are represented in Table 6.

Table 6. Bargaining Power of Suppliers in the Cement Industry.

BPS Drivers	BPS in the cement industry
Dominated by few suppliers and is more concentrated than the industry	Excluding the limestone that comes from the quarries, other raw materials (e.g. gypsum, bauxite, iron, fly-ash) are highly concentrated with a small number of suppliers. BPS is **high**.
There are substitute products for sale to the industry	There is no clear evidence about substitute products for cement raw materials. BPS is **high**.
Industry importance as a customer of the supplier group	Cement industry is a major buyer of raw materials and energy. BPS is **high**.
Supplier's product as an input to the buyer's business.	Other raw materials and energy are very important for the cement industry. When cement raw materials and fuel prices increase, BPB increases too. According to Cembeureau (2008) energy represents 20 to 40% of the total production costs of the cement industry. BPS is **high**.
Supplier's products are differentiated or it has built up switching costs.	Other raw materials and energy are commodities that are not differentiated and the switching cost is low. BPS is **low**.
Supplier groups posses a credible threat of forward integration	There is no clear evidence about forward integration in the cement industry. BPS is **low**.

We can conclude that the bargaining power of suppliers in the cement industry is **medium.**

A summary of the results of Porter's five forces for the cement industry is presented in Table 7.

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Table 7. Porter's Five Forces in Emerging Markets versus Developed Countries

Competitive Force	Emerging Markets	Developed Countries
Threat of entry	Medium to low	Medium to low
Rivalry among competitors	High	High
Pressure from substitute products	Low	Low
Bargaining power of buyers	**Low**	**High**
Bargaining power of suppliers	Medium	Medium

Porter (1979) suggests that when the forces are weak collectively, there is a major opportunity for superior performance. Therefore, we can conclude that the cement industry is unattractive in mature markets, but attractive in emerging markets. Figure 18 presents the graphical summary of Porter's five forces driving cement industrial competition.

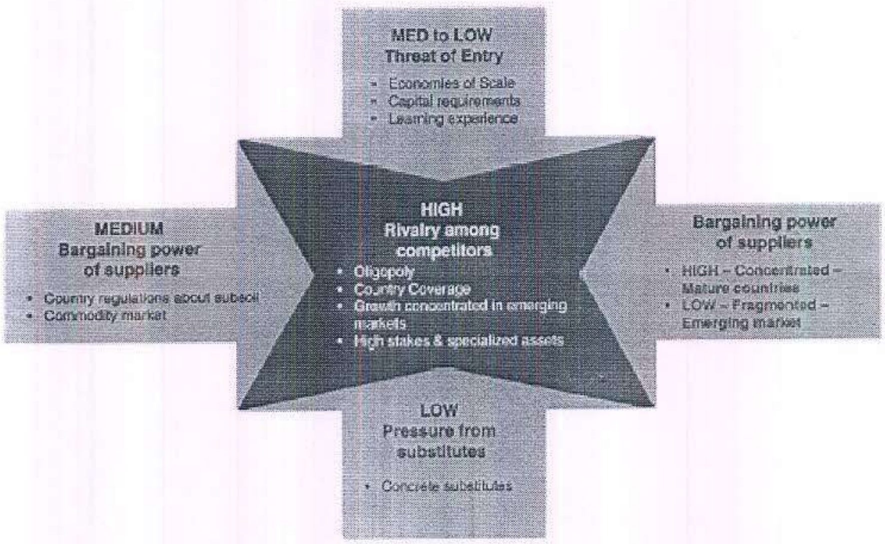

Figure 18. Porter's Five Forces Analysis for the Cement Industry

3.2 Supply Chain Strategy in the Cement Industry

The analysis of the supply chain strategy that best fits the strategy of the four largest cement producers was made using the Supply Chain Excellence framework that was created **by** Larry Lapide in **2006.** See Section 2.5 for details of Lapide's framework.

In his article, Lapide (2006) introduces the concept of absolute and relative operational performance triangles. The absolute triangle refers to the objectives that all the companies within the industry must possess in order to be able to play in the industry. The relative triangle refers to the objectives which companies should focus on, in order to achieve significant differentiation from their competitors.

We believe that the cement industry is located in the corner of asset utilization with some level of efficiency in the absolute triangle as show in Figure 19. The main reason for this location is that cement companies are focused in minimizing cost based on the economies of scale generated by their investment in large manufacturing plants. This is a given condition for all large cement companies in the industry.

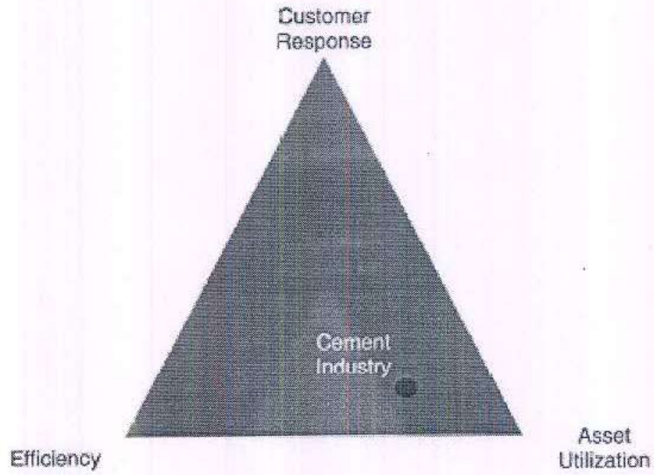

Figure 19. Absolute Triangle for the Cement Industry

The relative triangle requires a more detail analysis. The first step was to review the strategy of the four largest cement companies according to the information on their web sites and in their 2008 Year Reports. The summary of the companies' business strategy is presented in Table 8.

Table 8. Strategy of the Four Largest Cement Companies

Company	Corporate Strategy
Lafarge	The Group strategy can be broken down into clear and ambitious priorities: 2 strategic priorities: – Continuing development on emerging markets – Accelerating innovation to reach sales of €3bn with innovative products by 2012 3 operational priorities: – Ensuring the safety of our employees and targeting 0 accidents – Continuing with cost reduction – Developing the potential of the men and women in the Group
Holcim	– Our strategy is based on three central pillars: focusing on the core business, geographical diversification and balancing business responsibility between local and global leadership – Holcim value chain: We focus on our core business. Cement and aggregates are at the center of our activities – Geographic diversification: Holcim is more globally active than any other building materials group, with a strong foothold in each individual market – Local management, global standards: Our success lies in striking a balance between local responsibility and global leadership
Cemex	– Customer focus: We're committed to providing our customers with the most efficient and comprehensive building materials – CEMEX people: Our most important asset is our people—motivated employees who can deliver consistently positive results for our customers, our stockholders, our communities, and each other – Solid business model: Our portfolio of cement, ready-mix concrete, and aggregates assets is concentrated on markets that provide sustainable top- and bottom-line growth throughout the economic cycle – Dynamic enterprise: Since we made our first batch of cement in 1906, we set in motion a philosophy that still guides us today: continuous improvement – Sustainability: Our ultimate goal is sustainable growth and development for our company and our industry
Heidelberg	– Besides the traditional core business of cement, aggregates (sand, gravel and crushed rock) have become a second strategic pillar – Our strategy is clear and convincing: Concrete, the building material for which there is most demand worldwide, is by far our most important end product – Heidelberg Cement is pursuing a clear dual external growth strategy: expansion of the cement business in growth markets and North America; and focus on aggregates and downstream activities in mature markets and North America.

The second step is to build a relative triangle for the cement industry. Based on the strategy information in Table 8 and the information gathered in the interviews, we allocate a dot corresponding to each one of the four companies on the relative triangle.

We position Lafarge predominantly in Customer Response because of its focus on innovation and emerging markets. We position Holcim and Heidelberg in the middle of Customer

Response and Efficiency because they are focused in emerging markets and are also concentrated on their core businesses to gain efficiency. We place Cemex in the corner of Efficiency with some degree of Customer Response. Cemex is also concentrated in emerging markets but with special focus on continuous improvement.

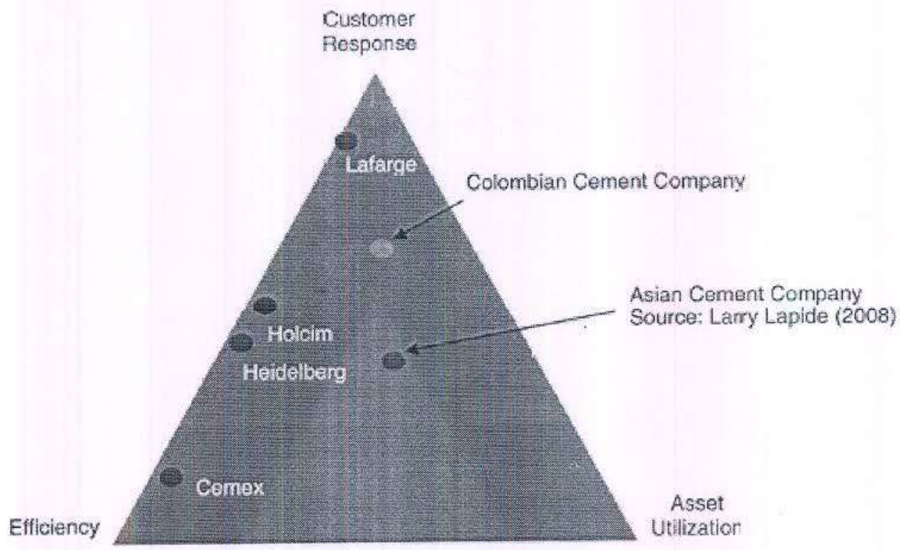

Figure 20. Relative Triangle for The Cement Industry

It is important to acknowledge that in the information gathered, there is no clarity about the strategy that the companies are going to use in the emerging markets. So, an additional understanding of the companies' strategy is recommended, using multiple relative triangles for domestic or international markets, or as per country or region.

3.3 Supply Chain Operating Model of the Cement Industry

Supply Chain Operating Model characteristics are analyzed according to two perspectives: processes and products.

3.3.1 Supply Chain Processes of the Cement Industry

Two frameworks were used to analyze the processes of the cement supply chain: the SCOR **model and the Push-Pull Supply Chain frameworks.**

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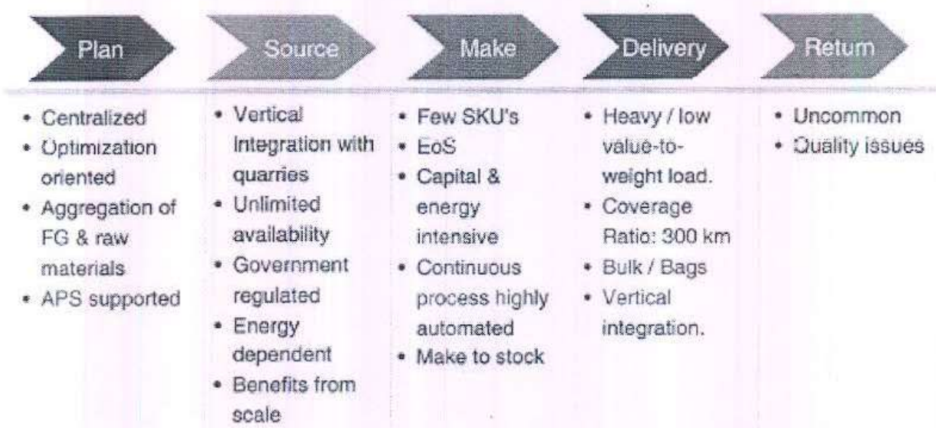
Figure 21 presents the diagram with the summary of the cement SC characteristics.



3.3.1.1 SCOR Model

The supply chain processes of the cement industry were described using the logistics processes in the SCOR Model: Plan, Source, Make, Deliver and Return. See Section 2.6.1.1 for details of SCOR Model.

3.3.1.1.1 Plan

- Currently, supply chain planning processes in large cement companies are centralized. Centralization was promoted by the desire of identifying and integrating SCM practices that were independent before the acquisitions made during the last three decades.

- There was also an opportunity to optimize supply chain processes and to significantly reduce costs by analyzing the cement supply chain as a whole and not as independent companies. SC integration was not only for cement as a final product, but also for raw materials and fuel.

- Optimization projects motivated the implementation of APS (Advance Planning System) tools in large cement companies and the creation of centralized groups of supply chain planning.

- Even though, there are variations on a company-to-company basis, optimization in the cement industry is concentrated on minimizing logistics cost.

- A current trend in the cement industry in emerging markets is the use of S&OP (Sales and Operations Planning) processes to align sales, manufacturing and supply chain activities to guarantee the required service level. S&OP meetings are normally weekly and some of them include coordination among different countries.

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3.3.1.1.2 Source

- Limestone is the principal cement raw material. Limestone comes from quarries.
Cement companies normally own the quarries or get license agreements with the government to exploit them. There is no clear evidence about limitations in the availability of limestone but some countries have more potential than others.

- In a majority of the countries, governments control cement and mining industries with environmental regulations related either to the exploitation of raw materials or to the environmental impact of the process. Cement is a highly controlled industry.

- Cement companies purchasing items organized by cost are coal, electricity, other raw materials, packaging, production elements and maintenance elements. There are benefits from scale in large cement companies but only for components that are common among many cement plants e.g. coal, refractory materials used in kilns or computers. Some components vary depending on the country so there is no opportunity for aggregation e.g. trucks.

- There is no evidence of collaboration among competitors in the cement industry even though it is easy to find similarities among the cement companies that operate in the same country or region.

3.3.1.1.3 Make

- Cement has low proliferation of SKU's. For example, Cementos Argos, which is mainly concentrated in emerging markets, has 27 SKU's, 8 of which are cement in bulk and 19 are cement in bags.

- Cement manufacturing process is capital and energy intensive and is designed to generate economies of scale. It is a highly automated continuous process. Because of the cost that is generated by stopping a plant, traditionally all the logistics processes were subordinated to avoid this situation, no matter the costs. Now, cement companies are committed to optimize the logistics costs along with avoiding stops in production.

- A cement plant is normally located near the quarries. Quarries have to be large enough to support a cement plant that is designed to last about 100 years on average. One of the challenges of cement companies is to maintain an appropriate reserve of raw materials by exploring the soil.

- Cement production process is make-to-stock. This means that production is made to satisfy a sales plan; final products are kept in warehouses and wait for demand to be delivered.

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- Cement manufacturing process is dependent on fuel and electricity. This is one of the major future concerns of the cement industry. It also has a very strong environmental impact especially in carbon emissions.

3.3.1.1.4 Deliver

- There is a natural boundary of action of a cement plant given by how competitive is the cost of transporting cement by truck. According to Cembeureau (2008) because of the weight of cement, it is not profitable to move it in by truck over distances longer than 300 kilometers. Maritime, river and railroad transportation enable the expansion of plants coverage by reducing the transportation cost per ton.

- There are physical characteristics of cement that challenge the distribution process.
Cement is a heavy load with low value-to-weight ratio which promotes practices such as FTL and the use low cost transportation modes such as sea, rail and river.Cement hardens with water which also creates a challenge in water transportation.

Cement shelf life is approximately 60 to 90 days. If the product is stored for longer periods, its physical properties might be affected and need to be tested for quality.

- Cement is distributed in bulk or bags. Bulk distribution requires a dedicated and expensive fleet that is owned or outsourced by cement companies. See picture in Figure 22. The load of a bulk truck varies depending on whether the distribution region is mountainous or plain. If is mountainous, the load has to decrease to compensate the motor effort.

- Other challenge in cement bulk deliveries is that specialized equipment is needed to unload the product. The equipment has to travel with the truck or it has to be present at the customer site when the truck arrives.

Figure 22. Bulk Cement Silos and Truck. Courtesy of Cementos Argos.

- Bags are more flexible, they can be moved in normal trucks with the advantages of backhauling. In emerging markets, distributors such as retailers and wholesalers are the distribution channel for cement in bags. Distributors require small and frequent orders because storage space and financial capital is limited. This situation creates a challenge for the logistics processes of ordering, picking and design of an efficient urban transportation routing process.

- Bags are also hard to load and to unload, especially under the circumstances of emerging markets. Loading is done in the cement plant where palletizers and lift trucks are available. Unloading is done in the customer location. In general, customers don't have appropriate equipment, so unloading is done manually.

Unloading is expensive and time consuming and affects the health of the workers in charge. There are initiatives from cement companies in emerging markets to introduce mechanization in the unloading process.

- The distribution process in emerging markets requires balance. On one side, cement characteristics limit the distribution process and promotes certain practices (.e.g. FTL, use of sea, river or train). On the other side, bag buyers require cement companies to formulate a logistics process that is similar to consumer product goods (CPG) logistics process (e.g. small orders, high frequency, urban deliveries).

Cement companies in emerging markets have to be able to cope with the challenges of both worlds.

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- Vertical integration with logistics providers and infrastructure is common in the cement industry. This decision depends on the company strategy, the political situation of the country, the competitor's strategy and the size of the market. In a period of steady or growth in demand, vertical integration has advantages that can become disadvantages in periods of demand contraction. Outsourcing, or a mix of private fleet and outsourcing, are the alternatives used by large cement companies.

If logistics contracts are flexible, this could be an interesting tool to convert fixed logistics cost to variable costs and reduce the impact of a decrease in demand during a crisis.

3.3.1.1.5 Return

Cement returns are uncommon. Returns can be generated by problems with the quality of the product (e.g. wet product) and they are normally resolved by replacing it.

3.3.1.1.6 SCM in the concrete industry

Concrete is a mix of cement, aggregates, water and sand. Concrete can be made and sold as a ready-mix formula that is transported in a specialized fleet of in-transit mixers to the construction projects. Concrete can also be made by hand mixing the components in a concrete mixer in the construction site. This option gives time to the construction workers to use concrete before it hardens. In emerging markets where labor is cheap, this process costs less than ready-mix concrete.

Ready-mix concrete distribution has particular challenges. Concrete is a perishable product that has to be use within 90 minutes after introducing the materials in the mixer; therefore in-transit mixers generally do not travel far from their plant. Another issue emerges from concrete needs of the construction companies that have tight schedules that they have to comply with. Ready-mix concrete logistics requires high coordination between supplier and buyer to get a quality product on time at the construction site.

Ready-mix concrete and cement industry are normally integrated. There are several reasons that might explain the integration. First, ready-mix concrete industry can be seen as a distribution channel of the cement industry. Ready-mix concrete customers are more loyal than cement customers. They are normally large construction companies in charge of large construction projects that are looking for service and product guarantee. Second, integration was a trend in the cement industry back in the 1980s that was followed by many of the large cement companies. Third, it could also be motivated by a desire of increase in revenues because one ton of cement produces approximately three cubic meters of concrete that is sold at a higher price than cement.

Cement and ready-mix concrete **SCM** are normally separated. There are some areas of integration that can be explored in maintenance of trucks in case of private fleets, routing optimization and truck tracking technology among others.

3.3.1.2 Push-Pull Supply Chain Analysis in the Cement Industry

Figure 23 represents the cement supply chain. Different colors were used represent each of the product flows in the cement supply chain: raw materials, clinker, cement in bulk, cement in bags and concrete.

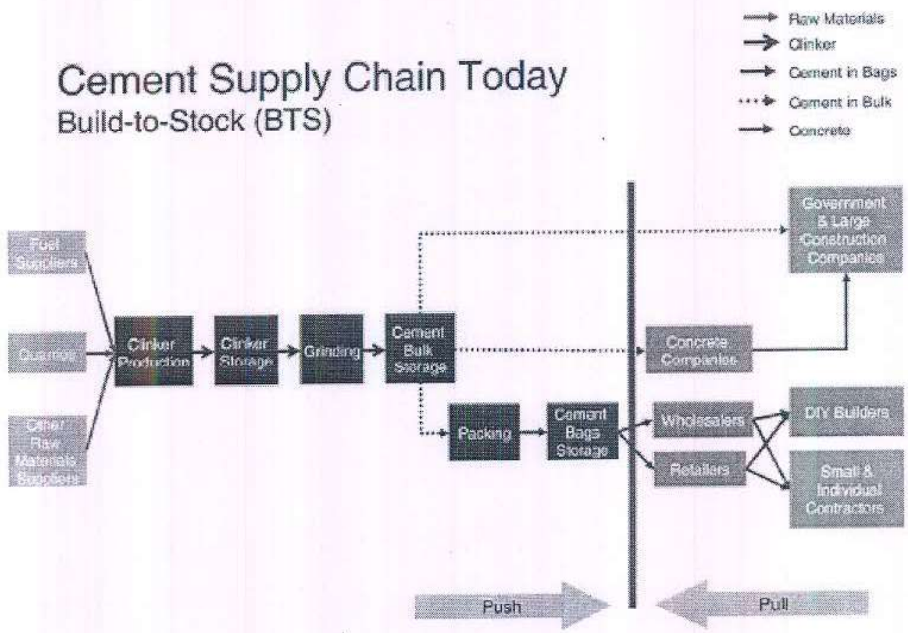

Figure 23. Cement Supply Chain

According to Reeve and Srinivasan (2005) there are four major supply chain designs: Built-to-Stock (BTS), Configure-to-Order (CTO), Built-to-Order (BTO) and Engineer-to-Order (ETO). See additional details in Section 2.6.1.2.1. At present, the cement industry supply chain has a BTS design where purchase orders are delivered from storage, the lead time to consumer is just the transportation time and the degrees of customer choice are limited. Cement BTS is shown in Figure 23.

According Reeve and Srinivasan (2005), CTO is the most appealing of the supply chain designs because CTO maximizes the benefits of the Raw-As-Possible (RAP) principle. CTO usually increases the customer lead time but offers flexibility in product configuration. Additional analysis should be made to confirm cement customers' willingness to wait for the product and how cement / concrete configuration requirements justify the implementation of the CTO model.

Simchi-Levi et al. (2008) push-pull supply chain concept is similar to Reeve et al. (2005) CTO design. See details of Simchi-Levi et al. framework in Section 2.6.1.2.2.

In Reeve's framework, the RAP principle is used to define the push-pull boundary that is more appropriate for the product. To evaluate how feasible is to move from BTS to CTO in the cement industry, an analysis of the cement BOM was made according to the RAP principle. Cement BOM is composed of clinker, gypsum, other mineral raw materials and paper bags (only for bagged products). Based on the cement BOM, we proposed two CTO alternatives: Grind-to-Order and Pack-to-Order.

- *Grind-To-Order (GTO):* Clinker is an intermediate product of the cement manufacturing process. GTO might be possible using clinker as a base, grinding it according to customer orders as shown in Figure 24. A trade-off analysis between the costs of storage and ordering from clinker versus the reductions of final product inventory and the benefit in cement / concrete configuration flexibility. Also, technical aspects related to the grinding machines have to be evaluated.

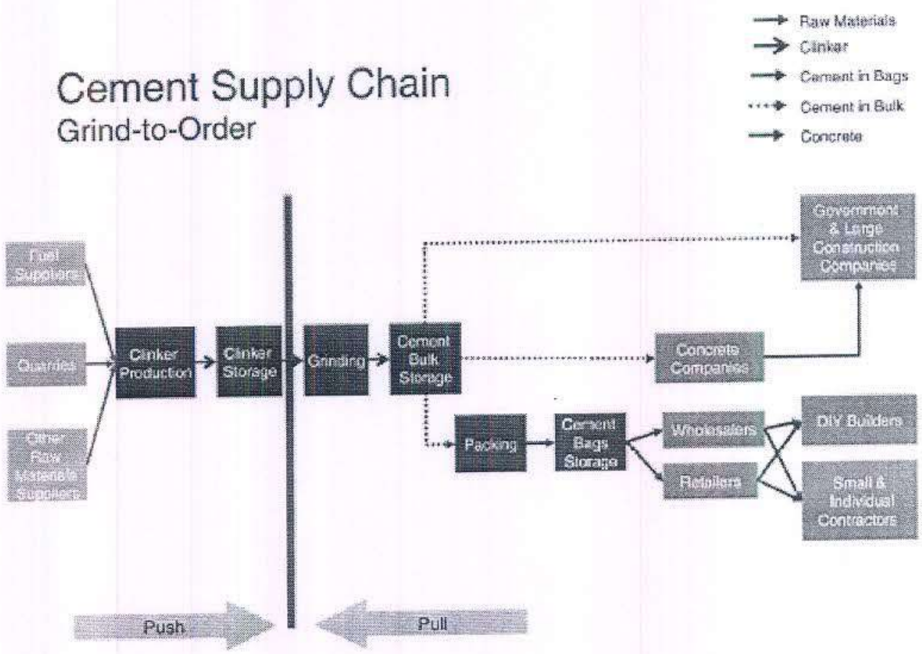

Figure 24. Grind-To-Order Cement Supply Chain

- *Pack-to-Order (PTO):* PTO is an opportunity in emerging markets where cement is sold in bags and where DIY builders and small contractors have the highest market share. Today, there are just a few variations in bag sizes in the cement industry in emerging markets. In the future, the number of bag size variations might increase.

Therefore, there is an opportunity for postponement in the packaging process. Cement packaging is a simple and highly automated process. The average speed of a cement bagging machine is 100 tons per hour. The packaging process is not a bottleneck. In this case, postponement can be used by keeping cement in bulk stored in silos until purchase orders

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arrived specifying the bag size that the customer needs as shown in Figure 25. A trade-off analysis between the carrying costs of cement in bulk versus the carrying cost of cement in bags is required.

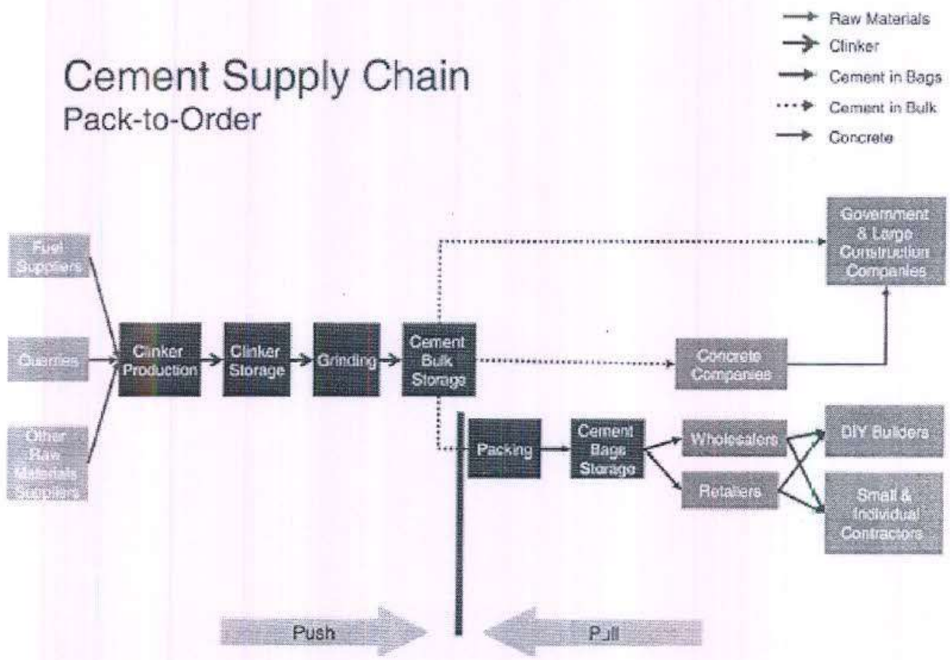

Figure 25. Pack-To-Order Cement Supply Chain

GTO and PTO aggregate demand in the manufacturing process reducing variability and improving forecast accuracy. Their implementation requires a continuous information flow and close coordination between order processing and manufacturing.

A minor opportunity for postponement is in packaging printing processes. In this case, plain bags can be stored and when purchase orders are received, the bag printing process starts. A trade-off analysis between the carrying costs of printed bags versus the benefits of print by demand is required.

3.3.2 Supply Chain Structure of the Cement Industry

Cement supply chain operating models were analyzed according to three frameworks: the Demand Uncertainty Framework (Fisher, 1997), the Uncertainty framework (Lee, 2002) and the Triple A framework (Lee, 2004).

Fisher (1997) proposes that there are two types of products according to their demand: functional and innovative. See Section 2.6.2.1 for details of Fisher's framework. Cement

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should be analyzed as two different products: bulk cement and bagged cement. Bulk cement is the cement configuration that is normally sold to ready-mix concrete companies or to large construction companies and governments.

Cement bulk is dominant in developed countries. Bagged cement is sold to wholesaler and retailers. Its final consumers are DIY builders and small contractors. Cement bags are dominant in emerging markets.

Table 9 presents the quantitative analysis comparing bulk cement and bagged cement according to Fisher's aspects of demand.

Table 9. Cement Classification According to Fisher's Aspects of Demand

Aspects of Demand	Bulk Cement	Bagged Cement
Product Life Cycle	Modern cement is more than 200 years old. The product is in mature stage.	
Contribution Margin	In general, cement margins are 25 – 35% depending on the country and the type of cement. According to the information in Appendix C, developed countries (bulk cement is dominant) account for 30-40% of the company's operational income.	In general, cement margins are 25 – 35% depending on the country and the type of cement. According to the information in Appendix C, emerging markets (bagged cement is dominant) account for 60-70% of the company's operational income.
Product Variety	Low. For example, Cementos Argos has 8 types of bulk cement.	Medium. For example, Cementos Argos has 19 types of bulk cement.
Forecast error	According to Cementos Argos, the average forecast error for bagged cement is 17%.	According to Cementos Argos, the average forecast error for bagged cement is 12%.
Stock out Rate	N.A.	It is estimated by the author that is higher than bulk cement.
Lead time for MTO	According to Cementos Argos, the MTO manufacturing process of a ton of cement is 62 minutes. This time doesn't include extraction.	

N.A.: Not Available

Based on Fisher's characteristics of functional and innovative products presented in Figure 4, we can conclude that bagged cement is more innovative than bulk cement.

Therefore, a cement company that produces these two varieties of cement should have different supply chains.

Table 10 presents the analysis comparing Fisher's recommendations for functional products with current characteristics of cement supply chain.

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Table 10. Cement Supply Chain Analysis

SC Characteristics	Current characteristics of cement SC
Primary purpose	Based on the information gathered, supply chain areas in cement companies are in the process of taking a strategic role in cost reduction. According to Lafarge "SCM potential for cost reductions is recognized in the cement industry. Optimization processes were quickly adopted by all large cement companies." In the case of bagged cement, it is important to gain the ability to respond quickly to unpredictable demand to reduce stock outs for cement wholesalers and retailers. Cement companies collaboration with wholesalers and retailers is vey low. There are significant opportunities for improvement, especially in emerging markets.
Manufacturing focus	Cement companies are committed to high utilization rates. Cement plants are built to generate economies of scale and they work 24x7 only stopping for maintenance or due to extreme falls in demand. In the case of bagged cement, it is important to create excess buffer capacity. One opportunity to get this capacity is by the use of postponement in the packing process where a buffer is created in bulk cement avoiding the possibility of not having inventory in the bag size that the customer is requiring. .
Inventory strategy	Given the 60 days of cement shelf life, cement companies are committed to generating high turns and minimizing the inventory of finished goods (FG).
	For bagged cement, it is necessary to create buffer stocks of finished goods close to the market given that cement plants are normally close to the quarries. According to Cementos Argos "We maintain 3 days of FG inventories in the warehouses" According to Cemex "The bagged cement business is about turnover".
Lead-time focus	Cement industry is make-to-stock. According to Cementos Argos, the local delivery lead time is approximately one day since product is normally available in inventory. For bagged cement, it is important to invest in practices to reduce the lead time even further. Practices such as moving the inventory closer to the customers or specialized software to optimize urban routing are interesting.
Approach to choosing suppliers	Cement is a commodity that is selected primarily by price, availability and quality. Availability is a key element in bagged cement. If the product is not available in the shelf in the purchasing moment, the final consumer easily switches to a different product. Collaboration with downstream partners is a key element to get the desired level of product availability in shelves.
Product-design strategy	Cement manufacturing process is highly automated and continuous. Cement companies are focused in maximizing performance and minimizing cost. Postponement ideas of grinding to order or packing to order might help in the case of bagged products.

Lee (2002) proposes an uncertainty framework with two components: demand and supply. Demand uncertainties are covered by Fisher (1997) in his classification of innovative and functional products. Supply uncertainties classify supply processes into two types, stable and evolving. See Section 2.6.2.2 for details of Lee's framework

Cement supply process can be characterized as stable. Cement manufacturing is stable with high production yields, low product quality problems, relatively unlimited supply sources, easy changeover because of the small number of references using just a few raw materials, and fixed cement production lead times.

Given that bulk cement is a functional product and that cement supply process is stable, bulk cement is located in the upper left corner of in Figure 27. According to Lee (2002), the right supply chain for bulk cement is an efficient supply chain.

Given that bagged cement is an innovative product and that the cement supply process is stable, bagged cement is located in the upper right corner of in Figure 26.

According to Lee (2002), the right supply chain for bagged cement is a responsive supply chain.

Supply Uncertainty	Demand Uncertainty: Low (Functional Products)	Demand Uncertainty: High (Innovative Products)
Low (Stable Process)	Efficient supply chains **Bulk cement**	Responsive supply chains **Bagged cement**
High (Evolving Process)	Risk-hedging supply chains	Agile supply chains

Figure 26. Uncertainty Framework in the Cement Industry. Source: Fisher (1997)

In recent years, cement companies are significantly improving their abilities to master an Efficient Supply Chain for their bulk products. The extensive implementation of optimization supply chain software in the cement companies is one of the key elements of progress in the cost efficiency aspect.

In the case of the Responsive Supply Chain that is necessary for bagged products, Fisher (1997) and Lee (2002) agreed on the importance of collaboration with upstream and downstream supply chain partners. Functional products like cement are price sensitive; therefore negotiations with upstream and downstream partners are difficult.

Collaborative programs between supply chain partners are the best way to avoid this situation, creating higher profits for the supply chain as a whole. Based on the information gathered, the level of collaboration in the cement industry is relatively low. In the upstream component, there is collaboration with the suppliers of raw materials with medium to long-term contracts but there is no evidence of continuous information sharing initiatives. In the downstream side, low level of collaboration between cement and concrete companies is evidenced.

According to Cemex, "There is a belief in the cement industry about the difficulty in combining cement and concrete supply chain processes. We believe that there are benefits in combining the two and we started this process by joint truck maintenance initiatives." The long-term relationships of concrete companies with large construction companies are the best example of collaboration in the cement / concrete industry.

Traditionally, the supply chain of the cement industry has been classified as an efficient supply chain. The cement supply chain was designed to maximize economies of scale with relatively centralized manufacturing and to minimize transportation costs with the use of FTL and low cost transportation modes. Efficient Supply Chain is effective for bulk cement, which is common in developed countries, but as we have discussed, it is not appropriate for emerging markets.

According to Lee's research in 2004, top performing supply chains have three characteristics: agility, adaptability and alignment. See Section 2.6.2.3 for additional details about the framework. In Table 11, bulk cement supply chain and bagged cement supply chain were assessed as high, medium or low in each SC characteristic.

Table 11: Cement Supply chain assessment in Triple framework

SC Characteristics	Bulk Cement Supply Chain	Bagged Cement Supply Chain
Agile	Medium - **Medium** flow of information with customers. - Medium level of development of collaborative relationship with suppliers.	Low - **No flow** of information with customers. - Medium level of development of collaborative relationship
		with suppliers.
Adaptable	Low - Limited use of intermediaries in logistics services. - High concern about final consumers.	Medium - High use of intermediaries in logistics services. - Medium concern about final consumers.
Aligned	Low - Limited flow of information with suppliers and customers. - Limited use of supply contracts sharing risk, costs or gains.	Low - Limited flow of information with suppliers and customers. - Limited use of supply contracts sharing risk, costs

In general, we identified opportunities in collaboration and information sharing with raw materials, energy suppliers and distribution channels, focus in final consumers and use of equitable supply contracts in supply chain processes such as logistics services (e.g. infrastructure, transportation or warehousing).

According to Fisher (1997), two additional elements should be addressed in functional products that are worth to analyzing for the cement industry.

- Aggressive cost reductions have been made in some functional product industries and after some point, diminishing returns were reached. For many years, cost reductions in the cement industry were concentrated on the manufacturing process.

Now, large investments are required to significantly reduce the cement manufacturing cost. In recent years, cement companies identified the benefits of SCM practices and used them as an opportunity for significant cost reduction.

Present and future SCM potential savings are considerable and they can be extended to the mineral extraction commodity industry in general.

- One cause of lack of effectiveness of functional products' supply chain strategy is forward buying. In general, forward buying is a game where everybody loses because buyer's carrying cost increase while supplier's manufacturing and distribution processes are disrupted by fictional peaks of demand. Forward buying is a common practice in the cement and commodity industry. It has been used for many years and customers are used to buy under this practice. Further research is required to establish the benefits and barriers of moving to an every day low prices strategy that companies in other industries have implemented successfully

4 Case Studies

Three case studies are presented to support the idea that SCM can add value to the corporate strategy of cement and mineral extraction commodity companies. The first case is the implementation of a single 3PL (Third Party Logistics Provider) by three of the largest oil companies in Colombia. The second case is a collaboration project between concrete and cement supply chain in Cemex Colombia. The third case is collaborative port operation contract in the steel industry.

4.1 Single 3PL for the oil industry

The first case study is the implementation of one single 3PL provider to serve three of the most important oil companies in Colombia. The project's name was "Integrated Logistics Operator" (OLI - Spanish acronym). The name of the companies are Petrol A, B and C'. These names are fictional.

Traditionally, supply chain management leaders in the oil companies in Colombia don't work collaboratively. In 2002, after an evaluation about the potential benefits that collaboration in supply chain management might bring to the oil companies, Petrol A supply chain leader promoted a meeting with his counterparts. This meeting was facilitated by a third person that was independent to the oil industry. The purpose of the meeting was to have a brainstorming session to identify potential areas of collaboration. As a result of the meeting, two areas of collaboration where identified.

The first area was Materials, Repair & Operations (MRO) parts visibility among the oil companies. The second area was developing common 3PL providers for the oil industry.

The first area of collaboration was motivated by the fact that oil companies have significant MRO inventories generated by the parts that are not used in the perforation of oil wells. The value of the industry inventory of MRO parts represents millions of dollars. Because the lack of inventory visibility, an oil company might buy a part that another company has in its inventory. This project was postponed because the significant IT integration investment that was required to consolidate the MRO inventory information of the companies in the oil industry.

The second area of collaboration was motivated by the opportunities of consolidating the purchasing processes of logistics services of the oil companies.

During the brainstorming meetings, the oil companies noticed that they were acquiring products from the same origins (US, mainland Europe and UK). They noticed that they normally bid for the same type logistics services (freight forwarding services, transportation and customs clearance services) but at different times during the year.

For example, Petrol A bids transportation in February, while Petrol B bids in May and Petrol C bids in June. They also noticed that they were bidding for the same type of logistics services with different 3PL providers. 3PL providers for the oil industry were not developed at that time; they were specialized as per service type.

Additionally, an opportunity to get benefits from the demand aggregation of the oil companies from a logistics and financial perspective was also identified. All the companies in the oil industry were invited to participate, but only three were committed to develop common 3PL providers. The three companies managed, handled, transported and delivered USD 140 millions per year worth of international purchases of materials, equipments and spare parts accounting for at least 60% of the Colombian oil industry.

The first step of the process was demand aggregation per logistic service. As a result, three aggregated purchasing processes were made, one for freight forwarding services, one for transportation and one for custom clearance service. The main reason for not moving to a single 3PL provider was a bad past experience by one of the oil companies with a 3PL provider covering the three logistics services. To reduce the risk from unreliable suppliers, the three oil companies decided to select two providers per logistics service for a two years period.

The individual logistics service contracting mode generated excellent results, but the supply chain leader of Petrol A insisted in the importance of the single 3PL provider.

Due to the large scope of the three logistics services required by the oil companies, a consortium of suppliers was required. Then, the bidding started and 11 consortiums quoted. Finally, two consortiums were selected; one for Petrol B, the largest of the three oil companies, and another for the remaining two companies.

An interesting innovation was the three oil companies' involvement in the details of the contract's costs and rates. This level of involvement requires the 3PL provider to open its accounting books and to support all the expenses specified in the contract. The contract was flexible enough to use the 3PL provider current tariffs for a certain period of time but after that period, if a component of the logistic service could be outsourced for better tariffs in the market, the 3PL provider has to work with these outsourcing companies. The motivation for this arrangement was to guarantee that the 3PL provider tariffs were always competitive. The oil companies were involved directly in the selection of the outsourcing company. This process was particularly valuable in the case of freight consolidation service where maritime and air tariffs were hidden in the general tariffs, and for customs brokerage services where ports operations costs were hidden too.

In the first 4 years of the implementation of the ILO, the cost savings were approximately 4 million dollars per year for the three oil companies. This figure represents a 20% reduction from the figure that the companies were paying for ILOS services before integration. Furthers savings are possible with the entrance of other oil companies and continuous improvement from the partners involved.

Based on the information gathered, these are the key success factors in the implementation of the single 3PL provider in the Colombian oil industry:

- Long term contracts (at least 5 years) allowing the 3PL provider to build the learning curve in the oil business and exploit it in the execution of the contract.
- One manager per company exclusively dedicated to the execution of the contract with significant knowledge about supply chain operations in the oil industry.
- Oil companies' involvement in the details of the contract cost and rates to unhide cost components and reveal additional savings opportunities.
- Use of key performance indicators and continuous performance reviews to assess the results of the ILO and adapt to changing environment.
- Training and exposure of ILO employees to logistics knowledge and continuous improvement in ILO logistics practices based on the requirements of the oil companies.

There were also challenges in the execution of the project such as changes in the renewal contract conditions from internal decisions of the oil companies or differences in the internal structures to manage the contract.

4.2 Collaboration between of concrete and cement supply chain

Traditionally, cement and ready-mixed concrete supply chains have worked independently from each other. This situation holds true even when they are part of the same company.

Cemex started operations in Colombia in 1996 by acquiring two local cement producers: *Cementos Diamante* and *Cementos Samper.* Cemex Colombia now produces bulk cement, bagged cement, aggregates and ready-mixed concrete. Cemex Colombia cement supply chain leaders have been committed to value generation. They have also been interested on extending these value generation practices to their readymixed concrete operations as well.

In April 2008, Cemex Colombia ready-mixed concrete operations had a private fleet of 319 mixer trucks but only 74% of them were operational due to mechanical problems. Taking into account that ready-mixed concrete lasts fresh for about 90 minutes, concrete mixer trucks availability is a crucial element to guarantee adequate customer service level.

Cemex cement operations had a very efficient maintenance facility for bulk and bagged cement trucks that was not utilized by concrete mixers. In one meeting, concrete leaders asked for help to cement maintenance managers to fix concrete mixers mechanical availability problem. Additionally, there was a problem with ten large ready-mixed concrete trailers that were pulled by third party contractors that were very old and usually broken/unavailable. To solve this problem, cement maintenance leaders reassigned ten of their own trucks to immediately eliminate the need of the old third party trucks.

The result was outstanding. In six months, mechanical availability of mixers increased from 74% to 93%, 109 mixer trucks were completely overhauled and total maintenance costs were reduced by 25%. Also, a state-of-the-art maintenance facility was built and a specialized team of engineers was hired to solve the maintenance needs of both; bulk cement trucks and ready-mixed concrete trucks.

This project started as a pilot but currently the maintenance function is fully integrated across the company; generating value for Cemex supply chain as a whole. Cemex also provides an example on how cement companies can create value trough end-user innovation, effectively de-commoditizing a traditional product like cement.

According to Flores et al. (2003), Cemex *"Patrimonio Hoy"* project facilitates access to emerging markets that are characterized by low-income large population. Flores et al. (2003) propose that customers in emerging markets are producers rather than consumers. The producers approach means that companies have to provide producers "a refinement of abilities that they can appreciate and from which they can profit." In the case of the Cemex, the company is concentrated in selling homes rather than selling cement. Because DIY building is dominant in emerging markets, Cemex is promoting building a house one room at a time. Cemex DIY customers are part of groups of three that are responsible for weekly payments. The payment covers the construction materials of one room. The customers are also members of a club where they get information about designing and construction. By 2003, *Patrimonio Hoy* has 39,000 members with a rate of complete payment of 99.6% after the materials are received. Other benefits are that DIY builders built at a rate that is three time the traditional rate and four-fifths of the traditional cost.

Cementos Argos, a cement company in Colombia, is also using end-user innovation projects, similar to Cemex *Patrimonio Hoy,* in collaboration with cement distributors and financial institutions.

4.3 Collaborative Supply Chain Contracts in the Steel Industry

Steel Inc. is a Latin-American manufacturer of flat and long steel products (e.g semi-finished steel, flat-rolled products, welded tubes and beam, and roll-formed products). Steel Inc.' customers come from diverse industries such as automotive, construction, agriculture and household electric products. Steel is an alloy composed of iron mixed with carbon and other mineral elements. Steel supply chain extends from the extraction of iron ore from mines, the transformation of raw materials into steel and its final products and the delivery to customers by sea, truck or river.

Steel Inc. mostly uses sea transportation to export its products to final customers. Normally, sea freights have three components: loading cost, sea freights and unloading cost. These costs are composed of vessel waiting time and fuel. The vessel waiting time is estimated with loading and unloading rates provided by port operators. The speed of loading and unloading is a critical element of cost; it reduces sea freight tariffs and penalties for vessel delays.

Before 2005, sea freight costs accounted for 20% of the total logistics cost of the company. Of this 20%, 18% was the cost of the vessels loading in port; this percentage represents approximately 10 million dollar per year. The port operator at that time had a loading rate of 2,400 tons per day. The main goal of the project was to select a new port operator. One major challenge was the specialized equipment required to load steel final products into vessels. To minimize this challenge, Steel Inc. made an up-front payment of several million dollars to purchase new equipment as a part of the five year contract. It was also agreed that Steel Inc. was the owner of the equipment.

The project was won by a multinational firm which operates other ports in Latin-America and Europe. The company reached a 40% increase in efficiency in one year, stabilizing on an average rate of 4,600 tons per day from 2006 to 2008. With this rate, the cost of the vessels waiting in port was reduced to 5 million dollars compared to the original 10 million dollars.

One element in this contract was the inclusion of an incentive model to foster the port operator to increase loading rates. The five year contract involved incremental yearly goals loading rates. The monitoring of real time data to calculate the inputs for the incentive model was made by a third party which was the last entity in contact with product before the loading process. The incentives model took into account the differences in loading efficiencies from different steel products. In addition, the port operator had full access to the planning and production systems and was part of the weekly review meetings.

The contract included the following processes: transportation from warehouse to dock *(Manejo* and *Caleta* in Spanish), unloading of raw materials, loading of finished goods *(Izaje* in Spanish), palletizing and product accommodation inside the vessel *(Trincado* in Spanish). See Figure 27 for details of the port process.

Significant improvements were collaboratively implemented such as: use of tractors and trailers in port internal movement to gain speed, new security procedures to use several docks in the loading process at the same time, new tools to accelerate product accommodation inside the vessel keeping a safe environment for workers, flexible shifts to guarantee continuous operations and mobile dining rooms to reduce worker's walking distance. The contract main goals were security, quality and productivity.

Figure 27. Steel Port Operations. Courtesy of Steel Inc.

In summary, four elements were crucial in the success of this contract: risk sharing in the initial steel port equipment, information sharing among the company, the union and the port operator, and an incentive model to promote continuous improvement

5 Conclusion

The purpose of this project was to understand the evolution of supply chain management in the cement industry, to propose the right supply chain for cement and to demonstrate that supply chain management can generate value for cement companies. The conclusions below present the key findings on these objectives.

- From an economic perspective, the oligopoly or monopoly that characterized cement industry might explain the lack of importance of **SCM.** Compared to a free market, oligopolies and monopolies have low pressure to reduce costs, low pressure from customers and limited number of competitors. The focus of companies in oligopolies or monopolies is concentrated on pricing and competition monitoring. Traditionally, **SCM** is not a priority for these companies.

- Cement is a mature industry. On average, the four largest cement companies are 200 years old. Change management processes for these companies require time and resistance may be the found. **SCM** importance within the companies might take time to be incorporated in the strategy but it could be an excellent opportunity for innovative managers to create value. The case studies presented were from companies in emerging markets; maybe this is a coincidence, but one can conclude that innovation in SCM is possible when the pressure from headquarters was relaxed because of local market situations.

- Traditionally, cement supply chain is driven by asset utilization. Assets are represented by production plants, infrastructure and transportation equipment. Asset utilization is a given for the largest companies in the cement industry. This is why they are moving to Efficiency and / or Customer Response objectives to differentiate and to gain competitive advantage in the market. This change in strategy requires cement companies to build supply chain management capabilities that traditionally asset utilization companies don't have, in order to succeed in the new competitive environment.

- Given the asset utilization focus of cement companies, there were significant investments to improve cement manufacturing processes. As a result, a highly automated and continuous production process was developed. Today, large investments are required to improve manufacturing capabilities, so SCM may be seen as the new frontier of cost reduction in the cement industry.

- The low price-to-weight ratio, which is a characteristic of cement, limits the geographical coverage of a production center. This situation reduces supply chain management to an operational role because it is solely responsible for moving the product by truck in a ratio of 300 kilometers. The use of maritime, rail and river transportation expanded the coverage of a production center allowing SCM to increase its scope facilitating the access to new markets and reducing costs significantly. Additionally, SCM costs are normally hidden in the company financial statements. Detailed cost analysis is required to uncover the potential of savings of SCM.

- Cement companies face a major challenge in emerging markets where bulk and bags coexist. To gain competitive advantage, these cement companies have to build two different supply chain strategies, one for each type of product. The bulk cement supply chain has to be focused on efficiency to obtain benefits from optimization processes and maximize utilization. The bagged cement supply chain has to be responsive and focused in availability. Bagged cement is more similar to a consumer good product than to bulk cement. To cope with the bulk and bagged challenge, supply chain leaders in the cement companies in emerging markets need a team which is able to work in these supply chain environments.

- Practices such as collaboration and information sharing with upstream and downstream supply chain partners are a significant opportunity to gain alignment for cement companies. Other elements such as the use of equitable contracts and the elimination of forward buying practices might generate value and increase the agility of these supply chains. One additional opportunity is supply chain collaboration with local or regional competitors in the purchasing of common components, equipment and services. Collaboration with competitors requires a significant change in the mind-set of the cement companies.

This set of conclusions can be expanded to the mineral extraction industry. SCM relevance varies significantly by commodity. It seems that for some products, SCM has to be more responsive like oil, and for other products more efficient like bulk cement or coal. Some mineral extraction companies outsourced to contractors most of their supply chain processes many years ago. In this process, some companies lost their SCM know-how and they have to start from scratch to rebuild it. A major concern in the commodity industry is the variability in the implementation of advance SCM practices within the companies in the same industry. This thesis project is an invitation for lagging commodity companies to evaluate the potential benefits of SCM and implement them in the near future.

A natural next step stemming from this research would be to repeat this analysis with other commodity products to understand their particular supply chain complexities.

From a strategic perspective, it is important to go deep in the supply chain strategy required to succeed in emerging markets. In this thesis emerging markets are treated as a single market with homogeneous characteristics for the sake of simplicity. Additional research at regional or country level in particular emerging markets is required to understand its particularities and define an appropriate supply chain strategy.

In this project, cement was characterized as two types of product, bulk cement and bagged cement; and a right supply chain was recommended for each of them. It is important to acknowledge that there are several types of bulk cement and bagged cement. Further research should be done in order to confirm if all the types of bulk cement or bagged cement should have the same supply chain structure.

At an operational level, further research has to be done to confirm if the proposed alternatives of Grind-To-Order and Pack-To-Order generate value for the cement supply chain. Also, a comparison could be made between bagged cement supply chain and consumer products supply chain to identify practices that might generate value in the cement industry.

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Appendix A. Respondent companies

Company	Position	Commodity Type
Lafarge North America	Logistic Manager	Cement
Holcim North America	Logistic Manager	Cement
Cemex Colombia	VP Supply Chain	Cement
Cementos Argos	VP Supply Chain & Functional Directors	Cement
Cerrejon Coal	Director of Logistics and Trade	Coal
Ecopetrol	Purchasing Manager	Oil
Empresa de Energía de Bogota	Supply Chain Director	Electricity
Ternium	VP Supply Chain	Steel

Appendix B. Questionnaire

Plan

- What is the company strategy?
- What is the role of SCM in the business strategy of your company?
- Where is SCM in the organizational chart? Has the position evolved over time? Why?
- Which are the activities/areas that fall under SCM? Have they evolved over time? Why?
- Which are the priorities / Key Performance Indicators of the SCM organization?
- How do you plan the network design of your company?
- What is the impact of the internationalization of your company in SCM?
- What are the benefits of M&A in your industry? Are these benefits related to SCM?
- What is the ideal SC for your product?
- How important is SCM in your industry? What is the level of development in SCM in your industry?
- Is the SCM organization global or regional? How much does it vary from region to region?
- Which are the future challenges that your industry is facing? How will these challenges be supported by SCM?
- What are the challenges in sustainability in your industry? Are these requirements different depending on the country? How?
- Why cement companies decided to integrate with concrete producers? Are there any benefits in SCM? (This question applies only to cement companies).

Source

- Which are the priorities / Key Performance Indicator of the Sourcing process?
- What are the components that are more significant for your company?
- Who are the major suppliers of your company? Are they short term / long term relationships?
- Is the sourcing centralized or decentralized?
- How do you plan the sourcing of your company?
- Do you use any IT in the sourcing process?
- Is there any limitation in raw materials availability in your industry?
- Do you have inventory of raw materials / components in your company? How large is this inventory?
- What are the challenges in sustainability in the sourcing process?

Make

- Which are the priorities / Key Performance Indicator of the Manufacturing process?
- How do you plan / schedule production in your company? MTO? MTS?
- Do you use any IT in the production planning / scheduling process?
- What is the size of a typical production batch?
- How many SKU's do you manufacture and how difficult it is to change from one product to the other?
- Does your plan have an excess of capacity at this moment? How do you manage this situation?
- What are the challenges in sustainability in the manufacturing process?

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- Which is the future challenges that manufacturing is facing?

Deliver

- Which are the priorities / Key Performance Indicator of the Distribution process?
- How do you describe the demand of your product? Is it variable / seasonal / trend?
- Which are the clients of your company? Which are the most important from a SCM perspective? Why?
- What is the difference between the distribution of cement in bags versus the distribution of cement in bulk? (This question applies only to cement companies).
- How do you plan the distribution in your company?
- What is the transportation modes preferred in your company? Why?
- Is your company vertically integrated in the logistics process? Transportation? Warehousing? How the integration has evolved over time? Why?
- Are there any physical characteristics of your product that limit the distribution process?
- Is it common for your product to be used as backhaul load?
- Do you have inventory of finished goods?
- Which are the future challenges that Distribution is facing?

Return

- Are there any returns in your industry? What are the causes? How big they are?
- Is the return cost significant?
- Is there any return in the concrete industry? What are the causes? How big they are? What do you do with the returned product? (This question applies only to cement companies).

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PROJECT PROPOSAL

on

Strategic Supply Chain Management & Logistics in Kesoram Cement Industries

Compiled By:

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<u>Contents</u> <u>Page No.</u>

IQAC COORDINATOR
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Chapter-I

Introduction

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India is one of the BRICS economy countries (Brazil, Russia, India, China and South Africa), which are characterized by fast-growing developing economies. In July 2014, the leaders of the BRICS countries launched the New Development Bank (NDB) as an alternative to the World Bank and the International Monetary Fund (IMF). Headquartered in Shanghai, China, it will start lending to any United Nations (UN) members in 2016. The plan to set up a bank to finance infrastructure projects began in 2012 after the BRICS countries saw investors divert money from emerging economies, hurting their currencies. The NDB was established for US$100bn and has an additional US$100bn in reserves.

India's GDP was US$1.49tn in 2013 (using official US$ exchange rate) and grew at a rate of 3.2% during the year (Figure 1). GDP by purchasing power parity (PPP) was US$7.28tn in 2014, the world's third-largest. GDP growth rates have stuttered in recent years, with a recent peak of 10.3% in 2010.[2] GDP/capita grew to US$4000 in 2013, compared to US$3900 in 2012 and US$3800 in 2011.

India's population grew by 1.25% in 2014, contributing to its ever-growing labour force and demand for housing. GDP is contributed to by agriculture (17.4%), industry (25.8%) and services (56.9%). Industrial production grew by 0.9% in 2013. The labour force, some 487m in 2013, worked primarily in agriculture (49%), compared to 20% in industry and 31% in services. Unemployment rose from 8.5% in 2012 to 8.8% in 2013, while inflation (GDP deflator index) fell from 7.2% in 2012 to 6.9% in 2013.

India is a major global trade hub with large import volumes and ever-increasing exports. In 2013, some US$313bn of goods were exported, up from US$297bn in 2012, while US$468bn of goods were imported, down from US$489bn in 2012. Imports and exports consisted mainly of petroleum products, crude oil, raw materials, machinery and chemicals.

Cement Industry-Overview

India is the second largest producer of cement in the world, second only to China. Cement industry was started in the year 1914. At that time the only plant of cement production was set in porbandar; Gujarat. Its capacity was only 1000 tones per annum. It was the starting of cement process or learning of cement process in India. No wonder, India's cement industry is a vital part of its economy, providing employment to more than a million people, directly or indirectly. Ever since it was deregulated in 1982, the Indian cement industry has attracted huge investments, both from Indian as well as foreign investors.

Cement production increased at a compound annual growth rate (CAGR) of 9.7 per cent in the period 2006– 2013, producing 272 million tonnes (MT). The production capacity is projected to reach 550 MT by FY 2020. The cement industry has been expanding on the back of increasing infrastructure activities and demand from the housing sector. The Department of Industrial Policy and Promotion (DIPP), report says that cement and gypsum products attracted foreign direct investment (FDI) worth Rs 13,370.32 crore (US$ 2.24 billion) between April 2000 and February 2014.

The housing segment accounts for a major portion of the total domestic demand for cement in India. In the 12th Five Year Plan of the Government, there is a strong focus on infrastructure development and construction sector and the cement sector is expected to largely benefit from it. Some of the recent major government initiatives such as development of 98 smart cities are expected to provide a major boost to the sector. The Government has plans to increase investment in infrastructure to an amount of US$ 1 trillion. The industry is expected to add a capacity of 150 MT during the Plan period.

Expecting such developments in the country and aided by suitable government foreign policies, several foreign players such as Lafarge-Holcim, Heidelberg Cement, and Vicat have invested in the country in the recent past. A significant factor which aids the growth of this sector is the ready availability of the raw materials for making cement, such as limestone and coal.

According to the United States Geological Survey (USGS), in 2014 India produced 280Mt of cement and had 280Mt/yr of clinker production capacity, unchanged from 2013. A large number of cement producers, both local and multinational, operate in India. Holcim, Lafarge, HeidelbergCement and Vicat all have a presence in the country, however, India's domestic producers hold the most sway, including UltraTech Cement, Chettinad Cement, JK Cement, Dalmia Group and The India Cements, among others.

According to the Global Cement Directory 2015 and independent research, in 2014 India had 174 integrated cement plants, 155 of which were active, with production capacity in excess of 301Mt/yr. There were also 91 grinding plants with more than 109Mt/yr of production capacity. The capacities of several integrated and grinding plants remain unknown. Of the integrated cement plants, capacity was localized in the west and south of the country. Andhra Pradesh, Rajasthan and Tamil Nadu all had capacities greater than 30Mt/yr. Plans for 13 new integrated plants were announced in 2014, mainly in Andhra Pradesh and Karnataka. One new cement plant was proposed by Meghalaya Cement in West Kameng, Arunachal Pradesh, which would be the state's first integrated plant if built.

As for the other BRICS economy countries, India's cement consumption is growing, primarily due to strong infrastructure and housing developments. In spite of heavy investments, factors including fuel and energy shortages, raw material availability and regional market trends have posed significant challenges to cement producers in 2014 - 2015.

S.No.	Company	Plants	Capacity (MT/YR)
1	Holcim	15	44.97
2	UltraTech Cement	15	32.16
3	Chettinad Cement	5	14.80
4	JK Cement	6	14.60
5	Dalmia Group	5	14.50
6	The India Cements	8	12.97
7	Ramco Cements	6	12.49
8	Century Cement	4	9.70
9	Vicat	2	7.75

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10	**Birla Shakti**	**2**	**7.25**
11	JSW Cement	2	5.40
12	Zuari Cement	2	5.20
13	Penna Cement	3	5.00
14	Sagar Cements	3	5.00
15	HeidelbergCement	3	4.70

Table 1: The top 15 cement producers in India in 2014, as ranked by installed integrated cement production capacity. **Sources:** The Global Cement Directory 2015 and Global Cement research.

Major initiatives of the Government to boost the cement industry:

An expert appraisal committee under Ministry of Environment, Government of India, has provided approval to India Cements to double its capacity and set up a 40 megawatt (MW) power plant at one of its facilities in Tamil Nadu. The proposed expansion project will come up at Dalavoi in Ariyalur district.

The Competition Commission of India (CCI) has approved the proposed acquisition of cement plants of Jaypee Cement Corporation Ltd, comprising an integrated cement unit at Sewagram and grinding unit at Wanakbori in Gujarat by Ultratech Cement Ltd.

Giving impetus to green initiatives, Goa State Pollution Control Board (GSPCB) has signed a memorandum of understanding (MoU) with Vasavadatta Cement, a company with its plant in Karnataka. The cement manufacturer will use the plastic waste collected from Goa as fuel for its manufacturing plant.

The cement industry in India is globally competitive as the industry continues to witness positive trends such as cost control, continuous technology up gradation and increased construction activities. Major cement manufacturers in India are also increasingly using alternate fuels, especially bioenergy, to fire their kilns. This is not only helping to bring down production costs of cement companies, but is also proving effective in reducing emissions. With the ever-increasing industrial activities, real estate, construction and infrastructure, in

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addition to the onset of various Special Economic Zones (SEZs) being developed across the country, there is remains a growing demand for cement.

In the 12th Five Year Plan, the Government of India plans to increase investment in infrastructure to the tune of US$ 1 trillion and increase the industry's capacity to 150 MT. The Cement Corporation of India (CCI) was incorporated by the Government of India in 1965 to achieve self-sufficiency in cement production in the country. Currently, CCI has 10 units spread over eight states in India. In order to help the private sector companies thrive in the industry, the government has been approving their investment schemes. Some such initiatives by the government in the recent past are as follows:

Budget 2016-17 has proposed a slew of measures to boost infrastructure and investment, which will be positive for the cement sector, as increased spending on infrastructure increases the demand for cement. 100 per cent deduction for profits to an undertaking in housing project for flats upto 30 square metres in four metro cities and 60 square metres in other cities approved during June 2016 to March 2019 and to be completed in three years.

The Government of India plans to enact a law that will allow the companies which have received mining licenses without having gone through the auction process, to transfer these leases, in a move that is expected to make mergers and acquisitions (M&As) easier in the steel, cement, and metals sectors.

The Government of Tamil Nadu has launched low priced cement branded 'Amma' Cement. The sale of the cement started in Tiruchi at Rs 190 crore (US$ 27.9) a bag through the Tamil Nadu Civil Supplies Corporation (TNCSC). Sales commenced in five godowns of the TNCSC and will be rolled out in stages with the low priced cement available across the state from 470 outlets.

The Government of Kerala has accorded sanction to Malabar Cements Ltd to set up a bulk cement handling unit at Kochi Port at an investment of Rs 160 crore (US$ 23.5 million).

The Andhra Pradesh State Investment Promotion Board (SIPB) has approved proposals worth Rs 9,200 crore (US$ 1.35 billion) including three cement plants and concessions to Hero

MotoCorp project. The total capacity of these three cement plants is likely to be about 12 MTPA and the plants are expected to generate employment for nearly 4,000 people directly and a few thousands more indirectly.

India has joined hands with Switzerland to reduce energy consumption and develop newer methods in the country for more efficient cement production, which will help India meet its rising demand for cement in the infrastructure sector.

The Government of India has decided to adopt cement instead of bitumen for the construction of all new road projects on the grounds that cement is more durable and cheaper to maintain than bitumen in the long run.

Key Drivers of Cement Industry Cement industry is driven by many factors or by many sectors such as infrastructure, housing sector, Indian government economy, GDP of India, government rural development programs etc.GDP of India affect housing and infrastructure development of India and this results in changed prices of cement. These changed prices of cement ultimately affect demand and supply of cement and it directly influence cement production of companies.

Market Size

Cement demand in India is expected to increase due to government's push for large infrastructure projects, leading to 45 million tonnes of cement needed in the next three to four years.

India's cement demand is expected to reach 550-600 Million Tonnes Per Annum (MTPA) by 2025. The housing sector is the biggest demand driver of cement, accounting for about 67 per cent of the total consumption in India. The other major consumers of cement include infrastructure at 13 per cent, commercial construction at 11 per cent and industrial construction at nine per cent.

To meet the rise in demand, cement companies are expected to add 56 million tonnes (MT) capacity over the next three years. The cement capacity in India may register a growth of

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account for almost 70 per cent of the total cement production of the country. A total of 188 large cement plants together account for 97 per cent of the total installed capacity in the country, with 365 small plants account for the rest. Of these large cement plants, 77 are located in the states of Andhra Pradesh, Rajasthan and Tamil Nadu.

Company-wise List of Cement Plants

0. ACC Limited

1.	Acc Ltd. Damodhar Cement Works	West Bengal
2.	Bargarh Cement Works	Orissa
3.	Chaibasa Cement Works	Jharkhand
4.	Chanda Cement Works	Maharashtra
5.	Gagal Cement Works-I	Himachal Pradesh
6.	Gagal Cement Works-Ii	Himachal Pradesh
7.	Jamul Cement Works	Chhatisgarh
8.	Kudithini Cement Works	Karnataka
9.	Kymore Cement Works	Madhya Pradesh
10.	Lakheri Cement Works	Rajasthan
11.	Madhukkarai Cement Works	Tamil Nadu
12.	New Wadi Cement Works	Karnataka
13.	Sindri Cement Works	Jharkhand
14.	Thondebhavi Cement Works	Karnataka
15.	Tikaria Cement Works	Uttar Pradesh
16.	Vizag Cement Works	Andhra Pradesh
17.	Wadi Cement Works	Karnataka

1. Adhunik Cement Ltd

1.	Adhunik Cement Ltd	Meghalaya

2. Aditi Industries

1.	Aditi Industries	Assam

4. Ambuja Cement Ltd

1.	Ambuja Cements Ltd (Unit: Ambuja Nagar)	Gujarat

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2. Ambuja Cements Ltd (Unit: Bhatapara II) Chhatisgarh
3. Ambuja Cements Ltd (Unit: Bhatapara) Chhatisgarh
4. Ambuja Cements Ltd (Unit: Bhatinda) (G) Punjab
5. Ambuja Cements Ltd (Unit: Dadri) (G) Uttar Pradesh
6. Ambuja Cements Ltd (Unit: Darlaghat) Himachal Pradesh
7. Ambuja Cements Ltd (Unit: Farakka) (G) West Bengal
8. Ambuja Cements Ltd (Unit: Magdalla) (G) Gujarat
9. Ambuja Cements Ltd (Unit: Maratha) Maharashtra
10. Ambuja Cements Ltd (Unit: Nalagarh)((G) Himachal Pradesh
11. Ambuja Cements Ltd (Unit: Rabriyawas) Rajasthan
12. Ambuja Cements Ltd (Unit: Rauri) Himachal Pradesh
13. Ambuja Cements Ltd (Unit: Roorkee) (G) Uttarakhand
14. Ambuja Cements Ltd (Unit: Ropar) (G) Punjab
15. Ambuja Cements Ltd (Unit: Sankrail) (G) West Bengal

5. Anjani Portland Cement Ltd
   1. Anjani Portland Cement Ltd Andhra Pradesh
6. Asian Concretes Cement Ltd
   1. Asian Concretes Cement Ltd Himachal Pradesh
7. Bagalkot Cement & Inds.Ltd
   1. Bagalkot Cement & Inds.Ltd Karnataka
8. Bharti Cement Corpn. Pvt. Ltd
   1. Bharti Cement Corpn. Pvt. Ltd Andhra Pradesh
9. Bhavya Cement Ltd
   1. Bhavya Cement Ltd Andhra Pradesh
10. Binani Cement Ltd
   1. Binani Cement Ltd - Sikar Rajasthan
   2. Binani Cement Ltd - Sirohi Rajasthan
11. Birla Corporation Ltd
   1. Birla Cement - Raebareli Uttar Pradesh
   2. Birla Cement Works & Chanderia Rajasthan
   3. Birla- Durga Hitech Cement West Bengal
   4. Birla- Durgapur Cement Works West Bengal
   5. Birla Vikas & Satna Cement Works Madhya Pradesh
12. Calcom Cement Ltd
   1. Calcom Cement Ltd Assam
13. Cement Corporation of India Ltd
   1. Cement Corporation of India Ltd- Adilabad Andhra Pradesh

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2. Cement Corporation of India Ltd- Bokajan — Assam
3. Cement Corporation of India Ltd- Nayagaon — Madhya Pradesh
4. Cement Corporation of India Ltd- Rajban — Himachal Pradesh
5. Cement Corporation of India Ltd- Tandur — Andhra Pradesh
6. Cement Corporation of India Ltd-Akaltara — Chhatisgarh
7. Cement Corporation of India Ltd-Chakhi Dadri — Haryana
8. Cement Corporation of India Ltd-Delhi — Delhi
9. Cement Corporation of India Ltd-Kurkunta — Karnataka
10. Cement Corporation of India Ltd-Mandhar — Madhya Pradesh

14. Cement Manufacturing Co.Ltd
   1. Cement Manufacturing Co.Ltd - Jaintia Hills — Meghalaya
   2. Cement Manufacturing Co.Ltd - Megha T & E Ltd — Meghalaya
15. Century Textiles & Inds.Ltd
   1. Century Cement - Mahiar — Madhya Pradesh
   2. Century Cement - Manikgarh — Maharashtra
   3. Century Cement - Raipur — Chhatisgarh
16. Chettinad Cement Corpn. Ltd
   1. Chettinad Cement - Ariyalur — Tamil Nadu
   2. Chettinad Cement – Karikali — Tamil Nadu
   3. Chettinad Cement - Puliyur — Tamil Nadu
   4. Chettinad Cement -Kallur — Karnataka
17. Dalmia Cement (Bharat) Ltd
   1. Dalmia Cement (Bharat) Ltd- Ariyalur — Tamil Nadu
   2. Dalmia Cement (Bharat) Ltd- Dalmiapuram — Tamil Nadu
   3. Dalmia Cement (Bharat) Ltd- Kadapa — Andhra Pradesh
18. Decan Cement Ltd
   1. Decan Cement Ltd — Andhra Pradesh
19. Green Valliey Industries Limited
   1. Green Valliey Industries Limited — Meghalaya
20. Gujarat Sidhee Cement Ltd
   1. Gujarat Sidhee Cement Ltd — Gujarat
21. Heidelberg Cement India Ltd
   1. Heidelberg Cement India Ltd- Ammasandra — Karnataka
   2. Heidelberg Cement India Ltd- Damoh — Madhya Pradesh
   3. Heidelberg Cement India Ltd- Jhansi — Uttar Pradesh
   4. Heidelberg Cement India Ltd- Raigad — Maharashtra
22. Hemandari Cement Ltd

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1. Hemandari Cement Ltd — Andhra Pradesh

23. India Cements Ltd

1. The India Cements Ltd- Chilamkur Works — Andhra Pradesh
2. The India Cements Ltd- Dalavoi — Tamil Nadu
3. The India Cements Ltd- Parli — Maharashtra
4. The India Cements Ltd- Raasi Cement — Andhra Pradesh
5. The India Cements Ltd- Sankari Durg — Tamil Nadu
6. The India Cements Ltd- Sankarnagar — Tamil Nadu
7. The India Cements Ltd- Trinetra — Rajasthan
8. The India Cements Ltd- Visaka Cement — Andhra Pradesh
9. The India Cements Ltd- Yerraguntla — Andhra Pradesh
10. The India Cements Ltd. - Vallur — Tamil Nadu

24. J. S. W Cement Ltd

1. J. S. W Cement Ltd — Maharashtra

25. J.K. Cement Ltd

1. J.K. Cement Ltd- Gotan — Rajasthan
2. J.K. Cement Ltd- Jharli — Haryana
3. J.K. Cement Ltd- Mangrol — Rajasthan
4. J.K. Cement Ltd- Muddapur — Karnataka
5. J.K. Cement Ltd- Nimbahera — Rajasthan

26. Jagdamba Industries Limited

1. Jagdamba Industries Limited — West Bengal

27. Jaiprakash Associates Ltd

1. Jaypee Cement - Bela — Madhya Pradesh
2. Jaypee Cement - Rewa — Madhya Pradesh
3. Jaypee Cement - Baga(Himachal) — Himachal Pradesh
4. Jaypee Cement - Bagheri — Himachal Pradesh
5. Jaypee Cement - Bakaro — Jharkhand
6. Jaypee Cement - Balaji — Andhra Pradesh
7. Jaypee Cement - Bhilai — Chhatisgarh
8. Jaypee Cement - Bhilai (clk) — Madhya Pradesh
9. Jaypee Cement - Dalla — Uttar Pradesh
10. Jaypee Cement - Kutch — Gujarat
11. Jaypee Cement - Panipat — Haryana
12. Jaypee Cement - Roorkee — Uttarakhand
13. Jaypee Cement - Sadva Khurd — Uttar Pradesh
14. Jaypee Cement - Sidhee — Madhya Pradesh

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15. Jaypee Cement - Sikandarabad	Uttar Pradesh
16. Jaypee Cement - Wanakbori	Gujarat
17. Jaypee Cement- Ayodhya	Uttar Pradesh
18. Jaypee Cement- Chunar	Uttar Pradesh
19. Jaypee Cement- Durga Cement Works	Andhra Pradesh
20. Jaypee Cement- Visaka Cement Works	Andhra Pradesh
28. Jammu & Kashmir Cements Ltd	
1. Jammu & Kashmir Cement Ltd.	Jammu & Kashmir
29. JK Lakshmi Cement Ltd	
1. JK Lakshmi Cement Ltd- Jharli	Haryana
2. JK Lakshmi Cement Ltd- Kalol	Gujarat
3. JK Lakshmi Cement Ltd- Sirohi	Rajasthan
30. K. J. S. Cement Ltd	
1. K. J. S. Cement Ltd	Madhya Pradesh
31. K.C.P. Ltd	
1. The K.C.P. Ltd- Muktyala	Andhra Pradesh
2. The K.C.P. Ltd.- Macherla	Andhra Pradesh
32. Kakatiya Cement & Sugar Industries Ltd	
1. Kakatiya Cement & Sugar Industries Ltd	Andhra Pradesh
33. Kalyanpur Cements Ltd	
1. Kalyanpur Cements Ltd	Bihar
34. Kamdhenu Cement Ltd	
1. Powercon Cement Ltd	Uttar Pradesh
35. Kesoram Cement	
1. Kesoram Cement- Basant Nagar	**Andhra Pradesh**
2. Kesoram Cement- Vasavadatta	**Karnataka**
36. Khyber Industries (P) Ltd	
1. Khyber Industries (P) Ltd	Jammu & Kashmir
37. Lafarge India (P) Ltd	
1. Lafarge India (P) Ltd- Arasmeta Cement	Chhatisgarh
2. Lafarge India (P) Ltd- Jojobera	Jharkhand
3. Lafarge India (P) Ltd- Mejia	West Bengal
4. Lafarge India (P) Ltd- Sonadih	Chhatisgarh
38. Lanco Industries Ltd	
1. Lanco Industries Ltd	Andhra Pradesh
39. Madras Cements Ltd	
1. Madras Cements Ltd- Alathiyur I & II	Tamil Nadu

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2. Madras Cements Ltd- Ariyalur | Tamil Nadu
3. Madras Cements Ltd- Jayanthipuram | Andhra Pradesh
4. Madras Cements Ltd- Kolaghat | West Bengal
5. Madras Cements Ltd- Ramasamyraja Nagar | Tamil Nadu
6. Madras Cements Ltd- Salem | Tamil Nadu
7. Madras Cements Ltd- Uthiramerur | Tamil Nadu

40. Malabar Cements Ltd
1. Malabar Cements Ltd- Palakhad | Kerala
2. Malabar Cements Ltd- Pallipuram | Kerala

41. Mancherial Cement Ltd
1. Mancherial Cement Ltd | Andhra Pradesh

42. Mangalam Cement Ltd
1. Mangalam Cement Ltd & Neershree | Rajasthan

43. Mawmluh Cherra Cements Ltd
1. Mawmluh Cherra Cements Ltd | Meghalaya

44. Meghalaya Cements Ltd.
1. Meghalaya Cements Ltd. | Meghalaya

45. My Home Inds. Ltd.
1. My Home Industries Ltd | Andhra Pradesh
2. My Home Industries Ltd-Vizag | Andhra Pradesh

46. OCL India Ltd
1. OCL India Ltd- Kapilas | Orissa
2. OCL India Ltd- Rajgangpur | Orissa

47. Orient Cement
1. Orient Cement- Devapur | Andhra Pradesh
2. Orient Cement- Jalgaon | Maharashtra

48. Panyam Cement & Mineral Industries Ltd.
1. Panyam Cement & Mineral Industries Ltd. | Andhra Pradesh

49. Parasakti Cement Ltd
1. Parasakti Cement Ltd | Andhra Pradesh

50. Penna Cement Industries Ltd
1. Penna Cement Industries Ltd- Boyareddypalli | Andhra Pradesh
2. Penna Cement Industries Ltd- Ganeshpahad | Andhra Pradesh
3. Penna Cement Industries Ltd- Tadipatri | Andhra Pradesh
4. Penna Cement Industries Ltd- Tandur | Andhra Pradesh

51. Prism Cement Ltd.
1. Prism Cement Ltd - I & II | Madhya Pradesh

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52. Purbanchal Cement Ltd

1.	Purbanchal Cement Ltd	Assam

53. Rain Cements Ltd

1.	Rain Cements Ltd- UN -I	Andhra Pradesh
2.	Rain Cements Ltd- UN- II- Line I	Andhra Pradesh
3.	Rain Cements Ltd- UN II- Line II	Andhra Pradesh

54. Reliance Cement Company Private Limited

1.	Reliance Cement Company Private Limited	Maharashtra

55. RNB Cements (P) Ltd

1.	RNB Cements (P) Ltd	Meghalaya

56. Sagar Cement Ltd

1.	Sagar Cement Ltd	Andhra Pradesh

57. Sanghi Cement Ltd

1.	Sanghi Cement Ltd	Delhi

58. Sanghi Industries Ltd

1.	Sanghi Industries Ltd	Gujarat

59. Saurashtra Cement Ltd

1.	Saurashtra Cement Ltd	Gujarat

60. Shree Cement Ltd

1.	Bangur Cement - A Unit of Shree Cement	Bihar
2.	Shree Cement Ltd - Jaipur	Rajasthan
3.	Shree Cement Ltd- Khushkhera	Rajasthan
4.	Shree Cement Ltd- Ras	Rajasthan
5.	Shree Cement Ltd- Roorkee	Uttarakhand
6.	Shree Cement Ltd- Suratgarh	Rajasthan
7.	Shree Cement Ltd.- Beawar	Rajasthan

61. Shree Digvijay Cement Co. Ltd

1.	Shree Digvijay Cement Co. Ltd	Gujarat

62. Shree Jagjothi Cement Ltd

1.	Shree Jagjothi Cement Ltd	Tamil Nadu

63. Shriram Cement Works

1.	Shriram Cement Works	Rajasthan

64. Tamil Nadu Cements Corpn. Ltd.

1.	Tamil Nadu Cements Corpn. Ltd.- Alangulam	Tamil Nadu
2.	Tamil Nadu Cements Corpn. Ltd.- Ariyalur	Tamil Nadu

65. Tatachemicals Ltd

1.	Tatachemicals Ltd	Gujarat

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66. UltraTech Cement Ltd

1.	UltraTech - AP Cement Works	Andhra Pradesh
2.	UltraTech - Hirmi Cement Works	Chhatisgarh
3.	UltraTech - Gujarat Cement Works	Gujarat
4.	UltraTech - Jafrabad CementWorks	Gujarat
5.	UltraTech - Magdalla Cement Works	Gujarat
6.	UltraTech - Panipat Cement Works	Haryana
7.	UltraTech - Rawan Cement Works	Chhatisgarh
8.	UltraTech- Aditya Cement Works	Rajasthan
9.	UltraTech- Aligarh Cement Works	Uttar Pradesh
10.	UltraTech- Arakkonam Cement Works	Tamil Nadu
11.	UltraTech- Awarpur Cement Works	Maharashtra
12.	UltraTech- Bathinda Cement Works	Punjab
13.	UltraTech- Dadri Cement Works	Uttar Pradesh
14.	UltraTech- Ginigera Cement Works (G)	Karnataka
15.	UltraTech- Hotgi Cement Works	Maharashtra
16.	UltraTech- Jharsuguda Cement Works	Orissa
17.	UltraTech- Kotputli Cement Works	Rajasthan
18.	UltraTech- Rajashree Cement Works	Karnataka
19.	UltraTech- Ratnagiri Cement Works	Maharashtra
20.	UltraTech- Reddipalayam Cement Works	Tamil Nadu
21.	UltraTech- Vikram Cement Works	Madhya Pradesh
22.	UltraTech- West Bengal Cement Works	West Bengal

67. Uma Cement Industries

1.	Uma Cement Industries	Jammu & Kashmir

68. Viket Sagar Cement

1.	Viket Sagar Cement	Andhra Pradesh

69. Wonder Cement Ltd

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1.	Wonder Cement Ltd	Rajasthan
70. Zuari Cement Ltd		
1.	Zuari Cement Ltd.- Chennai	Tamil Nadu
2.	Zuari Cement Ltd.- Krishnanagar	Andhra Pradesh
3.	Zuari Cement Ltd.- Sri Vishnu Cement	Andhra Pradesh

Investments

On the back of growing demand, due to increased construction and infrastructural activities, the cement sector in India has seen many investments and developments in recent times.

According to data released by the Department of Industrial Policy and Promotion (DIPP), cement and gypsum products attracted Foreign Direct Investment (FDI) worth US$ 3.101 billion between April 2000 and December2015.

Major Investments in Indian Cement industry:

- India's largest cement maker UltraTech Cement is looking forward to acquire Jaiprakash Associates six cement factories for a total value of Rs 16,500 crore (US$ 2.42 billion).
- Birla Corporation Ltd, a part of the MP Birla Group, has agreed to acquire two cement assets of Lafarge India for an enterprise value of Rs 5,000 crore (US$ 733.6 million).
- Dalmia Cement (Bharat) Ltd has invested around Rs 2,000 crore (US$ 293 million) in expanding its business in North East over the past two years. The company currently has three manufacturing plants in the region — one in Meghalaya and two in Assam.
- JSW Group plans to expand its cement production capacity to 30 MTPA from 5 MTPA by setting up grinding units closer to its steel plants.
- UltraTech Cement Ltd has charted out its next phase of Greenfield expansion after a period of aggressive acquisitions over the last two years. UltraTech has plans to set up two Greenfield grinding units in Bihar and West Bengal.
- UltraTech Cement Ltd bought two cement plants and related power assets of Jaiprakash Associates Ltd in Madhya Pradesh for Rs 5,400 crore (US$ 792.3 million).

- JSW Cement Ltd has planned to set up a 3 MTPA clinkerisation plant at Chittapur in Karnataka at an estimated cost of Rs 2,500 crore (US$ 366.8 million).
- Andhra Cements Ltd has commenced the commercial production in the company's cement plants – Durga Cement Works at Dachepalli, Guntur and Visakha Cement Works at Visakhapatnam.

Classification of Cement

Bonding minerals with the help of its adhesive and cohesive properties firmly is known as cement. It is adhesive in nature. It is used to bond bricks, stones, sand and other materials used inbuilding. Itis known as hydraulic as with the use of water, it got more hard and strong. There are different types of cement in markets. Every cement is used for its specific purpose in building. India produces different types of cement which are defined below and consist of different chemical proportion.

- Ordinary Portland cement
- Portland pozzolana cement
- White cement
- Water proof cement
- Specialized cement
- Rapid hardening Portland cement
- Portland blast furnace slag cement
- Ordinary Portland cement

SWOT Analysis of Cement Industry

Strengths

India is the second largest producer of cement in whole world and china is At first place. India is a developing country so production cost of cement is very less.

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Easy availability of labor for cement companies.

Availability of high grade limestone mines in India.

Weakness

Demand supply gap

Overcapacity

GDP impact over cement com

Increased cost of production or coal

High interest rates on housing sector

Opportunities

Strong growth of Indian economy.

Increased infrastructure growth

Technological advancements in machines and equipments for production Process

Rise in housing sector

Growing middle class

FDI

Threats

Overcapacity can decrease margins of cement price.

Power shortage may affect cement production.

Government rules to provide rebate for foreign companies.

Price of coal may be a threat in future.

Future Prospects and key issues:

During the financial year 2014-15 (FY15), India's cement industry grew by about 5.6% year-on-year (YoY) as compared to 3.1% YoY growth in the financial year 2013-14 (FY14). The growth was supported by pre-election spending and delayed monsoon in the first half of the fiscal. During the second half, the demand was impacted by low government spending and less demand from real estate and construction projects, and slow revival in infrastructure spending. The cement industry capacity utilisation rate stood at around 71%.

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Cement demand is closely linked to the overall economic growth, particularly the housing and infrastructure sector. The Modi government's thrust on housing and infrastructure development should augur well for cement demand. The crash in the global crude oil prices and other commodities should help cement companies to reign over cost pressures and improve profitability of the sector.

While medium term challenges remain in the form of excess capacity, slowdown in rural demand and slow offtake of infrastructure projects, the long term drivers for cement demand remain intact. The demand-supply mismatch is expected to reduce in the next three years as the rate of new capacity additions slows down and growth picks up pace. Higher government spending on infrastructure and housing, and rising per capita incomes will be key growth drivers for the cement industry.

Key Issues:

Supply	The demand-supply situation is highly skewed with the latter being significantly higher.
Demand	Housing sector acts as the principal growth driver for cement. However, industrial and infrastructure sectors have also emerged as demand drivers.
Barriers to entry	High capital costs and long gestation periods. Access to limestone reserves (key input) also acts as a significant entry barrier.
Bargaining power of suppliers	Licensing of coal and limestone reserves, supply of power from the state grid, etc. are all controlled by a single entity, which is the government. However, many producers are relying more on captive power.
Bargaining power of customers	Cement is a commodity business and sales volumes mostly depend upon the distribution reach of the company. Cement is sold in two segments – trade and non-trade. Trade cement is the one sold to the dealers. Non-trade cement is sold directly to the consumers, mainly institutional buyers. Trade cement sells higher compared to non-trade. As such, companies that have a strong distribution network and retail presence tend to have better cement realizations.
Competition	Intense competition with players expanding reach and achieving pan India presence. The industry is a lot more consolidated than a couple of decades ago with

a few large players controlling substantial market share.

Environmental Developments

In February 2013, a new 'Technology Roadmap: Low-carbon technology for the Indian Cement Industry' was released by the Cement Sustainability Initiative (CSI) and the International Energy Agency (IEA). The roadmap targets CO_2 emission reductions and an increase in the use of alternative fuels. Although several Indian producers have already started to use waste tyres, coffee, rice husk and cashew nut shells as alternative fuels, substitution rates are typically low and alternative fuels have not been a priority. However, recent years have seen uptake rates increase and alternative fuels are used in more Indian cement plants than ever before.

The majority of newsworthy environmental investments took place in Gujarat in 2014. According to the Gujarat State Pollution Control Board (GSPCB), the use of alternative fuels and raw materials for cement production increased from 15,693t in 2009 - 2010 to 543,569t in 2013 - 2014. Waste disposal had previously posed a major challenge in Gujarat. The board encouraged cement plants to provide waste collection centres and pre-processing facilities for hazardous waste. "The use of alternative fuels in Indian cement plants has been limited," said the GSPCB. "The thermal substitution rate is $<1\%$ in India compared to 10% in Japan and 40% in European nations. The board has set a target of three years to achieve a rate of 10%."

In 2014, Ambuja invested US$16.7m to set up a pre-processing facility for solid/semi-solid waste at its plant in Kodinar, Gujarat. Similarly, Sanghi commenced trial phase operations for using hazardous waste at its plant in Kutch, Gujarat. Sanghi also recently announced plans to invest US$40.5m in 2015 - 2016 for sustainable development, innovation and energy conservation. The plans include a US$24.3m 15MW WHR system at its Kutch plant, which will recover more than 70% of the waste heat generated. For the conservation of coastal soil, Sanghi will undertake a mangrove plantation on the Gujarat coast to protect the ecology and coastal environment and to improve socio-economic development.

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Alternative fuel use and other environmental concerns have also been evident in other areas of India. In December 2014, the Tamil Nadu Pollution Control Board despatched 20,000t of effluent sludge generated by textile units in Perundurai to cement plants in Ariyalur for use as an alternative fuel. Cement producers started to accept the sludge after the success of a trial run that indicated no variation in the strength or quality of cement. Following the first order, demand for another 8000t was expressed.

Despite the growing trend towards environmentally-friendly production, emissions are still common throughout India. In February 2014, the Odisha State Pollution Control Board (OSPCB) issued a show cause notice to UltraTech's grinding plant in Arda, Odisha for violating pollution norms. Local residents had complained that dust released by the plant was causing a health hazard. In October 2014, local concerns over the open-filling of fly ash at an NTPC-owned thermal power plant in Kahalgaon, Bihar led to the installation of six fly ash bagging machines with 4800bags/hr or 4000t/day of filling capacity. The plant provides fly ash to cement producers in the northeast of India.

Outlook- Cement Scenario:

The International Monetary Fund (IMF) has predicted that India's GDP will grow by 6.3% in 2015 and 6.5% in 2016, following 5.8% growth in 2014 (Table below). This is lower than the average for emerging and developing Asian countries, but much higher than the global average. According to the IMF, India's economic outlook has improved due to lower oil prices and growing industrial investments following policy reforms. The IMF warned of weaker trade demands due to India's economically-unstable neighbors.

Region	2014 (%)	2015 (%)	2016 (%)
India	5.8	6.3	6.5
Emerging Asia	6.5	6.4	6.2
World	3.3	3.5	3.7

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The GDP growth rate in 2014 and forecasts for 2015 and 2016 for India, emerging and developing Asia and the world.

Source: The IMF World Economic Outlook, January 2015 update.

Reports by analysts agree that India's cement sector should see significant improvements in the coming years. A study by management consultants AT Kearny, in association with the Confederation of Indian Industry, said that per capita cement consumption is expected to grow to 385 - 415kg in 2025 from 185kg in 2014. Cement demand is likely to increase by 2.5 - 2.7 times to 550 - 660Mt/yr in the same period. While infrastructure is expected to lead the growth, the residential segment will continue as the largest consumer, constituting 42 - 45% of total demand. Similarly, Research and Markets analysts have forecast that India's cement market will grow at a compound annual growth rate (CAGR) of nearly 9% in 2014 - 2019, with the housing sector as the main driver. It commented that the industry is currently in a turnaround phase, trying to achieve global standards in production, safety and energy-efficiency. Research and Markets also predicted further industry consolidation, with more small and medium companies entering into joint ventures.

India's cement producers are certainly upbeat on the country's outlook. A wealth of greenfield and expansion projects have been planned by many companies, indicative of anticipation of growing demand. Indeed, JSW Cement expects that a pick-up in demand will drive its capacity utilization to 75% by April 2015, up from 55 - 60% at the end of 2014.

Despite another challenging year, India's cement industry is headed towards a bright future. Through increased energy-efficiency investments, rising demand due to population growth, improved supply chain management and more transparent government policies, India's cement industry could become a force to be reckoned with on the basis of more than just its size

Chapter-II

Overview of Birla Shakti Cement

(Division of Kesoram Industries Limited)

Overview of Birla Shakti Cement

Kesoram was founded in 1919 under the name of Kesoram Cotton Mills Ltd. From its humble beginnings as a cotton textile mill in Calcutta, Kesoram expanded into the production of rayon. Its first rayon plant was built in 1959, with a production capacity of 4,635 metric tons of rayon yarn per year.

The spirit of entrepreneurship did not end there. Kesoram soon entered the tyres and cement industries. A change of name was needed to reflect the company's increasing portfolio of businesses. So in 1986, it changed its name to Kesoram Industries Limited. Since then, Kesoram's operations have grown from strength to strength. Its reputation is recognized today by its listings on four global stock exchanges – National Stock Exchange of India, Bombay Stock Exchange, Calcutta Stock Exchange Association, and the Societe de la Bourse de Luxembourg.

Kesoram Industries Limited Cement Division is an award-winning cement manufacturer and is one of the nation's largest producers to provide high quality products and reliable services to its clients and communities throughout India. Discover its manufacturing footprint, products, innovation methods, portfolio and their philosophies along the way.

Founded in 1969, Birla Shakti is one of the global leaders in cement technology. Besides being a leading supplier of cement and aggregates, we also offer consulting, research, trading, engineering and other services to complement our customers' business needs. Our headquarters is in India and we have production sites in several parts of the country.

To support Birla Shakti's production capabilities, a network of 491 sales engineers and 1,544 dealers are located conveniently throughout the region, so that every customer's need can be met. For over 40 years, Birla Shakti has helped laid the foundations of buildings everywhere. From schools and homes, to hospitals and skyscrapers, Birla Shakti helps build the dreams of people. When the safety of people depends on your product, you know that quality is of upmost importance. That is why Birla Shakti practices Total Productivity Maintenance (TPM). Combining the key principles of plant utilization, quality management and downtime

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minimization, every stakeholder's aim is to achieve zero product defects, zero equipment unplanned failures and zero accidents.

To support Birla Shakti's production capabilities, a network of 491 sales engineers and 1,544 dealers are located conveniently throughout the region, so that every customer's need can be met. Located near the limestone deposits of Sedam and Basantnagar, Birla Shakti's two cement manufacturing plants have a total combined capacity of 7.25 million metric tonnes, making it one of the leading cement manufacturers in the region. Each of our milestones reflected in the timeline is a reflection of our passion, dedication and persistence in Total Productivity Maintenance (TPM). And in this short period of time, we at Kesoram Cement and Vasavadatta Cement have grown from strength to strength – emerging as leaders of the cement industry.

Certificates

Birla Shakti's quality and efficiency is certified by the International Organization for Standardization for its world-class standards.

Learn more about our certifications below.

Certification for conformation with the occupational health and safety management system in accordance with IS/ISO 18001 : 2007 for Kesoram Cement Plant. **2 November 2014.**

Certification for conformation with the quality management system in accordance with IS/ISO 9001 : 2008 for Kesoram Cement Plant. **31 October 2014.**

Certification for conforming with the environmental management system in accordance with IS/ISO 14001 : 2004 for Kesoram Cement Plant.**7 August 2013.**

Location of Plants:

To meet the demand of highest quality cement there are two plants manufacturing Birla Shakti Cement.

1 BIRLA SHAKTI CEMENT, DIVISION OF KESORAM INDUSTRIES LIMITED UNIT: VASAVADATTA CEMENT, FACTORY. PO: Sedam, Dist: Gulbarga Karnataka - 585222

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2 BIRLA SHAKTI CEMENT, DIVISION OF KESORAM INDUSTRIES LIMITED
UNIT: KESORAM CEMENT, FACTORY, PO: Basantnagar, Dist: Karimnagar
Telengana – 505187

Head office:

Birla Shakti Cement Division of Kesoram Industries Limited

Kesoram Industries Ltd (Cement Division)
Office No. 613-616, Block-3, White House
6-3-1192/1/2, Kundanbagh, Begumpet
Hyderabad - 500016, Telangana, (India) Phone : 040-4334 4555

Product Range: Deal with three varieties of cement.

1. **Ordinary Portland Cement [OPC]- 43 Grade:**
- Most commonly used cement for a wide range of applications like dry-lean mixes, general-purpose ready-mixes, high strength pre-cast and pre-stressed concrete.

2. **Portland Slag Cement [PSC]-53 Grade:**
- Slag-based blended cement that imparts strength and durability to all structures.
- Manufactured by blending and inter-grinding OPC clinker, and granulated slag in suitable proportions for consistent quality.

3. **Portland Pozzolana Cement [PPC]:**
- Blended with pozzolanic materials like power-station fly ash, burnt clays, ash from burnt plant material or siliceous earths.
- High degree of cohesion and workability in concrete and mortar.

Production Capacity:

Located near the limestone deposits of Sedam and Basantnagar, Birla Shakti's two cement manufacturing plants have a total combined capacity of 7.25 million metric tonnes, making it one of the leading cement manufacturers in the region.

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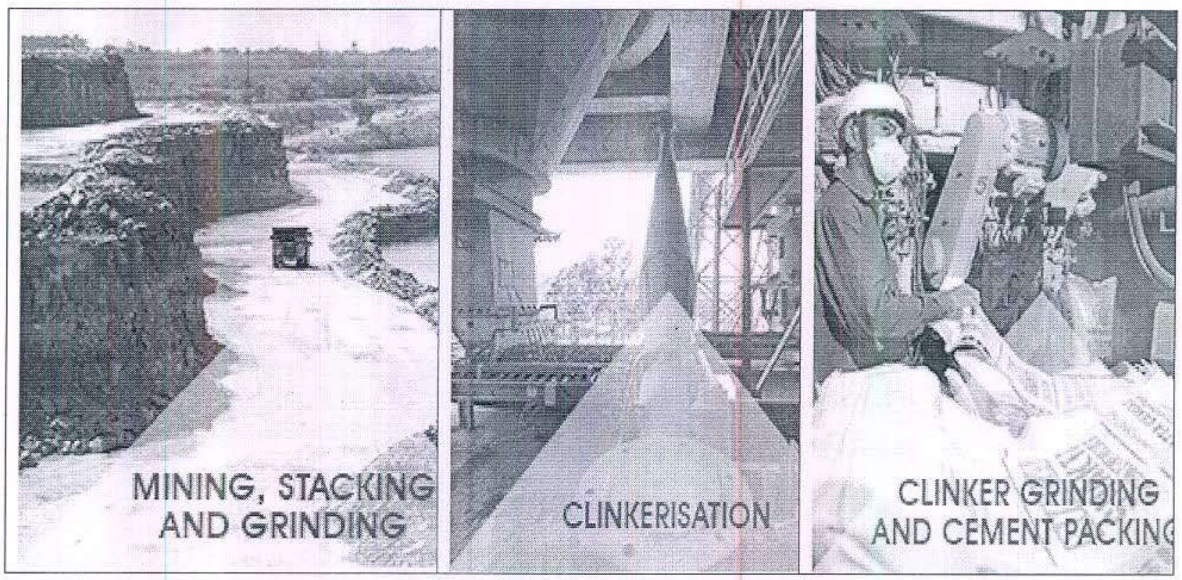
Channels (Network of Clients)

One of the main reasons for its tremendous success in the Indian market has been their reach across the nine highly industrialized states of Andhra Pradesh, Maharastra, Karnataka, Goa, Kerela, Madhya Pradesh, Orssia, Chhatisgarh and Tamil Nadu. their dealer network in the trade segment comprises 1,581 strong and loyal dealers across the territories. Most of these dealers have been associated with us for the last 35 years. This strong bond empowers us with the confidence and ability to grow further in this segment. Their clientele in the non-trade segment includes the following prestigious and renowned businesses:

Cement Production Process

The cement is manufactured in three process routes:



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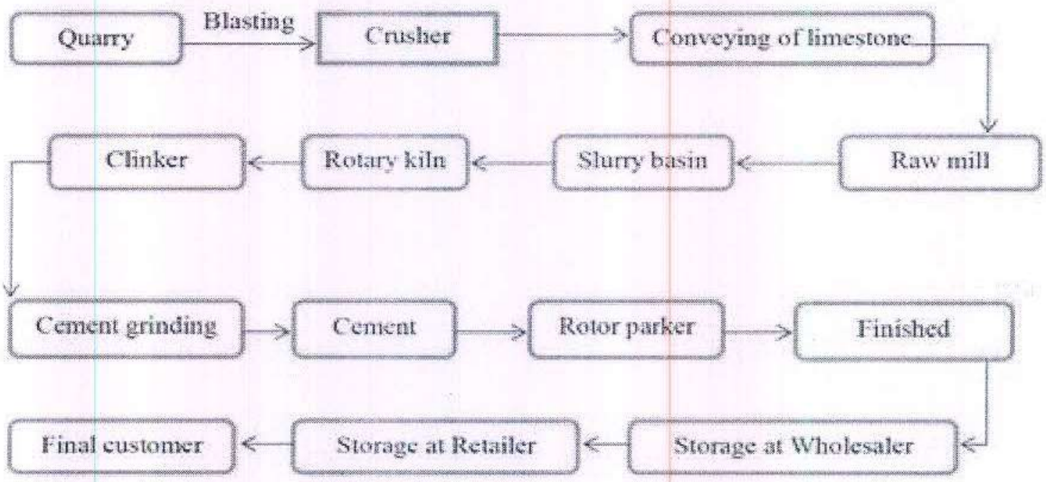

Detailed Production Process

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Research Design

Research design is the framework that provides the overall structures for the procedures that a researcher follow the data that the researcher collects and the data analysis the researcher conducts.

Main Objectives:

The main objective of the proposed project is to examine the strategic supply chain in cement industry. More specifically the specific objectives of the study are as follows:

1. To study the existing logistics and supply chain practices in the present unit.
2. To estimate demand and fulfill customer order in time.
3. To study the material handling (loading & unloading) equipments and reduce the manpower cost.
4. To study the manufacturing flow system to reduce the operation cycle.
5. To study the concept of suppliers relationship management in the company.
6. To study the inventory level of raw materials to run smooth production operation.
7. To determine the level of finished goods inventory to satisfying customer demand.
8. To study the marketing channels in the present unit.
9. To examine the existing problems in area of logistics and supply chain in the present unit.
10. To reduce the costs like storage, inventory, packaging, transportation, warehousing through implementation of effective supply chain and logistics.
11. To analyze the current problems in the supply chain management and logistics and suggest measure for the same.

Methodology:

The proposed project will be bases on primary data, which will be collected through specifically designed questionnaire, personal interviews and detail discussions with the official of the selected unit. Three set of questionnaire as customer's relationship, supplier's relationship, information communication and Environmental issues will be prepared for the data collection.

Sample Unit:

Birla Shakti Cement (Division of Kesoram Industries Limited) has been selected for the study.

Significance:

Globalization makes capital, knowledge, and skill to flow from every corner of the world and swallow the current complacent market. Dissatisfied customers could switch to competitors unless from the very beginning given proper services. Suppliers have to be considered as strategic partners of the business as they could leverage their resources, experience and knowledge in the era of competing one supply chain members against others. The outcome of the proposed study will be highly useful to the strategists/ top executives of the cement industry in general and Birla Shakti Cement in particular to reduce costs and provide efficient customer services.

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Chapter-IV

Strategic Supply Chain Management and Logistics

in

Birla Shakti Cement

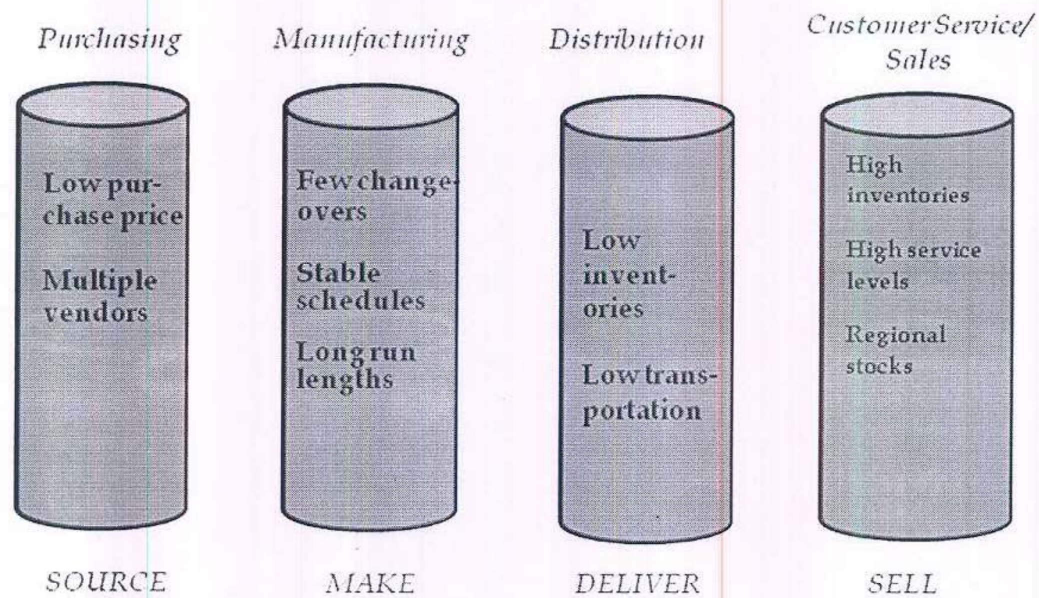
Supply chain management (SCM) is the management of the flow of goods and services. It includes the movement and storage of raw materials, work-in-process inventory, and finished goods from point of origin to point of consumption.

Supply chain management is a cross-functional approach that includes managing the movement of raw materials into an organization, certain aspects of the internal processing of materials into finished goods, and the movement of finished goods out of the organization and toward the end consumer. As organizations strive to focus on core competencies and become more flexible, they reduce their ownership of raw materials sources and distribution channels. These functions are increasingly being outsourced to other firms that can perform the activities better or more cost effectively. The effect is to increase the number of organizations involved in satisfying customer demand, while reducing managerial control of daily logistics operations. Less control and more supply chain partners lead to the creation of the concept of supply chain management. **The purpose of supply chain management is to improve trust and collaboration among supply chain partners, thus improving inventory visibility and the velocity of inventory movement.**

Supply chain serves as a link between suppliers and end-users, but the main goal of any supply chain is to deliver the right product, at the right time to the appropriate location. **Logistics is the management of the flow of things between the point of origin and the point of consumption in order to meet requirements of customers or corporations.** The logistics of physical items usually involves the integration of information flow, (information between the point of origin and the point of consumption in order to meet customer's requirements) material handling, production, packaging, inventory, transportation and warehousing.

Logistics and supply chain services; the rate of technological innovation and fluctuation in consumer demand are among the factors that have increased the dynamism of the competitive environment to which organizations must respond.

Steps for efficient Supply Chain



The peculiar features of the practice of Supply Chain Management in Indian cement industry. the optimal supply chain strategy demonstrates the best economic, ecological and social performance in the cement industry. Since 2000, supply chain management has played an operational role within cement and mineral extraction commodity companies. Recently, cost reduction projects have brought supply chain management into the limelight. The level of advancement in cement Supply Chain Management (SCM) can facilitate or constrain Indian economic development.

A cement plant is generally located near limestone deposits and cement produced in a particular region is mainly consumed in that region. A set of approaches are used to efficiently integrate the Suppliers, Manufacturers, Warehouses and Distribution centers so that the product is produced and distributed in the right quantities to the right locations at the right time.

STRATEGY	WHEN TO CHOOSE	BENEFITS
Make to Stock	standardized products, relatively predictable demand	Low manufacturing costs; meet customer demands quickly
Make to Order	customized products, many variations	Customization; reduced inventory; improved service levels
Configure to Order	many variations on finished product; infrequent demand	Low inventory levels; wide range of product offerings; simplified planning
Engineer to Order	complex products, unique customer specifications	Enables response to specific customer requirements

Ways to achieve a successful supply chain management could be the following:

1. To manage the resources of supply strategically in order to reduce the total cost of owning materials and services.

2. To pay attention to market signals and align demand planning accordingly, across the supply chain, ensuring consistent forecasts and optimal resource allocation.

3. Customize the logistics network to the service requirements and profitability of customer segments.

4. Segment the customers, based on the service needs of district groups, and adapt the supply chain to serve these segments profitability.

5. Develop a supply chain-wide technology strategy that supports multiple levels of decision making,

Operational Activities in Birla Shakti Cement:

One important fact related to the cement business is the global spreading of the cement groups and the consequent need to standardize technologies and plant layouts. Nine of top ten cement group leaders in the world adopted SAP, ERP in order to control and fast adjust to the new market needs. The same is valid to the plant layouts since cement groups tend to replicate the business models making small adjustments according to local market needs.

Key Issues in Supply Chain Management

1. Minimizing Uncertainty

2. Reducing lead time
3. Minimizing the number of stages
4. Improving flexibility
5. Improving process quality
6. Minimizing variety
7. Managing demand
8. Competing on services
9. Moving from functions to processes

Problems in Supply Chain Management:

The following are the common problems in an industry in the process of supply chain......

Poor coordination of effort

Incompatible information systems

Long cycle times

Communication problems

Customer service issues

Excessive waste

Relatively high inventory for the level of customer service achieved

Lower than optimal profits

Supply Chain Drivers:

The following are the main cost drivers used in supply chain in an industry. These three costs consists transportation -65%, packing - 15% and others -20% of the total costs. Transportation plays an important role in both moving purchased goods from suppliers to the buying organization, and moving finished goods to the customers. More so, due to the important role that it plays in the supply chain. It is an obvious fact that products are rarely produced and consumed in the same location, as such; transportation is a significant component of the costs that most supply chains incur.

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Transportation 65%)	**Freight charges from plants to warehouses & Outbound freight**	***Fuel Price *Lead Distance *Contracting with Transporter *Wagon/Truck Loading regulations *Road Conditions *Truck Type *Rail to road ratio**
Packing Costs (15%)	**Packing Bags (PPE) Cost & Bag Branding/ printing costs**	***Demand/Supply for PP granules *Bag makers conversion cost *Bag specifications *Price Risk Management *Market Structure *Tax levies *Alternative Packing Solutions**
Others (20%)	**Personnel Costs, Clearing & Forwarding costs at Dumps & Local**	**Local taxes (of Municipalities) *Dump Handling costs *Location of Dump & manpower costs *Packing Plant Manpower *Administrative Overheads**

In the proposed project, the following activities / processes will studies to find out the problems in Birla Shakti Cement in the area of logistics and supply chain management and appropriate strategies will be suggested.

Customer Relationship Management Process:

Under this process key customers are identified, the level of performances are specified, works are done closely with customers to eliminate the source of demand variability and service level and accordingly are evaluated to confirm the level of as delivered to the customers.

Demands Estimation Process

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The level of customer order is variable due to various reasons. Therefore, it is a process that balances the customer's requirement with the firm's supply capabilities.

Order Fulfillment Process:

Through an integrated effort of manufacturing, distribution and transportation, supply chain management works towards achieving high level of order fill rate to meet the customer need dates.

Physical distribution:

A best in class distribution performance makes firms to be the leaders in delivering goods and services to customers consistently in a defined set of quality and service levels at least possible costs. According to Micheal Porter's value chain frame work, this refers to the outbound logistics part of a chain. It involves finished goods warehousing, materials handling, freight delivery, order processing and scheduling.

This concerns the movement of a finished product or service to customers. In physical distribution, the customer is the final destination of a marketing channel, and the availability of the product or service is a vital part of each channel participant's marketing effort. It is also through the physical distribution process that the time and space of customer service become an integral part of marketing. Thus it links a marketing channel with its customers (i.e., it links manufacturers, wholesalers, and retailers).

Manufacturing Flow System:

Due to the nature of pull system in SCM, the process must be flexible enough to respond to the market changes. It is minimal lot size production as supported with mechanisms like just in time (JIT). The manufacturing system produces and supplies products to the distribution channels based on past forecasts. Manufacturing processes must be flexible in order to respond to market changes and must accommodate mass customization. Orders are processes operating on a just-in-time (JIT) basis in minimum lot sizes. Changes in the manufacturing flow system lead to shorter cycle times, meaning improved responsiveness and efficiency in meeting customer demand. This system manages activities related to planning, scheduling, and supporting manufacturing operations, such as work-in-process, storage, handling, transportation, and time phasing of components, inventory at manufacturing sites, and maximum flexibility in the coordination of geographical and final assemblies postponement of physical distribution operations.

Inventory Management:

Inventory management is a science primarily about specifying the shape and percentage of stocked goods. It is required at different locations within a facility or within many locations of a supply network to precede the regular and planned course of production and stock of materials.

Successful inventory management involves creating a purchasing plan that will ensure that items are available when they are needed (but that neither too much nor too little is purchased) and keeping track of existing inventory and its use. Two common inventory-management strategies are the **just-in-time method**, where companies plan to receive items as they are needed rather than maintaining high inventory levels, and **materials requirement planning**, which schedules material deliveries based on sales forecasts.

Transportation:

Any device used to move an item from one location to another. Common forms of transportation include planes, trains, and automobiles. There are several types of trucks according to the kind of loads (incoming trucks with raw material and outgoing trucks with final cement products). Transportation plays an important role in both moving purchased goods from suppliers to the buying organization, and moving finished goods to the customers. More so, due to the important role that it plays in the supply chain. It is an obvious fact that products are rarely produced and consumed in the same location, as such; transportation is a significant component of the costs that most supply chains incur.

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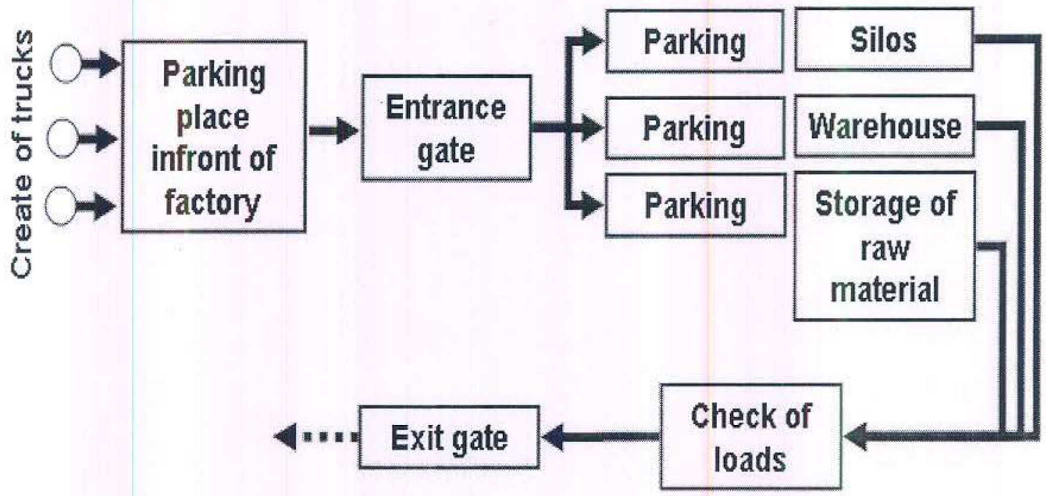

Figure: Simple Transportation system

These trucks must go through the entrance gates where they are registered and weighed. After that, they are sent into correct location in the plant for loading or unloading material. Then, trucks are weighed again and after final checking, they can leave the plant through the exit gates.

Through a preliminary analysis, some predictable problems would arise. Mainly, in this type of factories, the length of queues in some specific factory facilities-entrance gates, for example, always constitutes a relevant problem, causing long waiting times for customers. Usually this problem is due to inadequate number of facilities/resources available (e.g. loading places in warehouse) or to long loading times. Also, an inadequate control of work flows would lead to:

- Wrong destinations associated to trucks, once inside the plant;
- Trucks waiting even when facilities are available;
- Bad administrative options and absence of modern registration technologies as magnetic cards;
- Traffic jam inside plant;
- Incorrect loads;

- Breakdowns of key facilities;
- Inadequate Production scheduling.

Though, DES could be a powerful tool to improve processes and draw suggestions for modern control systems implementation.

The survey revealed that 73% of the respondents prefer to continue with the road-link logistics system. Though there is railway infrastructure in the country but due to research finding, the rail system is obsolete due to negligence and poor maintenance on this logistics system. A new railway infrastructure will have to be put in place for effective and efficient operation; and this is going to be costly for individual company to bear.

Information Communication:

Supply chain management could be mentioned as a co-ordination of materials, information and financial flows along supply chain to satisfy the ultimate need of the customers. These days information is not only a resource, but it is a main resource of securing a competitive advantage in coordinating within and across organizations activities. Information Technology enables one to exchange information instantly with a least cost. This technology enables various people, teams, functions and organizations to work together as a team along the supply chain.

Warehousing Management:

To reduce a company's cost and expenses, warehousing management is concerned with storage; reducing manpower cost, dispatching authority with on time delivery, loading & unloading facilities with proper area, inventory management system etc.

Loading System:

Loading of cement product into bulk trucks silos, where the truck is filled through automated equipment directly from the storage area. This type of loading can have a low automation level (conveyor and human power) or a higher level with the use of pallets (depending on the type of commerce and market requirements). This area is usually responsible for most failures

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in the process, as far as the correct type of material and correct amount of material is concerned. This area is identified as critical in a cement plant;

Loading processes

- the aim is to avoid errors in loading, making use of standard loading times;
- Avoiding plant overcrowding and traffic jams inside of the plant;
- Rationalizing the use of resources (gates, loading places or human resources) and allowing flexible reactions to specific customer requirements.

How to Enhance Efficiency and Responsiveness?

Responsiveness can be defined as the "ability to react purposefully and within an appropriate time-scale to customer demand or changes in the marketplace, to bring about or maintain competitive advantage". In contrast, a supply chain would be considered efficient if the focus is on cost reduction and no resources are wasted on non-value added activities

A. **Analysis & model simulation to innovative supply chain strategies in cement industry.** Cement is the second most consumed substance in the world after water. It is irreplaceable ingredient in a vast majority of the applications needed in our daily life. To gain better understanding about the nature of SCM in cement industry and its behaviour many tools can be used, for instance, SCOR-Model, ABC Analysis and Operational Performance Triangles.

   i. **SCOR Model** –Supply Chain Operations Reference (SCOR) Model is another tool. It is used as benchmark tool to analyze the cement supply chain processes. In general, SCOR Model is a cross-functional framework for evaluating and comparing supply chain activities.

   ii. **ABC Analysis** (Always Better Control) -This tool is used to help supply chain integration and Push-Pull boundary decision according to seasonal demand and Reorder Points ROP. ABC-Analysis is a range of items which have different levels of significance and should be handled or controlled differently.

   Class-A= clinker is a primary product

Class-B= bulk cement

Class-C =Cement in bags

iii. **Operational performance triangles**- Performance triangles could identify the actual position of company within their Competitors in the target market. Supply chain strategy execution needs to balance the operational performance objectives which are classified in three groups: (Customer Response; Efficiency; Asset Utilization).

B. **There are three types of supply chains that are necessary to match three types of products:** standard, innovative, and hybrid. They demonstrate that standard products, which tend to be simple products with limited amounts of differentiation, should be produced by a lean supply chain. Lean supply chain employ continuous improvement efforts and focus on eliminating wastes across the supply chain. On the other hand, innovative products which may employ new and complex technology require an agile supply chain. Agile supply chain responds to rapidly changing global markets by being dynamic and flexible across organizations. Hybrid products, which are complex products, have many components and participating companies in the supply chain; therefore, a variety of supplier relationships may be needed, which they refer to hybrid supply chains. Hybrid supply chains combine the capabilities of lean and agile supply chains to meet the needs of complex products.

C. **The evaluation and the comparison of such inventories make it possible to regard the extent of their environmental impact.** In the Eco-Balance structure of cement, three issues are discussed in the Life Cycle Assessment LCA: (Emissions reduction, Thermal energy efficiency and Electricity efficiency). Nowadays, about 60% of all CO2 emission from cement production originates from the basic calcinations process the heating of limestone to form lime. Ca. 30% comes from usage of fuel, and the remaining 10% from electricity usage and transportation. Reducing CO2 emission from cement production is a key focus of the cement producers and governments. Improvements of Greenhouse gases emission can be made by enhancing technology

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and design, striving for continuous measurements and full monitoring coverage, building cleaner plants within higher degree of automation, optimizing de-dusting systems and self-cleaning systems, environmental policies and protocols, as well as the optimization of cement distribution network

D. **Opportunities** - The Company has opportunity to expand its market share by introducing new products with reasonable price for which SCM can play vital role. - It has opportunity to increase its production & distribution by improving its distribution management as it came out as one of the improvement area during interviews. - People are opting for more stable structures and intensive use of cement is taking place, even government is spending heavily on infrastructure projects. Thus, this is the right time to fully tap these markets. Supply chain management strategies may be advantageous in grabbing this opportunity. - Foreign direct investment in infrastructure sector going to increase in coming years, which will increase the demand of cement. - Since market is expanding improved procurement strategies may be sought and there is an opportunity to manage its supply chain green and clean.

E. **To decide supply of material** (cement) from plant to the end customer when there is sudden increase in demand and transportation cost is to be minimized. To estimate how much quantity of cement will be suddenly required in future, analysis on the basis of previous record and distribution data of material (cement) from plant to distribution centers or distribution centers to retailers or customers is needed. To minimize transportation cost by eliminating unnecessary events which are related to the transportation, can be possible by the application of "Vogel's method". After application of Vogel's method, supply of cement with the systematic plan to required place and time is possible with reduction of unnecessary transportation charge.

Action 1: Look to consolidate Indian cement industry is highly fragmented with as many as ~ 50 companies with capacity of ~ 200 MTPA operating with varying degree of consolidation- As per our estimate ~ 60% of this capacity belongs to very few large players (higher than 6 MTPA capacities). Medium players (higher than 1 MTPA capacity) have another ~35 % capacity while the balance 15% comprises of small players. Due to obvious scale benefits, large players have traditionally managed better margins compared to their medium sized and smaller sized counterparts. In FY 08 large players on an average had 33% operating margin (OM) vis-à-vis 30% OM for

The domestic cement manufacturing industry is going through a tumultuous phase. While it is battling profitability woes on one hand, it also has to contend with increasing level of environmental activism that is keenly scrutinizing its various actions and their impact on environment and society.

Cement industry needs to proactively engage itself in the three dimensions of profitability; environmental consciousness and social obligations that will earn the industry "the right to grow and the license to operate" opine Arindam Chakrabarti, Deepak Nayak & Mainak Bhattacharya of Tata Strategic Management Group.

Long term players may hence look to grow their operations either organically or inorganically. In todays tight credit market, companies with attractive debt leverage position may have more than a few opportunities to buyout smaller sized companies and consolidate.

Action 2: Proactively change product mix - Ready Mix Concrete (RMC) usage in India is very low. As per a recent estimate RMC usage is ~ 3% of total concrete consumption. Historical growth of this segment is around 14%. RMC usage is however very high in developed countries at around 60%. Its usage is high even in other BRIC nations. RMC usage is primarily driven by growth in large construction projects which are generally undertaken by big institutional players. With large scale infrastructure related expenditure planned in India one can expect a substantial jump in RMC business. Industry expects RMC business to grow at around 25% per annum in near to medium term and reach a level of around 10% of concrete consumption by 2020.

An interesting piece of legislation in China has resulted in very healthy growth of RMC business. As per Chinese government decree # 341, on site concrete preparation is banned in 200 cities across China. This was done to prevent construction related pollution. Even though the chance of similar legislation coming in force in India looks

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slim at this moment, it remains a possibility that can alter the business landscape significantly. With profitability from RMC business on higher side, cement companies must look at consolidating / entering RMC business on a large scale.

Action 3: Develop logistics models to support changing product mix - Demand from large institutional players as well as higher RMC requirement in future will mean higher requirement of bulk cement. Movement of bulk cement requires specialized bulkers. The bulkers enable handling of bulk cement with the help of pneumatic loading and discharge mechanisms. Currently movement of bulk cement is primarily being done on Road. Rail mode has not been used even though it is half as costly. This is mainly due to unavailability of special purpose bulker tank wagons with Indian Railways. In this case manufacturers will have to either procure these wagons under Liberalized Wagon Investment Scheme (LWIS) or rent from Wagon Lessors. With high cost of a rake at ~ INR 20 crores & unavailability of lessers in current situation it becomes a difficult proposition for the manufacturers. However this opens up new business oppprtunities for a 3rd party service provider who can maintain sufficient quantity of railway rakes to service a host of manufacturers spread across india. It can also transport fly ash using the same wagons. Large cement producers can co-operate with dominant competitors in other geographies to develop such 3rd party service providers

Action 4: Look for alternate fuel sources -Power & fuel cost is second most important element of operations cost after raw material cost. Accordingly lot of efforts is being made worldwide to reduce this cost. One major direction in this regard has been usage of alternate fuel sources to fire the kilns in a cement plant. This approach helps to reduce operating cost by using cheaper alternative fuel source; it also helps to reduce the carbon footprint of the industry significantly. Amongst various sources tried, use of Tyre Derived Fuel (TDF) is gaining ground globally. Here scrap tyres are generally used in place of coal in clinker making kilns. It has its advantages. As per some studies done abroad, using TDF ensures that there is no negative impact to the environment due to emissions while it saves fossil fuel like coal. It also has positive commercial connotation for a company as scrap tyres is expected to be cheaper source of energy. An industry estimate puts 56% usage of scrap tyres as TDF in US alone. Indian companies must look at alternate fuel sources like TDF, Rice husk, etc.

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closely. However, putting in place a supply chain to make this alternate fuel available in sufficient quantity to cement plants is a big challenge.

Action 5: Optimally utilize Limestone Quarries -Limestone is the most important ingredient in manufacturing of clinkers. With limestone resources depleting fast due to its usage, availability might be constrained in future. So cement companies must look at ways to ensure that maximum possible lime stones are extracted from their existing quarries. This will save precious resources. Also spent limestone quarries can be put to commercial use by using some innovative methods. A spent quarry in Kenya was converted into a wildlife park!!

Action 6: Undertake a continuing dialog with affected community- Cement industry is considered a "dirty" industry due to the pollution it causes and its impact on the environment. While mining activities in limestone mines displaces many people, it also leads to depletion of forest cover. Dust from coal / cement handling, emission from its power plants / kilns cause's air pollution there by affecting the community living around the plant / quarry sites. In order to create a community friendly image across the society as a whole, a proactive & meaningful dialog must be sustained with them. This has positive rub offs on the organization and the brand.

Actions suggested above in some way or the other, impact the three dimensions of profitability, environmental concern and societal awareness. Indian companies will have to look at suitability of some of these proposed actions in their present context and chart out a meaningful action plan. This will help them in gaining advantage over their competitors and will equip them to take advantage of the next upturn.

SLV Internal Logistic System:

SLV Cement is a complete logistic system for cement plants developed by Cachapuz. This automatic and integrated logistic system deals with all the processes since the arrival of a truck to the cement plant to the shipping of cement. At the end of the process, even the administrative tasks like issuing and printing the necessary documentation are performed automatically. Another interesting SLV feature is the complete integration with SAP business software (ERP).

This proposed fully integrated logistic system will permit to increase throughput (trucks per unit time) and reduce the number of operators needed, thus avoiding human errors. The following picture (Figure), presents the main system architecture. Based on a central core, a set of different modules like reporting, automation and control, alerts (with SMS and mail sending), process logs and extensibility with external ERPs, were developed. Over these modules, the different plant areas like parking, check-in / check-out, raw material unloading zones, bag warehouses or bulk-loading, will be customized and automated. Additionally, as an answer to the global spread of the SLV system, the platform is fully prepared to remote support allowing fast diagnosis of and response to any factory needs.

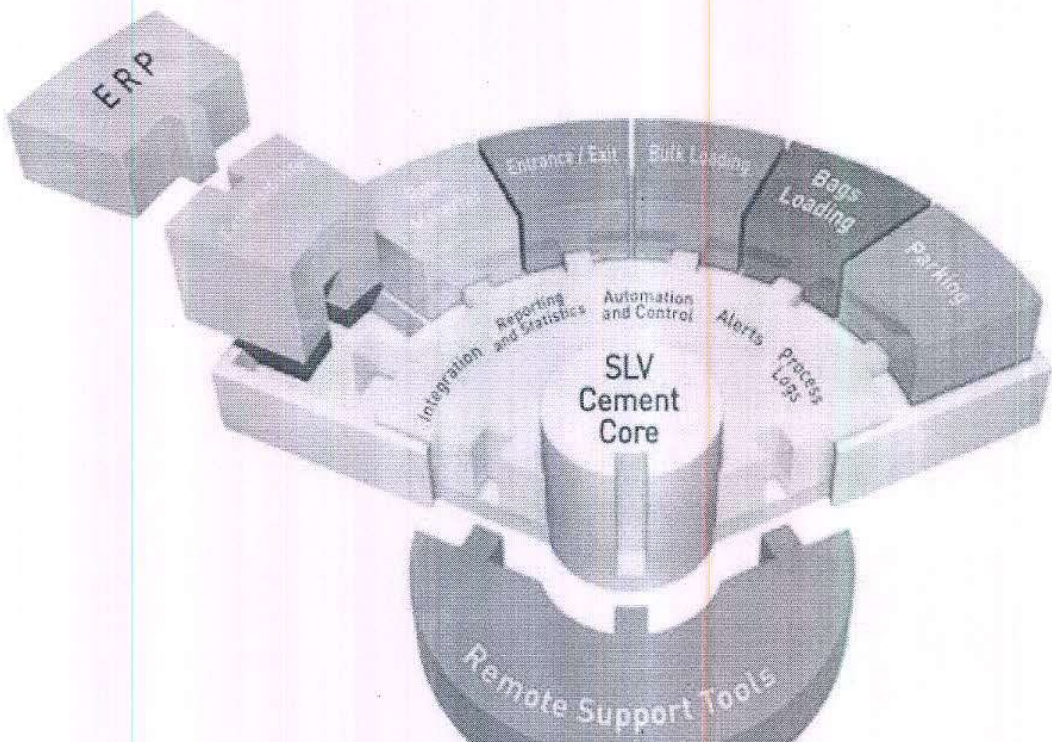

Figure: SLV Cement Logistic system

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Discrete Event Simulation (DES)

DES is the act of imitating the behavior of an operational system or process using an analog conceptual model on a computer. The arguments below will help understand why simulation would be a useful tool:

- All processes have stochastic behavior (Kulturėl 2007);
- It is a complex system with many resources and non deterministic conditional routing decisions;
- 3D graphic and animation is relevant for easy demonstration and presentation;
- Need for analysis of time dependent patterns of demand and facilities/resources availability.

The main issue of this project will involve the integration of the SLV Cement logistic system and a discrete-event simulation software tool (SIMIO). This approach will help find a high performance configuration and control of logistic components in cement plants. These components include weighing systems in both entrance and exit gates, registering and managing customer orders and requirements, truck flow control, etc. Our project focuses on the identification of bottlenecks in the system, finding a set of possible solutions and choosing the best one.

SIMIO

- SIMIO is a quite new **simulation tool**; it was developed in 2007 and represents a new approach in simulation - object orientation. Modeling evolution of system behavior by interaction of these objects (Pegden 2007). SIMIO supports:
- Creating 3D animation on one step, importing 3D objects from Google 3D Warehouse (Figure 9);
- Importing data from Excel worksheets (snapshot in Figure 6);
- Writing own logic functions (e.g. priority rules) in many languages (C++, Visual Basic, etc.) (snapshot in Figure 7);
- Creating our own intelligent objects and libraries.

- For this project, SIMIO simulation software was chosen in a perspective of a new challenge in this area (other simulation tools are discussed in Dias, Pereira, and Rodrigues 2007), and the issues below gained a great relevance for this project:
- Testing a new simulation tool for setting it as a part of currently used internal logistic system;
- Testing new possibilities for introducing this new simulation tool for educational purposes in our department.

Integration of a Simulation Tool and the Logistic System:

- According to mentioned issues, it is possible to identify why implementation of DES would be relevant in the context of a cement company:
- Currently used logistic application manages the flow of trucks in the plant;
- It helps answer what-if questions, checking (testing) the impacts of system changes;
- The plant processes and control logic are in the minds of managers and changes are made based on their knowledge (experience) and not on proved scenarios.
- It is possible to make use of the integration of these tools in two different contexts, Improving and optimizing a plant system that already uses SLV logistic system (current customers);
- Supporting the implementation of SLV system for new customers.
- The first approach (see schema in Figure 4, left side of the figure) can help in re-design tasks, testing different scenarios and suggesting configuration changes in the overall performance.
- Simulation can also be used for the implementation of a new logistic system in a new plant (Figure 4, right side of the figure). In this case simulation is a great tool and the 3D animation will help visualize a non-existing system and it is therefore possible to suggest and configure a complete system before its implementation in the plant. The DES will then help the specification of the global logistic system in close connection with the integrated automated weighing system proposed. According to the number of

known projects, it is possible to say that re-design tasks are much more often than the design of completely new logistic systems (Kulturel 2007) (Vik 2009).

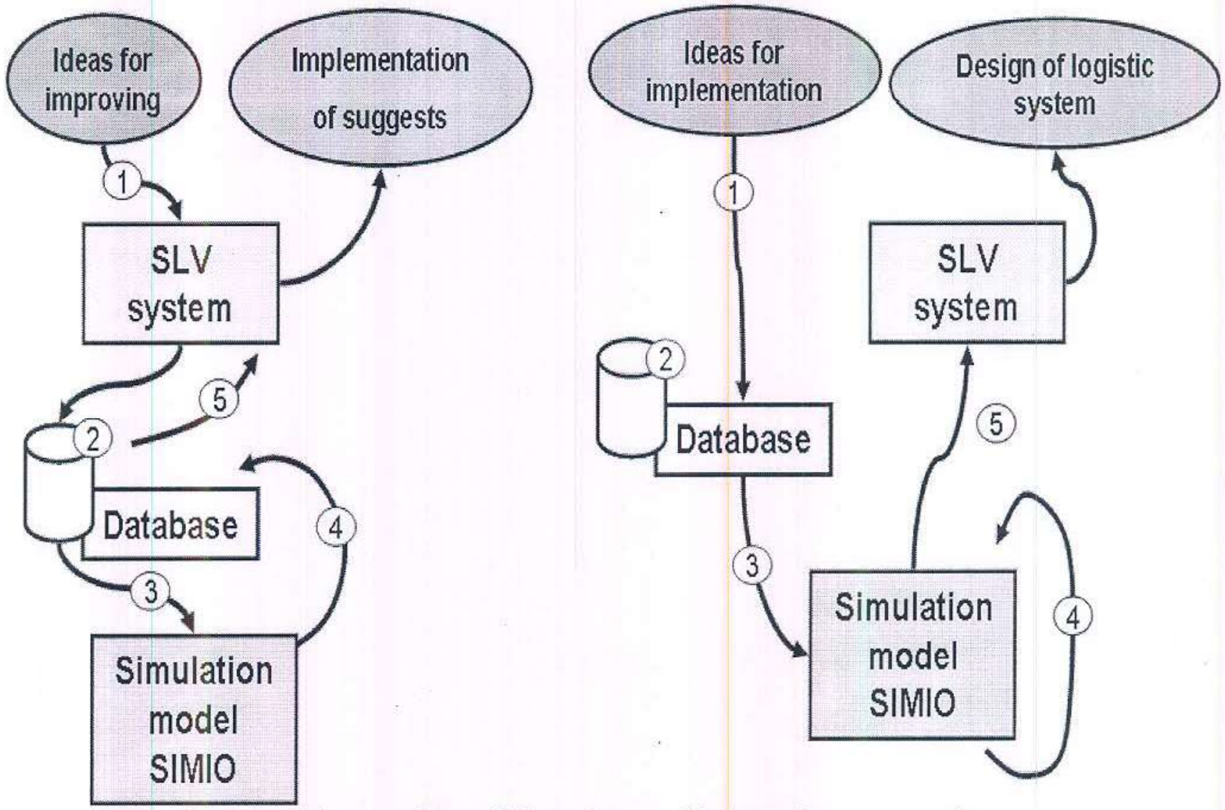

Figure: Schema of two different uses of integration approaches

Creation of the simulation model:

For the creation of a simulation model, standard elements like source, process and sink were used, connected by a set of paths.

Some main processes were identified:

- Loading request registration;
- Waiting for calling to entrance;
- Entrance gate and respective weighing (both empty and loaded trucks);

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- Loading/unloading (silos, warehouse, storage of raw material and storage of lime stone);
- Load checking;
- Exiting gate (weighing).
- Some random variables were studied:
- Patterns of time between arrivals at different periods of the day and different days;
- Operation times;
- Failures of facilities, errors in loading actions.

For describing a realistic behavior of the trucks in the plant, some special functions were created. For avoiding traffic jams inside the plant, a limitation function is used only a limited number of trucks could be inside the plant at the same time (remaining trucks should wait for a call outside the plant). In real plants (with SLV system), the waiting trucks are then called, using either an outside panel information.

For finding the next destination (in the model represented as element fork, another function is used. Process diagram of this function is shown in Figure . A typical use of this function would be for performing the task of finding the correct entrance gate. Each truck has a set of attributes like identification number and weight. According to these data, function finds optimal destination for a kind of truck. Searching is based on this information:

- Kind of truck (raw material trucks use a special gate);
- Weight limitation of gate (e.g. 60 tons);
- Current queues in front of each suitable gate;
- Current state of facility (if there is some failure, another gate should be chosen).

If there is no free gate, the truck will wait in the queue until another truck leaves some of the gates.

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Model of a real cement plant and its logistic processes
(Problem description and project steps)

As an illustrative example of the mentioned integration principles and for an easy understanding, we chose a simple model of a real cement plant and its logistic processes. This solution is based on general usage in any cement (or similar) kind of factory.

Our simulation approach included the following steps as...

1) **Definition of project aims**

- Definition of exact project targets according to customer requirements;
- Team building and its responsibility.

2) **Processing of input data**

- Technical data (facilities data, product data, information about material flows, production areas, breakdowns, shifts etc.);
- Organization data (production scheduling);
- Business data (costs, orders).

3) **Creation of simulation model**

- Conceptual model (schematic);
- Computer model.

4) **Simulation run and experiments**

- Validation and model verification;
- Setting of parameters, length of simulation run;
- Running of experiments.

5) **Interpretation of results and implementation**

- Data analysis;
- Interpretation of results, their presentation and comparing suggested alternatives and scenarios (graphs, tables, 3D animation).

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Suggestions on the Basis of Past Studies

1. Profit can only attained through a sustainable customer satisfaction. This process requires a customer focused and uninterrupted relationship.
2. Firms need to identify the need of the customers, collect feedbacks on any complaints and avail different products and service attributes to their customers.
3. Information technology should be instituted to foster information communication within and among all supply chain members.
4. Organizations should consider environmental issues.
5. Proper inventory must be maintained.
6. Packaging should be given high priority.
7. Speedy transportation must be used.
8. Market intermediaries must be motivated / encouraged.
9. Employees must be given due remuneration.
10. Training and development should be provided to employees on regular basis.

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PROJECT REPORT

ON

ADVANCED TRAINING IN CONNECTION WITH EXCEL TRAVEL ACCOUNTING SOFTWARE & RELATED CONSULTANCY

Compiled and submitted by:

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Chapter- 1

INTRODUCTION

1.1 React Js

React (also known as **React.js** or **ReactJS**) is an open-source JavaScript library for building user interfaces. It is maintained by Facebook and a community of individual developers and companies.

React can be used as a base in the development of single-page or mobile applications. However, React is only concerned with rendering data to the DOM, and so creating React applications usually requires the use of additional libraries for state management and routing. Redux and React Router are respective examples of such libraries.

1.1.1 Why React Js?

ReactJS is a stronger framework because of its ability to break down the complex interface and allow users to work on individual components. ReactJS comes with the core objective is to deliver the best rendering performance possible. Its strength stems from the emphasis on individual parts. ReactJS helps a developer to break down the complicated UI into smaller components, rather than operating on the entire web framework.

1.1.2 Features of React Js

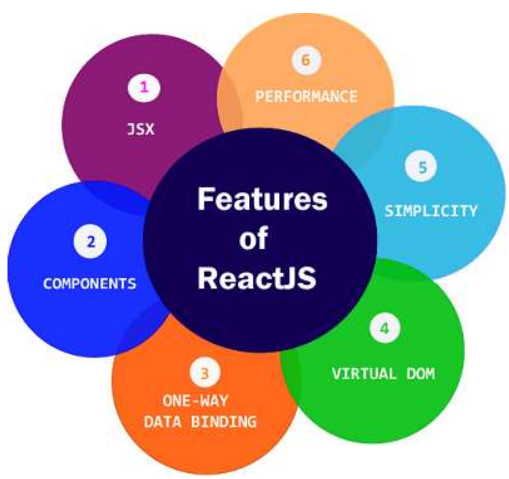

Fig 1.1 Features Of ReactJs

- JSX
- Components
- One-way Data Binding
- Virtual DOM
- Simplicity
- Performance

1.1.3 Introducing JSX

```
const element = <h1>Hello, world!</h1>;
```

The above syntax is called JSX, and it is a syntax extension to JavaScript. It is used with React to describe what the UI should look like. JSX may remind you of a template language, but it comes with the full power of JavaScript. JSX produces React “elements”.

1.2. Why JSX?

React embraces the fact that rendering logic is inherently coupled with other UI logic: how events are handled, how the state changes over time, and how the data is prepared for display.

Instead of artificially separating technologies by putting markup and logic in separate files, React separates concerns with loosely coupled units called “components” that contain both.

React doesn’t require using JSX, but most people find it helpful as a visual aid when working with UI inside the JavaScript code. It also allows React to show more useful error and warning messages.

1.3 Embedding Expressions in JSX

In the example below, we declare a variable called name and then use it inside JSX by wrapping it in curly braces:

```
const name = 'Josh Perez';

const element = <h1>Hello, {name}</h1>;

ReactDOM.render(
```

```
  element,
  document.getElementById('root')
);
```

You can put any valid JavaScript expression inside the curly braces in JSX. For example, 2 + 2, user.firstName, or formatName(user) are all valid JavaScript expressions.

In the example below, we embed the result of calling a JavaScript function, formatName(user), into an <h1> element.

```
function formatName(user) {
  return user.firstName + ' ' + user.lastName;
}

const user = {
  firstName: 'Harper',
  lastName: 'Perez'
};

const element = (
  <h1>
    Hello, {formatName(user)}!
  </h1>
);

ReactDOM.render(
  element,
  document.getElementById('root')
);
```

1.3.1 JSX is an Expression Too

After compilation, JSX expressions become regular JavaScript function calls and evaluate to JavaScript objects.

This means that you can use JSX inside of if statements and for loops, assign it to variables, accept it as arguments, and return it from functions:

```
function getGreeting(user) {
  if (user) {
    return <h1>Hello, {formatName(user)}!</h1>;
  }
  return <h1>Hello, Stranger.</h1>;
}
```

1.3.2 Specifying Attributes with JSX

You may use quotes to specify string literals as attributes:

```
const element = <div tabIndex="0"></div>;
```

You may also use curly braces to embed a JavaScript expression in an attribute:

```
const element = <img src={user.avatarUrl}></img>;
```

1.4 Rendering Elements

Elements are the smallest building blocks of React apps.

An element describes what you want to see on the screen:

```
const element = <h1>Hello, world</h1>;
```

Unlike browser DOM elements, React elements are plain objects, and are cheap to create. React DOM takes care of updating the DOM to match the React elements.

1.4.1 Rendering an Element into the DOM

Let’s say there is a <div> somewhere in your HTML file:

```
<div id="root"></div>
```

We call this a “root” DOM node because everything inside it will be managed by React DOM.

Applications built with just React usually have a single root DOM node. If you are integrating React into an existing app, you may have as many isolated root DOM nodes as you like.

To render a React element into a root DOM node, pass both to ReactDOM.render():

```
const element = <h1>Hello, world</h1>;
ReactDOM.render(element, document.getElementById('root'));
```

1.4.2 Updating the Rendered Element

React elements are immutable. Once you create an element, you can’t change its children or attributes. An element is like a single frame in a movie: it represents the UI at a certain point in time.

With our knowledge so far, the only way to update the UI is to create a new element, and pass it to ReactDOM.render().

Consider this ticking clock example:

```
function tick() {
  const element = (
    <div>
      <h1>Hello, world!</h1>
      <h2>It is {new Date().toLocaleTimeString()}.</h2>
    </div>
```

```
 );

ReactDOM.render(element, document.getElementById('root'));
}
setInterval(tick, 1000);
```

1.5 Component and Props

Conceptually, components are like JavaScript functions. They accept arbitrary inputs (called “props”) and return React elements describing what should appear on the screen.

1.5.1 Function and Class Components

The simplest way to define a component is to write a JavaScript function:

```
function Welcome(props) {
  return <h1>Hello, {props.name}</h1>;
}
```

This function is a valid React component because it accepts a single “props” (which stands for properties) object argument with data and returns a React element. We call such components “function components” because they are literally JavaScript functions.

You can also use an ES6 class to define a component:

```
class Welcome extends React.Component {
  render() {
    return <h1>Hello, {this.props.name}</h1>;
  }
}
```

The above two components are equivalent from React’s point of view.

1.5.2 Rendering a Component

Previously, we only encountered React elements that represent DOM tags:

```
const element = <div />;
```

However, elements can also represent user-defined components:

```
const element = <Welcome name="Sara" />;
```

When React sees an element representing a user-defined component, it passes JSX attributes and children to this component as a single object. We call this object “props”.

For example, this code renders “Hello, Sara” on the page:

```
function Welcome(props) {
 return <h1>Hello, {props.name}</h1>;
}

const element = <Welcome name="Sara" />;
ReactDOM.render (
  element,
  document.getElementById('root')
);
```

1.5.3 Composing Components

Components can refer to other components in their output. This lets us use the same component abstraction for any level of detail. A button, a form, a dialog, a screen: in React apps, all those are commonly expressed as components.

For example, we can create an App component that renders Welcome many times:

```
function Welcome(props) {
  return <h1>Hello, {props.name}</h1>;
}

function App() {
  return (
    <div>
```

```
    <Welcome name="Sara" />
    <Welcome name="Cahal" />
    <Welcome name="Edite" />
  </div>
 );
}

ReactDOM.render(
  <App />,
  document.getElementById('root')
);
```

1.5.4 Extracting Components

Don’t be afraid to split components into smaller components.

For example, consider this Comment component:

```
function Comment(props) {
  return (
    <div className="Comment">
      <div className="UserInfo">
        <img className="Avatar"
          src={props.author.avatarUrl}
          alt={props.author.name}
        />
        <div className="UserInfo-name">
          {props.author.name}
        </div>
      </div>
      <div className="Comment-text">
        {props.text}
      </div>
```

```
      <div className="Comment-date">
        {formatDate(props.date)}
      </div>
    </div>
  );
}
```

1.6 Converting a Function to a Class

You can convert a function component to a class in five steps:

1. Create an ES6 class, with the same name, that extends React.Component.
2. Add a single empty method to it called render().
3. Move the body of the function into the render() method.
4. Replace props with this.props in the render() body.
5. Delete the remaining empty function declaration.

```
class Clock extends React.Component {
  render() {
    return (
      <div>
        <h1>Hello, world!</h1>
        <h2>It is {this.props.date.toLocaleTimeString()}.</h2>
      </div>
    );
  }
}
```

1.7 Adding Local State to a Class

We will move the date from props to state in three steps:

1. Replace this.props.date with this.state.date in the render() method:

```
class Clock extends React.Component {
  render() {
    return (
      <div>
        <h1>Hello, world!</h1>

        <h2>It is {this.state.date.toLocaleTimeString()}.</h2>
      </div>
    );
  }
}
```

2. Add a class constructor that assigns the initial this.state:

```
class Clock extends React.Component {
  constructor(props) {
    super(props);

    this.state = {date: new Date()};
  }

  render() {
    return (
      <div>
        <h1>Hello, world!</h1>
        <h2>It is {this.state.date.toLocaleTimeString()}.</h2>
      </div>
    );
  }
}
```

Note how we pass props to the base constructor:

```
constructor(props) {

  super(props);
  this.state = {date: new Date()};
 }
```

Class components should always call the base constructor with props.

3. Remove the date prop from the <Clock /> element:

```
ReactDOM.render(
 <Clock />,
 document.getElementById('root')
);
```

The result looks like this:

```
class Clock extends React.Component {
 constructor(props) {
  super(props);
  this.state = {date: new Date()};
 }
 render() {
   return (
     <div>
       <h1>Hello, world!</h1>
      <h2>It is {this.state.date.toLocaleTimeString()}.</h2>
    </div>
   );
  }
}
```

```
ReactDOM.render(
 <Clock />,
 document.getElementById('root')
);
```

1.7.1 Using State Correctly

There are three things you should know about setState().

Do Not Modify State Directly

For example, this will not re-render a component:

// Wrong

this.state.comment = 'Hello';

Instead, use setState():

// Correct

this.setState({comment: 'Hello'});

The only place where you can assign this.state is the constructor.

State Updates May Be Asynchronous

React may batch multiple setState() calls into a single update for performance.

Because this.props and this.state may be updated asynchronously, you should not rely on their values for calculating the next state.

When you call setState(), React merges the object you provide into the current state.

1.8 Lifecycle of Components

Each component in React has a lifecycle which you can monitor and manipulate during its three main phases.

The three phases are: Mounting, Updating, and Unmounting.

1.8.1 Mounting

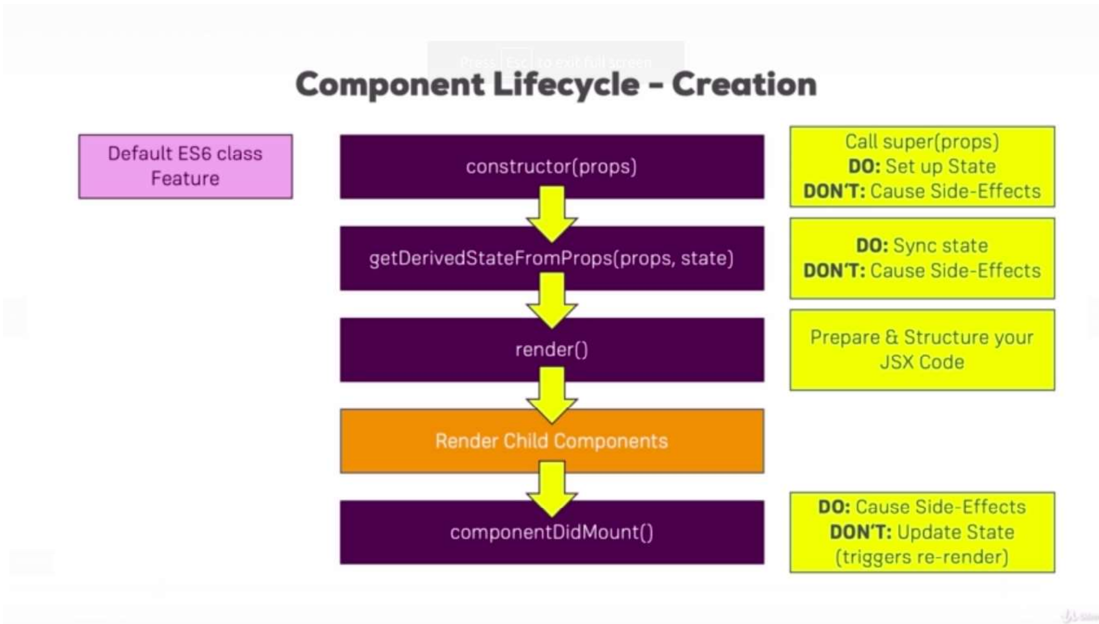

Fig: 1.2 Component Lifecycle Creation

Mounting means putting elements into the DOM.

React has four built-in methods that gets called, in this order, when mounting a component:

1. constructor()
2. getDerivedStateFromProps()
3. render()
4. componentDidMount()

The render() method is required and will always be called, the others are optional and will be called if you define them.

1.8.1.1 constructor

The constructor() method is called before anything else, when the component is initiated, and it is the natural place to set up the initial state and other initial values.

The constructor() method is called with the props, as arguments, and you should always start by calling the super(props) before anything else, this will initiate the parent's constructor method and allows the component to inherit methods from its parent (React.Component).

```
class Header extends React.Component {

  constructor(props) {

    super(props);

    this.state = {favoritecolor: "red"};

  }

  render() {

    return (

      <h1>My Favorite Color is {this.state.favoritecolor}</h1>

    );

  }

}
```

1.8.1.2 getDerivedStateFromProps

The getDerivedStateFromProps() method is called right before rendering the element(s) in the DOM.

This is the natural place to set the state object based on the initial props.

It takes state as an argument, and returns an object with changes to the state.

The example below starts with the favorite color being "red", but the getDerivedStateFromProps() method updates the favorite color based on the favcol attribute:

Example:

The getDerivedStateFromProps method is called right before the render method:

```
class Header extends React.Component {

  constructor(props) {

    super(props);
```

```
  this.state = {favoritecolor: "red"};
 }
 static getDerivedStateFromProps(props, state) {
  return {favoritecolor: props.favcol };
 }
 render() {
  return (
   <h1>My Favorite Color is {this.state.favoritecolor}</h1>
  );
 }
}
```

1.8.1.3 render

The render() method is required, and is the method that actual outputs HTML to the DOM.

Example:

A simple component with a simple render() method:

```
class Header extends React.Component {
 render() {
  return (
   <h1>This is the content of the Header component</h1>
  );
 }
}
```

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1.8.1.4 componentDidMount

The componentDidMount() method is called after the component is rendered.

This is where you run statements that requires that the component is already placed in the DOM.

Example:

At first my favorite color is red, but give me a second, and it is yellow instead:

```
class Header extends React.Component {
  constructor(props) {
    super(props);
    this.state = {favoritecolor: "red"};
  }
  componentDidMount() {
    setTimeout(() => {
      this.setState({favoritecolor: "yellow"})
    }, 1000)
  }
  render() {
    return (
      <h1>My Favorite Color is {this.state.favoritecolor}</h1>
    );
  }
}
```

1.8.2 Updating

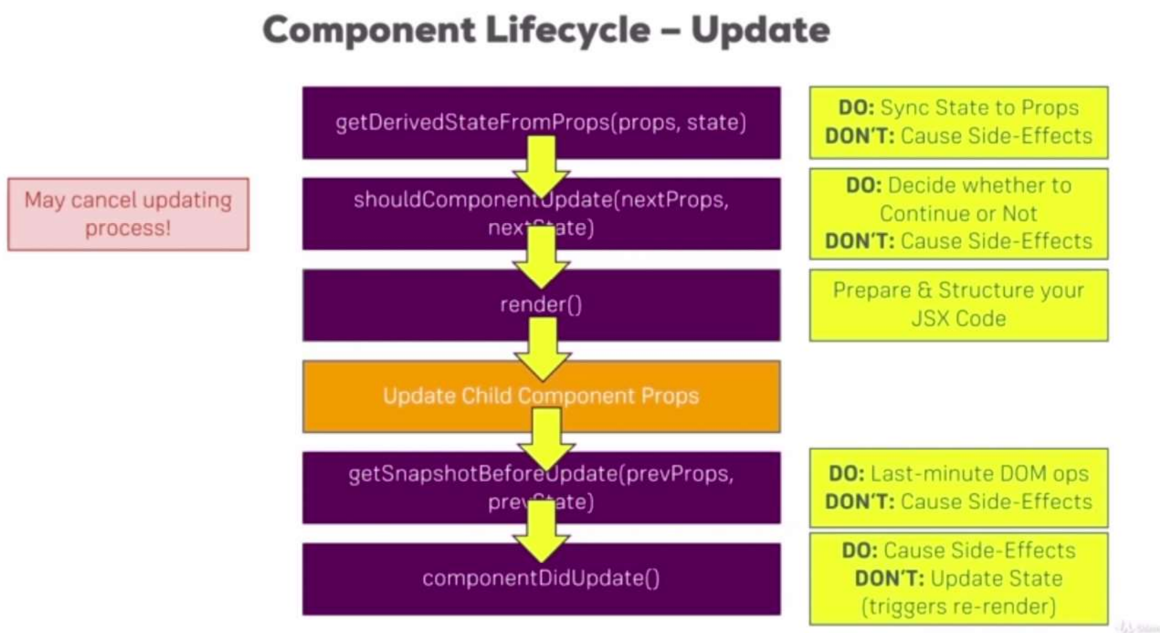

Fig 1.3 Component Lifecycle Update

The next phase in the lifecycle is when a component is updated.

A component is updated whenever there is a change in the component's state or props.

React has five built-in methods that gets called, in this order, when a component is updated:

1. getDerivedStateFromProps()
2. shouldComponentUpdate()
3. render()
4. getSnapshotBeforeUpdate()
5. componentDidUpdate()

The render() method is required and will always be called, the others are optional and will be called if you define them.

1.8.2.1 getDerivedStateFromProps

Also at updates the getDerivedStateFromProps method is called. This is the first method that is called when a component gets updated.

This is still the natural place to set the state object based on the initial props.

The example below has a button that changes the favorite color to blue, but since the getDerivedStateFromProps() method is called, which updates the state with the color from the favcol attribute, the favorite color is still rendered as yellow:

Example:

If the component gets updated, the getDerivedStateFromProps() method is called:

```
class Header extends React.Component {
  constructor(props) {
    super(props);
    this.state = {favoritecolor: "red"};
  }
  static getDerivedStateFromProps(props, state) {
    return {favoritecolor: props.favcol };
  }
  changeColor = () => {
    this.setState({favoritecolor: "blue"});
  }
  render() {
    return (
      <div>
      <h1>My Favorite Color is {this.state.favoritecolor}</h1>
      <button type="button" onClick={this.changeColor}>Change color</button>
      </div>
    );
  }
}
```

1.8.2.2 shouldComponentUpdate

In the shouldComponentUpdate() method you can return a Boolean value that specifies whether React should continue with the rendering or not.

The default value is true.

The example below shows what happens when the shouldComponentUpdate() method returns false:

Example:

Stop the component from rendering at any update:

```
class Header extends React.Component {
  constructor(props) {
    super(props);
    this.state = {favoritecolor: "red"};
  }
  shouldComponentUpdate() {
    return false;
  }
  changeColor = () => {
    this.setState({favoritecolor: "blue"});
  }
  render() {
    return (
      <div>
      <h1>My Favorite Color is {this.state.favoritecolor}</h1>
      <button type="button" onClick={this.changeColor}>Change color</button>
      </div>
    );
  }
}
```

1.8.2.3 render

The render() method is of course called when a component gets updated, it has to re-render the HTML to the DOM, with the new changes.

The example below has a button that changes the favorite color to blue:

Example:

Click the button to make a change in the component's state:

```
class Header extends React.Component {
  constructor(props) {
    super(props);
    this.state = {favoritecolor: "red"};
  }
  changeColor = () => {
    this.setState({favoritecolor: "blue"});
  }
  render() {
    return (
      <div>
      <h1>My Favorite Color is {this.state.favoritecolor}</h1>
      <button type="button" onClick={this.changeColor}>Change color</button>
      </div>
    );
  }
}
```

1.8.2.4 getSnapshotBeforeUpdate

In the getSnapshotBeforeUpdate() method you have access to the props and state before the update, meaning that even after the update, you can check what the values were before the update.

If the getSnapshotBeforeUpdate() method is present, you should also include the componentDidUpdate() method, otherwise you will get an error.

The example below might seem complicated, but all it does is this:

When the component is mounting it is rendered with the favorite color "red".

When the component has been mounted, a timer changes the state, and after one second, the favorite color becomes "yellow".

This action triggers the update phase, and since this component has a getSnapshotBeforeUpdate() method, this method is executed, and writes a message to the empty DIV1 element.

Then the componentDidUpdate() method is executed and writes a message in the empty DIV2 element:

Example:

Use the getSnapshotBeforeUpdate() method to find out what the state object looked like before the update:

```
class Header extends React.Component {
  constructor(props) {
    super(props);
    this.state = {favoritecolor: "red"};
  }
  componentDidMount() {
    setTimeout(() => {
      this.setState({favoritecolor: "yellow"})
    }, 1000)
  }
  getSnapshotBeforeUpdate(prevProps, prevState) {
    document.getElementById("div1").innerHTML =
    "Before the update, the favorite was " + prevState.favoritecolor;
  }
  componentDidUpdate() {
    document.getElementById("div2").innerHTML =
    "The updated favorite is " + this.state.favoritecolor;
  }
  render() {
    return (
      <div>
        <h1>My Favorite Color is {this.state.favoritecolor}</h1>
        <div id="div1"></div>
```

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```
      <div id="div2"></div>
    </div>
  );
 }
}
```

1.8.2.5 componentDidUpdate

The componentDidUpdate method is called after the component is updated in the DOM.

The example below might seem complicated, but all it does is this:

When the component is mounting it is rendered with the favorite color "red".

When the component has been mounted, a timer changes the state, and the color becomes "yellow".

This action triggers the update phase, and since this component has a componentDidUpdate method, this method is executed and writes a message in the empty DIV element:

Example:

The componentDidUpdate method is called after the update has been rendered in the DOM:

```
class Header extends React.Component {
 constructor(props) {
  super(props);
  this.state = {favoritecolor: "red"};
 }
 componentDidMount() {
  setTimeout(() => {
   this.setState({favoritecolor: "yellow"})
  }, 1000)
 }
 componentDidUpdate() {
  document.getElementById("mydiv").innerHTML =
  "The updated favorite is " + this.state.favoritecolor;
```

```
  }
  render() {
    return (
      <div>
      <h1>My Favorite Color is {this.state.favoritecolor}</h1>
      <div id="mydiv"></div>
      </div>
    );
  }
}
```

1.8.3 Unmounting

The next phase in the lifecycle is when a component is removed from the DOM, or unmounting as React likes to call it.

React has only one built-in method that gets called when a component is unmounted:

- componentWillUnmount()

1.8.3.1 componentWillUnmount

The componentWillUnmount method is called when the component is about to be removed from the DOM.

Example:

Click the button to delete the header:

```
class Container extends React.Component {
  constructor(props) {
    super(props);
    this.state = {show: true};
  }
  delHeader = () => {
```

```
    this.setState({show: false});
  }
  render() {
    let myheader;
    if (this.state.show) {
      myheader = <Child />;
    };
    return (
      <div>
      {myheader}
      <button type="button" onClick={this.delHeader}>Delete Header</button>
      </div>
    );
  }
}

class Child extends React.Component {
  componentWillUnmount() {
    alert("The component named Header is about to be unmounted.");
  }
  render() {
    return (
      <h1>Hello World!</h1>
    );
  }
}
```

1.9 Handling Events

Handling events with React elements is very similar to handling events on DOM elements. There are some syntax differences:

- React events are named using camelCase, rather than lowercase.
- With JSX you pass a function as the event handler, rather than a string.

For example, the HTML:

```
<button onclick="activateLasers()">
  Activate Lasers
</button>
```

is slightly different in React:

```
<button onClick={activateLasers}>
 Activate Lasers
</button>
```

Another difference is that you cannot return false to prevent default behavior in React. You must call preventDefault explicitly. For example, with plain HTML, to prevent the default link behavior of opening a new page, you can write:

```
<a href="#" onclick="console.log('The link was clicked.'); return false">
  Click me
</a>
```

In React, this could instead be:

```
function ActionLink() {
 function handleClick(e) {
   e.preventDefault();
   console.log('The link was clicked.');
 }
  return (
   <a href="#" onClick={handleClick}>
```

```
    Click me
   </a>
  );
}
```

Here, e is a synthetic event. React defines these synthetic events according to the W3C spec, so you don't need to worry about cross-browser compatibility. See the SyntheticEvent reference guide to learn more.

When using React, you generally don't need to call addEventListener to add listeners to a DOM element after it is created. Instead, just provide a listener when the element is initially rendered.

When you define a component using an ES6 class, a common pattern is for an event handler to be a method on the class. For example, this Toggle component renders a button that lets the user toggle between "ON" and "OFF" states:

```
class Toggle extends React.Component {
  constructor(props) {
    super(props);
    this.state = {isToggleOn: true};
   // This binding is necessary to make `this` work in the callback
   this.handleClick = this.handleClick.bind(this);
 }

 handleClick() {
   this.setState(state => ({
     isToggleOn: !state.isToggleOn
   }));
 }

  render() {
    return (
     <button onClick={this.handleClick}>
       {this.state.isToggleOn ? 'ON' : 'OFF'}
```

```
      </button>
    );
  }
}

ReactDOM.render(
  <Toggle />,
  document.getElementById('root')
);
```

1.10 Router

React Router is a standard library for routing in React. It enables the navigation among views of various components in a React Application, allows changing the browser URL, and keeps the UI in sync with the URL.

Let us create a simple application to React to understand how the React Router works. The application will contain three components: home component, about a component, and contact component. We will use React Router to navigate between these components.

1.10.1 Installing React Router:

React Router can be installed via npm in your React application. Follow the steps given below to install Router in your React application:

- Step 1: cd into your project directory i.e geeks.
- Step 2: To install the React Router use the following command:

```
npm install react-router-dom –save
```

After installing react-router-dom, add its components to your React application.

1.10.2 Adding React Router Components:

The main Components of React Router are:

- **BrowserRouter:** BrowserRouter is a router implementation that uses the HTML5 history API(pushState, replaceState and the popstate event) to keep your UI in sync with the URL. It is the parent component that is used to store all of the other components.
- **Route:** Route is the conditionally shown component that renders some UI when its path matches the current URL.
- **Link:** Link component is used to create links to different routes and implement navigation around the application. It works like an HTML anchor tag.
- **Switch:** Switch component is used to render only the first route that matches the location rather than rendering all matching routes. Although there is no defying functionality of SWITCH tag in our application because none of the LINK paths are ever going to coincide. But let's say we have a route (Note that there is no EXACT in here), then all the Route tags are going to be processed which start with '/' (all Routes start with /). This is where we need a SWITCH statement to process only one of the statements.

To add React Router components in your application, open your project directory in the editor you use and go to **app.js** file.

//App.js:

```
import {
   BrowserRouter as Router,
   Route,
   Link,
   Switch
} from 'react-router-dom';
import {
   BrowserRouter as Router,
   Route,
   Link,
   Switch
} from 'react-router-dom';
```


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1.10.3 Using React Router :-

To use React Router, let us first create a few components in the react application. In your project directory, create a folder named component inside the src folder and now add 3 files named home.js, about.js and contact.js to the component folder.

//Home.js:

```
import React from 'react';

function Home (){
        return <h1>Welcome to the Unthinkable Solutions!</h1>
}

export default Home;
```

//About.js:

```
import React from 'react';

function About () {
return <div>
                <h2>We provide you best solutions!</h2>
        </div>
}
export default About;
```

//Contact.js:

```
import React from 'react';

function Contact (){
return <address>
                You can find us here:<br />
```

```
            Unthinkable Solutions<br />
            9th Floor Sector 30 <br />
            Silokhera NH 9 Gurgaon (Haryana)
        </address>
}
export default Contact;
```

Now, let us include React Router components to the application:

- **BrowserRouter:**
  Add BrowserRouter aliased as Router to your app.js file in order to wrap all the other components. BrowserRouter is a parent component and can have only single child.

```
    class App extends Component {
    render() {
        return (
        <Router>
            <div className="App">
            </div>
        </Router>
            );
        }
    }
```

- **Link:**
  Let us now create links to our components. Link component uses the to prop to describe the location where the links should navigate to.

```
    <div className="App">
        <ul>
        <li>
            <Link to="/">Home</Link>
```

```
            </li>
            <li>
                <Link to="/about">About Us</Link>
            </li>
            <li>
                <Link to="/contact">Contact Us</Link>
            </li>
            </ul>
        </div>
```

Now, run your application on the local host and click on the links you created. You will notice the url changing according to the value in to props of the Link component.

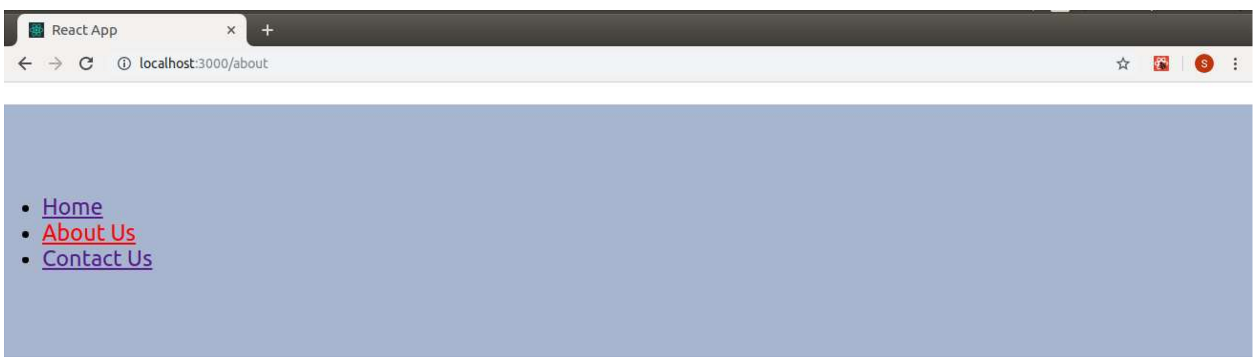

Fig 1.4 Routing

- **Route:**

Route component will now help us to establish the link between the component's UI and the URL. To include routes to the application, add the code given below to your app.js.

```
<Route exact path='/' component={Home}></Route>
<Route exact path='/about' component={About}></Route>
<Route exact path='/contact' component={Contact}></Route>
```

Let us now try to understand the props associated with the Route component.

1. **exact:** It is used to match the exact value with the URL. For Eg., exact path='/about' will only render the component if it exactly matches the path but if we remove exact from the syntax, then component will still be rendered even if the structure is like /about/10.
2. **path:** Path specifies a pathname we assign to our component.
3. **component:** It refers to the component which will render on matching the path.

- **Switch:**
  To render a single component, wrap all the routes inside the Switch Component.

```
<Switch>
        <Route exact path='/' component={Home}></Route>
        <Route exact path='/about' component={About}></Route>
        <Route exact path='/contact' component={Contact}></Route>
</Switch>
```

Switch groups together several routes, iterates over them and finds the first one that matches the path. Thereby, the corresponding component to the path is rendered.

After adding all the components here is our complete source code:

```
import React, { Component } from 'react';
import { BrowserRouter as Router, Route, Link, Switch } from 'react-router-dom';
import Home from './component/home';
import About from './component/about';
import Contact from './component/contact';
import './App.css';

class App extends Component {
render() {
        return (
```

```
        <Router>
            <div className="App">
                <ul className="App-header">
                <li>
                    <Link to="/">Home</Link>
                </li>
                <li>
                    <Link to="/about">About Us</Link>
                </li>
                <li>
                    <Link to="/contact">Contact Us</Link>
                </li>
                </ul>
                <Switch>
                <Route exact path='/' component={Home}></Route>
                <Route exact path='/about' component={About}></Route>
                <Route exact path='/contact' component={Contact}></Route>
                </Switch>
            </div>
        </Router>
    );
    }
    }
    export default App;
```

1.11. Redux

Redux is a predictable state container for JavaScript apps. As the application grows, it becomes difficult to keep it organized and maintain data flow. Redux solves this problem by managing the application's state with a single global object called Store. Redux fundamental principles help in maintaining consistency throughout your application, which makes debugging and testing easier.

More importantly, it gives you live code editing combined with a time-travelling debugger. It is flexible to go with any view layer such as React, Angular, Vue, etc.

Principles of Redux

Predictability of Redux is determined by three most important principles as given below −

- **Single Source of Truth**

The state of your whole application is stored in an object tree within a single store. As the whole application state is stored in a single tree, it makes debugging easy, and development faster.

- **State is Read-only**

The only way to change the state is to emit an action, an object describing what happened. This means nobody can directly change the state of your application.

- **Changes are made with pure functions**

To specify how the state tree is transformed by actions, you write pure reducers. A reducer is a central place where state modification takes place. Reducer is a function which takes state and action as arguments, and returns a newly updated state.

1.11.1 Installation

Run the following command in your command prompt to install Redux.

```
npm install --save redux
```

To use Redux with react application, you need to install an additional dependency as follows −

```
npm install --save react-redux
```

1.11.2 Core Concepts

Let us assume our application's state is described by a plain object called initialState which is as follows −

```
const initialState = {
  isLoading: false,
  items: [],
  hasError: false
};
```

Every piece of code in your application cannot change this state. To change the state, you need to dispatch an action.

What is an action?

An action is a plain object that describes the intention to cause change with a type property. It must have a type property which tells what type of action is being performed. The command for action is as follows −

```
return {
  type: 'ITEMS_REQUEST', //action type
  isLoading: true //payload information
}
```

Actions and states are held together by a function called Reducer. An action is dispatched with an intention to cause change. This change is performed by the reducer. Reducer is the only way to change states in Redux, making it more predictable, centralised and debuggable. A reducer function that handles the ‘ITEMS_REQUEST’ action is as follows −

```
const reducer = (state = initialState, action) => { //es6 arrow function
  switch (action.type) {
    case 'ITEMS_REQUEST':
      return Object.assign({}, state, {
        isLoading: action.isLoading
      })
    default:
      return state;
  }
}
```

Redux has a single store which holds the application state. If you want to split your code on the basis of data handling logic, you should start splitting your reducers instead of stores in Redux.

Redux components are as follows −

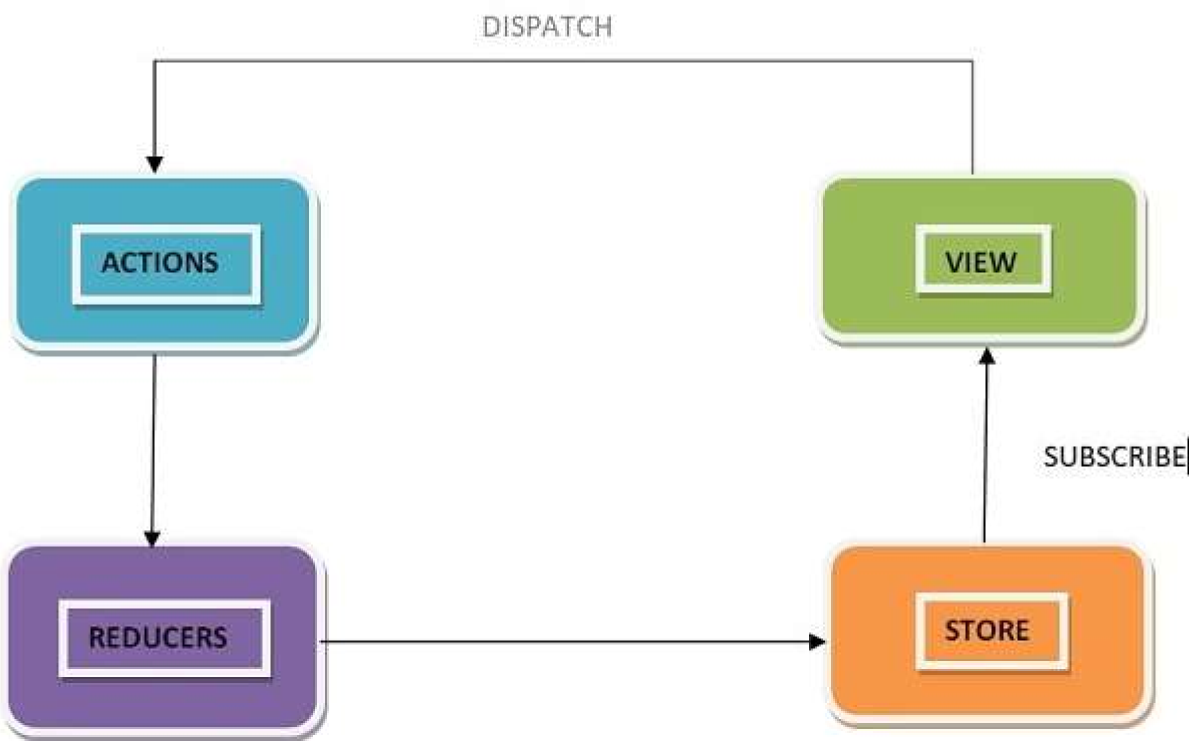

Fig 1.5 Redux Components

1.11.3 Data Flow

Redux follows the unidirectional data flow. It means that your application data will follow in one-way binding data flow. As the application grows & becomes complex, it is hard to reproduce issues and add new features if you have no control over the state of your application.

Redux reduces the complexity of the code, by enforcing the restriction on how and when state update can happen. This way, managing updated states is easy. We already know about the restrictions as the three principles of Redux. Following diagram will help you understand Redux data flow better −

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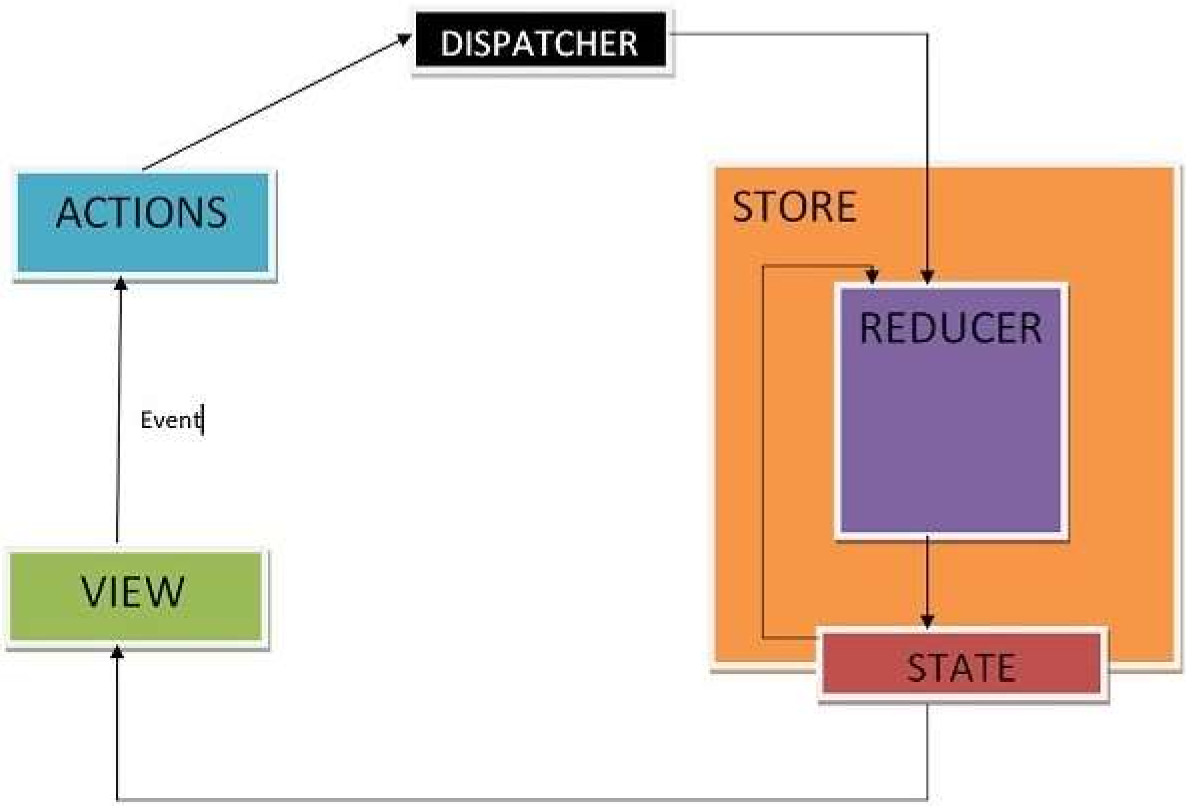

Fig 1.6 Data Flow

- An action is dispatched when a user interacts with the application.
- The root reducer function is called with the current state and the dispatched action. The root reducer may divide the task among smaller reducer functions, which ultimately returns a new state.
- The store notifies the view by executing their callback functions.
- The view can retrieve updated state and re-render again.

1.11.4 Store

A store is an immutable object tree in Redux. A store is a state container which holds the application's state. Redux can have only a single store in your application. Whenever a store is created in Redux, you need to specify the reducer.

Let us see how we can create a store using the createStore method from Redux. One need to import the createStore package from the Redux library that supports the store creation process as shown below −

import { createStore } from 'redux';

import reducer from './reducers/reducer'

const store = createStore(reducer);

A createStore function can have three arguments. The following is the syntax −

createStore(reducer, [preloadedState], [enhancer])

A reducer is a function that returns the next state of app. A preloadedState is an optional argument and is the initial state of your app. An enhancer is also an optional argument. It will help you enhance your store with third-party capabilities.

A store has three important methods as given below −

- **getState**
  It helps you retrieve the current state of your Redux store.

  The syntax for getState is as follows −

  store.getState()

- **dispatch**
  It allows you to dispatch an action to change a state in your application.

  The syntax for dispatch is as follows −

  store.dispatch({type:'ITEMS_REQUEST'})

- **subscribe**
  It helps you register a callback that Redux store will call when an action has been dispatched. As soon as the Redux state has been updated, the view will re-render automatically.

  The syntax for dispatch is as follows −

  store.subscribe(()=>{ console.log(store.getState());})

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Actions are the only source of information for the store as per Redux official documentation. It carries a payload of information from your application to store.

As discussed earlier, actions are plain JavaScript objects that must have a type attribute to indicate the type of action performed. It tells us what had happened. Types should be defined as string constants in your application as given below −

```
const ITEMS_REQUEST = 'ITEMS_REQUEST';
```

Apart from this type attribute, the structure of an action object is totally up to the developer. It is recommended to keep your action object as light as possible and pass only the necessary information.

To cause any change in the store, you need to dispatch an action first by using store.dispatch() function. The action object is as follows −

```
{ type: GET_ORDER_STATUS , payload: {orderId,userId } }
{ type: GET_WISHLIST_ITEMS, payload: userId }
```

Actions Creators

Action creators are the functions that encapsulate the process of creation of an action object. These functions simply return a plain Js object which is an action. It promotes writing clean code and helps to achieve reusability.

Let us learn about action creators which lets you dispatch an action, ‘ITEMS_REQUEST’ that requests for the product items list data from the server. Meanwhile, the isLoading state is made true in the reducer in ‘ITEMS_REQUEST’ action type to indicate that items are loading, and data is still not received from the server.

Initially, the isLoading state was false in the initialState object assuming nothing is loading. When data is received at browser, isLoading state will be returned as false in ‘ITEMS_REQUEST_SUCCESS’ action type in the corresponding reducer. This state can be used as a prop in react components to display loader/message on your page while the request for data is on. The action creator is as follows −

```
const ITEMS_REQUEST = ‘ITEMS_REQUEST’ ;
const ITEMS_REQUEST_SUCCESS = ‘ITEMS_REQUEST_SUCCESS’ ;
export function itemsRequest(bool,startIndex,endIndex) {
```

```
    let payload = {
      isLoading: bool,
      startIndex,
      endIndex
    }
    return {
      type: ITEMS_REQUEST,
      payload
    }
}
export function itemsRequestSuccess(bool) {
    return {
      type: ITEMS_REQUEST_SUCCESS,
      isLoading: bool,
    }
}
```

To invoke a dispatch function, you need to pass action as an argument to the dispatch function.

```
dispatch(itemsRequest(true,1, 20));
dispatch(itemsRequestSuccess(false));
```

You can dispatch an action by directly using store.dispatch(). However, it is more likely that you access it with the react-Redux helper method called connect(). You can also use bindActionCreators() method to bind many action creators with dispatch functions.

1.11.5 Pure Functions

A function is a process which takes inputs called arguments, and produces some output known as return value. A function is called pure if it abides by the following rules −

- A function returns the same result for the same arguments.

- Its evaluation has no side effects, i.e., it does not alter input data.
- No mutation of local & global variables.
- It does not depend on the external state like a global variable.

Let us take the example of a function which returns two times of the value passed as an input to the function. In general, it is written as, f(x) => x*2. If a function is called with an argument value 2, then the output would be 4, f(2) => 4.

Let us write the definition of the function in JavaScript as shown below −

```
const double = x => x*2; // es6 arrow function
console.log(double(2));  // 4
```

Here, double is a pure function.

As per the three principles in Redux, changes must be made by a pure function, i.e., reducer in Redux. Now, a question arises as to why a reducer must be a pure function.

Suppose, you want to dispatch an action whose type is 'ADD_TO_CART_SUCCESS' to add an item to your shopping cart application by clicking the add to cart button.

Let us assume the reducer is adding an item to your cart as given below −

```
const initialState = {
  isAddedToCart: false;
}
const addToCartReducer = (state = initialState, action) => { //es6 arrow function
  switch (action.type) {
    case 'ADD_TO_CART_SUCCESS' :
      state.isAddedToCart = !state.isAddedToCart; //original object altered
      return state;
    default:
      return state;
  }
}
export default addToCartReducer ;
```

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Let us suppose, isAddedToCart is a property on state object that allows you to decide when to disable the ‘add to cart’ button for the item by returning a Boolean value ‘true or false’. This prevents user to add same product multiple times. Now, instead of returning a new object, we are mutating isAddedToCart prop on the state like above. Now if we try to add an item to cart, nothing happens. Add to cart button will not get disabled.

The reason for this behaviour is as follows −

Redux compares old and new objects by the memory location of both the objects. It expects a new object from the reducer if any change has happened. And it also expects to get the old object back if no change occurs. In this case, it is the same. Due to this reason, Redux assumes that nothing has happened.

So, it is necessary for a reducer to be a pure function in Redux. The following is a way to write it without mutation −

```
const initialState = {
  isAddedToCart: false;
}
const addToCartReducer = (state = initialState, action) => { //es6 arrow function
  switch (action.type) {
    case 'ADD_TO_CART_SUCCESS' :
      return {
        ...state,
        isAddedToCart: !state.isAddedToCart
      }
    default:
      return state;
  }
}
export default addToCartReducer;
```

1.11.6 Reducers

Reducers are a pure function in Redux. Pure functions are predictable. Reducers are the only way to change states in Redux. It is the only place where you can write logic and calculations. Reducer function will accept the previous state of the app and action being dispatched, calculate the next state and returns the new object.

The following few things should never be performed inside the reducer −

- Mutation of functions arguments
- API calls & routing logic
- Calling non-pure function e.g. Math.random()

The following is the syntax of a reducer −

```
(state,action) => newState
```

Let us continue the example of showing the list of product items on a web page, discussed in the action creators module. Let us see below how to write its reducer.

```
const initialState = {
  isLoading: false,
  items: []
};
const reducer = (state = initialState, action) => {
  switch (action.type) {
    case 'ITEMS_REQUEST':
      return Object.assign({}, state, {
        isLoading: action.payload.isLoading
      })
    case ‘ITEMS_REQUEST_SUCCESS':
      return Object.assign({}, state, {
        items: state.items.concat(action.items),
        isLoading: action.isLoading
      })
    default:
      return state;
  }
}
```

```
export default reducer;
```

Firstly, if you do not set state to ‘initialState’, Redux calls reducer with the undefined state. In this code example, concat() function of JavaScript is used in ‘ITEMS_REQUEST_SUCCESS', which does not change the existing array; instead returns a new array.

In this way, you can avoid mutation of the state. Never write directly to the state. In 'ITEMS_REQUEST', we have to set the state value from the action received.

It is already discussed that we can write our logic in a reducer and can split it on the logical data basis. Let us see how we can split reducers and combine them together as root reducer when dealing with a large application.

Suppose, we want to design a web page where a user can access product order status and see wishlist information. We can separate the logic in different reducers files, and make them work independently. Let us assume that GET_ORDER_STATUS action is dispatched to get the status of order corresponding to some order id and user id.

/reducer/orderStatusReducer.js:

```
import { GET_ORDER_STATUS } from ‘../constants/appConstant’;
export default function (state = {} , action) {
  switch(action.type) {
    case GET_ORDER_STATUS:
      return { ...state, orderStatusData: action.payload.orderStatus };
    default:
      return state;
  }
}
```

Similarly, assume GET_WISHLIST_ITEMS action is dispatched to get the user’s wishlist information respective of a user.

/reducer/getWishlistDataReducer.js:

```
import { GET_WISHLIST_ITEMS } from ‘../constants/appConstant’;
export default function (state = {}, action) {
  switch(action.type) {
    case GET_WISHLIST_ITEMS:
```

```
        return { ...state, wishlistData: action.payload.wishlistData };
      default:
        return state;
    }
  }
```

Now, we can combine both reducers by using Redux combineReducers utility. The combineReducers generate a function which returns an object whose values are different reducer functions. You can import all the reducers in index reducer file and combine them together as an object with their respective names.

/reducer/index.js:

```
import { combineReducers } from 'redux';
import OrderStatusReducer from './orderStatusReducer';
import GetWishlistDataReducer from './getWishlistDataReducer';

const rootReducer = combineReducers ({
  orderStatusReducer: OrderStatusReducer,
  getWishlistDataReducer: GetWishlistDataReducer
});
export default rootReducer;
```

Now, you can pass this rootReducer to the createStore method as follows −

```
const store = createStore(rootReducer);
```

1.11.7 Integrating with React

In the previous chapters, we have learnt what is Redux and how it works. Let us now check the integration of the view part with Redux. You can add any view layer to Redux. We will also discuss the React library and Redux.

Let us say if various react components need to display the same data in different ways without passing it as a prop to all the components from top-level component to the way down. It would be ideal to store it outside the react components. Because it helps in faster data retrieval as you need not pass data all the way down to different components.

Let us discuss how it is possible with Redux. Redux provides the react-redux package to bind react components with two utilities as given below −

- Provider
- Connect

Provider makes the store available to the rest of the application. Connect function helps the react component to connect to the store, responding to each change occurring in the store's state.

Let us have a look at the root index.js file which creates a store and uses a provider that enables the store to the rest of the app in a react-redux app.

```
import React from 'react'
import { render } from 'react-dom'
import { Provider } from 'react-redux'
import { createStore, applyMiddleware } from 'redux';
import reducer from './reducers/reducer'
import thunk from 'redux-thunk';
import App from './components/app'
import './index.css';

const store = createStore(
  reducer,
  window.__REDUX_DEVTOOLS_EXTENSION__ && window.__REDUX_DEVTOOLS_EXTENSION__(),
  applyMiddleware(thunk)
)
render(
  <Provider store = {store}>
    <App />
  </Provider>,
  document.getElementById('root')
)
```

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Whenever a change occurs in a react-redux app, mapStateToProps() is called. In this function, we exactly specify which state we need to provide to our react component.

With the help of connect() function explained below, we are connecting these app's state to the react component. Connect() is a high order function which takes component as a parameter. It performs certain operations and returns a new component with correct data which we finally exported.

With the help of mapStateToProps(), we provide these store states as prop to our react component. This code can be wrapped in a container component. The motive is to separate concerns like data fetching, rendering concern and reusability.

```
import { connect } from 'react-redux'
import Listing from '../components/listing/Listing' //react component
import makeApiCall from '../services/services' //component to make api call

const mapStateToProps = (state) => {
  return {
    items: state.items,
    isLoading: state.isLoading
  };
};
const mapDispatchToProps = (dispatch) => {
  return {
    fetchData: () => dispatch(makeApiCall())
  };
};
export default connect(mapStateToProps, mapDispatchToProps)(Listing);
```

The definition of a component to make an api call in services.js file is as follows −

```
import axios from 'axios'
import { itemsLoading, itemsFetchDataSuccess } from '../actions/actions'
```

```
export default function makeApiCall() {
  return (dispatch) => {
    dispatch(itemsLoading(true));
    axios.get('http://api.tvmaze.com/shows')
    .then((response) => {
      if (response.status !== 200) {
        throw Error(response.statusText);
      }
      dispatch(itemsLoading(false));
      return response;
    })
    .then((response) => dispatch(itemsFetchDataSuccess(response.data)))
  };
}
```

mapDispatchToProps() receives dispatch function as a parameter and returns you callback props as plain objects that you pass to your react component.

Here, you can access fetchData as a prop in your react listing component, which dispatches an action to make an API call. mapDispatchToProps() is used to dispatch an action to store. In react-redux, components cannot access the store directly. The only way is to use connect().

Let us understand how the react-redux works through the below diagram −

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Fig 1.7

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Chapter 2-
PROJECT ANALYSIS

2.1 What is supportSME

SupportSME Community Inc. has launched a marketplace platform to help small businesses mitigate potentially catastrophic effects of coronavirus-related closures, lockdowns and other restrictions. According to a new survey, one in three businesses in Canada say that they cannot survive the current coronavirus pandemic conditions for more than a month. According to the Canadian Federation of Independent Business, 60 percent of small businesses have seen a significant drop in sales, with more than a third reporting a reduction greater than 75 percent. In these uncertain and chaotic times, the SupportSME platform targets all small and medium businesses including restaurants, spas, beauty salons, barber's shops, dental offices, physiotherapy/massage clinics, fitness centers, shops, and arts and entertainment venues that are directly or indirectly dependent on free movement of buyers arriving in-person to physical business locations. The platform provides a "natural" community-based financing solution to help businesses meet their liquidity and operating expense requirements by channeling immediately available cash funds from buyers who are willing to support their favorite service providers now in lieu of the services delivered later. The governments of all levels may benefit from the platform by leveraging it to channel available consumer cash in a form of pent-up demand for small business products and services instead of directly subsidizing business operational expenses during the COVID-19 economic downturn. Supportsme's marketplace platform allows local suppliers to list their businesses and offer services by issuing certificates. Customers will be able to purchase these certificates during the restrictions, making the funds immediately available for the businesses, and redeem them after the restrictions are lifted at the issuer-specified premium.

2.2 Technology Stack:-

- **Frontend:-** ReactJs for web App , react native for mobile app.
- **Backend:-** NodeJs.
- **DataBase:-** Postgresql
- **Other Technologies:-** AWS Elasticsearch, S3 bucket, Microservices Architecture

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2.3 Features Of Project:-

Admin Portal:-

- SignUp
- SignIn
- Adding Categories
- Adding Certificate Plans.
- Showing Business List
- Verifying / Reject Business
- Giving the default amount to businesses to publish certificates.

Business portal:-

- SignUp
- SignIn
- OnBoard Business
- View Profile
- Edit Profile
- Business Verification
- Create and Publish Certificates with his preferred offer.
- Redeem Certificate
- View Certificate History
- View Donation History
- Onboard multiple business
- Displaying Business Listing
- Edit Business

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Customer portal:-

- SignUp
- SignIn
- OnBoard Customer.
- Edit profile
- Display of All Businesses with their certificates.
- Display of Nearby Businesses.
- Purchase Certificate
- Checkout Payment
- Showing Purchase History
- Make Donation
- Showing Donation list
- Showing Top Donors
- Showing Trending Business
- Giving Rating and Feedback to business
- Displaying Feedback List

2.4 Hardware Configuration

Table 2.1 Hardware configuration

RAM	8 GB
Processor	Intel® Core™ i5-8265U CPU
Clockspeed	1.60GHz
No of cores	8
OS Type	64 bit

Harddrive	251.0 GB

2.5 Software Configuration

Table 2.2 Software configuration

Package Manager	npm
Architecture	create-react-app
Editor	VS Code
Repository	Bitbucket
OS	Linux

2.6 Roles & Responsibilities

- UI Designing of multiple Components.
- API Integrations.
- Business DashBoard.
- Customer Purchasing Certificate.
- Making reusable Components.
- Adding Multiple Business.
- Certificates Redemption.
- Integrating Payment Checkout
- Solving UAT Issues.

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Chapter- 3

RESULTS AND DISCUSSIONS

3.1 Admin portal:-

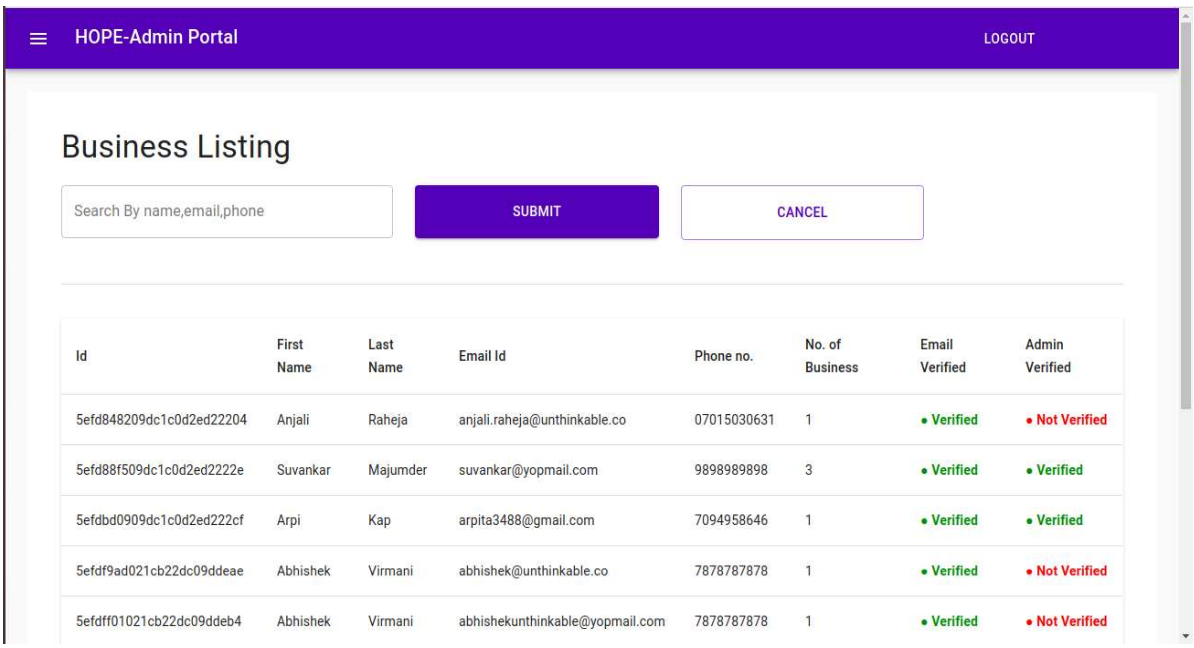

Fig 3.1:- Business List

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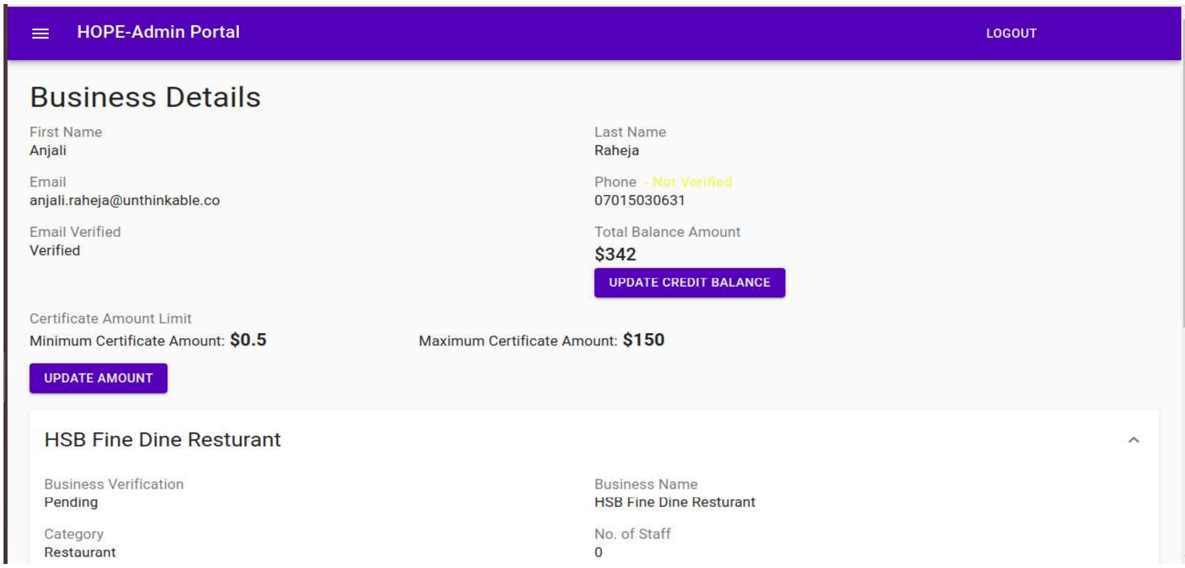

Fig 3.2:- Business Details

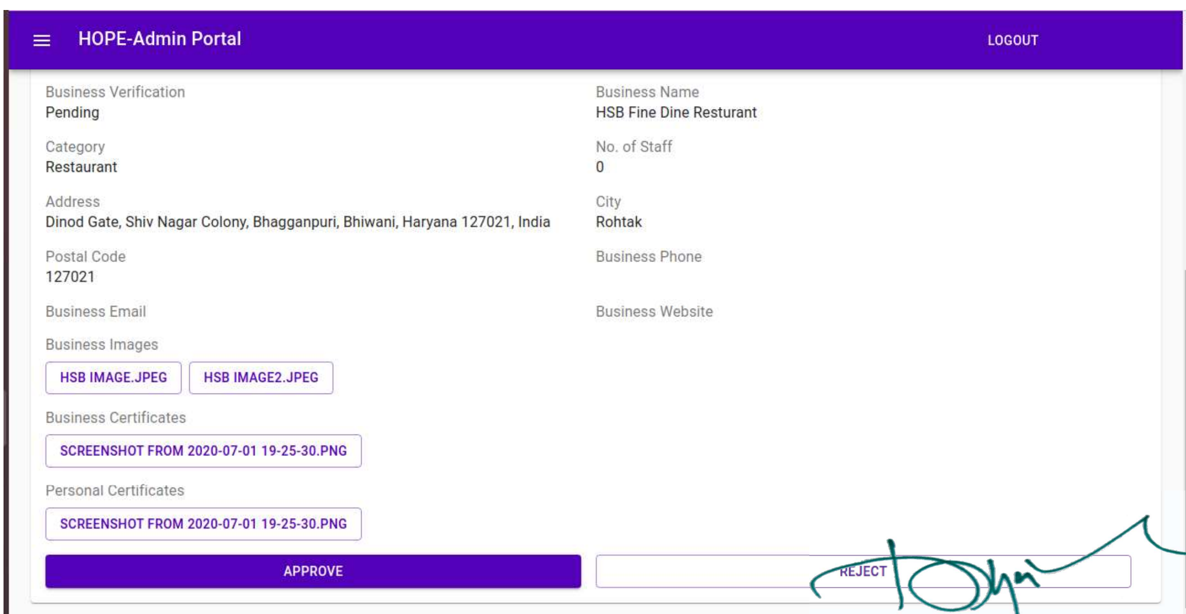

Fig 3.3:- Business Approve/Reject

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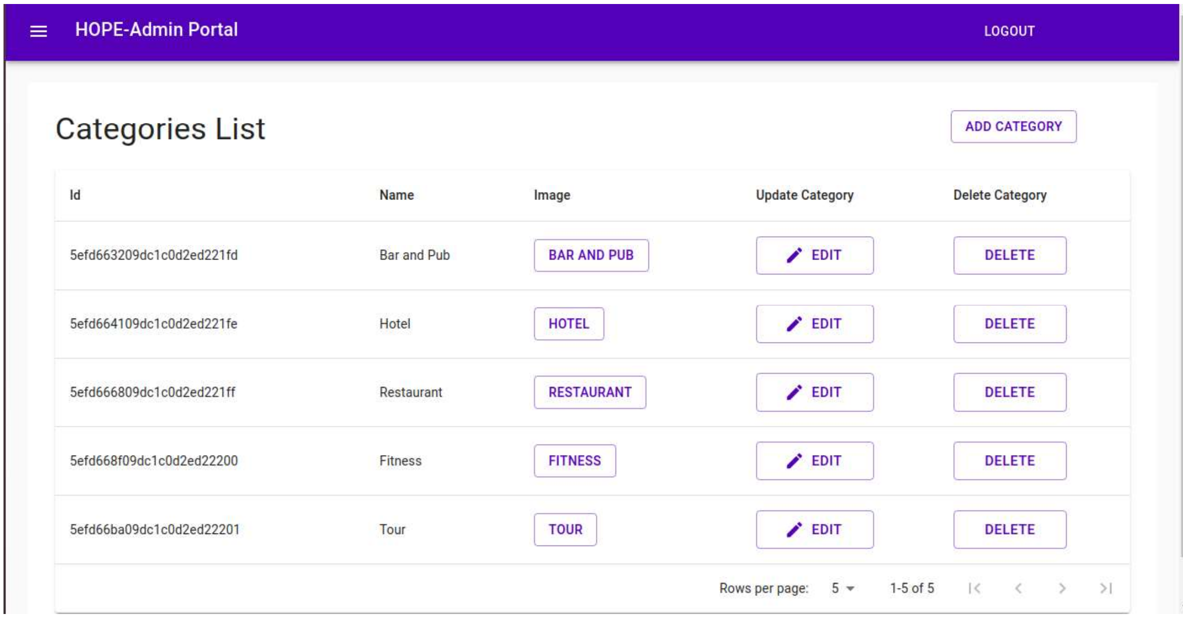

Fig 3.4:- category List

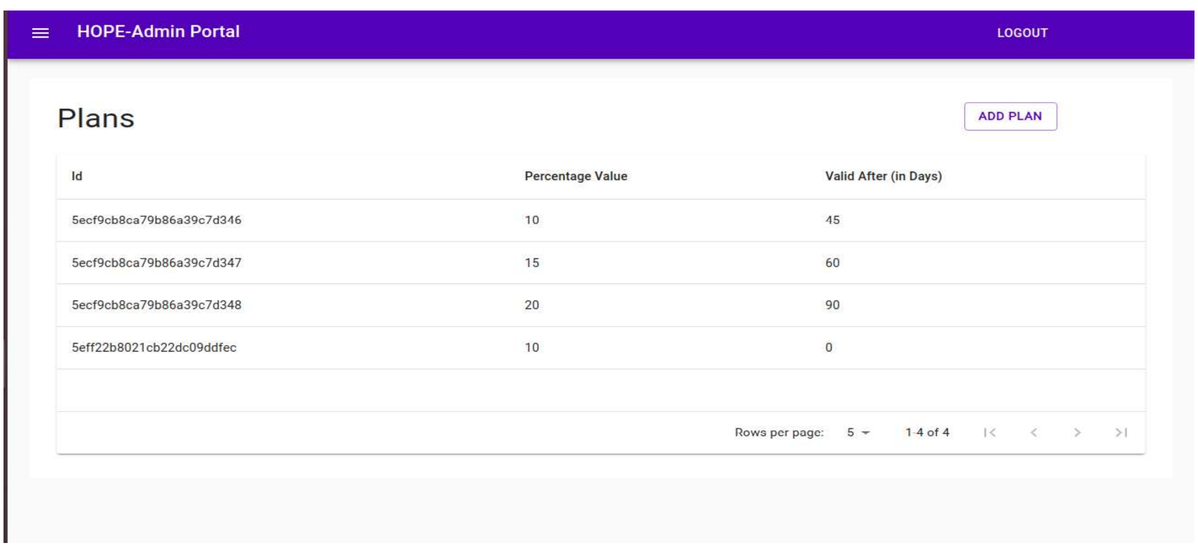

Fig 3.5:- Certificates Issuing Plans

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3.2 Business portal:-

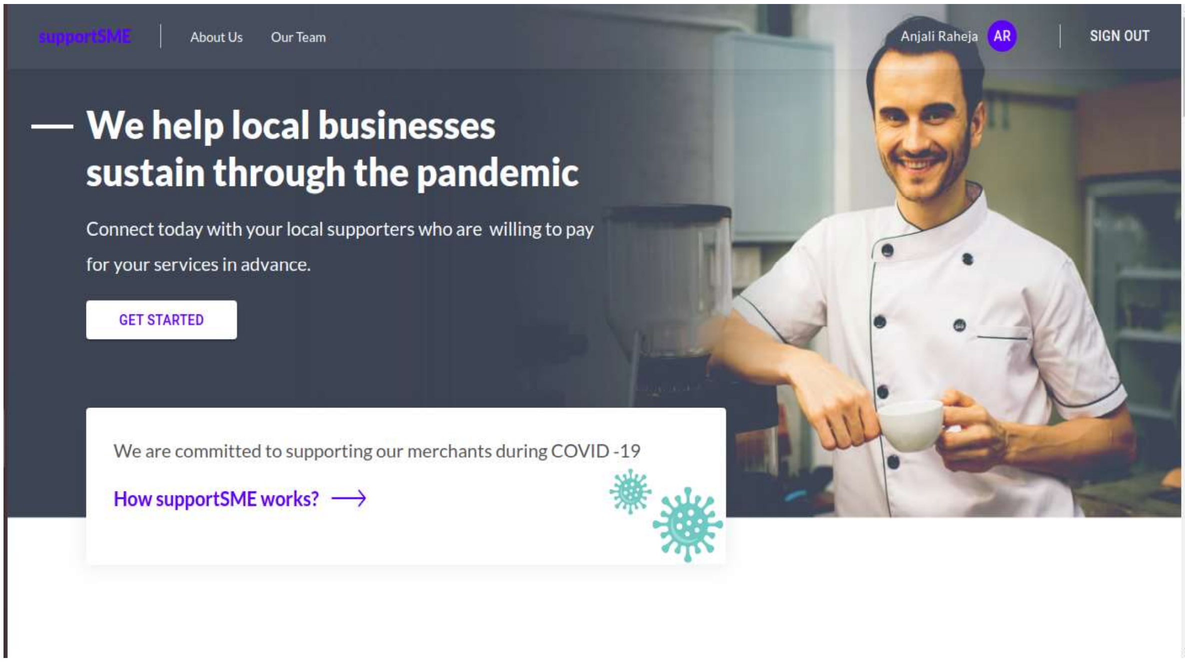

Fig 3.6:- Business Home Page

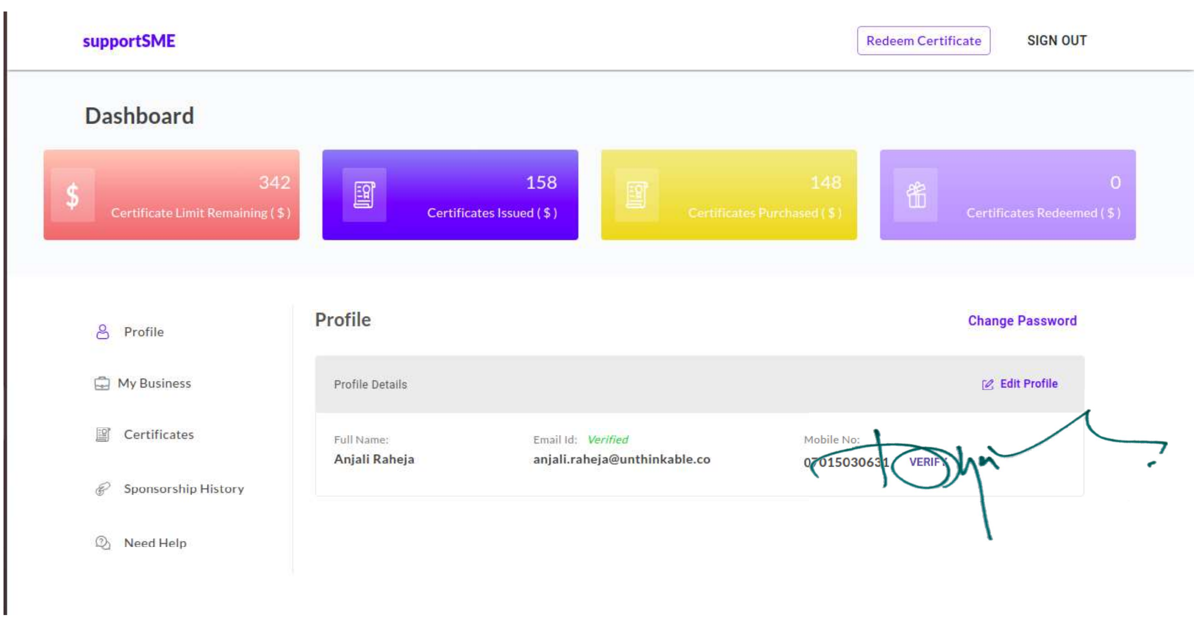

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Fig 3.7:- Business Profile

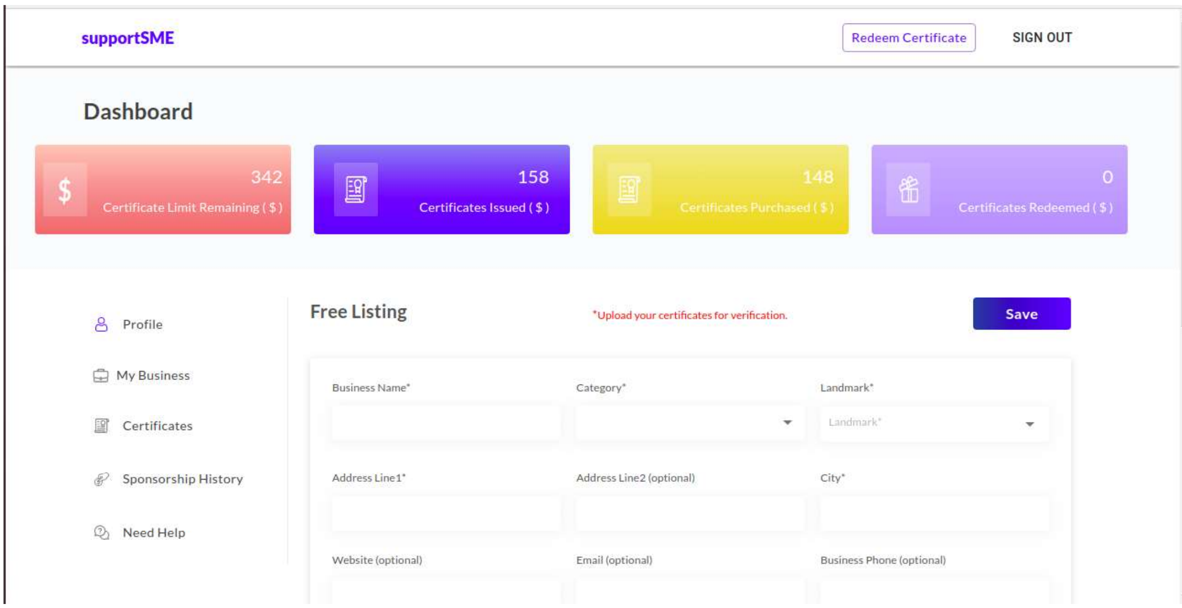

Fig 3.8:- Edit Business

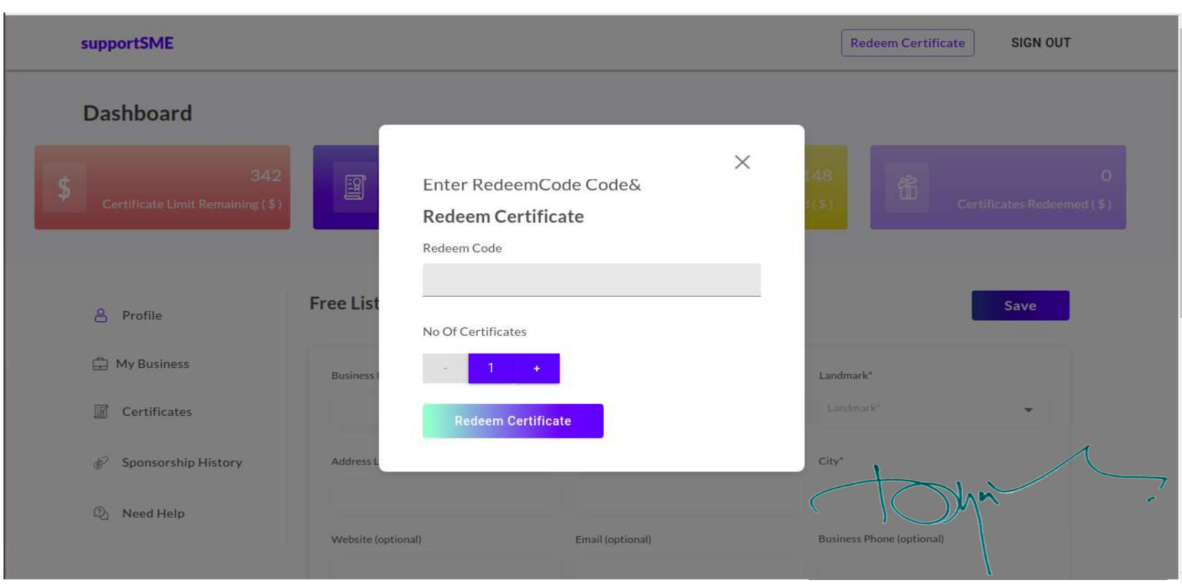

Fig 3.9:- Redeem Certificate

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3.3 Customer portal:-

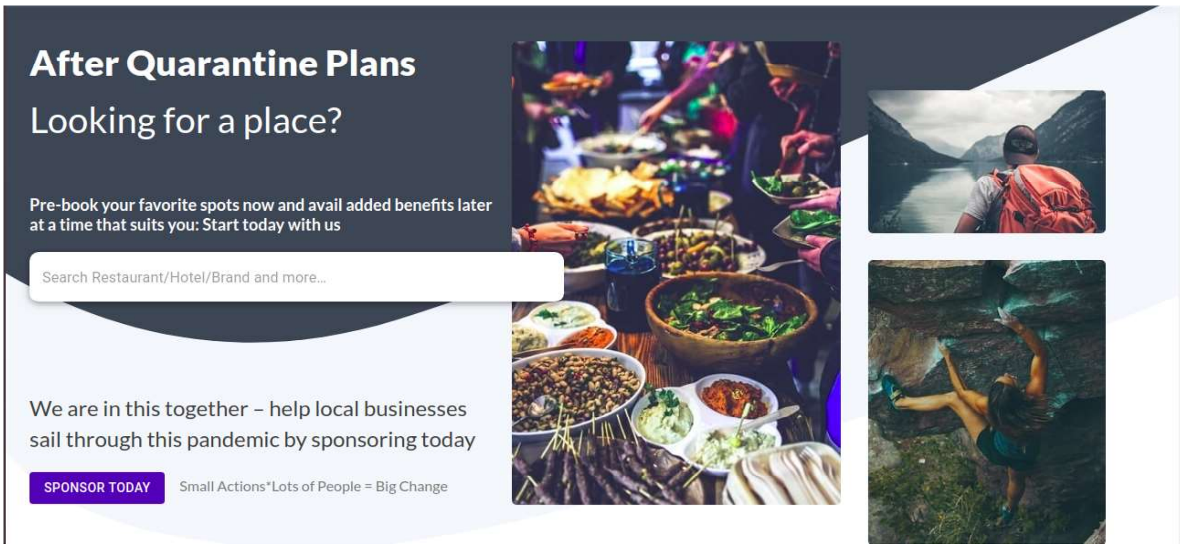

Fig 3.10:- Customer Home Page

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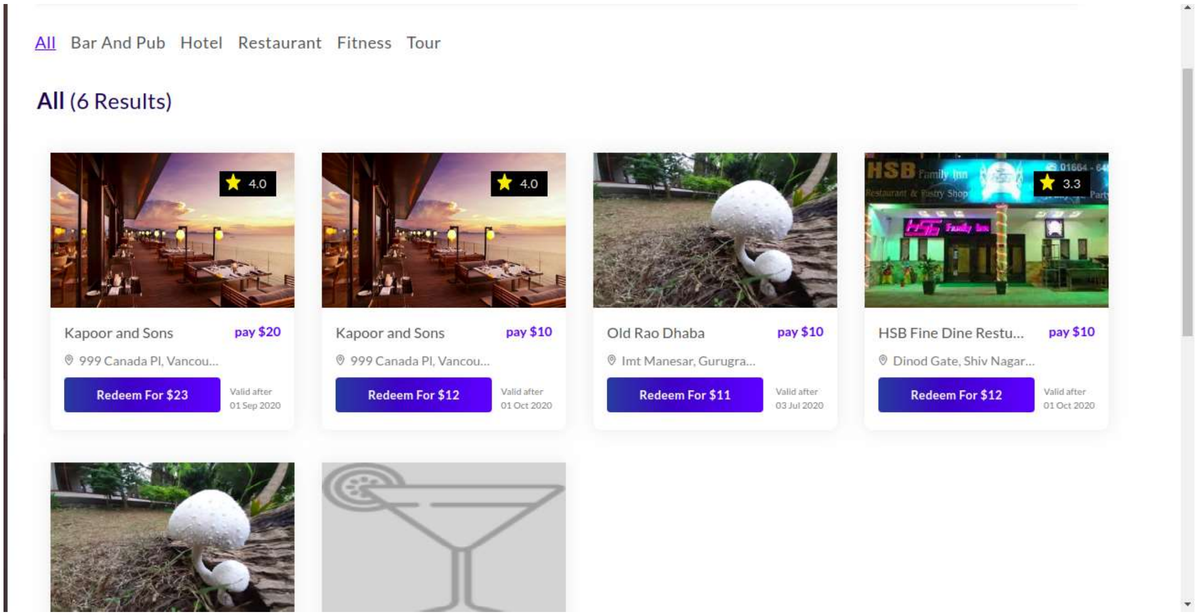

Fig 3.11:- Displaying Available Certificates

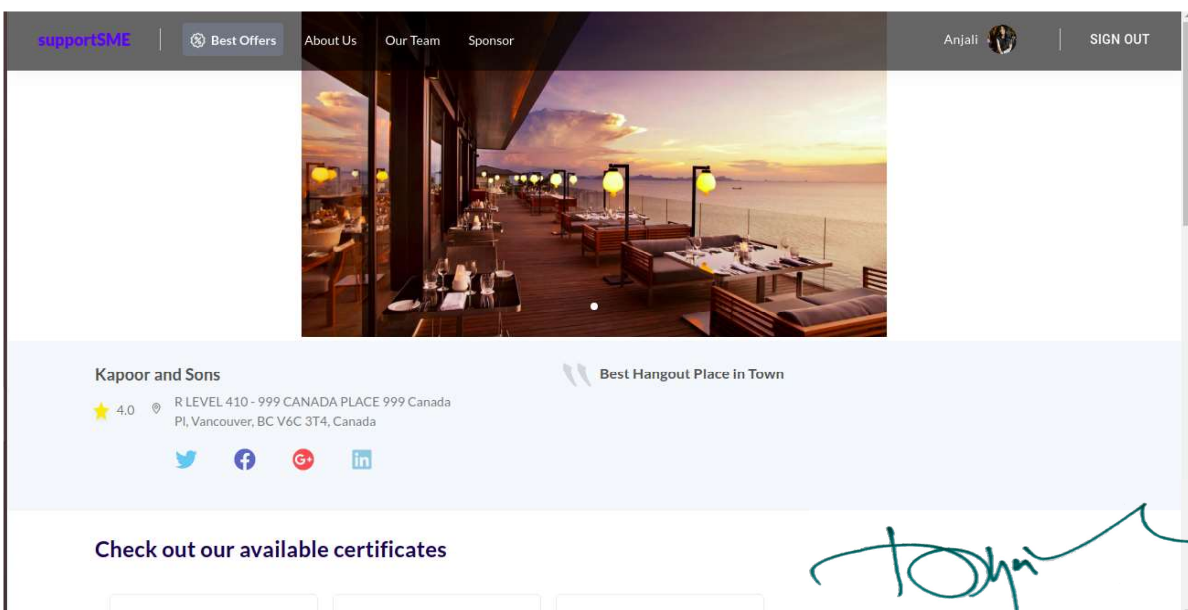

Fig 3.12:- Business Detail

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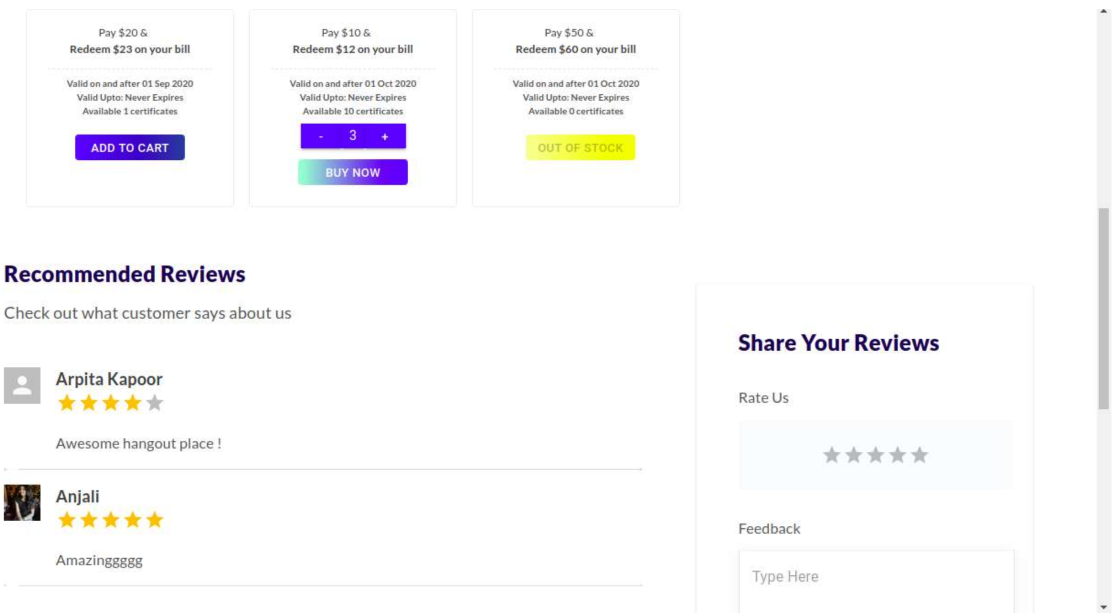

Fig 3.13:- Purchasing Certificate

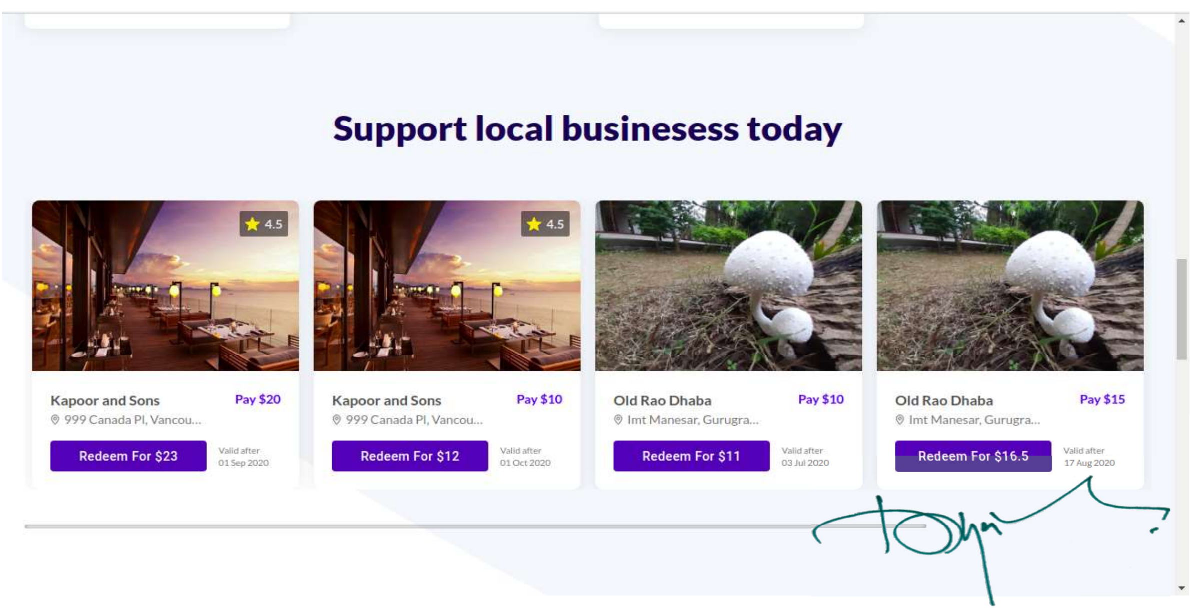

Fig 3.14:- Certificates on Home Screen

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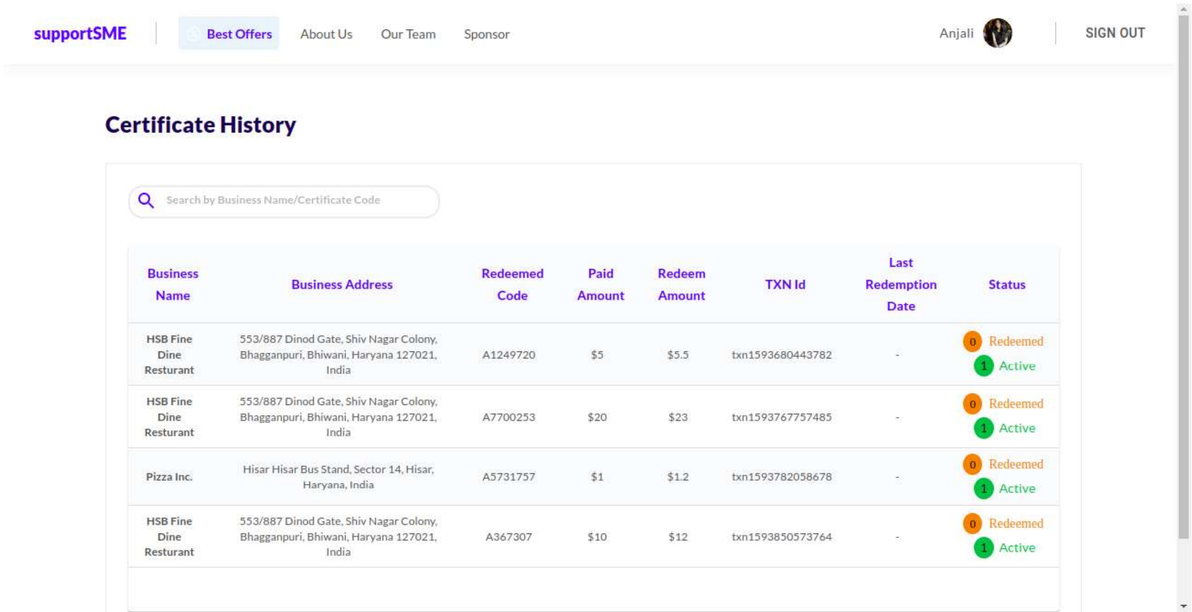

Fig 3.15:- Customer Purchase History

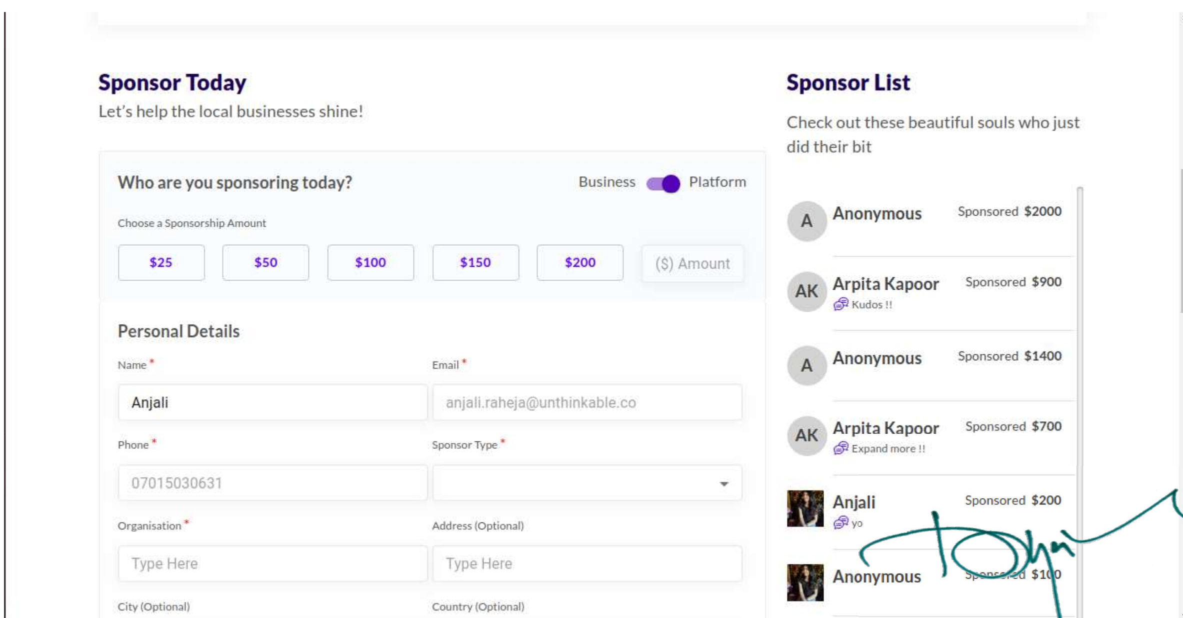

Fig 3.16:- Donation Form and Donor List

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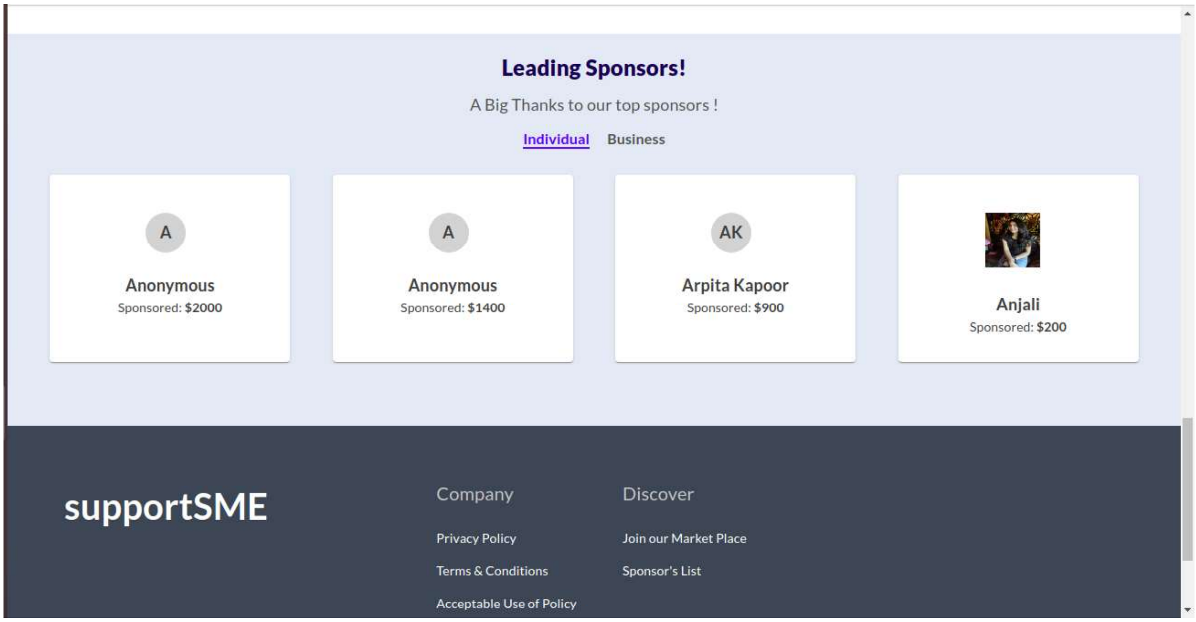

Fig 3.17:- Top Donors

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Chapter- 4

CONCLUSION AND FUTURE SCOPE

4.1 Present Scope

In today's digital world almost every system is getting computerized and proceeds very fast execution. Using a fast way computerized system for manipulating the data related to the project saves time, papers and minimum power which will further help in providing better services to the society along with providing social distancing among people in this global pandemic and helping various businesses financially. This E-commerce system provides the better facilities that totally fulfill the needs of the end user. That user can operate easily and conveniently.

4.2 Future Scope:

The system development is so flexible that it can be extended to include other features and it easily extended. Without any problem which will be of great benefit. Every businessman can utilize this for extending his business. This can be converted into a totally different paradigm for online shopping by adding a little php and bootstrap code. This application can be easily implemented under various situations. We can add new features as and when we require. Reusability is possible as and when require in this application. There is flexibility in all the modules.

4.2.1 Software Scope

- **Extensibility:** This software is extendable in ways that its original developers may not expect. The following principles enhances extensibility like hide data structure, avoid traversing multiple links or methods, avoid case statements on object type and distinguish public and private operations.

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- **Reusability:** Reusability is possible as and when require in this application. We can update it next version. Reusable software reduces design, coding and testing cost by amortizing effort over several designs. Reducing the amount of code also simplifies understanding, which increases the likelihood that the code is correct. We follow up both types of reusability: Sharing of newly written code within a project and reuse of previously written code on new projects.

- **Understandability**: A method is understandable if someone other than the creator of the method can understand the code (as well as the creator after a time lapse). We have used a method, which is small and coherent, to accomplish this.

- **Cost-effectiveness**: When the cost is within the budget and is completed within a given time period then the project is termed as most cost effective. It is desirable to aim for a system with a minimum cost subject to the condition that it must satisfy the entire requirement. Scope of this document is to put down the requirements, clearly identifying the information needed by the user, the source of the information and outputs expected from the system.

4.3 Conclusion:

From a proper analysis of positive points and constraints on the component, it can be safely concluded that the product is a highly efficient GUI based component. This application is working properly and meeting to all user requirements. This component can be easily plugged in many other systems. The SupportSME platform targets all small and medium businesses including restaurants, spas, beauty salons, clinics, fitness centers, shops, and arts and entertainment venues that are directly or indirectly dependent on free movement of buyers arriving in-person to physical business locations. The platform provides a "natural" community-based financing solution to help businesses meet their liquidity and operating expense requirements by channeling immediately available cash funds from buyers who are willing to support their favorite service providers now in lieu of the services delivered later. Supportsme's marketplace platform allows local suppliers to list their businesses and offer services by issuing certificates. Customers will be able to purchase these certificates during the restrictions, making the funds immediately available for the businesses, and redeem them after the restrictions are lifted at the issuer-specified premium and we have successfully onboarded 15 businesses on our platform and waiting to see our platform getting enhanced.

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