EFFECTS OF PERMEABILITY REDUCING ADMIXTURE ON THE PROPERTIES OF BINARY CEMENTITIOUS MATRIX CONCRETE

BY

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Declaration

I declare that the work in the Dissertation report entitled "EFFECTS OF PERMEABILITY REDUCING ADMIXTURE ON THE PROPERTIES OF BINARY CEMENTITIOUS MATRIX CONCRETE" has been done by me in the Department of Building, under the supervision of Prof. O. G. Okoli and Dr D. D. Danwata. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation report was previously presented for another degree at any university.

_____ _____ _____

Sanusi Abdul Mutakabbir Signature Date

(P14EVBD8115)

Certification

This is to certify that this dissertation entitled ”EFFECTS OF PERMEABILITY REDUCING ADMIXTURE ON THE PROPERTIES OF BINARY CEMENTITIOUS MATRIX CONCRETE ” by Sanusi Abdul Mutakabir, has been duly supervised, corrected, hereby approved and meets the regulations governing the award of the Masters Degree (MSc) in Construction Technology, Department of Building, Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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Dedication

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Abstract

Conventional concrete is porous and the network of pores allow the passage of harmful substances through the concrete internal structure thereby causing damage to the internal structure of the concrete and which resulted in consequential loss of concrete durability. Efforts have been made to protect concrete but problem still exist such as in adequate protection and high cost of protection in view of the drawbacks this research work investigates effects of permeability reducing admixture on thedurability properties of binary cementitious matrix concrete.A total of 342 sample specimens of 100mmx100mmx100mm cubes were cast with the following connotations, 100% cement, 2% PRA, 10% C S A, 15% C S A, 2% PRA + 10% C S A and 2% PRA + 15% C S A, The permeability reducing admixture was purchased from Market, The coconut shell was pre ashed in an open air for one hour and was allowed to cool then calcined at temperature of 800^0C in a kiln for 4hours and was allowed to cool to room temperature before it's removal from the kiln, the Coconut Shell ash was used to replace cement at 10% and 15% replacement. 90 specimens were tested for compressive strength, 90 specimens were tested for compressive strength in aggressive environment ($MgSO_4$), 162 specimens were tested for water absorption capacity, sorptivity and abrasion resistance. The plain concrete, the plain concrete modified with PRA, Blended concrete and Blended concrete modified with PRA were cured in water and their respective properties were evaluated at 14, 28, 56, 90 and 180 days curing period respectively. The control sample had the highest compressive strength test of 33.85N/mm^2 at 28 days, however at 56 days all the samples exceeded the control in strength except 15% CSA that had 32.95 N/mm^2, at 90 and 180 days all the samples exceeded the control, Ninety samples were immersed in aggressive media i.e exposure to 2.5% magnesium sulphate solution, compressive strength was used to determine the severity of the effects of $MgSO_4$on

concrete samples, at 90 days all the samples loss strength but the loss was more severe in control sample, the control loss 17.7% of its strength, 2% PRA loss 1.6% , 10% CSA loss 3.8% at 90 days, 15% CSA loss 4.75% at 90 days, 2% PRA+ 10% CSA loss 1.0% and 1.3% of its strength at 90 days, 2% PRA+ 15% CSA loss 0.76% at 90 days, at 180 days it was discovered the effect was more severe on control samples and less severe on all other samples, absorption capacity test revealed that the PRA modified Pozzolana blended cement concrete had the lowest water absorption of 0.87% at 90 days, the PRA modified Pozzolana blended cement concrete had the lowest sorptivity of 0.62 at 90 days. Based on the above findings it was concluded thatPRA modified pozzolana blended cement concrete is most durable, then it was recommended that it could be used for concrete production in soil that its Magnessiumsulphate content is high and where concrete may be subjected to water ingression.

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List of Abbreviations

ACI	American Concrete Institute
AM	Ampere
ASTM	American Society for Testing Materials
B.D	Bulk Density
BS	British Standard
BS EN	British Standard Engineering Norm
CCA	Corn Cob Ash
C.F	Compacting Factor
CH	Calcium Hydrate
CSH	Calcium Silicate Hydrate
CSA	Coconut Shell Ash
F.A	Fly ash
F.M	Fineness Modulus
FST	Final Setting Time
GGBS	Ground Granulated Blast Furnace Slag
IST	Initial Setting Time
ITZ	Interfacial Transition Zone
$MgSO_4$	MagnessiumSulphate
NPCT	National Pavement Concrete Technology
OPC	Ordinary Portland Cement
PCC	Portland Cement Concrete
PRA	Permeability Reducing Admixture

RHA	Rice Husk Ash
SCM	Supplementary Cementitious Materials
S.F	Silica Fume
S.G	Specific Gravity

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Waste is one of the major threat facing present generation (Safiuddin, Zamin, Salam, Islam, and Hashim, 2010). Large quantities of waste materials and by-products are generated from manufacturing processes, agricultural activities, service industries, construction activities and municipal solid wastes, solid waste management has become one of the major environmental concerns in the world, with the increasing awareness about the environment, scarcity of landfill space and due to its ever increasing cost, and strict environmental control laws in some countries there hasbeen a growing emphasis on the utilisation of waste materials and by-products as construction materials, especially concrete (Patricija, Aleksandra, Korjakson, and Stokeman, 2012).

According to Dahiru(2007) Construction activities consumes approximately 40% natural resources and 40% waste is generated as a result of such development, that is why two of the basic actions towards sustainability highlighted in Rio generio in Brazil agenda 21 are minimization of total waste generation and maximization of environmental sound waste management and recycling. Remedial measures were outlined to solve the problems of waste prominent among them is what is popularly called Three Rs – Reduce, Re use and Recycle (Zongji, 2011).

Recently, the interest for utilization of waste materials in cement or concrete has increased significantly (Karim, Zain, Jamil, Lai and Islam, 2012). In advanced countries, partial

replacement of cement with pozzolanic industrial wastes is well documented and recommended(Manaseh, 2010). In the developing countries, the most common and readily available materials that are used to partially replace cement without economic implications are agro based wastes, with inherent multiple benefits (Manaseh, 2010). One of the locally available agricultural wastes that satisfies the requirement of sustainable development and, which can be used as partial replacement of Ordinary Portland Cement is Coconut Shell Ash (CSA).Coconut Shell ash essentially contains amorphous silica 37.97%, Al_2O_3 24.12%, $Fe2O_3$ 15.48%, Cao 4.98%(Vignesh, Aruna, Manohari, and Maria, 2014). Supplementary cementitious materials reduce lime content in hydrated Portland cements and replace it with pore filling cement hydrates, which are known to improve the ultimate strength, impermeability and concrete resistance to chemical attack (Shetty, 2009).

Pozzolans are materials that consist predominantly of silica and aluminaand are able to combine with ordinary Portland cement in the presence of water to produce new reaction products exhibiting a binding character. Therefore, they are widely used as an additive in cement in which portlandite is a major hydration product. Their widespread use can be explained both by their beneficial effect on the properties of concrete as well as by the economic and ecologic advantage of their use (Martens*etal*., 2009).Some of the pozzolanas are natural, others are by-products (artificial) and both contains silica in amorphous form and will react with calcium hydroxide ($CaOH_2$) to form more cementitious calcium silicate hydrate (C S H) and contribute to the concrete strength (Habeeb and Mahmud, 2010). The improvement in the properties of concrete with blended cements is attributed to the pozzolanic reactions taking place between the oxides

originating from the supplement material and the hydration products of ordinary portland cement (Khan, 2010).

Blended cement is defined as Portland cement containing other finely dividedparticles in different but well-defined proportions (Salaudeen and Leeyee, 2008). Mostrecently blended cement based on industrial and agricultural waste, are well known fortheir improved long-term strength and durability. The blending agents are such as fly ash (FA), ground granulated blast furnace Slag (Slags), rice husk ash (RHA), palm oil fuelash (POFA), SF (SF), coconut shell ash (CSA) calcined clay etc. It is reported to improve rheology andcohesiveness, lower heat of hydration, lower permeability and higher resistance to chemical attack. In some cases, a boostingearly strength becomes apparent, while in others, an increase in later strength occurs.In recent years, the applications of blended cements have been further extended(Salaudeen and Leeyee, 2008).

Many researches have been conducted on Cocoanut shell ash as partial replacement of ordinary portland cement and strength was used as its quality performance index (e.g Oyedepo,Olanitori, and Akande, 2014: Vignesh *et al.,* 2014: Utsevu and Taku, 2012). It was reported that 10% replacement of cement with coconut shell ash gives highest strength of 20.74N/mm^2, 31.78 N/mm^2 , and 31.78 N/mm^2 respectively, However Utsevu and Taku (2012) further recommended 15% replacement level with strength of 23.23 N/mm^2. However the durability properties of cocoanut shell ash blended cement was not assessed. One of the main reason for deterioration of concrete in the past is that too much emphasis is placed on compressive strength, as a matter of fact advancement in concrete technology has been generally on the strength of concrete it is now

recognized that strength of concrete is not sufficient (Shetty, 2009). The degree of aggressiveness of the environmental condition to which the concrete is exposed over it's entire life is equally important (Shetty, 2009). Therefore one of the essence of this research work is to assess the durability properties of concrete produced using Cocoanut Shell Ash (C S A) ash as partial replacement of ordinary Portland cement.

Permeability reducing admixture is added to the concrete mix and can be in liquid form or powdered form and are introduced into the concrete mix according to the manufacturer's specifications which is 2% the weight of cement (AC1 212 3R, 2010).Mukeshi, Singh and Singh (2009) carried out research on the effects of water proofing admixture on the hydration of Portland cement and concluded that properties of concrete that contains water proofing admixture (strength and durability) improve when compared with conventional concrete. However there still exist the need to investigate the effect of Permeability Reducing Admixture on properties of binary cementitious matrix concrete made with coconut shell ash as partial replacement of ordinary Portland cement.

Therefore this research work seek to assess the effects of permeability reducing admixture on the properties of binary cementitious matrix concrete produced with coconut shell ash as partial replacement of cement.

1.2 Statement of Research Problem

Concrete and other cementitious surfaces are porous, the pore size of concretes lies between (10 nano to 50 micronmeters). These pores allow water and soluble contaminants to penetrate the structure leading to degradation. The effects of degradation can include efflorescence, laitance and physical defects such as cracking and spalling (Mukeshi et *al.*,2009).

The crack joints and other defects in the concrete facilitate the ingress of water, which is actively transported from area of high concentration to those of low concentration within the interior space of concrete. Water seeping is a major problem in construction industries particularly when the buildings are constructed in damped environment, when concrete is under hydrostatic pressure on one surface, water passes through the channels formed by the inter connecting cracks and voids to the other sides surface (Mukeshi *et al.,* 2009).

Water in its various forms, such as seawater, groundwater, river water, lake water, snow, ice, and vapor, is undoubtedly the most abundant fluid in nature. Water molecules are very small and, therefore, are able to penetrate into extremely fine pores or cavities. As a solvent, water is noted for its ability to dissolve more substances than any other known liquid. This property accounts for the presence of many ions and gases in some waters which, in turn, become instrumental in causing chemical decomposition of solid materials (Mehta and Monteirro, 2006).

The use of concrete has been extended to aggressive environment and this greatly resulted in defective concrete and durability failure of concrete, a tremendous effects on the economy and environment (Naik *et al.,* 2006). In industrialized countries over 40% of the total resources of

the building industry are applied to repair and maintenance of existing concrete structures and less than 60% are applied to new installations (Naik *et al.,* 2006).

Many researches have been conducted on the possibility of improving the durability of plain concrete, one of the materials commonly used are pozzolana. In order to reduce concrete pore structure, addition of pozzolanic materials provides secondary hydration which reduces pore volume to achieve denser, stronger and durable concrete (Siyu, *et al.*, 2013). Many researches have also been conducted on the performance of plain and blended concrete exposed to aggressive environment i.e magnesium sulphate attack, water absorption, sorptivity test etc. It was reported that blended concreteconserves higher strength than plain concrete after exposed to aggressive environment (Vedalakhshimi, Sundra, Siwasan and Gana, 2005: Ramezanni, Pourbek and Moodi, 2013). Zhang and Zhong(2014) reported that blended concrete reduces water absorption and sorptivity.

Beatrix (2010) reported that the incorporation of supplementary cementitious materials into concrete matrix as partial replacement of cement may slowdown chemical attack on concrete for sometime but may not prevent chemical attack on concrete for a long period of time. Blended cement is not good enough for protecting concrete under aggressive environment for example exposure to magnesium sulphate for a long period of time (Ahmad *et al.*,2008).According to Ahmad (2014) Although partial replacement of cement with pozzolans decreased the pore volume, surface scaling increases due to the increased proportion of small diameter pores and the associated growth of capillary suction and surface area for evaporation. Many additional efforts have been made in order to protect the concrete against the influence of aggressive environment

example of such is surface coating of concrete, surface coating of concrete provides adequate protection. However problems still exist these include, adequate curing of the concrete before coating is applied in order to eliminate the separation of the surface treatment, the application of surface coating requires training of the operatives and potential of decohesion when exposed to weather elements. Using a water-based solid acrylic polymer resin did not provide adequate protection of concrete against physical sulphate attack (Ahmad, 2014).

However this research seek to investigate if addition of permeability reducing admixture to a binary cementitious matrix concrete will improve the performance of binary cementitious matrix concrete when it is exposed to aggressive environment.

1.3 Significance of the Study

The recycling process appears to be a good way of conserving natural resources (limestone) and eliminates the need for waste disposal and its harmful effects by recycling available waste materials (Safiudeen *et al.*,2010: Obilade, 2013: Akinkunrolero, Aribisala, Oke and Ogundipe, 2013). Utilization of waste materials and by products in concrete will present partial solution to environmental and ecological problems (Sarath, Vamsi and Saha, 2012).

Permeability reducing admixture will provide efficient and effective protection to concrete by blocking concrete pores through creation of crystals in the presence of water, prevents water percolation in concrete and becomes a permanent part of concrete therefore protecting the concrete and enhancing it's performance during service life (Mukeshi *et al.*,2009). Permeability reducing admixture provides cost effective means of concrete protection when compared with membrane coatings because membrane coating requires training of the operatives, purchase of

spraying devices and prone to decohesion when exposed to weather elements (Yuers, 2013). Sussane (2013) Adding Permeability reducing admixture treatment to the concrete mix at the batch plant ensures that the crystalline formation occurs uniformly throughout the structure, rather than penetrating from the surface, as would be the case with a surface application.

There is need to conduct more research on the compatibility of permeability reducing admixture with binary cementitious matrix concrete derived from agro waste (Rice Husk Ash, Coconut Shell Ash etc) and industrial by products (Fly ash, Ground granulated blast furnace slag) and potential benefits that such combinations will yield for concrete.

When both chemical and mineral admixtures are added during hydration of cement, the process of hydration become more complex but at the same time the properties of cement especially strength and durability are modified considerably (Mukeshi *et al.,*2009). Improved durability of infrastructure materials has ecological benefits, a durable concrete has far reaching positive influences on sustainable development in the construction industry (Naik *et al.,* 2006).

Therefore adding permeability reducing admixture to binary cementitious matrix concrete that contains coconut shell ash as partial replacement of cement will improve concrete durability through complex hydration chemical reaction that took place between the cement paste and pozzolana and the crystal develop by the PRA. The pozzolana will react with $Ca(OH)_2$ and produce secondary hydration process CSH there by refining the concrete pore structures, and the crystals produced by the PRA will also block the concrete pores, heal autogenous crack and there producing synergistic effects of delay hydration process, delay strength and thereby result in

improve strength at later age and improve pore structure thereby improving durability of concrete (resistance to chemical attack, water absorption and fluid transport through concrete).

1.4 Aim and Objectives

1.4.1 Aim

The aim of this study is to evaluatethe effects of permeability reducing admixture on properties of binary cementitious matrix concrete with a view to establishing it's suitability for concrete production.

1.4.2 Objectives

(1) To determine physical and chemical properties of Cocoanut shell ash

(2) To determine the properties of fresh concrete samples

(3) To assess the durability properties of concrete samples

(4) To evaluate thecompressive strength of concrete samples

1.5 Scope and Limitations

1.5.1 Scope

This study concentrated on evaluation of workability of fresh concrete (Using slump and compacting factor test), compressive strength, abrasion resistance and water absorption and sorptivity of various specimen samples, strength retained after exposure to aggressive environment.

1.5.2 Limitations

The non-availability of standard apparatus for conducting permeability test limited this research work. Indirect methods of measuring permeability test were adopted which are Sorptivity and water absorption, These tests were conducted in place of permeability test. The results of sorptivity and water absorption tests were presented and explained. Since permeability test was assessed indirectly in the research work, the potential of utilization of permeability reducing admixture was partially assessed.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concrete

In construction industry, the most widely used material is concrete which is obtained by mixingcementitious materials, water and aggregates. The mixture when placed in forms and allowed to cure hardens into a rocklike mass known as hardened concrete. The hardening is caused by chemical reaction between water and cement and it continues for a long time (Olubisi, 2013). It may also be considered as an artificial stone in which the voids of larger particles (coarse aggregate) are filled by the smaller particles (fine aggregates) and the voids of fine aggregates are filled with cement (Olubisi, 2013).

2.1.1 Composition of Concrete

A good quality concrete is essentially a homogeneous mixture of cement, coarse and fine aggregates and water which solidifies into a hard mass as a result of chemical action between the cement and water. Each of the four constituents has a specific function. The coarser aggregate acts as a filler. The fine aggregate fills up the voids between the paste and the coarse aggregate. The cement in conjunction with water acts as a binder (Duggal, 2008).

2.1.2 Chemical Composition of Cement

The chemical composition is the basis for the characterization of cement. The materials used for the manufacture of cement consists mainly of lime, silica and aluminates. These oxides interacts with one another in the kiln at high temperature to form more complex compounds (Shetty, 2009). Cement with higher content of certain compound relative to each othes could cause

retardation or accellerate the rate of setting and hardening. These compounds could also affect the rate of heat evolution as the content hydrates. Chemical like calcium chloride and calcium sulphate are used to accelerate or retard the rate of setting of cement paste (Aka, 2011) table 2.1 Shows the oxide composition of cement while table 2.2 shows the chemical composition of cement.

Table 2.1 Oxide Composition of Cement

Oxide	**Function**	**Composition (%)**
CaO	Controls strength and soundness	60-65
Si02	Gives strength, excess causes slow setting	17-25
Al2O3	Responsible for quick setting, excess lower strength	3-8
Fe2O3	Gives colour and fussion of different ingredients	0.5-6
Mgo	Impart colour and hardness excess cause cracking	0.5-4
Na2O+ k2O	These are residue, and in excess cause efflorescence	0.5-1.3
TiO2	And cracking	0.1-0.4
P2O5		0.1-0.2
SO3	Makes cement sound	1-2

Source :Duggal(2008)

Table 2.2 : Chemical Composition of Cement

Principal Compounds in Portland Cement	**Mineral Formulae**	**Name**	**Symbol**
Tricalcium Silicate	$3Cao.SiO_2$	Alite	C_3S
Dicalcium Silicate	$2CaO.SiO_2$	Belite	C_2S

Table 2.2Continuation :

Principal Compounds in Portland Cement	**Mineral Formulae**	**Name**	**Symbol**
Tricalcium Silicate	$3Cao.Al_2O_3$	Celite	C_3A

Dicalcium Silicate	$3Cao.Al_2O_3$	Celite	C_3AF

2.2 Aggregates

Aggregates constitute a skeleton of concrete. Approximately three-quarters of the volume of conventional concrete is occupied by aggregate. It is inevitable that a constituent occupying such a large percentage of the mass should contribute important properties to both the fresh and hardened product. Aggregate is usually viewed as an inert dispersion in the cement paste. However, strictly speaking, aggregate is not truly inert because physical, thermal, and, sometimes, chemical properties can influence the performance of concrete (Zongji, 2011).

2.2.1 Classification of Aggregates

Aggregates can be divided into several categories according to different criteria, such as size, source, and unit weight.

2.2.1.1 In accordance with size

(a) Coarse aggregate

Aggregates predominately retained on a No. 4 (4.75-mm) sieve are classified as coarse aggregate. Generally, the size of coarse aggregate ranges from 5 to 150 mm. For normal concrete used for structural members such as beams and columns, the maximum size of coarse aggregate is about 25 mm. For mass concrete used for dams or deep foundations, the maximum size can be as large as 150 mm (Zongji, 2011).

(b) Fine aggregate (sand)

Aggregates passing through a No. 4 (4.75 mm) sieve and predominately retained on a No. 200 (75 um) sieve are classified as fine aggregate. River sand is the most commonly used fine

aggregate. In addition, crushed rock fines can be used as fine aggregate. However, the finish of concrete with crushed rock fines is not as good as that with river sand. There are other method of classifications e.g classification by weight, by size and source (Zongji, 2011).

2.3 Fresh Concrete

Fresh concrete can be viewed as a concentrated suspension of solid particles (aggregates) in a viscous medium, i.e. cement paste. The behaviour of a specimen of fresh composite material is defined in terms of its workability and is measured by numerous consistency methods(Zongji, 2011).

2.3.1 Workability

Workability of concrete is defined in ASTM C125 as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity (uniform). The term manipulate includes the early-age operations of placing, compacting, and finishing. The ease of placement, consolidation and finishing of freshly mixed concrete and degree to which it resist segregation is termed workability. The ingredients of workable concreteshould not fall apart during transport and handling (Steeve, Beatrix and William, 2003).Shetty(2009) defines workability as internal useful work necessary to produce full compaction, ease with which concrete can be compacted 100 percent having regard to mode of compaction and place of deposition.

2.3.1.1 Factors Affecting Workability

(1) Water content

(2) Mix proportion

(3) Size of aggregate

(4) Shape of aggregate

(5) Surface Texture of Aggregate

(6) Grading of aggregate

(7) Use of Admixture

2.3.2 Measurement of Workability

The most widely used test, which mainly measures the consistency of concrete, is called the slump test. For the same purpose, the second test in order of importance is the Vebe test, which is more meaningful for mixtures with low consistency. The third test is the compacting factor test, which attempts to evaluate the compactability characteristic of a concrete mixture. The fourth test method is the ball penetration test that is somewhat related to the mechanical work (Zongji, 2011).

(1) Slump Test

(2) Compacting Factor Test

(3) Vebe Test

(4) Flow Table Test

(5) Penetration Test

2.3.2.1 Slump test

The equipment for the slump test is indeed very simple. It consists of a tamping rod and a truncated cone, 300mm in height, 100mm in diameter at the top, and 200mm in diameter at the

bottom. To conduct a slump test, first moisten the slump test mold and place it on a flat, nonabsorbent, moist, and rigid surface. Then hold it firmly to the ground by foot supports (Zongji, 2011). Next, fill 1/3 of the mold with the fresh concrete and rod it 25 times uniformly over the cross section. Likewise fill 2/3 of the mold and rod the layer 25 times, then fill the mold completely and rod it 25 times. If the concrete settles below the top of the mold, add more. Strike off any excessive concrete. Remove the mold immediately in one move. Measure and record the slump as the vertical distance from the top of the mold to average concrete level (Zongji, 2011).

Three types of slump usually observed:

(1) True slump

is observed with cohesive and rich mixes for which the slump is generally sensitive to variation in workability.

(2) Shear slump

Shear slump occurs more often in leaner mixes than harsh mixes. Whenever shear slump is obtained the test should be repeated and, if persistent, this fact should recorded together with test result.

(3) Collapse slump

Is usually associated with very wet mixes and is generally indicative of poor quality concrete and most frequently result from segregation of its constituents materials. The standard slump apparatus is only suitable for concretes in which the maximum aggregate size does not exceed 37.5mm.

2.3.2.2 Compaction factor

This test measures the degree of compaction for standard amount of work and thus offers a direct and reasonably reliable assessment of the workability of concrete (Rahim, 2010). It consists of two hoppers and one cylindrical mold stacked in three levels. To perform an experiment, the upper hopper is first fully filled with fresh concrete. Then the hinged door is slid open and hence the concrete will fall into the lower hopper by gravity. Next, the hinged door of the power hopper is slid open and the concrete free falls into the 150 × 300mm cylindrical mold. After the excessive concrete is struck off on the top of the mold, the weight of the cylinder is measured and noted as Mp, representing a partially compacted cylinder mass. Another cylinder is made with same concrete by three layers with 25 times rodding on each layer and striking off any excessive concrete.The weight of the cylinder is measured as Mf, representing the fully compacted cylinder mass.

The compaction factor is defined as

$$\text{compaction factor} = \frac{MP}{MF} \quad \text{.....2.1}$$

Usually, the range of compaction factor is from 0.78 to 0.95 and concrete with high fluidity hasa higher compaction factor (Zongji, 2011). For the normal range of concretes the compacting factor lies between 0.8 and 0.92. The test is particularly useful for drier mixes for which the slumptest is not satisfactory, And is appropriate for concrete with a maximum size of aggregate up to 40mm (Rahim, 2010).

2.3.3 Uniformity and Stability

Fresh concrete, properly designed, batched and mixed, needs to be sensibly uniform and to remain reasonably so through the remaining normal processes of transporting, placing,

compacting, finishing and thereafter, until the stiffening process of hydration provides the necessary rigidity (Dewar and Anderson, 2004). Extreme construction conditions may require additional precautions. The range of relative densities of the normal materials used, 1 for water to over 3 for cement, means that there is always a tendency for segregation to take place, particularly at high workability. This tendency will generally be smaller for richer mixes, finer cementitious materials, finer sands, higher sand contents, lower water demand concretes, in warm weather, and when air-entraining and certain water-reducing admixtures are used. Agitation during transport or remixing before discharge of medium- and high-workability concrete may be necessary to maintain uniformity, whereas for low-workability mixes, agitation may be detrimental, causing aggregation or 'balling' of the fine components (Dewar and Anderson, 2004).

2.3.4 Segregation

According to Neville and Brooks (2011) segregation can be defined as separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform. In the case of concrete, it is the differences in the size of particles and in the specific gravity of the mix constituents that are the primary causes of segregation,but its extent can be controlled by the choice of suitable grading and by care in handling.

2.3.5Bleeding

Bleeding is sometimes reffered to as water gain, it is a particular form of segregation, in which some of the water from the concrete ascends to the concrete top, being of the lowest specific gravity among all the constituent materials used in concrete production, it is more pronounced in

highly wet mix, disproportionate and insufficient mixed concrete, in thin members like roof or road slabs and when concrete is placed under sunny weather. Due to this water come up and accumulates at the surface. Sometimes, along with certain quantity of cement (Shetty, 2009).Water while travelling from bottom to top, makes continuous channels. If the water cement ratio used is more than 0.7, the bleeding channels will remain continuous and unsegmented by the development of gel. This continuous bleeding channels are often responsible for causing permeability of the concrete (Shetty, 2009).

2.3.6 Setting Time of Concrete

Setting time of concrete differs widely from setting time of cement. Setting time of concrete does not coincide with the setting time of cement with which concrete is made of. The setting time of concrete depends upon the w/c ratio, temperature condition, type of cement, use of mineral admixture, use of plasticizer. The setting parameter of concrete is more of practical significance for site engineers than setting time of cement. When retarding plasticizers are used, the increase in setting time, the duration up to which the concrete remain in plastic state is of significance interest. The setting time of concrete is determined by penetrometer test. This method of test is prescribed by ASTMC-403.

2.3.7 Rheology

Rheology is the science of the deformation and flow of matter (John and Ban, 2003). The need to define and control the properties and performance of materials is part of technological development and the rheology of cement-based materials is no exception to this process. Applying Kelvin's condition to the meaning of "understand", namely that a phenomenon is not

properly understood unless it can be measured, three levels of understanding may be identified. These may or may not coincide with a chronological progression. Considering the phenomenon of workability, in level 1, the property is described in comparative terms only, using subjective assessments such as “stiff”. In level 2, a quantitative numerical scale based on an empirical measurement, such as slump, is established. In level 3, the property is rigorously defined in terms of physical constants, derived from the fundamental quantities of mass, length and time, which describe the material itself and do not depend on the circumstances of the test or the use of the material. This last level involves the use of sound scientific methods, such as rheology, in which physical and analytical models are developed and applied to the situation under consideration (Banfill, 2006).Fresh concrete that is not under vibration begins to flow only when the yield stress value is exceeded (Sandra, 2011). Many authors have concluded that, when vibration is applied, the yield stress is reduced to the extent that concrete can flow due to its own weight.

2.4 Properties of Hardened Concrete

Concrete is most widely used construction material today. Concrete has attained the status of a major building material in all the branches of modern construction. It is difficult to point out another material of construction which is as variable as concrete. Concrete is the best material of choice where strength, durability, impermeability, fire resistance & absorption resistance are required (Sathish, 2012).

2.4.1 Curing

All concrete requires curing in order that cement hydration can proceed so as to allow for development of strength, durability and other mechanical characteristics (Akeem,Aliu and

Amaka, 2013). To obtain good concrete, the placing of an appropriate mix must be followed by curing in a suitable environment, especially during the early stages of hardening. Curing is the name given to procedures used for promoting hydration of cement, and consists of a control of temperature and moisture movement from and into the concrete. Curing as the process of protecting concrete for a specified period of time after placement, to provide moisture for hydration of the cement, to provide proper temperature and to protect the concrete from damage by loading or mechanical disturbance (Akeem*et al.*,2013). Proper curing application has significant impact on density and compressive strength of concrete (Shohanna, 2015).

2.4.1.1 Importance of Curing to concrete

The longer the moist curing period the higher the strength (Mehta and Monteirro, 2006) continuous water curing resulted in an improved microstructure of the concrete specimens (Abalaka and Okoli, 2013). Adequate curing at early ages as well as at later ages is essential in the strength development of PCC concrete (Alhaz, Muhammad, Habibu, Noor, Sadiq, Shainnu and Khan, 2012).

2.4.2 Strength

Strength of concrete is commonly considered to be its most valuable property, strength usually give an over all picture of the quality of concrete because of it is directly related to the structure of cement paste. The strength of a material is defined as the ability to resist stress without failure (Mehta and Monteiro, 2006). Cement paste strength is typically defined in three ways: compressive, tensile and flexural. These strengths can be affected by a number of items including: water cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate,

curing conditions, size and shape of specimen, loading conditions and age (Vigneshi *et al.*, 2014).

2.4.2.1 Compessive strength Test

The compressive strength of concrete is taken as the maximum compressive load it can carry per unit area. Concrete strength up to 80 N/mm^2 can be achieved by selective use of the type of cement, mix proportion, method of curing conditions.Concrete structures, except for road pavements, are normally designed on the basis that concrete is capable of resisting only compression, the tension being carried by steel reinforcement. The standard method described in BS 1881:Part 3 requires that the test specimen should be cured in water at 20 ^{0}C and crushed immediately after it has been removed from the curing tank(Rahim, 2010).

$$Fct = \frac{P}{A} \quad \text{.....2.2}$$

Where:

P = Applied load

A= Surface Area

2.4.3.2 Tensile strength

The tensile strength of concrete is of importance in the design of concrete roads and runways.However, in the design of some structures that are required to contained liquids the tensile strength is taken into consideration (Omotola and Idowu, 2011). Concrete members are also required to withstand tensile stresses resulting from any restraint to contraction due to drying or temperature variation. Unlike metals, it is difficult to measure concrete strength in direct tension and indirect methods have been developed for assessing this property (Rahim, 2010).

2.4.3.3 Split cylinder test

The simplest and most widely used. This test is fully described in BS 1881 Part 4 and entails diametrically loading a cylinder in compression along its entire length. This form of loading induces tensile stresses over the loaded diametrical plane and the cylinder split along the loaded diameter. The magnitude of the induced tensile stress

Fctat failure is given by:

$$Fct = \frac{2F}{\pi l d} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

where:

F = the maximum applied load

l = the cylinder length

d = the diameter of the cylinder

2.4.3.4 Flexural strength

The flexure strength of concrete is another indirect tensile value which is also commonly used (BS 1881:Part 4). In this test a simple supported plain concrete. Beam is loaded at is third points, the resulting bending moments inducing compressive and tensile stresses in the top and bottom of the beam respectively. The beam fails in tension and the flexure strength (modulusof rupture) fcr is defined by:

$$Fcr = \frac{FL}{bd^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

where:

F = the maximum applied load

L = the distance between the supports

B&d =are the beam breadth and depth respectively at the section which failure occurs.

The tensile strength of concrete is usually taken to be about one- tenth of its compressive strength. This may vary, however, depending on the methods used for measuring tensile strength and the type of concrete. In general the direct tensile strength and the splitting strength vary from 5 to 13 per cent and the flexure strength from 11 to 23 per cent of the concrete cube compressive strength. In each case, as the strength increases the percentage decrease (Rahim, 2010).

2.4.3Density

The mechanical properties of concrete are highly influenced by its density. A denser concrete generally provides higher strength and fewer amount of voids and porosity. The Smaller the voids in concrete, it becomes less permeable to water and soluble elements. So water absorption will also be less and better durability is expected from this type of concrete(Shohanna, 2015).The density and compressive strength of concrete cement paste are affected by several parameters like water cementitious materials ratio, supplementary cementitious materials, use of admixture, curing, cement type (Shohanna, 2015).

2.5Concrete Durability

A long service life is considered synonymous with durability. As durability under one set of conditions does not necessarily mean durability under another, it is customary to include a general reference to the environment when defining durability. According to ACI Committee 201, *durability* of portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. In other words, a durable

concrete will retain its original form, quality, and serviceability when exposed to its intended service environment. No material is inherently durable .As a result of environmental interactions.

The microstructure and consequently the properties change with time (Mehta and Monteirro, 2006). A material is assumed to reach the end of service life when its properties, under given conditions of use, have deteriorated to an extent that its continued use is ruled either unsafe or uneconomical (Mehta and Monteirro, 2006).Durability of concrete is considered as important as concrete strength, since conditions such as temperature changes, humidity, loading characteristics and frequency are determinant of a quality product meeting predetermined expectation (Radu and José, 2007). In many cases, the effect of harmful conditions on the durability of concrete can be evaluated only qualitative, since mathematical models that allow prediction of the magnitude of deterioration with time have been investigated during the last decades, without the scientific community agreeing in one model in particular that satisfy all possible considerations (Radu and José, 2007).

2.5.1 Water as an Agent of Deterioration

Water in its various forms, such as seawater, groundwater, river water, lake water, snow, ice, and vapor, is undoubtedly the most abundant fluid in nature. Water molecules are very small and, therefore, are able to penetrate into extremely fine pores or cavities. As a solvent, water is noted for its ability to dissolve more substances than any other known liquid. This property accounts for the presence of many ions and gases in some waters which, in turn, become instrumental in causing chemical decomposition of solid materials (Mehta and Monteirro, 2006).

The durability of concrete subjected to aggressive environments depends largely on transport properties, which are influenced by the pore (Javier, Dale and Jason, 2011). Three main mechanisms govern transport in cementitious systems: permeability, diffusion and absorption (Javier, Dale and Jason, 2011). Therefore it will become necessary to discuss pore structure in concrete before transportation in concrete will be discussed.

As a porous media, cement and concrete materials adopt a pore structure with broad pore size distribution from nanometer to micrometer scales. Generally speaking, the pores of concrete are classified into four major types (Jun *et al.*, 2014).

2.5.2 Forms in Which Water Exist in Concrete

Water may be present in hydrated cement paste in many forms that may be classified on the basis of the degree of difficulty in eliminating it.

2.5.2.1 Capillarity Water

The water contained in the capillarity pores account for the greatest part of water. Water retained by capillarity tension in pores of diameter smaller than 50nm(nano micro meter) will evaporate at when the value of relative humidity is lower as the diameter of capillarity pore decreases from 50nm to 5nm (Luca, Bernard, Pieto and Rob, 2004).

2.5.2.2Adsorbed Water

Some water will still remain adsorbed to the inner surface in the form of a very thin layer of adsorbed water even when water has evaporated from the capillarity pores. This water can be removed if the external humidity falls below 30%. It contributes little to transport processes, It has insignificant effect on corrosion of reinforcement. Its elimination give rise to shrinkage of the cement paste and influences creep behavior(Luca*et al.*, 2004).

2.5.2.3Interlayer water

Concrete losses retained water between the C-S-H layers if the external humidity falls below 11%. This water do not contribute to corrosion of reinforcement because the gel pores are too small to allow transport processes at any level but rather influences shrinkage(Luca*etal.*, 2004).

2.5.2.4 Chemically combined water

This is the water form integral part of C-S-H or other hydration products. It is not lost on drying . It can only be released when the hydration decompose on heating at temperature that exceed 1000^0C, it does not contribute to any transport phenomenon (Luca*et al.*, 2004).

2.5.3 Concrete Porosity

The pore structure of cement-based materials contains air voids, capillary pores, and gel pores, and the pores are randomly sized, arranged, and connected. It is a well-established fact that porosity is one of the important parameters which directly affect the strength and durability of cement-based materials. Lower porosity in concretes with sufficient binding material content enhances higher strength concretes. The traditional classification of pores in concrete, two classes of pores were considered: gel pores (<10 nm), which are associated with the formation of hydration products, and capillary pores (10 nm~10000 nm), which dominate transport processes. And the existence of diffusivity of concrete on pore structure attributes mainly to the effect of capillary porosity and connectivity of these capillary pores (Haito, Qi, Donghui and Shipping, 2014). Since concrete porosity relates with concrete strength and Durability it is necessary to discuss types of pores that exist in concrete.

2.5.3.1 The gel pores

The gel pores, which are mostly of 1.5–2.0 nm(nano micro meter) size gel pores (diameter < 10 nm), do not influence the strength of concrete adversely through its porosity, although these pores are directly related to creep and shrinkage (Rakesh and Bhattacharjee, 2003). Gel pores basically are smaller in size and numerous, created by existing cavities in the hydration products of the cement. The gel pores are really interconnected interstitial spaces between gel particles. Although the gel pores constitute a network of communicating pores, it seems that the permeability of this network, by calculation of Power's Law, it is very low: 7.10-16 m/s (Meter/Second) (Saladin and Leyo, 2008).

2.5.3.2 Transitional pores (diameter 10–100 nm)

The coarse aggregate surface has an interfacial transition zone (ITZ) of about 100-Am depth. This ITZ includes two layers: One is a duplex film at the surface of the coarse aggregate, about 1 Am deep. Its components are CH crystals and C –S –H gels, The other layer is the porous transition zone, about 20– 100 Am deep, which contains more CH crystals, some C –S–H gels and little ettringite. These weak faces will influence the durability of concrete. With the progress of hydration, the discontinued pores of cement particles will be gradually filled with hydration products (Kuo-Yu, Ping-Kun, Yaw-Nan and Chih-Chang, 2004).

2.5.3.3 Capillary pores

Capillary pores are responsible for reduction in strength and elasticity (capillary pores diameter, 100–1000 nm)(Rakesh and Bhattacharjee, 2003). It is generally larger in size in which the formation depends on the evaporation of the water used in the pastes. The volume of the capillary system will reduce with the progress of hydration. In any stage of hydration the capillary pores filled the part of the gross volume, which has not been filled by the products of

hydration. The average volume and size of the pores decreases, and the network progressively breaks down (segmentation of the capillaries) (Saladin and Leyo, 2008).

2.5.3.4 Macropores (diameter > 1000 nm)

Pores whose diameter of 100 nm is defined as threshold, since the size of the pores are assumed to be detrimental to durability for cement and concrete composites (Jun*etal.*,2014). Such greater porosity also makes cement pastes more vulnerable to chemical attack by aggressive agents, reducing the service life of structures (Saladin and Leyo, 2008).

2.6 Transport Mechanisms in Concrete

Concrete should have low permeability. This is important not only for its direct bearing on water tightness but also because of it's influence on durability and the protection of embedded steel from corrosion(John and Ban,2003). The durability of concrete subjected to aggressive environmentsdepends largely on transport properties, which are influenced bythe pore system. Three main mechanisms govern transporting cementitious systems: permeability, diffusion and absorption(Javier, Castro and Jason, 2011).

Main typesof Transport Mechanisms in Concrete

1) Permeation
2) Diffusion
3) Electromigration
4) Combined transport

2.6.1 Permeation

Water Flow and Water Permeability :Permeability is a broader term than porosity. The ability of liquid water, under pressure, to flow through porous materials is permeability and is described by the permeability coefficient (Patrick, 2000). The equation used to calculate the D'Arcy's coefficient is as follows:

$$Q = \frac{k.A.\Delta H}{t} \quad \text{.....2.5}$$

Where:

K = water permeability or D'Arcy's coefficient (m/s)

Q = flow rate through the sample (m3/s)

A = cross section area of sample (m2)

Δh = water pressure differential across the samples (m)

l = sample length (m)

This equation applies (more or less) for the case where the concrete is saturated (all the pores are filled with water) and there is liquid water on both the up-steam and down-stream side. Water permeability of the concrete matrix is a useful indicator of the quality of the concrete for durability reasons. The lower the D'Arcy's coefficient, the higher the quality of the material. A concrete with a low water permeability may be relatively durable but may still require a waterproofer e.g., to prevent leakage through cracks (Patrick, 2000).

2.6.2 Diffusion

The ingress of aggressive ions dissolved in water is one of the most important concepts to understand with respect to the durability. Dissolved ions move into concrete by diffusion or are dragged in by D'Arcian flow. In diffusion, a high concentration of ions will move to areas of low

concentration much like how smoke or perfume will move to fill a room (Patrick, 2000). At a further distance the concentration becomes less and less. This is the case for the diffusion of chloride into concrete, which is largely responsible for reinforcing steel corrosion. The basis diffusion equation is as follows:

$$J = -D\frac{dc}{dx} \quad \text{.....2.6}$$

Where:

D = diffusion coefficient (m2/s)

J = flux (ion flow rate) into the material (mol/m2s)

C = concentration of ions (mol/m3)

x = distance in the direction of flow (m)

The equation is an oversimplification. Useful related parameters can be obtained by laboratory testing and can be used in concrete specifications. The important things to note about the diffusion coefficient are: D is a property of the concrete quality; higher quality concrete will have lower D values, concentration reduces at greater distance into the concrete, higher surface concentration will result in higher flow rates. Diffusion of gasses may also occur. It has already been mentioned that water vapour moves by diffusion. Other gasses too may be of concern, for example, atmospheric carbon dioxide that can cause carbonation damage(Patrick, 2000). In some regions, radon or methane gas may be present in soil and may diffuse into occupied space causing health hazards. Diffusion is not the only means by which dissolved ions such as chloride can move into concrete. Salts may be dragged along with water during liquid flow. This occurs when water flows through cracks or during wetting (sorption) of concrete. Salts are also dragged

along with liquid flow in the case of the basement wall efflorescence example.The understanding of diffusion is important to concrete for the following reasons:

(a)Diffusion of aggressive chemicals, particularly chloride ion, is the leading cause of failure of concrete structures world-wide. The application of a coating (and to a lesser extent a sealer) greatly reduces diffusion and is a primary defense against durability problems.

(b) Vapour moves by diffusion as mentioned above. Even seemingly dry concrete may have significant vapour flow by diffusion.

(c) The diffusion coefficient is a fundamental property of concrete and an approximate measurement can be easily obtained in the laboratory; this may be used to assist in the decision as to whether a durability enhancing treatment is required or if the concrete can be left bare (Patrick, 2000).

2.6.3 Electromigration

Electromigration occurs when an electric field (voltage difference) is present. This may be derived from an external source such as leakage from a direct current power supply but is also frequently caused by the electrical potential of pitting corrosion on reinforcing steel. If an electric field is applied across the concrete, the negative ions will move towards the positive electrode (Peter, 2000).

Electromigration can be measured from the electrical resistance of the concrete because it is the only mechanism by which concrete can conduct electricity. Because it is conducted in this way, rather than with electrons as in a metal, direct current will carry chloride ions into the concrete or

possibly hydroxyl ions out of it. This mechanism is used in the desalination process in which a positive voltage is applied to the surface of a concrete structure in order to extract the chlorides from it. This process has the added advantage of applying a negative voltage to the reinforcing steel which will directly inhibit corrosion in the same way as cathodic protection. Unfortunately it also has the disadvantage of removing other negative ions from the concrete which may cause problems in practice (Peter, 2000).

2.6.4 Combined transport

The transport of a substance in concrete may be derived from a combination of transport processes. When a substance is part of a fluid, a gas mix or a solvent containing ions, and the fluid moves, the substance is transported by *convection*, but the fluid moves by permeation. Within the fluid the substance may diffuse or move because of electromigration. A substance, especially water, might move in concrete in different states. In such a case it is usually referred to as 'moisture', being a combination of water vapour in the air of the pores, the liquid water in the larger pores, bound water at the pore walls and bound water in the gel. The total transport of moisture is a combination of transport of water vapour by diffusion in air, liquid water by permeation and bound water by another type of 'diffusion' because of differences in the state of the bound water; a kind of solid-state diffusion. In practice these different processes may not be distinguished since they cannot be separately measured. In transport laws and test methods the totalmoisture flow is described(John and Ban,2003).

2.7Causes of Deterioration of Concrete

Deterioration of concrete can be caused by internal causes and External causes (Sulaiman, 2016).

2.7.1 Internal Causes

These are causes within the concrete composition itself. Adequate test and meticulate material selection are means of correcting internal causes of deterioration, The causes of internal deterioration can be attributed to type of cement, alkali aggregate reaction, aggregate type, permeability of concrete, thermal properties of aggregate and cement paste (Sulaiman, 2016).

2.7.2 External Causes

The external causes of concrete deterioration are classified into physical and chemical causes. The deterioration effects of external causes can be corrected through appropriate assessment of the environment which the concrete is exposed to and application of adequate protection techniques. The external causes can be physical or external (Balim, 2012).

Chemical Deterioration

Physical Deterioration

Source :(Balim, 2012).

2.7.2.1 Physical Deterioration

The main causes of physical deterioration of concrete are:

(a) Abrasion (b)Fire (c) Erosion (d) Cavitation (e)Freezing

(a) Abrasion of Concrete

Under many circumstances, concrete surfaces are subjected to wear. This may be due to attrition by sliding, scraping or percussion.In the case of hydraulic structures, the action of the abrasive materials carried by water leads to erosion. Another cause of damage to concrete in flowing

water is cavitation (Neville, 2011). Abrasion damage to concrete may be caused by the sliding or scraping of equipment across the concrete (Nagesh, 2012) .

(1). That abrasion resistance is clearly related to the compressive strength of the concrete, Strong concrete has more resistance than weak concrete (Abol, 2012: José, 2010: Mehta and Monteiro, 2006).

(2) Since compressive strength depends on the water-cement ratio and adequate curing, a low water-cement ratio and proper curing of the concrete are necessary for abrasion resistance (Abol, 2012: Radu and Jose, 2010).

(3) Hard aggregates are more abrasion resistant than soft aggregates (Tarun,Shiw andMohammad, 2012).

(4) Steel-trowelled surfaces resist abrasion more than a surface that is not trowelled (Tarun *et al.*,2012).

(5) Incorporation of pozzolana into mix increases abrasion resistance (Radu and José, 2010: Tarun*et al.*,2012).

(b) Fire

When concrete is subjected to elevated temperature, concrete responds not just in instantaneous physical changes,such as expansion, but by undergoing various chemical changes. This response is especiallycomplex due to the non-uniformity of the material. Concrete contains both cement and aggregate elements, and these may react to heating in a variety of ways (Fletcher, Audun, Neil and Stephen, 2010).

First of all, there are a number of physical and chemical changes which occur in the cement subjected to heat. Some of these are reversible upon cooling, but others are 1rreversible and may significantly weaken the concrete structure after a exposure. Most porous concretes contain a certain amount of liquid water in them. This will obviously vaporise if the temperature significantly exceeds the moisture plateau range of 100-140°C or so, normally causing a build-up of pressure within the concrete. If the temperature reaches about 400°C, the calcium hydroxide in the cement will begin to dehydrate, generating further water vapour and also bringing about a significant reduction in the physical strength of the material. Other changes may occur in the aggregate at higher temperatures, for example quartz-based aggregates increase in volume, due to a mineral transformation, at about 575°C and limestone aggregates will decompose at about 800°C. In isolation, the thermal response of the aggregate itself is more straightforward but the overall response of the concrete due to changes in the aggregate may be much greater (Fletcher *et al.,* 2010).

These physical and chemical changes in concrete will have the effect of reducing the compressive strength of the material. Generally, concrete will maintain its compressive strength until a critical temperature is reached, above which point it will rapidly drop off. This generally occurs at around 600°C (Fletcher *etal.,* 2010).Several factors influence the behavior of concrete at high temperatures. These factors include concrete moisture content, aggregate type and stability, cement content, duration of concrete exposure, the rate that temperatures rise, the age of the concrete, and any restraint (Nagesh, 2012).

(c)Erosion

Erosion refers to wearing of the concrete surface by the abrasive action of fluids and suspended solids as well as by wind-borne sand particles. Erosion is therefore a special case of abrasion (Balim, 2012: Emiley, 2012).Erosion whichprovokes the removal of material from the surface of concrete. It depends on the speed, the content of hard dust particles and the quality of the concrete. In this case, the only remedy is to take special care when mixing the concrete.

(d)Cavitation

Cavitation can be a problem in any open channel where the velocity of the flowing water is higher than 12 mls (meter/second) (39.4 ft/s) feet/second. In a closed pipe or conduit, cavitation can occur at velocities as low as 7.5 mls (24.6 ft/s). Concrete damage that is due to cavitation can be minimized if irregularities in the flow of the water are eliminated or if the velocity of the flowing water is reduced. Concretes that have the best resistance to cavitation damage have a high strength, a low water-cement ratio, a small aggregate size that does not exceed 20 mm (3/4 inch), and a good pasteaggregate bond (Nagesh, 2012).

(e) Freezing

Problems caused by freezing of concrete are seldom encountered in Southern Africa because of the relatively mild climate in this region. However, there are some applications, such as cold rooms or cold liquid storage facilities, in which concrete is exposed to very low temperatures and could be damaged by the freezing of water in the pore structure (Balim, 2012).According to Balim (2012) damage by freezing is derived from the fact that water undergoes a 9% volume increase when it turns to ice. Hence, damage occurs when the water in the pore structure expands upon freezing and there is not enough empty space in the pore structure to accommodate this

expansion. Tensile stresses are then set up and microcracking of the cement paste occurs. In freeze-thaw deterioration, the cracks are propagated by the cyclic freezing and thawing actions.

2.7.2.2 Chemical Deterioration

(a) Sulphate Attack on Concrete

Sulfate attack is one of the most aggressive environmental deteriorations that affect the long-term durability of concrete structures. The sulfate attack of concrete leads to expansion, cracking, and deterioration of many civil engineering structures exposed to sulfate environment such as piers, bridges, foundations, concrete pipes, etc. The sulfate ions in the solution, which come from soil, ground water, and seawater, are found in combination with other ions such as sodium, potassium, magnesium and calcium ions. The sulfate ions react with C_3A and $Ca(OH)_2$ to produce expansive and softening types of deterioration (Ramez,Pourbeik and Moodi, 2012).

2.8 Sulphate Attack

Sulphate attack is one of the most aggressiveenvironmental factors that affect long term durability ofconcrete structures. It can result in cracking, expansion anddeterioration of concrete structures . Sulphate attack is thereaction of sulphate ions with calcium hydroxide and calciumaluminate hydrate to form ettringite and gypsum, theseproducts are voluminous and lead to expansion, cracking,deterioration, and deformation of concrete structures when formed after concrete has hardened (Collerpadi, 2003).

Sulphate attack can also lead to leaching of calciumcompounds, degradation of calcium silicate hydrate (C-S-H),and overall deterioration of cement paste matrix (Bolanle and adeshina, 2014).

One ofthe most severe conditions for durability of concrete is thesulphate or acid environment caused by industrial wastes orchemical residues at re-claimed grounds (Bolanle and adeshina, 2014). Deterioration ofconcrete as a result of sulphate attack can be in form ofinternal attack due to sulphate content of the cement, andexternal attack due to exposure of concrete to sulphateenvironment. Both forms of sulphate attack are manifested byexpansion and cracking of concrete (Bolanle and Adeshina, 2014).

The effects of sulphate attack in cementitious visible to naked eye include spalling,dilapidation,macro cracking and possible loss of cohesion. These are the repercussory outcome of complex chemical reaction and processes between the components of hydrated cement and sulphate compounds. The reactions that take place are as follow absorption,dissolution or precipitation and crystallization reaction (Collarpardi, 2003).

2.8.1 Damage Mechanisms due to Sulphate Attack

Three kinds of macroscopic damage due to sulfate ion interaction with the cementitious matrix have been reported: expansion (cracking, spalling), softening and decohesion (Aude, 2010).

(a) *Expansion*

Sulfate attack is generally associated with, and even defined, in the literature as the formation of sulfate-bearing products within the cement paste leading to macroscopic expansion. Expansion is generally attributed to ettringite formation (Aude, 2010).

Cement is known to perform very well in compression but very badly under tension with a failure criterion in the range of few MPa (e.g.; in the order of 4 MPa). Hence, anymicrostructural effects responsible of macroscopic expansion should be able to generate stresses in such a range. Various different theories exist regarding the mechanism of expansion increase in solid volume, topochemical reaction,swelling, crystal growth pressure (Aude, 2010).

(b) *Softening*

Gypsum is mainly found as precipitates in macroscopic cracks. Nevertheless, it may also be found intermixed in the cement matrix. This suggests that gypsum can form from portlandite and also from calcium in C-S-H which becomes decalcified. Monosulfoaluminate is usually assumed to be the source of aluminium for ettringite formation but a source of calcium is also needed. In ordinary Portland cement paste, the experimentally determined Ca/Si-ratio is around 1.7-1.8,compared to the upper limit of synthetic C-S-H of 1.5(Aude, 2010). This implies that in real cement matrix the C-S-H has an excess of calcium, which become available for gypsum and ettringite formation.Both gypsum and ettringite formation therefore lead to a relative decalcification of C-S-H, which is the main hydrate of cement matrix and stands for its cohesive property. This would result in a softening of this phase.

(c) *De cohesion*

Decohesion mainly occurs when thaumasite formation is observed. Thaumasite is indeed a very brittle material whose fracture produces small conchoidal fragments, it does not possess the cohesive properties proper to the cementitious matrix. Thaumasite forms in presence of carbonate from a sulfate source and drawing silicon from the C-S-H, the consumption of the silica of the C-S-H can lead to a loss of its binding

properties.There is no evidence that ettringite is theoretically required as a precursor to thaumasite formation, but thermodynamically as sulfate concentration increases, ettringite forms first(Aude, 2010).Ettringite and thaumasite can also enter into partial solid solution (Aude, 2010).

2.8.2 Magnesium Sulphate

In the presence on magnesium sulphate, the products of reaction differ from those exhibited in other forms of sulphate attack. Conventionally, ettringite and gypsum are products of the attack. Inaddition to these, the presence of the Mg2+ cation in the gypsum's reaction kinetics leadsto the formation of magnesium hydroxide ($Mg(OH)_2$), and eventual substitution of the calcium component in the C-S-H by magnesia (Julie, 2008). Therefore, this is the most disruptive form of sulphate attack and more disruptive than either calcium or sodium sulphate (Julie, 2008).

Mg2+SO42-+Ca(OH)2+ 2H2O → Mg(OH)2 (s) + CaSO4•2H2O ……2.7

This additional salt is also called brucite (Mg(OH)2 (s).

In this environment, the stability of C-S-H is reduced and its decomposition begins. At a progressed stage of the attack, "all the calcium content of the binder may be substituted bymagnesium,non-cementitious magnesium silicate hydrate (M-S-H) is thus produced until equilibrium is reached causing disintegration of the paste (Julie, 2008).

Table 2.3: Degree of Severity of Magnesium Sulphate

Severity of	Water –	Sulphate (SO_4)	w/cm by mass,	Cementitious

Potential Exposure	soluble Sulphate (SO_4)	in Water, ppm	max	material requirements
Class O Exposure	0.00 t0 0.10	0 to 150	No special requirements for sulfate resistance	
Class 1 Exposure	>0.1 and < 0.2	> 150 and < 1500	0.5	C 150 Type II or equivalent
Class 2 Exposure	0.2 to< 2.0	1500 to < 10,000	0.45	C 150 Type V or equivalent
Class 3 Exposure	2.0 or greater	10,000 or greater	0.40	

Source : Julie, 2008

2.8.3 Methods of Controlling Sulphate Effects on Concrete

According to Shetty (2009)the following steps may be adopted for controlling effects of sulphate on concrete:

(a)Use of Pozzolana : replacing part of cement by some pozzolanas reduces the sulphate attack. Incorporation of pozzolanic material into the concrete convert the leachable calcium hydroxide ($Ca(OH)_2$) into insoluble non leachable cementitious product. The pozzolanic action improves the impermeability of concrete. The reduction in $Ca(OH)_2$ reduces the possibility of sulphate attack on concrete.

(b)Use of Sulphate Resistance Cement : In order to control or resist the sulphate effects on concrete the most effective and sufficient method is the use of low calcium aluminates (C_3A).

(c)Quality of concrete: A well designed, prepared dense and impermeable concrete exhibits better resistance to sulphate attack. Similarly a concrete prepared with reduced water cement ratio exhibits a higher resitance to sulphate.

(d) The Use of High alumina Cement : The use of high alumina cement has been found to check the sulphate attack partly due to the absence of any free $Ca(OH)_2$ in the set concrete in contrast to Portland cement.High alumina cement contains approximately 40% aluminate.

(e)Quality Concrete : A well designed placed and compacted concrete which is dense and impermeable exhibit higher resistance to sulphate attack, also concrete with low water cement ratio also offer higher resistance to sulphate attack.

(f) Use of Air Entrainment : Use of air entrainment around 6% has beneficial effects on the sulphate resising qualities of concrete.

(g)High pressure Steam Curing : High pressure steam curing improve the resistance to sulphate attack.

2.9 Pozzolana

Pozzolana are siliceous materials which though not cementitious but contains materials which when combine with lime at ordinary temperature in the presence of water to form a compound which have low solubility and posseses cementing properties. In other words Pozzolana is a siliceous and aluminous material which in itself possesses little or no cementitious quality, but will, in finely divided form and in presence of moisture, chemically reacts with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (Karim, Hussein, Khan, Zain, Jamil and Lai, 2014).

2.9.1 Types of Pozzolana

Pozzolanas can be divided into two groups:

natural pozzolana (such as volcanic ash and diatomite) artificial pozzolana (such as calcined clay, pulverized fuel ash, and ash from burnt agricultural waste). Many plant ashes have high silica content and are therefore suitable as a pozzolana **(**Tsado, Yewa, Yaman, and Yewa, 2014).

Table: 2.4 Types of Pozzolana

Natural Pozzolana	**Artificial Pozzolana**
Clay and Shale	Fly ash
Opaline Charts	Blast Furnace Slag
Diatomaceous Earth	Silica fume
Vulcanic tuffs and Pumices	Rice Husk Ash
	Metakaoline

Source : Shetty (2009)

2.9.2 Coconut Shell Ash

Many researchers have made efforts for preparing carbon black from agricultural by-products such as coconut shell apricot stones, sugarcane bagasse, nutshells, forest residues and tobacco stems. Coconut shells have little or no economic value and their disposal is not only costly but may also cause environmental problems. Coconut shell is suitable for preparing carbon black due to its excellent natural structure and low ash content. Conversion of coconut shells into activated carbons which can be used as adsorbents in water purification or the treatment of industrial and municipal effluents would add value to these agricultural commodities, help reduce the cost of waste disposal, and provide a potentially cheap alternative to existing commercial carbons (Vignesh *et al.*,2014). Coconut shell is a carbonaceous material which has aninherently strongstructure and contains a high fixed carbon content (about 21%) with very low ash content (less than 1.0 wt%) (Juejun, Supunnee, and Chaiyot, 2013).

2.9.3 Properties of Coconut Shell Ash

Coconut shell ash is a very fine material. The average particle size of Coco nut shell ash ranges from 5 to 10µm, coconut shell ash is rich in silica content, it is generally around 40%. For coconut shell ash to be used as pozzolana in cement and concrete .It must satisfy the chemical composition of pozzolana according to ASTM C618. The combined proportion of silicon dioxide (SiO_2),Aluminium Oxide (Al_2O_3) and iron oxide ($Fe2O_3$) in the ash should not be less than 70% as stipulated in the ASTM requirement.

2.9.4 Pozzolanic Reaction of Coconut Shell Ash

According to Utsevu and Taku (2012) research indicates that most materials that are rich in amorphous silica can be used in partial replacement of cement. It has also been established that amorphous silica found in some pozzolanic materials reacts with lime more readily than those of crystalline form. Use of such pozzolanas can lead to increased compressive and flexural strengths. The American society of testing materials (ASTM) defines Pozzolans as siliceous or aluminous materials which possess little or no cementitious properties but will, in the presence of moisture, react with lime [$Ca(OH)_2$] at ordinary temperature to form a compound with pozzolanic properties. Examples of pozzolans include class C fly ash, which contain more than 10% CaO, blast furnace slag and silica fumes . ASTM C 618 – 05 specifies that any pozzolana that will be used as a cement binder in concrete requires a minimum of 70 % silica, alumina and ferric oxides. BS 3892: (1965) parts 1 and 2 specify a maximum loss on ignition of 12%, maximum MgO content of 4% and SO_3 of 2.5% respectively (Utsevu and Taku, 2012).

2.9.5 Pozzolanic Strength requirements

According to Vignesh*etal.* (2014) the pozzolanic activity index of coconut shell ash at 28 days is about 94% of the strength developed by the control samples. According to ASTM C 618 1978, The rate of reaction and strength of pozzolana increases with rise in temperature and this is the behavior of pozzolanic cement, pozzzolans concrete that developed about 56% and 66% at at 7 and 28 days of the strength gained by the OPC when both were cured under adiabatic conditions with rising temperature. However at lower temperature the rate of strength development of pozzolan is lower compared with control, it has been reported that the onset of the pozzolanic reaction of fly ash at the curing temperature of 20^{o}C is at 28 days or longer, and the pozzolanic reaction of fly ash in cement paste highly depends upon the curing temperature. The strength developed at any age depends on percentage replacement of OPC with pozzolan, the type of pozzolanas and mineralogical composition of the pozzolana(Mongkhon and Toyoharu,2014). According to alp, Devecci, Sungun, Yilmaz, Kesimal and Yilmaz (2009) it was reported that despite the lower early concrete strengths, the addition of natural pozzolan (up to 20-30%) could also improve the compressive, splitting and flexural strengths of the concrete in the long term, for example, over a 365 day period.

2.9.6 Pozzolanic Reaction Mechanisms (CSA)

The fundamental property of pozzolans is its ability to react with lime (Edwin and Dustan, 2012). When mixed with lime and water, pozzolans react with portlandite forming hydration cements similar to those found upon hydration of PC and hydraulic limes. Pozzolans accelerate the slow hardening process (carbonation) of calcium limes by imparting a hydraulic set. Utsevu and Taku (2012) observed that coconut shell ash behaves as more or less inert material and serves as precipitation nucleus for lime and calcium silicate hydrate gel originating from OPC

hydration. Pozzolanic reaction is slow, thus early strength does not increase, however, when combined in the right ratio, pozzolans increase the ultimate strength of lime composites, the compressive strength at 2 years can be as high as 3 times the 28-day strength (Walker and Pavĺa, 2012). As suggested by Neville and Brooks, (2008) the pozzolanic reaction starts when the glassy portion of the pozzolanic particles dissolves.

2.9.7 Chemical Composition of Pozzolana (Coconut Shell Ash)

The chemical composition of pozzolana (Coconut Shell Ash) satisfy the requirements according to ASTM C618. The combined proportion of silicon dioxide (SiO_2), Aluminium Oxide (Al_2O_3) and iron oxide ($Fe2O_3$) in the ash should not be less than 70%. However, Researches have shown that the properties of coconut shell ash vary depending upon factors like pre treatment, burning condition and calcination temperature, as it can be seenin table (2.4) the chemical composition of coconut shell ash processed by vignesh*etal.* (2014) and Utsevu and Taku (2012) are similar, The former deed controlled calcinations between 600^0C and 800^0C while the later deed open air burning, while Madakson*et al.*(2010) calcined his at 1300^0C and this condition also affect the silicon contents. Coconut Shell Ash can withstand temperature up to 1500^0C(Madakson*et al.*,2010).According to Vignesh *etal.* (2014) ash obtained from burning of coconut shell has been confirmed to be pozzolanic with pozzolanic index of 94 %. The total content of silicon dioxide (SiO_2) Aluminium oxide (Al_2O_3) and Fe_2O_3 was approximately 77.567%, which exceed the minimum requirement of 70% specified by ASTM C 618.

Table 2.5: Chemical Composition of Pozzolana (CSA)

Chemical constituents	Apasi	Kumar	Vignesh	Utsevu
Silica [$S10_2$]	45.05	37.97	37.97	37.97

AluminiumOxide [Al_2O_3]	15.6	24.12	24.12	24.12
Iron oxide [Fe_2O_3]	12.4	15.48	15.80	15.48
Calcium Oxide [CaO]	0.57	4.98	4.98	4.98
MagnessiumOxide[Mgo]	16.2	0.81	1.89	0.81
Sodium oxide [Na_2O]	1.12	0.95	0.95	0.95
Pottassium oxide [K_2O]	3.68	0.83	0.83	0.83
Sulfur oxide [SO_3]	0.24	0.71	0.71	0.71
Lead oxide [P_2O_5]		0.32	0.32	0.32
Loss on Ignition	8.55	11.94	11.94	11.94

Source (Madakson*et al.,* 2010: Kumar and Kumar, 2012: Vigneshi *etal,* 2014 : Utsevu and Taku, 2012).

2.9.8 Heat of Hydration of Pozzolana

Conventional concrete is made of cement, water and aggregate (Olubisi, 2013). Generally speaking, cement plays the most important role in affecting most of the properties of concrete. When cement is mixed with water, a series of chemical reactions occur. These reactions are called hydration, and for cement this hydration is an exothermic process (Mukeshi*et al.,*2009). The compounds of cement, being produced at very high temperatures, are in a state of high energy. Upon reacting with water they form more stable hydration products with lower energy, while the rest of the energy stored in the clinker compounds is released as heat. This heat, called the heat of hydration of cement, is important for many aspects of concrete use such as mass concreting, hot and cold weather concreting and for determining the degree of hydration (Derya, 2012).

Cements are composed of different constituents and different compounds of varying proportions. Therefore, the hydration process is complex. The setting is affected by the phase composition, presence of foreign ions in the individual components, fineness, water content, ambient temperature and presence of admixtures and additives (Mehta and Monteiro, 2006). Utsevu and Taku conducted research on the setting time of cement that contains coconut shell ash as partial replacement of cement and discovered that the initial setting time and final setting increase with increase of coconut shell ash content. According to ASTM C 192; 1990, there are two stages in the hardening of pozzolanic cements, firstly it is the hydration of Portland cement minerals, second is the interaction of the active pozzolana with the calcium hydroxide released during the hardening of the OPC, hydration takes a longer period of time for pozzolanic cement, more curing days are usually observed in order to maximize the full potentials of pozzolana (Walker and Pavĺa, 2012).

2.9.9 Particle Size Distribution of Pozzolana

The pozzolanic materials must consist of siliceous or alumino-siliceous materials in finely divided form. In the presence of moisture, siliceous or alumino-siliceous chemically reacts with calcium hydroxide (formed by the hydration of Portland cement) to form compounds possessing cementing properties. Some researchers (Obilade,2016: Chimwuba, Catherine and Grace, 2013). Studied the feasibility of using RHA for a pozzolanic materials due to RHA has a high silica content and high porosity. However good Pozzolanic activity of RHA it must have small particle size (< 10μm) and high amorphous SiO_2 content (80 – 90% by weight). The ASTM C 618 defines that the pozzolanic materials class N and F should have SiO_2+$Al2O_3$+Fe_2O_3 more than 70%. The properties of cement-based solidification, such as compressive strength, leachability,

depend on composition ratio and particle size of Portland cement and pozzolanic materials (Piya, Penjit, Premrudee and Supamas, 2015).

According to Aka(2011) the particle size distribution of pozzolana is important in hydration process, the rate of hydration of hydration depends on the finness of a pozzolan particles and for rapid development of strength, a high fineness is necessary, fineness is one of the most important properties of pozzolana. BS 12(1992) gives the minimum specific surface area of pozzolanas as 2500sq.cm/g, which is close to that of OPC of 2250 sq.cm/g. This properties is important because fineness enhances the reactivity of pozzolans. The ground POFA (Pulverized Fly Ash) with high fineness of 10 μm can be used to produce high- strength durable concrete higher than that of control concrete and POFA 45 concrete (Mohammad, Mohammad, Ahmad and Khairunisai, 2009).

2.9.10 Reactivity of Pozzolana

Shetty (2009) explained that in the reaction of pozzolana, calcium hydroxide, other wise, a water soluble material is converted into insoluble cementitious material by the reaction of the pozzolanic materials. The reaction can be as Pozzolaa + Calcium Hydroxide + Water+ C-S-H (Gel). This reaction is called pozzolanic reaction. The reaction is initially very slow with the consequential result that heat of hydration and strength development will be accordingly slow but faster as age advances as an ingredient in a finely divided pozzolanic admixture.

2.10 Blended Cement

Blended cement is defined as Portland cement containing other finely dividedparticles in different but well-defined proportions (Salaudeen and Leeyee, 2008). Mostrecently blended

cement based on industrial and agricultural waste, are well known fortheir improved long-term strength and durability. The blending agents are such as fly ash (FA), ground granulated blast furnace Slag (Slags), rice husk ash (RHA), palm oil fuelash (POFA), SF (SF), coconut shell ash (CSA) calcined clay etc. It is reported to improve rheology andcohesiveness, lower heat of hydration, lower permeability and higher resistance to chemical attack. In some cases, a boost in early strength becomesapparent, while in others, an increase in later strength occurs .In recent years, the applications of blended cements have been further extended(Salaudeen and Leeyee, 2008).

2.10.1Binary Blended Cement (BBC)

BBC system is Portland cement blended with single mineral admixture in producing cementitious material in well-defined proportions. This system was firstly approached as the basic strategies to restructure the cement industry into environmentally compatible (Salaudeen and Leeyee, 2008).

2.10.2Multi blended cement

The combination of two or three kinds of mineral admixtures has emerged as a superior choice over single admixture to improve concrete properties. Currently, the information pertaining to the multi and ternary blended systems and their practical used is rather limited. However, the multiple binder combinations is now an option which can be seriously considered for conventional structural concrete. The use of ternary binder concrete has been implemented in major infrastructure project such as the Stoerbelt bridge/tunnel in Denmark and the Chek Lap Kok bridge, linking to the new Hong Kong airport The common additional binder materials such as PFA, SF, slag, and RHA are now well established. Usually these individual pozzolanic materials possess different properties and reacts differently in the presence of water (Salaudeen and Leeyee, 2008).

2.11Properties of Blended Cement Concrete

Various studies have been carried out to determine the various properties of Blended Cement Concrete.

2.11.1 Fresh Properties ofPozzolana Blended Cement Concrete

(a) Setting time of pozzolana blended cement

Utsevu and Taku (2012) conducted research on the setting time of blended cement tnat contains coconut shell ash as partial replacement of cement they reported that setting time increases or delay as level of replacement increases. Vigneshi *et al.* (2014) made similar discovery, However kwabena attributed the cause of delay setting and hardening to slow reaction rate of the active pozzolana constituents with the liberated $Ca(OH)_2$ from the Portland cement (Kwabenna, 2012).

(b) Workability of pozzolana blended cement

Sadaqat, Muhammad, Tehmina and Nasir (2014) conducted research on the effects of different pozzolana on the workability of concrete and reported that slump loss in concrete increase with increase in quantity of Fly ash, he also reported that Silica Fume reduces the workability of concrete. According to Osei and Jackson (2016) workability and slump of blended concrete reduce with increase in replacement and attributed the cause in loss of slump and compacting factor to consumption of water by the pozzolana according to Sanusi (2014) the reason for lower slump is attribute to absorption of the mixing water by the pozzolana.

2.11.2Hardened Properties of Blended Cement Concrete

(a) Curing of Pozzolanic Blended Cement Concrete

Pozzolanic blended cement concrete develop low early strength due to delay hydration process (Mukeshi*et al.*, 2009). Prolonged periods of moist curing for concrete containing flyash are important are important for adequate strength development, poorly cured flyash concrete exhibited greater strength losses than conventional concrete especially at higher temperature (Muhammad, Steeve, Stephanie, 2009). Pozzolanic cement concrete requires long curing over a comparative period of time (Alhaz, Mohammed, Habir, Noor, Sadiq and Shahinnu, 2012). Vignesh *et al.* (2014) conducted research on the suitability of replacement cement with Coconut Shell Ash it was concluded pozzolanic cement concrete requires curing over a long time.

(b)Abrasion Resistance of Blended Cement Concrete

The influence of FA on the abrasion resistance of concrete has been investigated extensively. Generally, there is no obvious improvement of abrasion resistance by FA. Some studies revealed that partial replacement of portland cement by FA decreases the abrasion resistance due to a loss of compressive strength, Some other studies found that at certain FA replacement level, the abrasion resistance of FA concrete is comparable to the control concrete. Emiley (2014) reported an improved abrasion resistance of FA concrete when FA is used to partially replace cement according to (Abol, 2012:Jose, Klebe, and Aline, 2010). Abrasion Resistance of concrete is dependent on strength of concrete. Recent studies have shown an improvement on the performance of concrete subjected to abrasive environment when fly ash is used as a cement substitute due to the increase in strength as concrete matures (Jose and Radu, 2007). Concrete Strength is the governing factor affecting the abrasion resistance of concrete, In general an increase in compressive strength is accompanied by an increase in abrasion resistance (Emiley, 2014). King (2012) conducted research on the abrasion resistance of silica fume concrete he

attributed the reason for the increase in abrasion resistance to increase in strength and increase in bond between the matrix and aggregate.

(c) Sorptivity and Water absorption Capacity of Blended Cement Concrete

Sorptivity is an index of moisture transport into unsaturated specimens, and recently it has also been recognized as an important index of concrete durability, During sorptivity process, the driving force for water ingress into concrete is capillary suction within the pore spaces of concrete, and not a pressure head (Zhang and Zong, 2014). It was explained that concrete permeability depends on water absorption. Kartini, Mahmoud and Hamidah (2010) conducted experimental research on the absorption and permeability of RHA they concluded that RHA improves the durability of concrete. The time taken for the capillary suction for the RHA concrete is longer as compared to OPC and attributed the cause densification of the pores by through pozzolanic activities. Jayesh and Umrigar (2013) conducted experimental research on the water absorption and sorptivity of fly ash concrete shows lower water absorption and sorptivity at 10% replacement with fly ashfor M25 and M40 grade concrete. There after the water absorption and sorptivity showsan increasing trend. Esam, Amr, El Hefnawy and Rania (2014) conducted research on sorptivity and water absorption of concrete samples that contain silica fume and concluded that samples that contains silica fumes have lower sorptivity index compared to concrete samples, They also emphasize on the important of adequate curing on sorptivity, the better the curing the lower the sorptivity.

(d)Resistance of blended cement concrete to sulphate attack

Sulphate are chemicals salts that are dissolved in water to form solution. According to Gupta and Gupta (2012) they are found in the soil as calcium, potassium, sodium and magnesium Sulphate, Magnessium sulphate is the most destructive compared to other sulphates because it decomposes the hydrated calcium silicate as well as calcium hydroxide $Ca(OH)_2$ and hydrated tricalcium to form hydrated magnesium silicate which has no binding properties (Gupta and Gupta, 2012). Vedalakhshimi,*etal.*(2005) exposed blended cement concrete and conventional concrete to magnesium sulphate attack noted that there was initial increase in the compressive strength of conventional concrete he explained that the initial increase in compressive strength was mainly contributed by the densification of the pore structure by the precipitation of hydrated cement products as well as expansive products such as gypsum and ettringite within the voids and micropores. However after 21 months of exposure there was significant decrease in compressive strength of OPC cement concrete this shows that sulphate attack has became more dominant In the case of blended cement concrete, sulphate attack was not initiated because of the reduced diffusion of sulphate ions.

Ramezani *etal.*(2013) conducted research on the effects of Magnessium Sulphate on Plain and Blended Cement and reported that all concrete samples showed a continuous increase in compressive strength up to 2 months except control specimens. The first increase in strength may be attributed to two types of reactions: (I) the continuous hydration of unhydrated cement components to form more hydration products, in addition to the reaction of RHA (in case of blended cements) with the free lime to form more C-S-H leading to increased compressive strength and (II) reaction of sulfate ions with hydrated cement components to form gypsum and ettringite. At earlier ages, these two reactions lead to a denser structure. Whereas, at later ages,

the second type of reactions (sulfate attack) become more dominant leading to the formation of microcracks and this decreases the strength.

(e)Compressive Strength

Vigneshi *et al.*(2014) conducted research on the compressive strength of coconut shell ash blended concrete that cont and reported that 10% replacement gives highest strength of 31.78 N/mm^2 at 28 days Utsevu and Taku (2012) recommended 10 and 15% replacement have strength of 31.78 N/mm^2 and 23.23 N/mm^2 respectively after 28 days curing. However none of the concrete samples attain the same compressive strength as the control sample after 28 days curing. Kwabenna (2012) conducted experimental research on the compressive strength and setting time of pozzolan he explained that pozzolana cements are noted for their slow strength development resulting in low early strengths. For replacement level up to 30%, the strength at ages about 3 to 6 months will often exceed that of Portland cement concrete. They also exhibit slow rate of setting and hardening. These undesirable properties rise from the slow reaction rate of the active pozzolana constituents with the liberated $Ca(OH)_2$ from the Portland cement (Kwabenna, 2012).

Alhaz *et al.* (2012) conducted research on five different brands of pozzolan and concluded that the compressive strength of five different compositions cement increased withincreasing curing time. Adequate curing at early ages as well as at later ages is essential in thestrength development of PCC concrete. Numerous researchers have reported that mineral admixtures require a relatively long curing period for the favourable pozzolanic effect on the performance of concrete to be realized (Zhang and Zong, 2014).

2.12 Admixtures

Concrete is strong in compression but weak in tension. In order to make desirable changes in properties of concrete various studies have been carried out with the use of admixtures (Rahul, Gupta and Babita, 2016). Admixtures are the ingredients other than the key ones that are added during the process of mixing concrete to adjust to different atmospheres and at different steps of construction to make the process convenient. Adequate precaution during the use of admixtures should be taken as they should not affect the strength of concrete. They should be environment friendly and easily degradable. Some of them are available in natural state and few are being obtained through scientific processes. Admixtures can be classified into Mineral Admixture, Chemical Admixture (Zayed, 2016).

2.12.1 Mineral Admixtures

Mineral admixtures are inorganic in nature that has pozzolanic or hydraulic properties. These fine grained materials are added to the mixture to improve concrete properties or as replacement of cement. Various types of mineral admixtures are fly ash, ground granulated blast furnace slag (GGBS), Silica Fume (SF), High Reactivity Metakaolin (MK), Rice Husk Ash (Rahul *et al.*, 2016).

2.12.2Chemical Admixtures

According to Zayed(2016) an admixture is defined as “a material other than water, aggregates, hydraulic cementitious material, and fiber reinforcement that is used as an ingredient of a

cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing," and a chemical admixture is defined as "an admixture in the form of a liquid, suspension, or water-soluble solid (David and James, 2003).

2.12.3Types of Admixture

(1)Plasticizers (2) Superplasticizers (3) Retarders and Retarding Plasticizers (4) Acceleators and Accelerating superplasticizers (5)Air entraining Admixture (6) Damproofing Admixtures and Water Proofing Admixture (7)Gas foaming Admixture (8)Air detraining Admixture (9) Alkali Aggregate expansion inhibiting Admixtures (10) Workability Admixture (11) Grouting Admixture (12) Corrosion Inhibiting Admixture (13) Bonding Admixtures (14) Fungicidal, Germicidal Inhibiting Admixture (15) Colouring Admixture (Shetty, 2009).

2.13Permeability Reducing Admixture

Permeability reducing admixture is added to the concrete mix and can be in liquid form or powdered form and are introduced into the concrete mix according to the manufacturer's specifications which is 2% the weight of cement (AC1 212 3R, 2010).Permeability Reducing Admixtures are chemical admixtures used to protect concrete from the damaging effects of water and water borne chemicals. PRAs are a distinct tool for making durable concrete, and compliment rather than replace other tools such as Supplementary Cementitious Materials Supplementary Cementitious Materials (SCMs).

With proper selection and use, PRAs have been used to replace surface applied sealers, water repellents and membranes. Often referred to as "integral systems" (Yuers, 2013). Although

some researchers question the effectiveness of these admixtures in the long term (NPCT, 2014). These admixtures claim to provide concrete with lower permeability, lower water absorption, slower ingress of aggressive elements, reduced drying shrinkage, and the self-healing of minor cracks (NPCT, 2014). Like all additives, these materials may have side effects on other properties of the mixture, such as extended setting time and reduced strength (NPCT, 2014).

2.13.1 Types of Permeability Reducing Admixture

(i) Permeability Reducing Admixture for Hydrostatic (PRAH): for concrete exposed to hydrostatic conditions (PRAH) : PRAs for concrete exposed to hydrostatic conditions (PRAH).PRAH Permeability Reducing Admixture under hydrostatic pressure are intended for use under in concrete exposed to hydrostatic pressure and are sometime called water proofing admixture, they provide the highest level of water resistance and are suitable for permanently damped or submerged environments, PRAHs use a pore blocking mechanisms that is stable even under high hydrostatic pressure. Typical application include installed underground, tunnels and water reservoirs (ACI, 2013).

(ii) Permeability Reducing Admixture for Non hydrostatic Pressure (PRAN) : PRAs for concrete exposed to nonhydrostatic conditions (PRAN).PRANs Permeability Reducing Admixture under non hydrostatic pressure and are sometime called damproofing admixtures, most PRANs contain water repellent chemicals that shed water and reduce water absorption into the concrete. Water repellent ingredients can include various soaps, oils and long fatty acids derivatives . Other PRANs are based on finely divided solids such as tal, bentonite, colloidal silica and silicates. These fillers reduce water migration through pores, although not to the same degree as PRAH and are some times called densifier (ACI, 2013).

2.13.2 Advantages of Permeability Reducing Admixture

PRAs provide integral protection against water and chemicals throughout the full depth of a concrete element(Yuers, 2013).

PRAs can eliminate the labor needed to apply surface protective systems.

PRAs are not vulnerable to surface damage.

The installation of PRAs is less affected by environmental factors (particularly rain)

Depends on the PRA, but may include:

Reduced chemical ingress

Reduced corrosion of steel reinforcement

Reduced efflorescence

Reduced drying shrinkage

Enhanced autogenous sealing of cracks

It is recyclable

2.13.3 Categories of Permeability Reducing Admixture

Depending on the manufacturer, PRAs include, but are not limited to, materials from one or more chemical families. They are as follows:

(a) Hydrophobic or water-repellent chemicals: Hydrophobic or water-repellent chemicals are the largest group and include materials based on soaps and long-chain fatty acid derivatives, vegetable oils (tallows, soya-based materials, and greases), and petroleum (mineral oil, paraffin waxes, and bitumen emulsions). These materials provide a water-repellent layer along pores in the concrete, but the pores remain physically open.

(b) Finely divided solids **:** Finely divided solids include materials such as inert and chemically active fillers (talc, bentonite, silicious powders, clay, hydrocarbon resins, and coal tar pitches) and chemically active fillers (lime, silicates, and colloidal silica). Fine solids act as densifiers and physically restrict the passage of water through the pores, some authors include SCMs in this category as well (Saurabh and Ghadge, 2016).

(c) Crystalline materials : Crystalline materials consist of proprietary active chemicals provided in a carrier of cement and sand. The hydrophilic nature of these materials causes them to increase the density of calcium silicate hydrate (CHS) and/or generate pore-blocking deposits thatresist water penetration.

2.13.4 Properties of Permeability Reducing Admixture

(a) Create waterproof concrete without the need for addition membranes or perhapssupplemented with additional protection is certain instances.

(b) Result in a concrete that is durable to environmental degradation, primarily through reduction in permeability, diffusivity and sorptivity on the various size scales mentioned but perhaps also providing supplemental chemical protection.

(c) Result in no major side effects to the concrete, i.e. will not seriously affect concrete properties in a negative manner.

(d) Have the ability to self-heal cracks, (although sealing of larger dynamic cracks maybeimpractical) and ideally reducing the amount cracking and other defects, be able to transmit vapour where required (Patrick, 2000).

(e) Be practical, in that it is not overly expensive either from an initial capital cost or a life cyclecost perspective.

(f) Permanent – ideally, the treatment would not need to be repeated in the future (Patrick, 2000).

2.13.5 Applications

PRAs can be incorporated into virtually any concrete mixture. Usage of these admixtures, however, is usually limited to structures that will be exposed to moisture, salt, salt water, wicking, or water under hydrostatic pressure (Yuers, 2013). Prevention of water-related problems such as water migration, leaking, freezing-and-thawing damage, corrosion, carbonation, and efflorescence are reasons to choose a PRA.

PRAHs are incorporated in concrete structures such astunnels and subways, bridges and dams andrecreational facilities such as aquatic centers.These materials in a properly proportioned mixture with a *w*/*cm* of 0.45 or less can generally withstand aggressive environments withexposure to salt spray and some chemicals (Mukeshi *et al.*, 2009).

2.13.6Mechanism of Permeability Reducing Admixture (Crystalline)

The crystalline material waterproofing effect in concrete is achieved by the reaction of various chemical components contained in the solution when combined within the concrete matrix the process only works when the porous system of concrete reaches a sufficient level of moisture and has open character, which is typical for the concrete of lower grades.

Crystalline materials in principle work so that the chemical components react with a cementitious matrix in the process of hydration with the temporary formation of $Ca(OH)_2$ and the

subsequent formation of disilicate and polysilicate anions. It is probable that the cumulative process is accompanied by the formation $3Ca{\cdot}2SiO_2{\cdot}3H_2O$, together with the creation of 3Ca·2SiO2·3H2O. The product of this chemical reaction is the growth of needled-shape crystals change in the pore structure of concrete, which result in water proofing effects.These crystalline deposits develop throughout the depth of the concrete and become a permanent part of the concrete mass. The crystalline deposits resist water penetration against hydrostatic pressure, and can be categorized as PRAHs. As hairline cracks form over the life of concrete,crystalline admixtures continue to activate in the presence of moisture and seal additional gaps (ACI 212 3R- 10). However Mukeshi *et al.* (2009) claimed that the mechanisms of permeability Reducing Admixture is not fully understood.

2.13.7 Disadvantages of Surface Coating

Water proofing system such coating and membranes in general may due to improper workmanship and damages to the membrane, when applied on the negative side the treatment may fail due to

(a) Lower bond strength of the system than water pressure

(b) The effective vapour pressure on the system

(c) Delamination due to the vapour pressure below the membrane

2.14. Properties of Concrete Modified with Permeability Reducing Admixture.

Various has been studies have been carried out to determine the various properties of Concrete modified with Permeability Reducing Admixture.

2.14.1 Fresh Properties

(a)Setting time

The permeability-reducing admixtures tested did not significantly affect the initial and final setting time at the recommended dosages. The permeability-reducing admixtures tested did not significantly affect the initial and final setting time at the recommended dosages (NPCT, 2014). However, when the selected dosage was higher than the recommended dosage, as in one case, the setting time was significantly affected and resulted in set retardation. (NPCT, 2014). The admixture mildly decelerate the setting time of concrete and the cause can be attributed to absorption(Jiri and Eva, 2016). Robert *etal*. (2010) reported that Permeability Reducing Admixtures retard setting time significantly.

(b) Workability

Test results show that the addition of permeability-reducing admixtures mostly did not affect the workability of concrete, The permeability-reducing admixtures are mainly added into concrete for their effect on reducing and blocking the passage of water. While the admixtures make concrete more watertight, it would be undesirable for an admixture to have unexpected side effects such as on the workability. Therefore, it is recommended that mix water should be reduced to balance the amount of water in the admixture in order to maintain a constant w/cm (NPCT, 2014).

2.14.2 Hardened Properties of Concrete Modified with Permeability Reducing Admixture

(a)Strength

Improving the strength is not the aim of using permeability-reducing admixtures, and strength is not an adequate indicator of concrete durability (Jiri and Eva, 2016). However, because it is

considered to be among the performance criteria, the strength of the mixtures containing PRAN or PRAH permeability-reducing admixtures should not be less than 90% of the reference mix at 28 days, or design guidance should be provided on how to achieve specified strengths for a given product and mixture (NPCT, 2014). Mukeshi *etal*.(2009) conducted research on the effects of water proofing admixture on the hydration of cement and concluded that Permeability Reducing Admixture increases strength by 9% after 28 days curing, Robert *etal.* (2010) also made similar declaration and many manufacturers of Permeability Reducing Admixture e.g Kristol International Membrane, Aquafine and Xypex etc. However Jiri and Eva (2016) declared that concrete that contain crystalline admixture have almost the same strength with the conventional concrete after 28 days curing and requires longer period of curing before it can increase concrete strength this delay is attributed to delay in hydration process.

(b)Sorptivity

NPCT (2014) Conducted research on the sorptivity of Permeability Reducing Admixture and concluded that an overall trend is that the addition of the permeability-reducing admixtures provided lower sorptivity than the reference mixture, significantly decreased (up to 50%) the rate of absorption at the recommended dosage at both early and later ages (NPCT, 2014).

(c)Water absorption of concrete

Kim(2012) conducted research on the permeability of concrete modified with PRA he reported PRA reduced permeability by 70% he attributed the cause in the reduction of permeability to crystalline formation and pore blocking properties of PRA.

(d)Aggressive Environment

Robert *etal.*(2010) reported concrete modified with PRA when exposed to aggressive environment that contains exhibits lower expansion due to MgSO4 when compared with the conventional concrete, Mukeshi *et al.* (2009) made similar declaration and attributed the performance to the formation crystal throughout the entire depth of concrete.

2.15Properties of Concrete Modified with Mineral and Chemical Admixture (PRA)

When both chemical and mineral admixtures are added into concrete mix the process of hydration becomes much more complex but at the same time the properties of concrete especially strength and durability are modified considerably (Mukeshi *etal*., 2009).

2.15.1 Fresh Properties ofConcrete Modified with Mineral and Chemical Admixture (PRA)

(a)Setting time

Robert *et al.* (2010) Adding Permeability reducing Admixture into concrete mixture that contains blended cement retard setting time.

2.15.2 Hardened properties of Concrete Modified with Mineral and Chemical Admixture (PRA)

(a)Strength

Robert *et al.* (2010) conducted a study on the compatibility of PRA with Blast Furnace slag concrete, he concluded that PRA modified Slag concrete gave higher strength than control at all ages by 2 to 13%, he attributed the strength gained to crystallization in concrete pores resulting in a finer and denser microstructure than in the control.

(b)Sulphate Resistance

Robert *et al*.(2010) reported that PRA modified slag concrete demonstrated lower expansion than Portland cement and slag cement when exposed to sulphate the cause was attributed to formation of crystalline deposit and pore refining by the pozzolana.

(c) Water Absorption

It was reported by ACI 212 3R (2010) PRA modified Fly Ash blended cement concrete has higher resistance to permeability than plain concrete and blended cement concrete, the cause was attributed to formation of crystalline deposit and pore refining by the pozzolana ACI 212 3R (2010).

CHAPTER THREE

3.0 MATERIALS AND METHODS

This chapter gives a detail description of all the materials used in the experimental programme and the methods used for conducting the various tests.

3.1. Materials

The materials used in this research include the following: Ordinary Portland Cement, Fine Aggregate, Coarse Aggregate, Permeability Reducing Admixture, Coconut Shell Ash and water.

3.1.1 Cement

Ordinary Portland Cement was used for the experimental work (OPC, Dangote Brand) conforming to the requirement of BS EN 197-1 :(2011). The portland cement was purchased from reliable supplier along Sokoto Road in Samaru Zaria.

3.1.2 Permeability Reducing Admixture

M.B London permeability reducing admixture was used throughout the research and complieswith the requirement of ACI 212 3R- 10. The admixture was obtained from the Panteka Building materials market opposite Kaduna polytechnic Tudun wada Campus.

3.1.3 Coconut Shell Ash

The cocoanut shells were cleaned thoroughly and sundried for about 4hours and was pre heat in an open air for approximately one hour. The pre heated coconut shell were taken to Department of Industrial Design where it was calcined at temperature of 800^0C for 4hours. The calcined coconut shell was then allowed to cool after which it was sieved with 75micron sieve size, the samples that passed through 75microns sieve size were used for the laboratory work.

3.1.4 Fine Aggregate

The fine aggregate used was natural sand. It was sieved with a 4.75mm BS sieve so as to remove impurities and larger aggregates. The fine aggregate was obtained from nearby river (ABU Dam). It complies with provisions of BS EN 12620: 2013.

3.1.5 Coarse Aggregate

The coarse aggregate used were crushed gravels which were be obtained from single quarry. It is in conformity with the requirement of BS EN 12620: (2013).

3.1.6 Water

The water that was used for mixing the concrete was clean tap water free from injurious oils, chemicals and vegetable matters or other impurities and complying with the provisions of BS EN 1008: (2002)The water was fetched from tap.

3.1.7 Magnessium Sulphate

The magnesium sulphate was purchased from Steeve Moore agro chemical company along Sokoto Road.

3.2 Experimental Programme

The experiments were conducted as follows

3.2.1 Preliminary investigation

The tests carried out include the physical, mechanical and chemical properties of materials used for the research which include:

(i) Particle Size Distribution

The particle size distribution for the coarse aggregate, fine aggregate and combined aggregate was carried out using sieve analysis as described in accordance with BS 812-103.1:(1985). This was done in order to determine the grading of the aggregate.

(ii) Specific Gravity

The specific gravity of permeability Reducing Admixture, cement, fine aggregate, coarse aggregate and coconut shell ash was determined by using pyconometer method in accordance to BS 1377:2(1970). The apparatus used include density bottle and stopper, funnel, spatula and weighing balance. The relationship used to find the specific gravity is given by:

$$\text{Specific Gravity} = \frac{W2-W1}{(W4-W1)(W3-W1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

Where :

W_1= Weight of density bottle

W_2 = Weight of density bottle + Sample

W_3 = Weight of density bottle + Water (full) + Sample

W_4 = Weight of density bottle + Water (full)

(iii) Bulk Density

This was determined in accordance to BS 812: Part 2 (1995) for the permeability reducing admixture, cement, fine aggregate, coarse aggregate and coconut shell ash. The formulae below was used to determine the bulk density of the sample.

$$\text{Bulk Density} = \frac{W1-W}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Where:

W1 = Weight of container + sample

W = Weight of empty container

V = Volume of container

(iv) Water Absorption Capacity

The absorption capacity test was carried out on the aggregate (i.e. the coarse and fine aggregate). In line with BS 1881-122 (1983).

(v) Moisture Content.

This test was determined in accordance to BS 812:109 (1990). The procedure for the test was carried as stipulated by Gambo (2014).

(vii) Setting Time

The setting time of the pastes were carried out according to the procedures highlighted by ASTM C 451 -89 and the apparatus used was vicat apparatus.

vii. Soundness

The soundness test was conducted according to the method stipulated by IS 4031-part 3 1988. The apparatus used was Le chatelier apparatus.

(viii) Chemical properties

The chemical analysis was conducted at the Defence Industries Corporation of Nigeria (DICON), Kakuri Industrial Layout, Kaduna, Kaduna state of Nigeria using XRF test to determine the percentages of chemical composition of oxide such as Silicon Oxide (SiO_2), Aluminium Oxide (Al_2O_3), Iron Trioxide (Fe_2O_3) and others. To investigate if they are in line with the ASTM C 618-05 classes of pozzolana because the ASTM standard stipulated that for any material to be used as pozzolana, it should fall within the following classes Class *N*, Class *F*, Class *C.*

(vx) Loss on Ignition.

The loss on ignition of Coconut shell ash was performed in accordance to the standard specified by ASTM C 311-13 and ASTM C ASTM C 114-15. The sample was pre heat at temperature of 110^0C and fired at temperature of 950^0C for 15minutes, cool to room temperature in a dessicator and was reweighed.

$$L.O.I = \frac{W1-W2}{W2} \quad \text{.....3.3}$$

Where

W_1 = Initial weight of samples

W_2= Weight after Ignition

3.2.1 Production of Concrete Samples

(i) Mix design

Grade 30 concrete was designed because the target strength was 30N/mm^2. This was done in order to determine the mixing proportion for a particular class of strength. In this case, building research establishment (BRE) method of mix design was used for designing the grade of concrete. Details are shown in appendix C.

(ii) Mixing and casting of the concrete samples

The constituent materials required for each sample were measured and weighed on a digital weighing balance i.e cement, sand and aggregate, (Permeability Reducig Admixture and Coconut Shell Ash). After mixing the fresh concrete was cast into 100mm X 100 mm X100 mm moulds in two layers and was compacted manually by giving it 25 blows with a tapping rod in order to achieve smooth and level compaction for each sample.

(iii)Curing of Samples

Samples were allowed to set for 24hours before demoulding and immersed in a pool of water tank at 14days, 28days, 56days, 90days and 180 days. The reason for the adoption of the above curing period is that the strength development of coconut shell ash concrete is lower when compared with control samples at 28 days and below(Vignesh, *et al.*,2014), And also NPCT (2014) recommended that PRA modified concrete strength development should not be less than 90% the strength of the control at 28 days. Therefore it was assumed that the control sample specimens have higher strength at early age.

(iv)Concrete Specimens Produced

Six different specimens were produced and tested at various ages of (14, 28, 56 and 90 days). They include Specimen A which is control, Specimen B which is 2% PRA + Control, Specimen C 10% CSA, Specimen D 15% CSA, Specimen E which is 10% CSA + 2% PRA and 15% CSA + 2% PRA. The variation in the percentage replacement of cement with coconut shell ash was to have a stronger basis for comparison, A total of 342 cubes were cast for this research, Summary of the samples specimens is on Appendix E1 and E2.

3.2.2 Tests Conducted on Fresh Concrete Samples Specimens

Workability Test

(i)Slump

The slump value of the fresh concrete was measured in order to determine the workability of each mix. This was done as recommended by BS 1881-102 (1983). The apparatus used in carrying out the slump test includes steel tamping rod, base plate, hand scoop, trowel and metal cone.

(ii) Compacting Factor test

The compacting factor of fresh concrete was measured in order to determine the degree of workability and possible area of applications. This was done as recommended by BS 1881:Part 103(1947). The apparatus used in carrying out the compacting factor include the following, compacting factor apparatus, digital weighing balance, tamping rod, base plate and metal cone.

The compacting factor was determined using the formulae

$$C.F = \frac{W1}{W2} \quad \text{……..3.4}$$

3.2.3 TestsConducted on Hardened Concrete Samples Specimens

After curing the samples they were subjected to the following tests at the end of each curing ages which include:

(i) Compressive Strength Test

Compressive strength was carried out after different curing ages of 14, 28, 56 and 90 days for all the concrete samples (control, 2% PRA Samples, CSA Samples, CSA + 2% PRA Sample). A total of 72 specimens were tested for compressive strength and it was done as stipulated by ASTM C 39-05. Three cubes were tested to failure for all specimens. The maximum failure load was then recorded and the compressive strength was calculated using the relation:

$$\text{Compressive Strength} = \frac{\text{Maximum load (KN)X1000}}{CrossSectional\ \ Area}\ (\text{N/mm}^2) \quad \text{…….3.5}$$

(ii) Exposure to Chemically Aggressive Environment of Magnesium Sulphate ($MgSO_4$)After casting, the concrete samples were cured in Magnesium Sulphate ($MgSO_4$) for required hydration period of 14days, 28 days 56 and 90 days respectively before test was conducted on them. A total of 72 cubes were cured in ($MgSO_4$) with each specimen containing (Cement, 2%

PRA Samples, CSA Samples, CSA + 2% PRA Sample). Three cubes were tested and their compressive strength determined after 14days, 28days, 56days and 90 days curing age. 2.5% concentration of $MgSO_4$ was used because according to (Gupta and Gupta 2012: Thomas *etal.*, 2010) 2.5% concentration is categorized as severe attack. The relationship adopted by Ibrahim (2015) was used to achieve the quantity of $MgSO_4$ that gives the concentration, the concentration was prepared in the laboratory using chemical water dissolution method (Aka, 2011). The relationship is thus:

If 50 liters of water = 5000g by weight

5000g of water = 100% concentration

Using 2.5% concentration, the quantity of water = xg

Therefore, mathematically

$$Xg = \frac{5000\,g \times 2.5}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Therefore for every 5000g of water, 125 of $MgSO_4$was dissolved in the water.

(iii) Water Absorption Test

The water absorption test were carried out in accordance to BS 1881-122(1983). The apparatus used for carrying out the experiment include weighing balance, oven and water tank. Three specimen from each samples were placed in an oven at temperature of 105^0C for 72 hours. The specimen were then removed and allowed to cooled down to room temperature in an airtight container. The specimens were weighed (W_1) and submerged in a water tank for 24 hours. After 24 hours the specimens were removed from the water tank and were surface dried with cloth. The specimens were then re weighed and the values recorded. The results were evaluated as the

increase in mass resulting from the submersion of the concrete specimens in the water tank and expressed as the percentage of the dried specimen.

$$\text{Water absorption} = \frac{(W2 - W1)}{W2} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

Where:

W_1 = Oven dry weight of cylinder in grams

W_2 = After 24 hours wet weight of cylinder in grams.

(iv) Sorptivity test

The sorptivity can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material (Jayesh and Umrigar, 2013). Water was used as the test fluid. The cubes after casting were immersed in water for 28 days, 56days and 90days curing. The specimen size 100mm x 100mm x 100mm were dried in oven at temperature of 100 + 5 °C.

For 72hours the samples were then removed and allowed to cool in an airtight container, the samples were drowned in a water container with water level not more than 5 mm above the base of specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating (Silicon Sealant). The quantity of water absorbed in time period of 3hrs, 6hours, 24hours and 48 hours were measured by weighting the specimen on a top pan balance weighting up to 0.1 mg (W_2). Surface water on the specimen was wiped off with a dampened tissue and each weighting operation was completed within 30 seconds. Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. The cumulative water absorption (per unit area of the inflow surface)

increases as the square root of elapsed time (t)(Jayesh and Umrigar, 2013: Abalaka and Okoli, 2012). The Sorptivity test was conducted in accordance to the stipulations of ASTM C1585.

$$I = \frac{Mt}{a \times d} \quad \text{…………………………………………………………….3.8}$$

where:

I = the absorption,

Mt= the change in specimen mass in grams, at the time *t*,

a = the exposed area of the specimen, in mm^2, and

d = the density of the water in g/mm^3.

(v) Abrasion Test

Abrasion resistance is used to measure resistance of aggregate to surface wear by abrasion, it is aimed at determining the abrasion resistance of a material through sliding or scraping thus causing a wearing down friction. Gupta and Gupta, (2012) explain that abrasion value should not be more than 30% for wearing surface and 50% for other surfaces.

Each specimen was weighed and the value recorded as W_1, before the abrasion commenced. A 3.6KG weight was attached to wire brush and was used to glide the surface of each specimen upto 60 times at uniform speed (Oscillatory motion). The specimen were re weighed and the values were recorded as W_2. The weight lost was calculated by substracting the final weight from the initial weight(W_1-W_2) Percentage weight loss was determined. The result is expressed as the ratio in percentage of the loss in weight to the original weight. The test was carried out in accordance with the specifications of IS 9248 (1979).

$$\text{Abrasion Resistance} = \frac{W1 - W2}{W1} X\ 100 \quad \text{…………………………………………….3.9}$$

Where:

W=Loss in weight

W_1=Weight of the sample before Abrasion

W_2=Weight of the sample after Abrasion.

CHAPTER FOUR

4.0 PRESENTATION OF RESULTS, ANALYSIS AND DISCUSSION

4.1 Presentation of Results

The results presented in this chapter are obtained from the tests carried out on the type of materials and concrete samples used for this research. Physical properties and chemical analysis

tests for the materials used in the experiment as well as the test results for both the fresh and hardened concretes are presented and discussed in this chapter.

4.2 Physical, Mechanical and Chemical Properties of Materials

4.2.1 Particle size Distribution ofFine Aggregates

Table 4.1 depicts the result of sieve analysis of fine aggregate, 500g of fine aggregate was measured and adopted, the sieves were arranged in order of aperture (20mm, 10mm, 5mm, 2.36mm, 1.18mm, 600um, 300um, 150um and pan, weight retained was determine for each sieve size, no weight was retained on 20mm, 10mm and 5mm sieve size thus the definition of Zongji (2011) was fulfilled. 600um retained highest weight of 226g 2.36mm sieve size has the highest weight passing of 463g, 2.36mm sieve size has the highest percentage passing followed by 1.18mm sieve size and percentage passing 600um was 26.2 which fall in grade zone 1 and is applicable for structural works (Duggal, 2008).Cumulative retained weight on the pan was 500g and fineness modulus was 3.37 this is slightly above the range established by Neville and Brooks, 2010 which specifies 2.3 – 3 and any value above 3 means coarser grading, Jayesh and Umrigar (2013) got 3.35 as fineness modulus of fine aggregate.

Table 4.1: Particle Size Distribution of Fine Aggregate

BS Sieve Size	Weight Retained (g)	Weight passing (%)	Percentage passing (%)	Cumulative Retained passing%)	Fineness Modulus
20mm	0	500	100	0	0
10mm	0	500	100	0	0
5mm	0	500	100	0	0
2.36mm	37	463	92.6	37	25.87
1.18mm	106	357	71.4	143	38.75
600 µm	226	131	26.2	369	77.35
300 µm	108	23	4.6	477	97.1

150 µm	14	9	1.8	491	98.2
Pan	9	0	0	500	337.2
% F.M					3.37

Figure 4.1 presents the grading curve for combined aggregate (Coarse and Fine aggregate). It can be seen that the combined aggregate fell between zone 1 and zone 4. This means that the aggregate are suitable for general structural work. Details of the results are presented in appendix A.1.

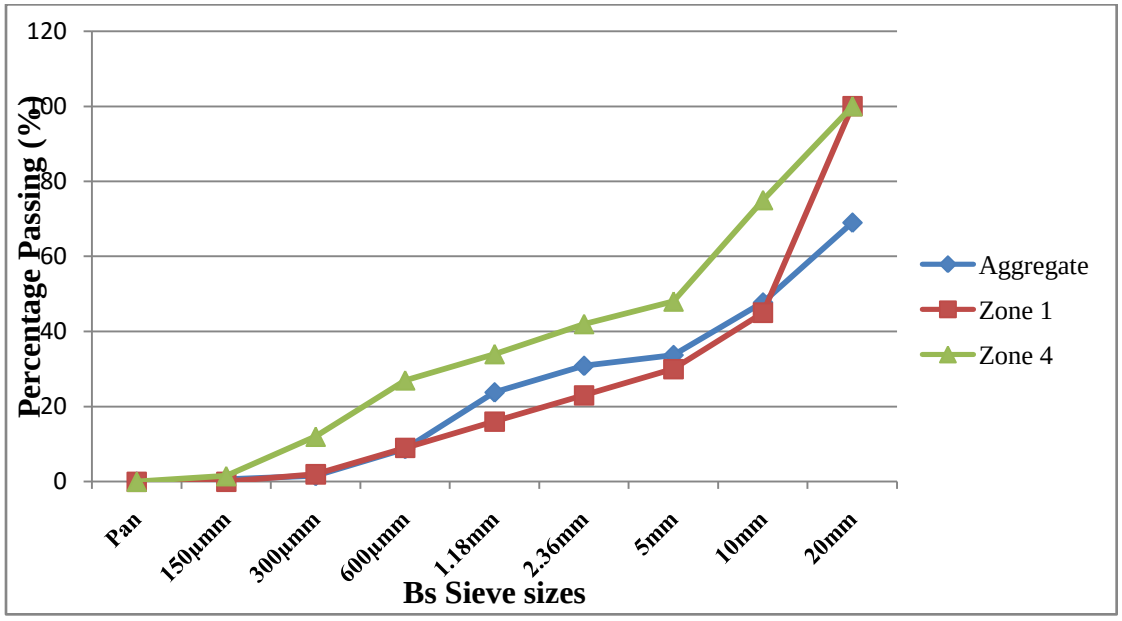

Fig. 4.1 Sieve Analysis Curve of Combined Aggregate

4.2.2 Specific Gravity of Materials

Table 4.2 shows the values of specific gravity for the aggregate (coarse and fine), permeability reducing admixture, cement and coconut shell ash. The specific gravity of coarse aggregate was found to be 2.86kg/m^3 and fine aggregate was 2.51kg/m^3. This shows that the result of specific

gravity of aggregates falls within the range of 2.3kg/m^3 to 2.9kg/m^3 respectively as specified by ACI 201 (2001) and the coarse aggregate can be classified as heavy weight aggregate because according to Duggal (2008) aggregate with specific gravity of 2.8 to 2.9kg/m^3 are classified as heavy weight aggregate. The specific gravity of cement was 3.20kg/m^3 which is slightly above the average value specified ASTM C 188 and falls within the range specified by standard, the specific gravity of PRA was 2.36kg/m^3, this value falls below the value specified by KIM, 2014 that specific gravity of PRA is 2.8kg/m^3, the specific gravity of CSA was found to be 2.23kg/$m^3$and this value is in agreement with the views of Dennis, 2003 who stated that the Specific gravity of pozzolana ranges between 2.2kg/m^3 and 2.8kg/m^3.

Table: 4.2 Specific Gravity of Materials

Sample	**Specific Gravity Kg/m^3**
Coarse Aggregate	2.86
Fine Aggregate	2.51
PRA	2.36
Cement	3.20
CSA	2.23

4.2.3 Aggregate Moisture Content, Absorption Capacity and Bulk Density

Table 4.3 present the results for aggregate moisture content, absorption capacity and bulk density of cement, PRA and CSA, 0.89% and 0.43 were obtained as moisture content of coarse aggregate and fine aggregate they both fall within the acceptable limits of 0.2-4% and 0.2-2%, the absorption capacity of 1.02% and 1.68% were obtained for the fine aggregate and coarse

aggregate they both fall within the range of 0.5%-2% and 2%-6% respectively as reported by (Hamad and Alkhoud, 2010).

The bulk density of coarse aggregate was 1498.4kg/m^3 and the bulk density of fine aggregate was 1767kg/m^3 , this shows that an equal volume of fine aggregate is heavier than an equal volume of coarse aggregate, though they both satisfy the requirements of BS 812: part 2 (1995) that states that the range of bulk density for normal weight aggregate to be between 1280 and 1920 Kg/m^3.

The bulk density of cement was 1620 Kg/m^3 and the bulk density of PRA was 1200 Kg/m^3 this shows that an equal volume of cement is heavier than an equal volume of PRA, they both satisfy the requirement that bulk density of cement varies between 830Kg/m^3 -1638Kg/m^3(Hamad and Alkhoud, 2010). The bulk density of Coconut Shell Ash is 1006kg/m^3, that is an equal volume of coconut shell ash is lower than an equal volume of cement and Permeability Reducing Admixture, andthe bulk density is lower than the bulk density of F.A which ranges between 1050-1375 kg/m^3.

Table 4.3:Summary of Preliminary Tests Results

Materials Tests	**Cement**	**F.Aggregate**	**C.Aggregate**	**C. S. A**	**P. R .A**
Compacted Bulk Density	1620	1767	1498.3	1006	1200
Uncompacted Bulk Density	1353	1233.4	1359.24	794	1196.1
Moisture Content%	0	0.89	0.43	0	0

Water Absorption	0	1.68	1.02	0	0

4.2.4 :Chemical Properties of Coconut Shell Ash

Table 4.4 shows the chemical composition of Coconut Shell Ash adopted in this Research. The major oxides detected were combined proportion of silicon oxide (SiO_2) Aluminium oxide (Al_2O_3) and Iron oxide (Fe_2O_3) with percentage value of 38.15 %, 23.94 % and 15.48% respectively this result is similar to that of Utsevu and Taku (2012) except slight difference in the percentage composition of SiO_2 and Al_2O.This means that Coconut Shell Ash satisfies the requirement of ASTM C 618-05 that specifies that the minimum requirement for class F pozolana should not be below 70% Silicon oxide, Aluminium oxide and Iron oxide, The summation of the composition of the three major elements exceeded 70% i.e ($SiO_2$38.15 %, + $Al_2O_3$23.94 % + , $Fe_2O_3$15.48% = 77.57%), The high silicon content shows that it is an active pozzolana this agrees with the views of Walker and Pavia (2012)that pozzolana with high siliceous compound are considered active while weak pozzolana have a low siliceous compound. The loss of Ignition is 10.3 this is below the value gotten by Utsevu and Taku (2012) and corresponds with the views of ASTM C618 that permits up to 12% loss for pozzolana.

Table 4.4: Chemical Composition of Coconut Shell Ash

Chemical Compounds	Percentage Composition (%)
Silica (SiO_2)	37.97
Aluminium (Al_2O_3)	24.12
Iron Oxide (Fe_2O_3)	15.80
Sodium Oxide (Na_2O)	4.98
Calcium Oxide (CaO)	0.81
Magnessium Oxide (Mgo)	0.95
Potassium Oxide (K_2O)	0.83
Sulfur Oxide (SO_3)	0.71

P_2O_5	0.32
Loss on Ignition (LOI)	10.3

4.3Results ofTests conducted on Fresh Concrete Samples Specimens

4.3.1 Setting Time of Cement Pastes (Samples Specimens)

Table4.5 presents the result of setting time test and soundness test of different cement pastes samples. The control has least initial setting time and final setting time of 113 minutes and 188minutes respectively, the initial setting time and final setting time increases as the percentage replacement of cements with coconut shell ash increases (Pozzolana) this is as a result of absorption by the Coconut Shell Ash and delayed Hydration.

The permeability reducing admixture do not have adverse effect on the initial setting time and final setting time of the mix but resulted in mild retardation of the mix. The specimens that contains CSA and PRA (PRA modified blended cement) delayed initial and final setting time, and the effect increases as the percentage replacement of cement with CSA increases, this could be attributed to the combined effects of absorption by the pozzolana, delayed hydration by pozzolana and PRA and crystalline formation by PRA, it is expected that therefore higher strength will be developed after prolonged curing. It may be recommended that all the mixes can be used for structural work since the expansion due to soundness do not exceed 10mm.

Table : 4.5. Setting Time and Soundness Test Result
Effects of C.S.A and P.R.A in Cement Mortar

Sample	Replacement	IST	FST	Water (g)	Soundness
A	0	113	188	126	1
B	5	181	245	130	1
C	10	202	310	133	2

D	15	238	326	138	3
E	20	248	356	145	3
F	25	268	415	155	3
G	PRA	121	195	125	1
H	10+PRA	240	318	130	2
I	15+PRA	258	366	142	2

4.3.2. Slump of Samples Specimens

Figue 4.2 shows the result of workability determined by slump test method the control has slump of 55 mm the samples that contains 2% PRA had 48mm slump 12.72% lesser than control thereby reduces the slump this is in agreement with (Kim, 2014) that reported that PRA reduces concrete slump, this can be attributed to formation of crystalline by the PRA this will make the concrete dense and more cohesive, therefore PRA modified concrete will need to be compacted and vibrated.

The specimens that contain coconut shell ash as partial replacement of cement reduces the slump of the fresh concrete and the slump reduces further as percentage replacement increases (14.5% and 27%),this finding agrees with Osei and Jackson(2012): Sadaqat, *et al.*(2014) reported that Chemically active mineral admixtures (highly reactive pozzolan) increase the cohesiveness of concrete,this can be attributed to absorption by the pozzolanasince it has smaller surface areathan cement, therefore additional mixing water will be required to maintain the same level of workability with the control specimen, it can be may be recommended that pozzolana blended cement concrete will require compaction and vibration.

The PRA modified pozzolana blended cement reduces the slump of fresh concrete and the reduction increase as the percentage replacement of cement increases (30.9% and 41.8) this can be attributed to the combined effect of delayed in hydration, absorption by pozzolana, and

formation of crystalline by PRA (complex chemical reaction) this is in accordance to the findings of Robert*etal.* (2010) that modified pozzolana blended cement reduces slump of concrete, and therefore requires more mixing water in order to achieve the same level of workability with conventional concrete, it is therefore recommended that all the concrete specimen may be used for structural work depending on the strength development required.

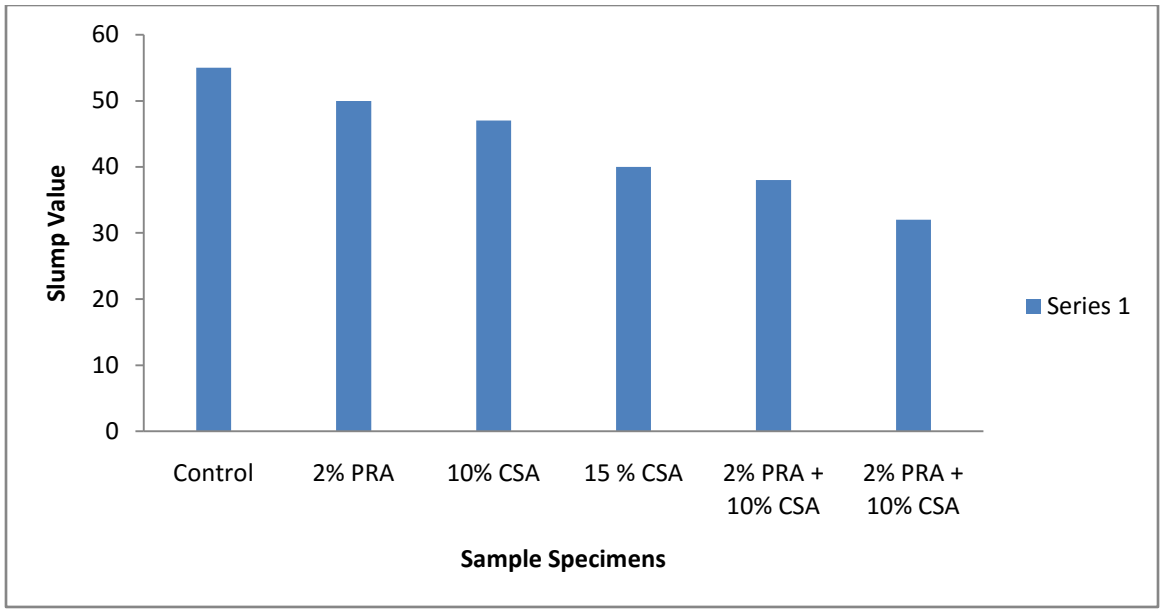

Fig. 4.2 : Slump of Samples Specimens

4.3.3Compacting Factor of Samples Specimens

The slump test correlates with the compacting factor, since the value of control mixes higher it means that it is more workable than other mixes, however none of the mixes fall below the acceptable value for structural work Usually, the compacting factor of all the mixes range between 0.92 to 0.85 this is agreement with the findings of Zongji(2011) who reported thatthe range of compaction factor is from 0.78 to 0.95 (Zongji, 2011). For the normal range of concretes the compacting factor lies between 0.8 and 0.92.the test is particularly useful for drier mixes for which the slumptest is not satisfactory, And is appropriate for concrete with a maximum size of aggregate up to40mm (Rahim, 2010). Therefore all the concrete mixes can be

used for structural works and the mixes with lower compacting factor will require additional mixing water and or compaction and vibration.

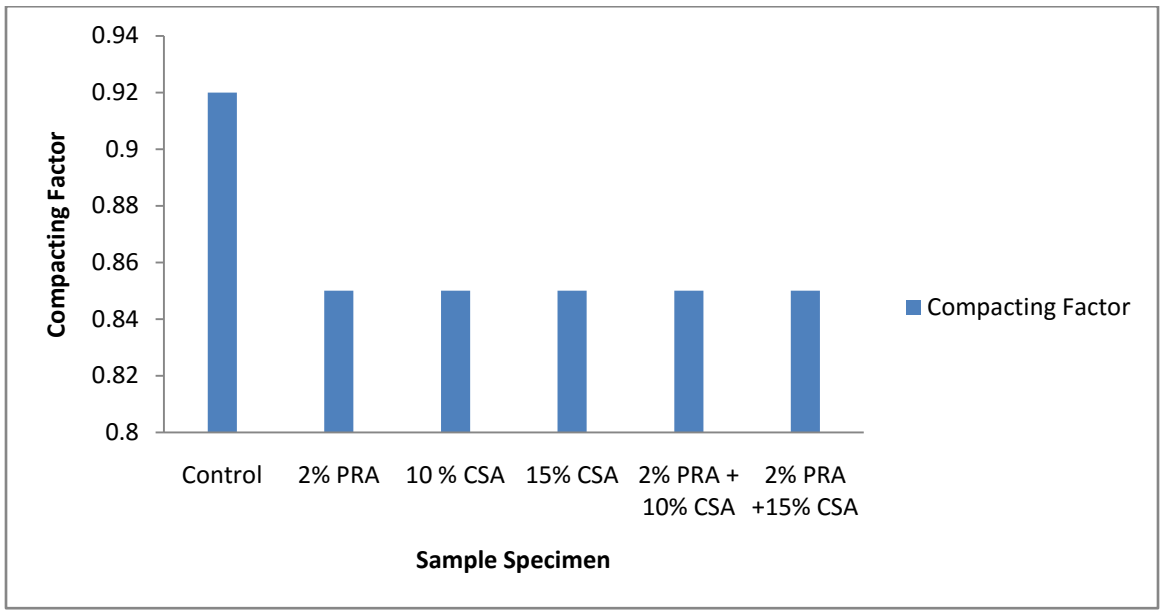

Fig. 4.3:Compacting factor of Samples specimens

4.4Results of Tests Conducted on Hardened Concrete

4.4.1 Compressive Strength of Samples Specimens

Figure 4.4 shows the compressive strength of all the sample specimens at 14 days, 28 days, 56 days, 90 days and 180 days respectively, at 14 and 28 days the control sample has highest compressive strength of 23.52 N/mm^2 and 33.85 N/mm^2.This can be attributed to the fact that strength increase at the early stage due to higher temperature during placing and setting but undesirably affect the strength at later ages while samples are continuously cured in water this can be as a result of rapid hydration process in the paste therefore the conventional concrete

develop high early strength at early age this is an agreement with the findings of (Utsevu and Taku, 2012 :Vignesh *et al.,* 2014) reported that coconut shell ash blended cement concrete have lower strength than the control, at 56 days , 90 days and 180 days the rate of strength development of the conventional concrete decrease significantly, the strength were 35.69 and 37.73N/mm^2 and 38.21N/mm^2.

The samples that contain 2% PRA developed 21.64 N/mm^2, 33.38 N/mm^2, 38.84 N/mm^2, 42.68 N/mm^{2}and 43.38 N/mm^2 at 14days, 28days , 56 days and 90 days respectively the performance indices are 92%, 98%, 1.08%, 1.13% and 1.13%, e.g early age strength is lower this is as a result of slower/delay hydration process which result in low early strength and high strength after prolonged curing, this result agrees with NPCT (2014) that reportedthat samples contains PRA should not develop strength that is less than 90% the strength of control, later age strength is higher than control samples this result corroborates with the views of Jirí and Eva(2016)It is probable that a crystalline admixture, added in an amount of 2% of the cement weight, caused a mild deceleration of the hardening of concrete (during the first 28 days) therefore resulting in low early strength. It is, therefore, likely that even though the admixture increases the compressive strength, this effect occurs later than after 28 days curing.

The samples that contain CSA (10% and 15%), the strength developed by 10% CSA are 21.21 N/mm^2, 31.84 N/mm^2, 37.71 N/mm^2, 41.46 N/mm^2 and 45.56 N/mm^2 at 14days, 28days, 56 days, 90days and 180 days respectively the pozzolanic activities index are 90%, 94%, 1.05%,1.09% and 1.18% respectively at 14 days, 28 days, 56 days, 90 days and 180 days respectively , the strength developed by 15% CSA are 16.73 N/mm^2, 27.01 N/mm^2, 32.95

N/mm^2, 39.62 N/mm^2 and 41.46N/mm^2 at 14days, 28days, 56 days, 90days and180 days respectively the pozzolanic activities index are 71%, 79%, 92% and 1.05% and 1. 08% respectively at 14 days, 28 days, 56 days, 90 days and 180 days respectively, However at 90 days and 180 days there is 5% and 8% increase in strength when compared with control, the strength gain reduces as the pozzolana content increase this can be attributed to slower consumption of $Ca(OH)_2$.The reason for low early strength can be attributed to delay hydration. The result agreed with the findings of (Vigneshi *etal.,* 2014:Utsevu and Taku, 2012). It was reported that the higher the CSA content the lower the strength development, the reason for lower early strength can be attributed to slower hydration processes at the onset of curing, therefore pozolana blended cement concrete requires prolonged curing order to maximize its full potentials.

For the PRA modified blended cement concrete, the samples that contain 10% CSA and 2% PRA developed 22.34 N/mm^2, 34.0 N/mm^2, 40.45 N/mm^2 and 46.03 N/mm^2 and 48.56 N/mm^2at 14days, 28 days, 56 days, 90 days and 180 Days respectively Mechanical activity index are 94%, 100 %, 113.3% and 122.0 % and 127.1 % respectively (13.3% and 22% and 27.1% increase at 56, 90days and 180 days), the samples that contain 15% CSA and 2% PRA developed 18.92 N/mm^2, 29.96 N/mm^2, 38.18 N/mm^2, 43.0 $N/mm^2$and 46.50 N/mm^2at 14days, 28 days, 56 days, 90 days and 180 days respectively, the mechanical activity index are 80%, 88%, 106% and 114% and 121 at 14days, 28days, 56days , 90days and 180 days respectively. The behavior is similar to the 10% CSA and 2% PRA but less reactive.The reason for lower early strength can be attributed to delayed complex chemical reaction that was taking place between the cement paste, pozzolana and PRA, this chemical reaction affect the strength development, this result is in line with the views of Robert*etal.* (2010) that PRA modified pozzolana blended cement concrete

develops higher strength than the conventional concrete.It can be concluded that all samples may be used for structural purposes,this is because all the samples exceeded the maximum strength specified by ASTM 24.2 N/mm^2 at 28 days

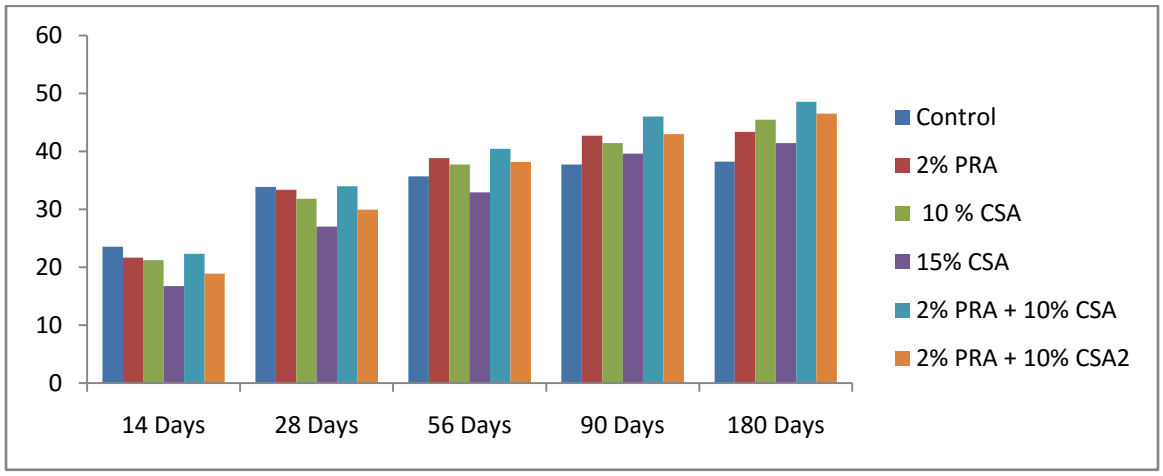

Fig. 4.4 : Compressive Strength of Samples Specimens.

4.4.2 CompressiveStrength of Samples Specimens Exposed to Sulphate

Figure 4.5 Shows the Compressive Strength of Samples Cured in Mgso4 (2.5%) Strength and durability properties are usually used to judge the performance of concrete, Surrounding environment and exposure conditions play a major role in durability of reinforced concrete (Asad and Najmus, 2011). At 14 and 28 days none of the samples show any loss in strength, except control samples that increased in strength by 3.01% and 7.56%, this can be attributed toexpansive products such as gypsum and ettringite within the voids and micropores, which will later result into strength loss,however at 56 days only control sample shows significance strength loss 3.57 % strength reduction was noticedwhen compared with the sample cured in water this is in compliance with the findings of Ramez *etal.*(2012) although he reported that control sample loss strength at 28 days.

At 90 days control samples loss 11.05% of it's strength respectively, The samples that contains PRA losses 0.98% of its strength when compared with samples cured in water at and 90 days respectively. For samples that contain CSA strength loss increase as percentage replacement increases 2.57% loss in strength was noticed at 10% replacementat 90 days, at 15% replacement of cement with CSA strength loss was 3.55% at 90 days respectively.The samples that contains 2%PRA+ 10 CSA shows 0.36% strength loss when compared with samples cured in water at 90days, 2%PRA+ 15 CSA loss 0.76% of its strength after 90day curing period.

At 180 days the control sample loss 17.7% of its strength, the samples that contain 2% PRA loss 1.6% of its strength, the blended cement concrete that contains 10% and 15% replacement of cement with CSA loss 3.8% and 4.75% of their respective strength, the samples that contains PRA modified blended cement concrete (2% PRA + 10% CSA and 2% PRA + 15% CSA)loss 1.00% and 1.3% of their strength respectively.

The large strength loss in control sample after 28 days can be attributed to the reaction of $MgSO_4$with all cement compounds including CSH thereby causing cement decomposition of CSH and causing formation of gypsum and ettringites, these two are responsible for expansion, cracking, deterioration and disruption of structure (Ramez, *etal.*, 2012). The reason for good performance of blended samples can attributed to improvement of C_3A content when a portion of Portland cement is replaced through the formation of CSH and pore refinement Ahmad *et al.*(2008) reported that pozzolana blended concrete has better resistance to sulphate attack than plain concrete, The lower strength loss in samples that contains 2% PRA can be attributed to the formation of crystalline throughout the entire depth of the concrete and pore refinement therefore

blocking all the pores in the concrete and denying the sulphate ion access into paste Mukeshi*et al.*(2009)reported that concrete modified with PRA have better resistance to sulphate attack than plain concrete. The outstanding performance of samples that contains 2% PRA and CSA (10 and 15%) can be attributed to the combined effects of pozzolanic reaction (CSH formation and Pore refinement) and crystalline formation, thereby forming synegystic effects of pore refinement and crystalline formation through complex chemical reaction,Robert *etal*.(2010) reported PRA modified pozzolana blended cement concrete offers better resistance to sulphate attack than other samples.

Thus it may be recommended that all the samples can resist sulphate attack. But strength conservation reduces as exposure period increases. However when considering long term exposure of concrete to aggressive environment PRA modified concrete can offer good resistance to concrete degradation, and PRA modified pozzolana blended cement are better than PRA modified concrete and pozzolana blended cement samples while pozzolana blended cement concrete samples are better than control samples. However increase in length was not noticed up to 90 days and formation of DEF (Delay Entriggite formation whitish deposit on concrete samples) was slightly noticed on control samples at 56days, at 90 days it was noticed on the Pozzolana blended cement concrete.

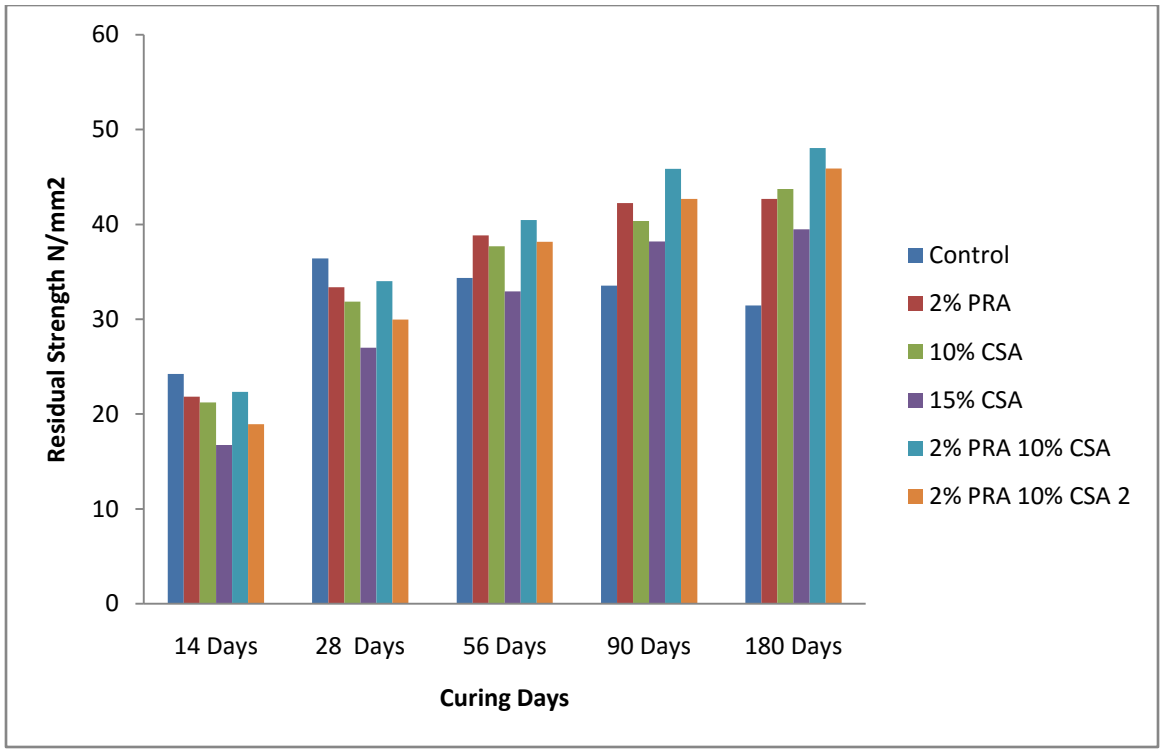

Fig. 4.5 : Compressive Strength of Samples SpecimensExposed to sulphate.

4.4.3 Water Absorption Capacity of Samples Specimens

Figure 4.6 shows water absorption capacity of all the specimens, at 28 days, 56 days and 90 days the control samples absorbed water equivalent to 5.14%, 4.6% and 4.02% respectively, the water absorbed decrease as the curing age increases this can be attributed to the influence of rich mix, and improved microstructure therefore making it less susceptible to water ingression, the result also agreedwith the requirement of Neville and brooks (2011) that states that water absorption of concrete sample fired at temperature of 105^0C and immersed in water for 24 hours should not exceed 7.4% the weight of concrete.

The samples that contains PRA absorbed 2.05%, 2.03% and 1.43 % 0f its own weight at 28 days, 56 days and 90 days respectively, thus 60% , 62% and 64.4 % reduction when compared with control, this is as a result of crystalline formation in the concrete pores and through out the entire depth of concrete, therefore making the concrete less susceptible to moisture ingressionthis is in line with the findings of Annu and Jeena (2016). There fore concrete modified with PRA is less prone to the attack by dissolved substances in water.

The sample that contains CSA (15% and 10%) absorbed 3.54% and 3.82% of their weight respectively 33% and 27% 10CSA absorbed 3.41, 2.76 and 1.56% of its at 28 days, 56days and 90 days respectively and conserved 33.6%, 40% and 46.29%, The samples that contains 15% CSA absorbed 3.67%, 3.32% and 2.56% at 28 days 56 days and 90 days respectively and conserved 28%, 32.6% and 36 % respectively when compared with the quantity absorbed by the control, it can be observed that water absorption increase with increase in pozzolanic content, this may be attributed to insufficient $CaOH_2$ that will trigger pozzolanic reaction and water absorption decrease as curing age decreases, this may be attributed to improved micro structure from curing thereby making the concrete less permeable, this is in agreement with the investigation of Jayesh and Umrigar (2013). Therefore pozzolana blended cement concrete reduces water absorption into concrete.

The samples that contains 2% PRA +10 CSA absorbed 1.25%, 1.09% and 0.87% of its weight at 28days, 56days and 90days respectively, and portrayed 75.6%, 76.3% and 78.4% reduction when compared with control, The samples that contains 2% PRA +15 CSA absorbed 1.78%, 1.48% and 1.19 % of its weight respectively, when compared with control the percentage

reduction are 65%, 67% and 70.3% reduction. The reduction in quantity of water absorption as curing ages progress can be attributed to improved internal microstructure, attributed to pore refinement and crystalline throughout the entire depth of the concrete (synergistic effect of pozzolana and PRA) therefore making the concrete less impermeable and less susceptible to harmful substances dissolved in water. This agrees with the findings of ACI 21 3R (2010) that PRA modified blended pozzolana cement has lesser absorption than pozzolana cement concrete, and therefore it is less susceptible to moisture absorption and dissolved injurious substance.

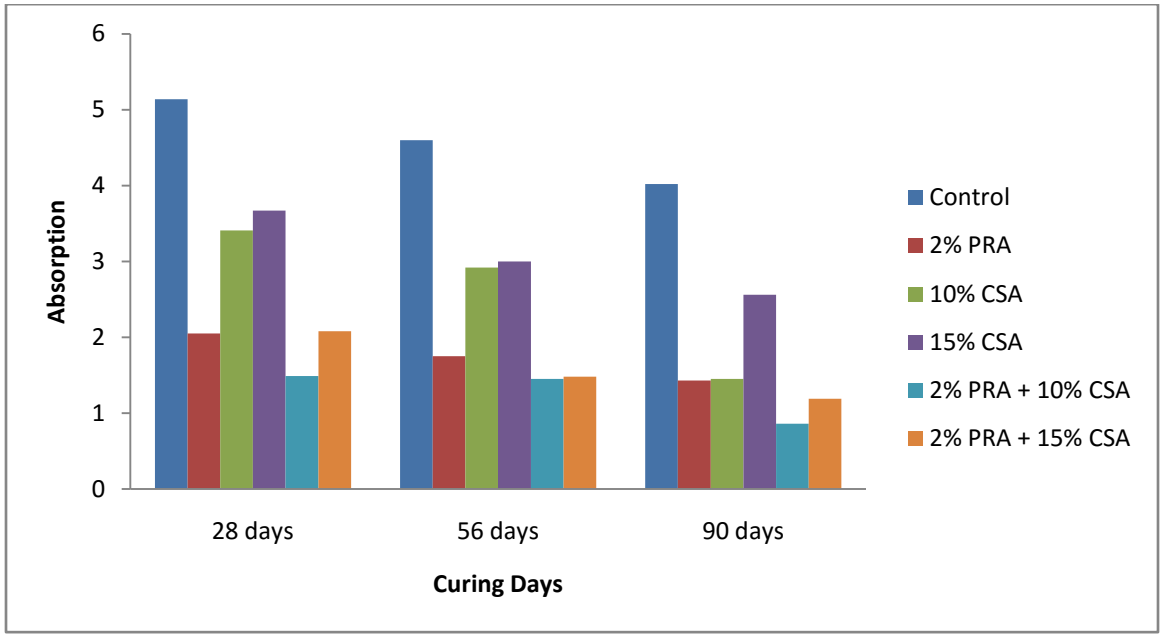

Fig. 4.6 Water Absorption Capacity of Samples Specimen

4.4.4 Sorptivity of Samples Specimens

Figure 4.7 Shows the sorptivity of concrete samples, the sorptivity was determined followingthe procedure specified by ASTM C 1585, the control has sorptivity of $16.64x10^{-5}$, $13.66x10^{-5}$ and $24.06x10^{-5}$at 28days, 56days and 90 days, the sorptivity reduces as curing age increases this can be due to long curing period and improved internal structure of concrete,

therefore improving concrete properties this is in line with the findings of Esam *et al.* (2014)that adequate curing improves concrete resistance to sorptivity.

However the samples that contain 2% PRA had $5.71x10^{-5}$, $4.96x10^{-5}$ and $4.22x10^{-5}$ sorptivity at 28 days, 56 days and 90 days respectively, the sorptivity were lower than that of control by 75%, 77%, and 78.7% at 28 days, 56 days and 90 days respectively, the reason for the reduction of sorptivity may be attributed to crystalline formation thereby blocking the pores in the concrete and improving the internal structure of the concrete specimen samples, therefore reducing water ingression due to capillary suction, this is in agreement with the findings of NPCT (2014) they reported that PRA reduced sorptivity by 50% after 30minutes exposure.Therefore it may be concluded that PRA modified concrete sample specimens are less prone to capillary suction as a result of improved internal structures due to capillary suction.

The samples that contain pozzolana e.g 10 % CSA and 15% CSA, for 10% CSA the sorptivity were $11.91x10^{-5}$, $10.43x10^{-5}$ and $6.72x10^{-5}$ at 28days, 56 days and 90 days respectively, and there was 38.47%, 40.1% and 45% reduction when compared with the control samples, the 15%CSA had $12.42x10^{-5}$, $12.17x10^{-5}$ and $7.94x10^{-5}$ sorptivity at 28 days, 56 days and 90 days, the percentage reduction when compared to control samples specimen were 35.34%, 37.04% and 39% the higher replacement level the lower the resistance to sorptivity this can be attributed to insufficient $Ca(OH)_2$ that will trigger sufficient pozzolanic reaction, therefore causing reduction in the resistance of the mortar to capillary suction, this is in agreement to the views of Jayesh and Umrigar (2013) that pozzolana improves the resistance of mortar to capillarity suction through densification of the pore structure, therefore causing reduction in the rate of capillary suction,

based on the above findings it may be concluded that pozzolana lowers the rate of capillary suctionthus these sample are less prone to deterioration of concrete due to ingression of harmful substances.

The samples that contains 2% PRA+10CSA, the sorptivity are4.2 $x10^{-5}$, $3.43x10^{-5}$and $3.23x10^{-5}$at 28, 56 and 90 days respectively the percentage reduction when compared with control are 80.2%, 82% and 83% respectively. For the samples that contains 2% PRA+15CSA the sorptivity were $5.46x10^{-5}$, $4.22x10^{-5}$ and $3.73x10^{-5}$ at 28days, 56days and 90days respectively, percentage reduction are 76%, 77.9% and 78.6% at 28 days, 56 days and 90 days respectively. The good performance can be attributed to combined effects of pozzolanic reaction and formation of crystals through out the entire depth of the concrete, therefore improving their resistance to resistance to capillary suction this is in line with the findings of ACI 212 2R (2010) :Robert*etal*.(2010) that PRA modified pozzolana blended cement concrete have better resistance to water penetration.

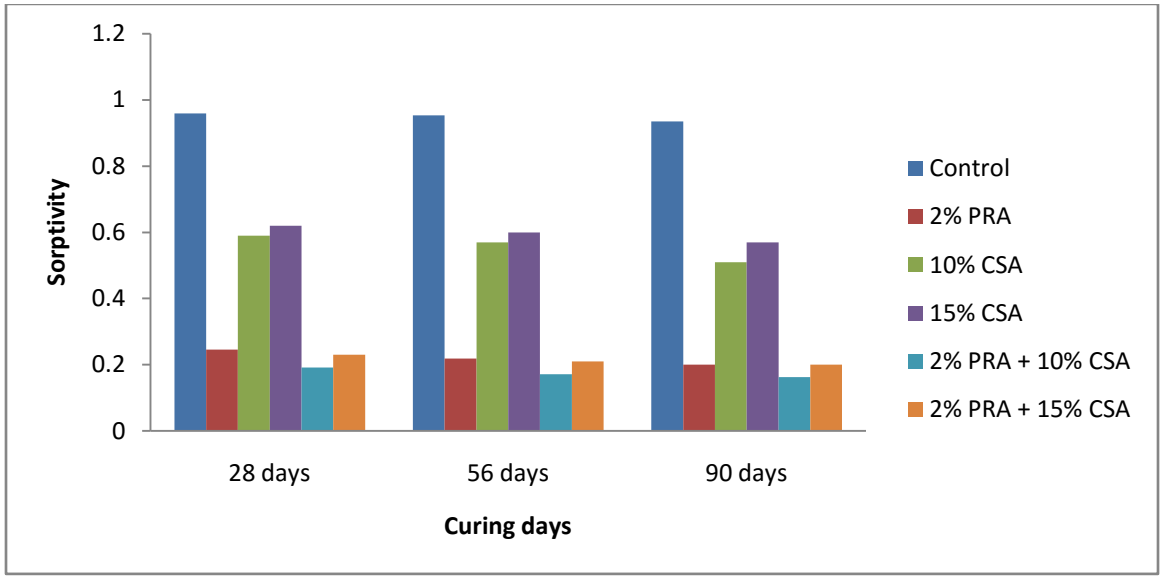

Fig. 4.7: Sorptivity of Samples Specimens

4.4.5 Abrasion Resistance of Samples Specimens

Figure 4.8 shows the abrasion resistance of concrete, The control sample shows 0.13%, 0.12% and 0.085 % lost at 28days, 56 days and 90days respectively however the surface wear due to abrasion lost reduces as the curing age increases and as the strength increases, this may be attribute to increase in strength and improved internal structure, improved bonding between the paste and the aggregate,therefore adequate curing improves abrasion resistance of concrete.

The samples that contains 2% PRA offer lesser resistance to abrasion loss than control sample at 28 days. However at 56 days and 90 days it offered better resistance to abrasion loss 0.23%, 0.15% and 0.045 % at 28days 56days and 90 days respectively, this characteristic can be attributed to strength development because the higher the strength the better the resistance to abrasion, this is in agreement with the findings of (Abol, 2012: José, 2010).

Samples that contains pozzolana had better abrasion resistance than control samples, for 10% the surface wear due to abrasion are 0.16%, 0.09% and 0.042% at 28days, 56days and 90 days respectively, 15CSA abrasion loss are 0.21%, 0.12% and 0.04% at 28days, 56days and 90days respectively, this can be attributed to hardened surface as a result of pozzolanic reaction and improved strength development. Incorporation of pozzolana into mix increases abrasion resistance (José, 2010) and long curing period (Abol, 2012: Radu and Jose, 2010) that compressive strength is directly proportional to abrasion.

The samples that contain 10% CSA and 15% CSA, 10% CSA abrasion loss was 0.16 %, 0.09% and 0.042% at 28 days, 56days and 90 days , for 15% CSA were 0.21%, 0.12% and 0.04 % at 28

days, 56 days and 90 days respectively, the abrasion resistance reduces as the percentage replacement of cement with pozzolana increase, this may be attributed to delayed in hydration process due to insufficient $Ca(OH)_2$, therefore causing increase in abrasion loss due to delayed strength,the increase in abrasion resistance at 10% replacement and at later age may be attributed to increase in strength and increase in bond between the matrix and aggregate this agrees with the findings of Emiley (2014) that reported Flyash blended cement concrete outperformed conventional concrete during abrasion test.

For Samples that contains 2% PRA +10% CSA the abrasion loss are 0.16%, 0.09% and 0.043% respectively at 28 days, 56 days and 90 days respectively, the samples that contains 2% PRA + 15% CSA, The wear due to abrasion are 0.16%, 0.10% and 0.043% respectively at 28days, 56days and 90days respectively the outstanding results can be attributed to incorporation of pozzolana and strength there by improving bond between the matrix and aggregate, and complex chemical reaction that take place between the pozzolana, PRA and cement therefore resulting in strength development.

Based on the encouraging result that none of the samples exceeded 30% abrasion loss which is in line with Gupta and Gupta (2012) requirement. It may be recommended that all the samplesmay be used in areas that are prone to abrasion and friction.

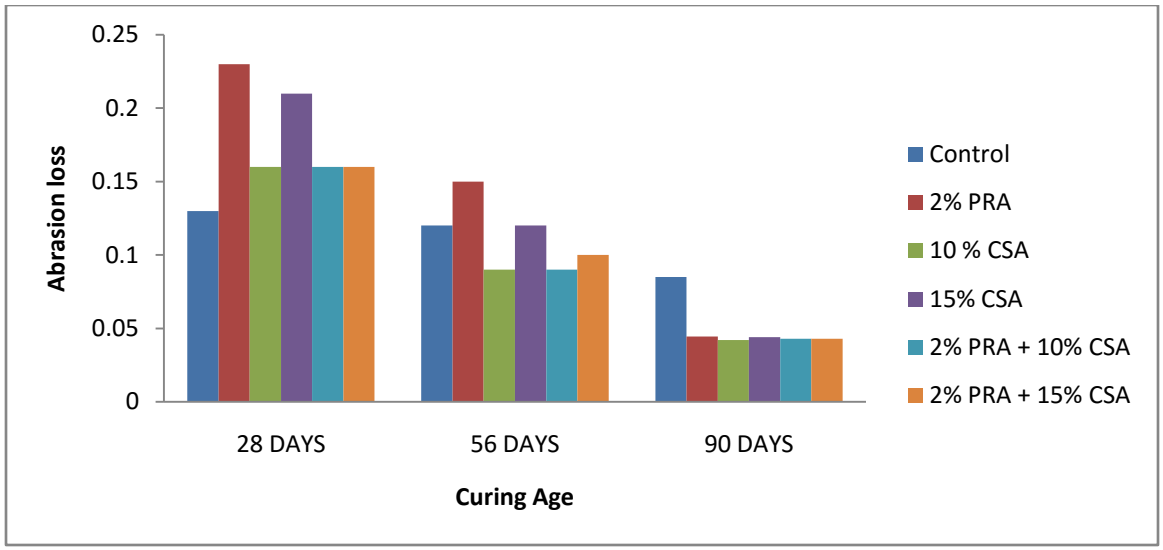

Fig. 4.8 Abrasion Resistance of SamplesSpecimens.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the Research Findings

A study was conducted on the effects of permeability reducing admixture on properties of binary cementitious matrix concrete that contains coconut shell ash as partial replacement for cement. The concrete samples were tested for compressive strength, Water absorption test, sorptivity test and abrasion resistance test. The highlights of the major findings are listed below.

(1)The specific gravity, bulk density, moisture content and absorption capacity of Coarse Aggregate, Fine aggregate, Cement, Permeability Reducing Admixture and Coconut Shell Ash was found to be 2.86, 2.51, 3.2, 2.36 and 2.23, the moisture contents were 0.89% and 0.43 % for Coarse and Fine aggregate, Water Absorption was 1.02% and 1.68% for Coarse and fine aggregate. The bulk density are 1498.4 Kg/m^3, 1767 Kg/m^3, 1620 Kg/m^3, 1200Kg/m^3, 1006 Kg/m^3 for Coarse aggregate, Fine aggregate, Cement PRA and CSA.

(2)The summation of elements (Silica, Aluminium and Iron) found in Coconut Shell Ash was77.44%. However it contains SiO_2 Silicon Oxide 38.15 %, Aluminium Oxide (Al_2O_3) 23.49% and Iron oxide (Fe_2O_3) 15.80 %.

(3)The initial and final setting time of control specimen were 113 and 188 minute, PRA modified concrete sample had 121min and 195min initial and final setting time, while specimen modified with CSA delays initial and final setting time further as the replacement level increased, PRA modified pozzolan blended cement specimen had 240 min and 318min initial and final setting time.

(4) The workability of control was within speculated limit which is medium workability of 55mm, Specimen modified with PRA had 50mm workability, Pozzolana modified Specimen had 47mm and 40mm slump respectively, PRA modified pozzolana blended samples had 38mm and 32mm workability respectively.

(5)The control samples had the highest compressive strength at 14 days and 28 days, however the rate of strength development started declining after 28 days, The PRA modified specimen had 8% and 13% increase in strength at 56 days and 90 days, the pozzolana blended cement concrete sample (10% replacement) had 5.6% and 9.8% increase in strength at 56 days and 90 days, 15% replacement had 5% increase in strength at 90 days, PRA Modified Pozzolana blended cement (10%) had 13% and 21% increase in strength at 56 and 90 days, while 15% had 7% and 14% increase in strength at 56 and 90 days respectively.

(6)For the control specimen exposed to $MgSO_4$ solution, there was increase in strength at 14 days and 28 days, strength started diminishing at 56days and there was 3.73% and 11.05% strength loss at 28 days, 56 daysand 90 days. The specimens modified with PRAloss 0.98% at a 90 days when compared with samples cured in water, Pozzolan modified specimens loss 2.67% and 3.55% for 10% replacement at 90 days. PRA modified pozzolana blended cement specimen the strength loss 90 days were 0.36% and 0.76%.

(7)For water absorption at 28 days the control absorbed 5.14% of its weight, PRA modified specimens absorbed 2.05% of its weight, (60% reduction when compared with control), Pozzolana blended cement concrete absorbed 3.41% and 3.67% of their weight for 10% and 15% replacement level (33.65% and 28.6%). The PRA modified pozzolana blended cement concrete absorbed 1.49% and 2.08% of their weight respectively for 10% and 15 % replacement level and

conserved 71% and 59.53 when compared with control. The trend continues at 56 days and 90 days.

(8)For water sorptivity at 28 days the control has 0.959 PRA modified specimens has 0.246 of its weight, (75% reduction when compared with control), Pozzolana blended cement concrete have 0.59 and 0.62 of their weight for 10% and 15% replacement level (38.5% and 35.3%). The PRA modified pozzolana blended cement concrete absorbed 0.191% and 0.23% of their weight respectively for 10% and 15 % replacement level and conserved 80% and 76% when compared with control, similar trend continue at 56 days and 90 days.

(9)For abrasion resistance at 56 days the specimen PRA modified pozzolana cement concrete shows least percentage weight loss of 0.09 and pozzolana modified cement concrete had the same weight loss (10% CSA). Similar trend continues up to 90 days.

5.2 Conclusions

After the completion of the experiments, observation and analysis on the physical and durability properties of all the samples, control, PRA + Control, CSA (10 and 15% replacement) , 10% CSA+PRA and 15% CSA+PRA

(1)All the preliminary tests conducted satisfy the requirements of their peculiar standards.

(2)The mix design can be used to produce grade 30 concrete.

(3)Workability of PRA modified specimen, pozzolana modified specimen and PRA modified pozzolana blended specimen are lower than that of control specimens.

(4)Mechanical properties of Hardened specimens, PRA modified specimen, pozzolana modified specimen and PRA modified pozzolana blended specimen are lower than that of control specimens at 28 days, however they showed higher compressive strength at 56days and 90 days except 15% CSA that showed higher compressive strength at 90 days.

(5)Hardened specimens, PRA modified specimen, pozzolana modified specimen and PRA modified pozzolana blended specimen have better resistance to abrasion, water absorption, sorptivity and retained higher compressive strength than control after exposure to magnesium sulphate attack.

(6)PRA modified pozzolana blended cement concrete specimen had best hardened properties both physical and durability properties, then PRA modified specimens and then pozzolana modified specimens then control specimens had the least.

5.3 Recommmendations

The Nigerian Institute of Building (NIOB) and other relevant professional bodies in the construction sector should emphasise on the usage of Permeability Reducing admixture for structures that are proned to water ingression, and also incorporation of Permeability Reducing admixture with locally available pozzolanic materials.

(1)It is recommended that PRA admixtures can be incorporated into concrete in order to make it more impermeable and improve concrete resistance to chemical attack.

(2)Supplementary cementitious materials improves concrete properties such as physical properties and resistance to chemical attack.

(3)PRA modified pozzolana blended cement concrete had better resistance to chemical attack, improved physical properties of concrete and therefore can be used for structural pursposes.

(4)Since PRA modified pozzolana blended cement concrete reduces workability, superplasticizer can be introduced in to the mix.

(5) Government should encourage production and usage of blended cement that contains agro residual waste e.g RHA, CSA etc.

5.4Recommendations for Further Studies

(1) Futher research should be conducted on the suitability of incorporating PRA with other locally available pozzolanic agro waste, eg RHA, CCA etc.

(2)Research should be carried out on how to produce permeability Reducing Admixture locally.

(3)Research should be conducted on effects of Permeability Reducing Admixture and Superplasticizer on the properties of pozzolanic blended cement concrete.

(4) Durability properties such as exposure to aggressive environment, elevated temperature and Radiation Shielding should be carried out on PRA modified blended cement concrete that contain RHA, CCA etc.

(5) Research should be conducted using different methods of assessing durability of concrete eg Non destructive Testing, eg Rapid Chloride penetration test, ultrasonic test etc

5.5 Contribution to Knowledge

The research established that:

(1) Permeability reducing admixture is compatible with blended cement.

(2) Strength development of PRA modified blended concrete exceeded the control samples by 13.3%, 22% and 27.1% at 56days, 90days and 28 days respectively.

(3) PRA modified blended concrete conserved more compressive strength than the control after 180 days exposure to aggressive environment. It conserved 98.7% of its strength against the control that conserved 82.1% of its strength.

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APPENDICES

Appendix A : Particle Size Distribution of Aggregates

Appendix A.1.

Combined Particle Size Distribution Result for Fine aggregate and Natural Coarse Aggregate (20mm and below)

Table A 1: Sieve analysis of Coarse Aggregate

Sieve Sizes	Weight Retained (g)	Weight Passing (g)	Percentage Passing (g)	Cummulative Retained Passing (g)	Fineness Modulus
20mm	465	1035	69	465	58.86
10mm	325	710	47.73	790	79.47
5mm	204	506	33.73	994	95.85
2.36mm	43	463	30.87	1037	90.73
1.18mm	106	357	23.8	1143	83.49
600	226	131	8.73	1369	92.68
300	108	23	1.53	1477	99.1
150	14	9	0.6	1491	99.4
Pan	9	0	0	1500	699.2

	6.99

Appendix A.2

Particle Size Distribution Result for Natural Coarse Aggregate (20mm and below)

Table A 2: Sieve analysis of Coarse Aggregate

Sieve size	Weight Retained (g)	Weight Passing (g)	Percentage Passing (%)	Cumulative retained Passing (%)
20mm	465	535	53.5	465
10mm	325	210	21.0	790
5mm	204	6	0.60	994
Pan	6	0	0.00	1000

Source: Laboratory Research Work (2016)

Appendix A.3

Table A 3: Sieve analysis of Natural Fine Aggregate

BS Sieve Size	Weight Retained (g)	Weight Passing (g)	Percentage passing (%)	Cumulative retained Passing (%)	Fineness Modulus
20mm	0	500	100	0	0
10mm	0	500	100	0	0
5mm	0	500	100	0	0
2.36mm	37	463	92.6	37	25.87
1.18mm	106	357	71.4	143	38.75
600 µm	226	131	26.2	369	77.35
300 µm	108	23	4.6	477	97.1
150 µm	14	9	1.8	491	98.2
Pan	9	0	0	500	337.2
					3.37

Source: Laboratory Research Work (2016)

Appendix B : Tests Conducted on Materials

Appendix B.1

Table B.1:Specific Gravity Test Table of Coarse Aggregate

Sample	**1**	**2**	**3**
W_1 = Weight of Cylinder	244	244	244
W_2 =Weight of cylinder + Water	1190	1190	1190
W_3 Weight of cylinder + Sample	559	548	534
W_4 = Weight of cylinder + Sample + Water	1399	1386	1387
Specific Gravity =	2.97	2.81	2.81
Average		2.86	

Source: Laboratory Research Work (2016)

Appendix B.2

Table B2 : Compacted Bulk Density Test Table of Coarse Aggregate

Samples	**1**	**2**	**3**
W_1 = Weight of Container	1.46	1.46	1.46
W_2 = Weight of container + Sample	6.86	6.82	6.88
W = Weight of sample	5.4	5.36	5.42
V = Dimension of container	0.0036	0.0036	0.0036
Bulk Density = $\frac{W}{V}$	1500	1489	1506
Average		1498	

Source: Laboratory Research Work (2016)

Appendix B.3 : Uncompacted Bulk Density Test Table of Coarse Aggregate

Samples	**1**	**2**	**3**
W_1 = Weight of Container	2.92	2.92	2.92
W_2 = Weight of container +	3.2	3.18	3.19

Sample			
W = Weight of sample	0.28	0.26	0.27
V = Dimension of container	0.00034	0.00034	0.00034
Bulk Density = $\frac{W}{V}$	823.5	765	794.1
Average		794	

Appendix B.4 : Moisture Content Test Table of Coarse Aggregate

Samples	**1**	**2**	**3**
W_1= Surface dried weight of sample	920	940	940
W_2 = Oven dried Weight	915	937	936
Moisture Content = W_1 - W_2	2	2	1
Percentage Difference	0.55 0.320.43		
Average		0.43	

Appendix B.5 : Test Summary Table

	Materials				
Tests	**Cement**	**F.Aggregate**	**C.Aggregate**	**C. S. A**	**P. R .A**
SpecificGravity	3.29	2.51	2.86	2.23	3.16
Bulk Density	1706	1767	1498	1009	1451.3
UncompactedBulk Density	1353	1233.4	1359.24	794	1196.1
Moisture Content%	0.93	0.88	0.79	1.00	0.52

Source: Laboratory Research Work (2016)

Appendix C : Mix Design

Appendix C.1Mix Design for Grade C30 Concrete Using Building British Research Establishment Method (BRE)

Design Stipulations and Test data for Materials

Compressive strength at 28 days = 30N/mm^2

Type of concrete = Plain Concrete

Grade of cement = 42.5

Coarse aggregate type = crushed granite

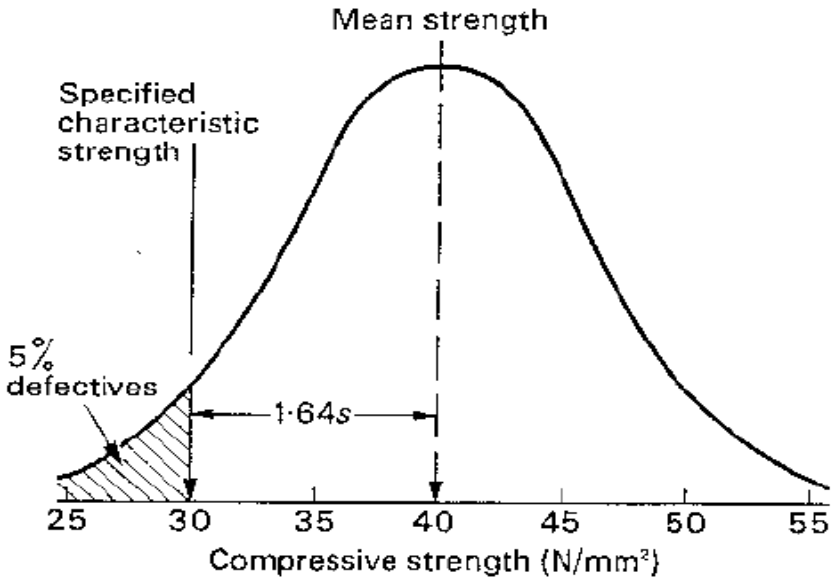

Fig. C.1: Normal Distribution of Concrete Strength

Source: Building Research Establishment (1997)

Table C1: K factor used in Statistical Control

Percentage	K
16	1.00
10	1.28
5	1.64
2	2.05
1	2.33

Source: Building Research Establishment (1997)

<u>Step 1</u>: Compute Mean Target Strength

$$f_m = f_c + ks$$

Where

f_m= the target mean strength

f_c=the specified characteristic strength

ks = the margin, which is the product of:

s = the standard deviation, and

k = a constant

From fig. A2.1 select margin factor = 5

From table A2.1, k = 1.64 and s =4

f_m= 30N/mm^2 +(1.64 x 4)

f_m =30+8.2

f_m= 38.2/mm^2

Step 2: **Information on the Materials to be used**

i. Coarse aggregate = 20mm Maximum sieve size

ii. Percentage of fine aggregate passing through 600µm sieve = 26%

iii. Specific gravity of coarse aggregate based on SSD = 2.50

iv. Condition of Exposure = Sea water and Salt spray

v. Step 3: Determine the Required Water Cement Ratio

vi. Using cement grade 42.5 and crushed course aggregate at 28 day as it is seen from table A2.2

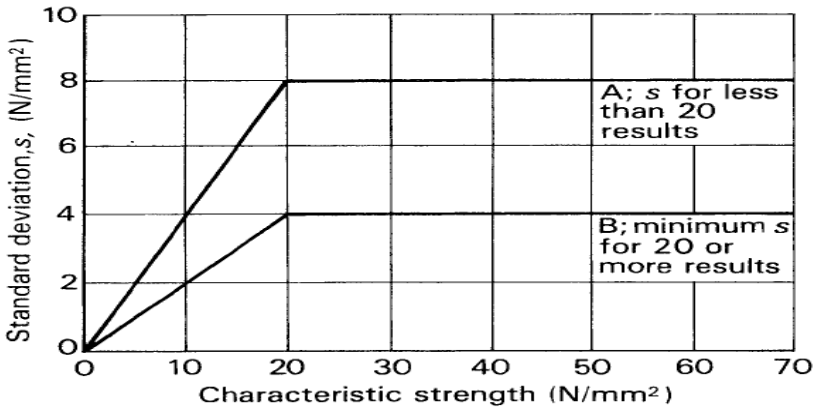

Fig. C.2: Characteristic Strength Versus Standard Deviation Relationship

Source: Building Research Establishment (1997)

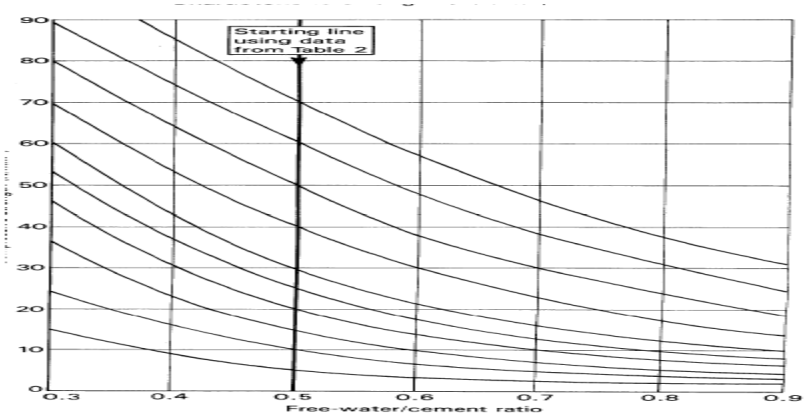

Figure C.3: Relationship between Compressive Strength and Water/Cement Ratios

Source: Building Research Establishment (1997)

Table C.2: Approximate Compressive Strength of Concrete Mix with a Free-Water/Cement Ratio of 0.5

Cement Strength Class	Type of Coarse Aggregate	Compressive Strengths N/mm^2 Age (days) 3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Source: Building Research Establishment (1997)

Table C.3: Maximum water cement ratio for reasonable durability

Condition of Exposure	Maximum Water Cement Ratio	
	Plain Concrete	Reinforced Concrete

Internal subject to heavy Condensation	0	0.60
Alternate wetting and drying	0.6	0.60
Freezing and Thawing	0.55	0.50
Seawater or salt spray	0.50	0.45
Water retaining structure		0.5

Source: Building Research Establishment (1997)

Anticipate strength = 49N/mm^2

Target strength = 38.25N/mm^2

Free water/cement ratio =0.5

To determine the new free water/cement ratio to be used:

From Figure A2.3

Use the curve drawn from 0.5 free water/cement ratio and 49N/mm^{2}anticipated strength to trace the new water/cement ratio with target strength of 38.56N/mm^2

New free water/cement ratio = 0.6 which is not OK according to the standard because from table A2.3, maximum allowable water/cement ratio for alternate wetting and drying condition of exposure, plain concrete = 0.5

Therefore, maximum allowable water/cement ratio = 0.50

Step 4: Selecting an appropriate degree of Workability (Slump)

Table C.4 :Workability, Slump and Compacting factor of concrete with 19mmor 38mmsize of aggregate

Degree of Workability	**` Slump**	**Compacting Factor**	**Use for which Concrete is Suitable**

	mm		in	
Very low	0-25	0-1	0.78	Roads vibrated by power machines, At the workable end of this group, concrete may be compacted in certain cases with hand operated machines
Low	25-50	1-2	0.85	Roads vibrated by Hand operated workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or lightly reinforced sections with vibration
Medium	25-100	2-4	0.92	At the less workable end of this group, manually compacted flat slabs using crushed aggregate. Normal reinforced Concrete, manually compacted and heavily reinforced sections with vibration
High	100-175	4-7	0.95	For sections with congested reinforcement. Not normally suitable for vibration.

(Building Research Establishment, Crown copyright)

From C.3 :Select medium degree of workability with a slump ranging from 25 - 100mm.

<u>Step 5</u>:Determine the Required Free Water Content (kg/m^3)

From Table A3.4,based on the selected workability, maximum size and type of aggregate, the

required free water content = 210kg/m^3

Table C.5: Approximate Free-Water Content (Kgm^3) Required to Give Various Levels of Workability.

Slump (mm)		**0-10**	**10-30**	**30-60**	**60-180**
Vebe time (s)		**>12**	**6-12**	**3-6**	**0-3**
Max. size of aggregate (mm)	**Type of Aggregate**				

10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Source: Building Research Establishment (1997)

Step 6:Calculate the Cement Content by using the W/C Ratio

Cement content (kg/m^3) $= \frac{WaterContent \quad (kg/m^3)}{w/c}$

Cement content (kg/m^3) $= \frac{225 kg/m^3}{0.50}$

Cement (kg/m^3) = 450kg/m^3

Step 7: Compare the Amount of the Cement Obtained with the minimum Allowable Content for Durability.

Table C.6: Maximum Cement Content for Concretes with 20mm Maximum Aggregate Size under Different Condition of Exposure

Exposure Conditions	**Minimum Cement Content for Concrete (Kg/m^3)**		
	Plain	**Reinforced**	**Pre-stressed**
Non-corrosive	220	250	300
buried or sheltered from rain	250	290	300
Exposed to alternate wetting and drying or seawater	310	360	360
subject to de-icing salt	280	390	300

Source: Building Research Establishment (1997)

From Table A2.4, the minimum cement content for plain concrete exposed to alternate wetting and drying = 310kg/m^3 which is less than the 450kg/m^3. Therefore, 450kg/m^3 is adequate.

<u>Step 8</u>: Determine the Wet Density of the Concrete using Free Water Content

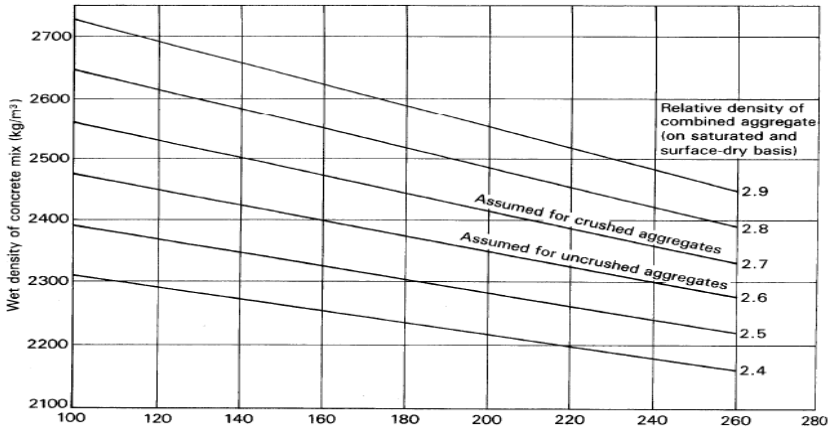

Fig.C.4: Relationship between free-water content and wet density of concrete

Source: Building Research Establishment (1997)

From Figure A2.3

Free water content = 210kg/m^3 (from step 5)

Combined specific gravity of aggregate at SSD = 2.50

Therefore, Wet density (plastic density) = 2280kg/m^3

<u>Step 9</u>:Deducing the Proportion of the Fine Aggregate.

Water/cement ratio= 0.60, Slump = 50mm Maximum aggregate size = 20mm

Percentage of fine aggregate that passed through 600µm BS sieve = 26.3%

From Figure.A2.4,the proportion of fine aggregate = 45%

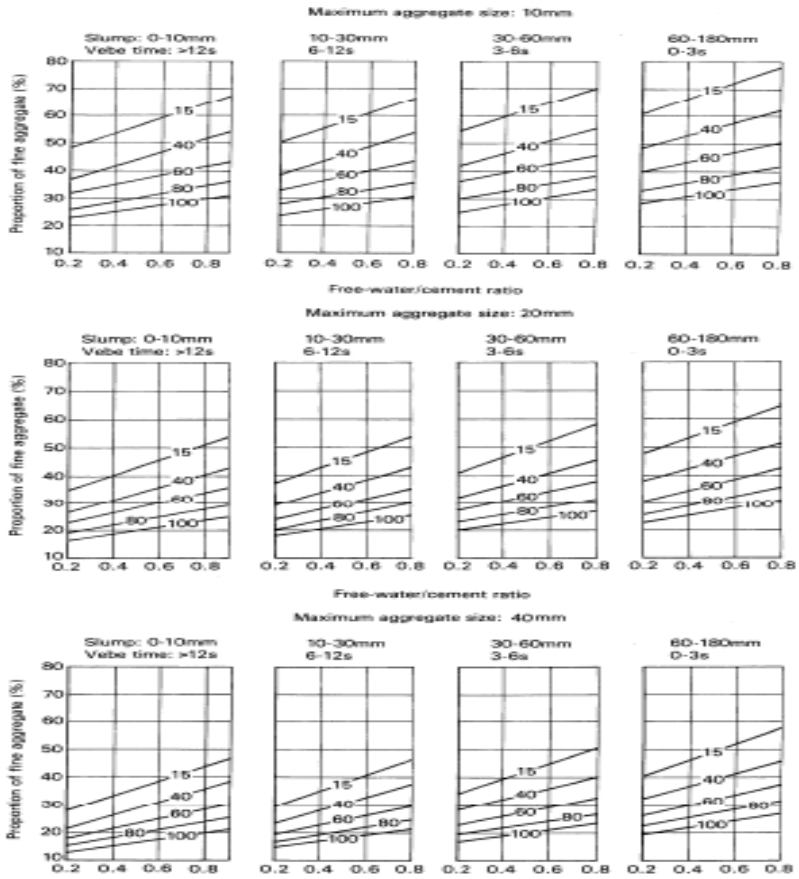

Fig.C.5: Recommended Percentages of fine aggregate in total aggregate as a function of free-water/cement ratio for values of workability and maximum size of aggregate

Source: Building Research Establishment (1997)

<u>Step 10</u>: Compute the Quantity of Aggregate

1. Total Aggregate Content based on Supersaturated surface dry (SSD)

Total Aggregate Content= Plastic Density – Cement content – Water content
(TAC) (PD) (CC) (WC)

TAC = $2380kg/m^3 – 450kg/m^3 – 210kg/m^3$

TAC = $1720kg/m^3$

2. Fine Aggregate Content (FAC) = TAC x Proportion of fine aggregate(FA)

FAC = $1720\ kg/m^3 x \frac{45}{100}$

FAC = 774 kg/m^3

3. Course Aggregate Content (CAC) = TAC – FAC

CAC = 1720kg/m^3 – 774 kg/m^3

CAC = 946 kg/m^3

<u>Step 11</u>: Deducing the Mix Proportion by Weight Taking Cement as 1

Cement Content = 450kg/m^3

Fine Aggregate Content = 774kg/m^3

Coarse Aggregate Content = 946 kg/m^3

Water Content = 210kg/m^3

Mix Proportion = $\frac{450}{450}$: $\frac{774}{450}$: $\frac{946.}{450}$ and $\frac{210}{450}$

= 1: 1.70: 2 .0 and W/C = 0.5

<u>Step 12:</u> Adjust the quantity of mix water to take care of moisture condition of the aggregate on site if necessary (the aggregates used were at saturated surface dry condition)

<u>Step 13</u>: Quantity of materials in kg per the required volume of concrete

Computing the total volume of concrete required.

Unit volume of cube = 0.1 x 0.1 x 0.1 = 0.001m^3 .

Add 15% waste of the total volume of concrete = $0.001 + (\frac{15}{100} X\ 0.001)$

$= 0.00115m^3$

Quantity of Material required by volume for 0.46w/c ratio required per m^3

Quantity of Cement = $0.00115m^3$ x 450kg/m^3 = 0.52kg

Quantity of Fine Aggregate = $0.00115m^3$ x 774kg/m^3= 0.89kg

Quantity of Natural Coarse Aggregate = $0.00115m^3$ x 946kg/m^3= 1.08kg

Quantity of water = 0.00115m^3 x 210kg/m^3= 0.24kg

Total quantity of material required for each sample

Table C.7 : Mix Proportion for100 0% Cement

Cement	FineAggregate	Coarse Aggrgate	Water
$\mathbf{0.52kg}$	$0.89\ kg$	$1.08\ kg$	$0.24kg$

Sample 1

Containing 100% Cement

Cement = 0.52 kg x 45 = 23.4 kg

Fine Aggregate = 0.89kg x 45 = 40.1kg

Natural Aggregate = 1.08kg x 45 = 48.6kg

Water = 0.24 x 45 = 10.8L

Table C.8 Quantity of Materials Required for the Production of 45 cubes

Cement	Fine Aggregate	Coarse Aggregate	Water
23.4 kg	40.1kg	48.6kg	10.8L

Sample 2

Containing 100% Cement and 2% Permeability Reducing Admixture

Cement = 0.52 kg x 45 = 23.4 kg

WPA= 23.4 X $\frac{2}{100}$ = 0.47kg

Fine Aggregate = 0.89kg x 45 = 40.1kg

Natural Aggregate = 1.08kg x 45 = 48.6kg

Water = 0.24 x 45 = 10.8L

Table C.9 Quantity of Materials Required for the Production of 45 cubes

Cement	PRA	Fine Aggregate	Coarse Aggregate	Water
23.4 kg	0.47kg	40.1kg	48.6kg	10.8L

Sample 3

Containing 90% Cement and 10% Coconut Shell Ash

Cement = 0.52 kg x 45 = 23.4 kg

CSA= 23.4 X $\frac{10}{100}$ = 2.34kg

Fine Aggregate = 0.89kg x 45 = 40.1kg

Natural Aggregate = 1.08kg x 45 = 48.6kg

Water = 0.24 x 45 = 10.8L

Table C.10 Quantity of Materials Required for the Production of 45 cubes

Cement	Coconut Shell Ash	Fine Aggregate	Coarse Aggregate	Water
23.4 kg	2.34kg	40.1kg	48.6kg	10.8L

Sample 4

Containing 85% Cement and 15% Coconut Shell Ash

Cement = 0.52 kg x 45x0.85 = 19.9 kg

CSA= 23.4 X $\frac{15}{100}$ = 3.51kg

Fine Aggregate = 0.89kg x 45 = 40.1kg

Natural Aggregate = 1.08kg x 45 = 48.6kg

Water = 0.24 x 45 = 10.8L

Table C.11 Quantity of Materials Required for the Production of 45 cubes

Cement	Coconut Shell Ash	Fine Aggregate	Coarse`Aggregate	Water
19.9 kg	3.15kg	40.1kg	48.6kg	10.8L

Sample 5

Containing 90% Cement and 10% Coconut Shell Ash + 2% Permeability Reducing Admixture

Cement = 0.52 kg x 45x0.9 = 21.1 kg

CSA= 21.1 X $\frac{10}{100}$ = 2.11kg

PRA = 21.1 X $\frac{2}{100}$ = 0.42kg

Fine Aggregate = 0.89kg x 45 = 40.1kg

Natural Aggregate = 1.08kg x 45 = 48.6kg

Water = 0.24 x 45 = 10.8L

Table C.12 Quantity of Materials Required for the Production of 45 cubes

Cement	CSA	Fine Aggregte	Coarse Aggregate	PRA	Water
21.1 kg	2.11	40.1kg	48.6kg	0.42kg	10.8L

Sample 6

Containing 85% Cement and 15% Coconut Shell Ash + 2% Permeability Reducing Admixture

Cement = 0.52 kg x 45x0.85 = 19.9 kg

CSA= 23.4X $\frac{15}{100}$ = 3.51kg

PRA = 19.9 X $\frac{2}{100}$ = 0.4kg

Fine Aggregate = 0.89kg x 45 = 40.1kg

Natural Aggregate = 1.08kg x 45 = 48.6kg

Water = 0.24 x 45 = 10.8L

Table C.13 Quantity of Materials Required for the Production of 45 cubes

Cement	CSA	Fine Aggregte	Coarse Aggregate	PRA	Water
19.9 kg	3.51	40.1kg	48.6kg	0.4kg	10.8L

Appendix D

Table D1 : Fresh Properties of Concrete

SAMPLES	SLUMP TEST	COMPACTING FACTOR	RANGE
Control	55	0.92	
PRA	50	0.92	
10 CSA	47	0.85	
15CSA	40	0.85	
10CSA + 2%PRA	38	0.85	
15CSA+ 2%PRA	32	0.85	

Source : Laboratory Research Work (2016)

Appendix E : Breakdown and Summary of Samples Specimens

Appendix E1: Breakdown of samples Specimens cast in the research work

TEST	**CURING DAYS**	**SPECIMENS**					
		XA B C	**SAMPLES**				
		X	A	B1	B2	C1	C2
		100% Cement	2% PRA	10% CSA	15% CSA	2% PRA + 10 % CSA	2% PRA + 15 % CSA
Compressive Strength		3	3	3	3	3	3
Aggressive Environment $MgSO_4$		3	3	3	3	3	3
Absorption Capacity	14	3	3	3	3	3	3
Sorptivity Test		3	3	3	3	3	3
Abrasion Test		3	3	3	3	3	3
Compressive Strength		3	3	3	3	3	3

Aggressive Environment $MgSO_4$	28	3	3	3	3	3	3
Absorption Capacity		3	3	3	3	3	3
Sorptivity Test		3	3	3	3	3	3
Abrasion Test		3	3	3	3	3	3
Compressive Strength		3	3	3	3	3	3
Aggressive Environment $MgSO_4$	56	3	3	3	3	3	3
Absorption Capacity		3	3	3	3	3	3
Sorptivity Test		3	3	3	3	3	3
Abrasion Test		3	3	3	3	3	3
Compressive Strength		3	3	3	3	3	3
Aggressive Environment $MgSO_4$	90	3	3	3	3	3	3
Absorption Capacity		3	3	3	3	3	3
Sorptivity Test		3	3	3	3	3	3
Abrasion Test		3	3	3	3	3	3
Compressive Strength		3	3	3	3	3	3
Aggressive Environment $MgSO_4$	180	3	3	3	3	3	3

Appendix E2: Summary of Specimens

Specimen Name	Types of Specimens	No of Samples Specimens
X (Control, 100% Cement	Cubes	57
A (2% PRA)	Cubes	57
B (10% CSA)	Cubes	57
B (15% CSA)	Cubes	57
C (10% CSA + 2% PRA)	Cubes	57
C (15% CSA + 2% PRA)	Cubes	57

Appendix: F : Compressive Strength Sample Specimens Cured in Water

Appendix F.1 Compressive Test of Strength SampleSpecimens water at 14days

SAMPLE	Weight	14days Failure Load KN/m^2	Compressive Strength N/mm2	Average Compressive StrengthN/mm^2

	W_1 =2390	235.9	23.59	
Control 100% CMT	W_2 =2340	221.6	22.16	23.52
	W_3 =2420	248.2	24.82	
	W_1 =2336	228.9	22.89	
Control+ 2% PRA	W_2 =2362	211.6	21.16	21.64
	W_3 =2382	233.6	23.36	
	W_1 =2320	200.3	20.03	
10% CSA	W_2 =2328	224.0	22.40	21.21
	W_3 =2362	21.20	21.20	
	W_1 =2316	162.8	16.28	
15% CSA	W_2 =2328	169.0	16.90	16.73
	W_3 =2356	170.1	17.01	
	W_1 =2324	235.2	23.52	
10 CSA+2% PRA	W_2 =2338	218.8	21.88	22.34
	W_3 =2372	216.2	21.62	
	W_1 =2320	192.8	19.28	
15CSA+2% PRA	W_2 =2334	181.1	18.11	18.92
	W_3 =2460	193.8	19.38	

Appendix F.2 Compressive Strength Test of SampleSpecimens cured at 28days

SAMPLE	**28days**			
	Weight	**Failure Load KN/m^2**	**Compressive Strength N/mm2**	**Average Compressive Strength N/mm^2**
	W_1 =2346	333.8	33.38	
Control 100% CMT	W_2 =2365	338.9	33.89	33.85
	W_3 =2394	342.8	34.28	
	W_1 =2338	329.7	32.97	
Control+ 2% PRA	W_2 =2366	334.8	33.48	33.38
	W_3 =2388	336.7	33.67	

	W_1 =2373	322.8	32.28	
10% CSA	W_2 =2324	313.8	31.38	31.84
	W_3 =2336	318.3	31.87	
	W_1 =2358	273.9	27.39	
15% CSA	W_2 =2332	269.5	26.95	27.01
	W_3 =2318	266.9	26.69	
10 CSA+2% PRA	W_1 =2340	348.7	34.87	
	W_2 =2328	334.6	33.46	34.00
	W_3 =2376	356.8	35.68	
	W_1 =2326	273.0	27.30	
15CSA**+2% PRA**	W_2 =2342	297.9	29.79	29.96
	W_3 =2368	327.9	32.79	

Appendix F.3 Compressive Strength Test of SampleSpecimens cured at 56days

SAMPLE		**56days**		
	Weight	**Failure Load KN/m^2**	**Compressive Strength N/mm2**	**Average Compressive Strength N/mm^2**
	W_1 =2356	355.2	35.52	
Control 100% CMT	W_2 =2366	349.7	34.97	35.69
	W_3 =2398	335.9	33.59	
	W_1 =2392	392.9	39.29	
Control+ 2% PRA	W_2 =2400	403.4	40.34	38.84
	W_3 =2380	369.1	36.91	

	W_1 =2346	383.9	38.39	
10% CSA	W_2 =2358	385.0	38.50	37.71
	W_3 =2344	362.4	36.24	
	W_1 =2344	334.2	33.42	
15% CSA	W_2 =2340	347.6	34.76	32.95
	W_3 =2340	306.7	30.67	
10 CSA+2% PRA	W_1 =2328	395.4	39.54	
	W_2 =2300	389.5	38.95	40.45
	W_3 =2338	428.6	42.86	
	W_1 =2300	389.2	38.92	
15CSA+2% PRA	W_2 =2280	366.8	36.68	38.18
	W_3 =2334	390.0	39.00	

Appendix F.4 Compressive Strength Test of SampleSpecimens cured at 90days

SAMPLE		**90days**		
	Weight	**Failure Load KN/m^2**	**Compressive Strength N/mm2**	**Average Compressive Strength N/mm^2**
	W_1 =2390	371.2	37.12	
Control 100% CMT	W_2 =2350	366.4	36.64	37.73
	W_3 =2420	394.3	39.43	
	W_1 =2362	411.0	41.10	
Control+ 2% PRA	W_2 =2424	439.8	43.98	42.68
	W_3 =2380	429.8	42.98	
	W_1 =2366	421.5	42.15	

10% CSA	W_2 =2352	417.5	41.75	41.46
	W_3 =2346	404.8	40.48	
	W_1 =2306	402.1	40.21	
15% CSA	W_2 =2316	380.8	38.08	39.62
	W_3 =2300	410.0	41.00	
10 CSA+2% PRA	W_1 =2360	450.8	45.08	
	W_2 =2342	442.5	44.25	46.03
	W_3 =2368	487.6	48.76	
	W_1 =2338	449.7	44.97	
15CSA+2% PRA	W_2 =2328	418.9	41.89	43.01
	W_3 =2308	421.5	42.15	

Appendix F.5 Compressive Strength Test of SampleSpecimens cured at 180days

SAMPLE		**180days**		
	Weight	**Failure Load KN/m^2**	**Compressive Strength N/mm2**	**Average Compressive Strength N/mm^2**
	W_1 =2396	385.2	38.52	
Control	W_2 =2354	376.4	37.64	38.21
100% CMT	W_3 =2428	384.8	38.48	
	W_1 =2366	412.0	41.20	
Control+ 2% PRA	W_2 =2434	449.8	44.98	43.38
	W_3 =2388	439.8	43.98	
	W_1 =2368	451.5	45.15	
10% CSA	W_2 =2362	447.5	44.75	45.46

	W_3 =2356	464.8	46.48	
	W_1 =2306	403.1	40.31	
15% CSA	W_2 =2318	412.8	41.28	41.56
	W_3 =2330	431.0	43.10	
10 CSA+2% PRA	W_1 =2360	480.8	48.08	
	W_2 =2352	482.5	48.25	48.56
	W_3 =2388	493.6	49.36	
	W_1 =2348	471.7	47.17	
15CSA+2% PRA	W_2 =2338	461.9	46.19	46.50
	W_3 =2318	461.5	46.15	

Appendix G: Compressive Strength of Samples Specimens Exposed to Sulphate

Appendix G.1: Compressive Strength of Samples Specimens Exposed to Sulphate at 14days

SAMPLE		**14days**		
	Weight	**Failure Load KN/m^2**	**Compressive Strength N/mm2**	**Average Compressive Strength N/mm^2**
	W_1 =2396	242.4	24.24	
Control	W_2 =2346	235.8	23.58	24.23
100% CMT				
	W_3 =2428	248.8	24.88	
	W_1 =2400	228.9	22.89	

Control+ 2% PRA	W_2 =2388	233.6	23.36	21.85
	W_3 =2368	213.7	21.37	
	W_1 =2326	202.1	20.21	
10% CSA	W_2 =2330	212.3	21.23	21.21
	W_3 =2356	22.19	22.19	
	W_1 =2320	162.8	16.28	
15% CSA	W_2 =2326	169.0	16.90	16.73
	W_3 =2336	170.1	17.01	
	W_1 =2328	216.2	21.62	
10 CSA+2% PRA	W_2 =2340	218.8	21.88	22.34
	W_3 =2362	235.2	23.52	
	W_1 =2322	192.8	19.28	
15CSA+2% PRA	W_2 =2336	181.1	18.11	18.92
	W_3 =2364	193.8	19.38	

Appendix G.2: Compressive Strength of Samples Specimens Exposed to Sulphate at 28days

SAMPLE		**28days**		
	Weight	**Failure Load KN/m^2**	**Compressive Strength N/mm2**	**Average Compressive Strength N/mm^2**
	W_1 =2364	355.2	35.52	
Control 100% CMT	W_2 =2365	363.9	36.39	36.41
	W_3 =2400	373.3	37.33	
	W_1 =2338	328.5	32.38	
Control+ 2% PRA	W_2 =2366	336.7	33.68	33.38
	W_3 =2388	341.1	34.11	

	W_1 =2373	317.7	31.77	
10% CSA	W_2 =2324	308.7	30.87	31.84
	W_3 =2336	328.8	32.88	
	W_1 =2358	280.2	28.02	
15% CSA	W_2 =2332	26742	26.47	27.01
	W_3 =2318	265.5	26.55	
10 CSA+2% PRA	W_1 =2340	343.7	34.37	
	W_2 =2328	327.6	32.76	34.00
	W_3 =2376	350.8	35.08	
	W_1 =2326	273.0	27.30	
15CSA+2% PRA	W_2 =2342	296.9	29.79	29.96
	W_3 =2368	328.9	32.79	

Appendix G.3: Compressive Strength of Samples Specimens Exposed to Sulphate at 56days

SAMPLE	**56days**			
	Weight	**Failure Load KN/m^2**	**Compressive Strength N/mm2**	**Average Compressive Strength N/mm^2**
	W_1 =2360	343.6	34.36	
Control	W_2 =2370	344.2	34.42	34.36
100% CMT	W_3 =2402	373.1	37.31	
	W_1 =2396	393.0	39.30	
Control+ 2% PRA	W_2 =2408	403.3	40.33	38.84
	W_3 =2386	369.0	36.90	

	W_1 =2346	386.6	38.66	
10% CSA	W_2 =2358	384.0	38.40	37.71
	W_3 =2344	361.0	36.10	
	W_1 =2340	336.3	33.63	
15% CSA	W_2 =2338	342.4	34.24	32.95
	W_3 =2336	309.8	30.98	
10 CSA+2% PRA	W_1 =2348	395.2	39.52	
	W_2 =2360	429.8	42.98	40.45
	W_3 =2336	388.5	38.85	
	W_1 =2346	371.0	37.10	
15CSA+2% PRA	W_2 =2368	393.2	39.32	38.18
	W_3 =2348	381.2	38.12	

Appendix G.4: Compressive Strength of Samples Specimens Exposed to Sulphate at 90days

SAMPLE		**90days**		
	Weight	**Failure Load KN/m^2**	**Compressive Strength N/mm2**	**Average Compressive Strength N/mm^2**
	W_1 =2388	343.7	33.05	
Control	W_2 =2360	352.8	33.96	33.56
100% CMT	W_3 =2410	349.9	33.67	
	W_1 =2362	417.4	41.74	
Control+ 2% PRA	W_2 =2424	428.0	42.80	42.26
	W_3 =2380	422.4	42.24	
	W_1 =2366	439.2	43.92	

10% CSA	W_2 =2352	392.5	39.25	40.35
	W_3 =2346	378.8	37.88	
	W_1 =2326	392.5	39.25	
15% CSA	W_2 =2300	371.3	37.13	38.20
	W_3 =2296	382.3	38.23	
10 CSA+2% PRA	W_1 =2358	459.0	45.90	
	W_2 =2338	449.2	44.92	45.86
	W_3 =2364	467.6	46.76	
	W_1 =2336	439.2	43.92	
15CSA+2% PRA	W_2 =2326	418.8	41.88	42.68
	W_3 =2304	422.4	42.24	

Appendix G.5: Compressive Strength of Samples Specimens Exposed to Sulphate at 180days

SAMPLE		**180days**		
	Weight	**Failure Load KN/m^2**	**Compressive Strength N/mm2**	**Average Compressive Strength N/mm^2**
	W_1 =2336	315.6	31.56	
Control	W_2 =2314	322.5	32.25	31.44
100% CMT	W_3 =2328	305.1	30.51	
	W_1 =2362	412.6	41.26	
Control+ 2% PRA	W_2 =2434	439.8	43.98	42.68
	W_3 =2380	428.2	42.82	
	W_1 =2350	440.5	44.05	

10% CSA	W_2 =2352	447.5	44.75	43.73
	W_3 =2356	424.8	42.48	
	W_1 =2326	393.1	39.31	
15% CSA	W_2 =2318	397.9	39.79	39.49
	W_3 =2330	403.3	40.33	
10 CSA+2% PRA	W_1 =2362	479.2	47.92	
	W_2 =2350	472.5	47.25	48.07
	W_3 =2386	493.6	49.36	
	W_1 =2342	466.8	46.68	
15CSA+2% PRA	W_2 =2332	458.9	45.87	45.91
	W_3 =2312	451.5	45.15	

Appendix H: Absorption Capacity of Samples Specimens

Appendix H.1 : Absorption Capacity of Samples Specimens at 28days (24HRS)

SAMPLE	**28days**				
	Weight Oven Dry	**Weight At SSD**	**Difference**	**%**	**Average %**
	W_1 =2120	W_1 =2240	120	5.36	
Control 100%CMT	W_2 =2280	W_2 =2400	120	5.00	5.14
	W_3 =2345	W_3 =2470	125	5.06	
	W_1 =2200	W_1 =2248	48	2.14	
Control+ 2% PRA	W_2 =2260	W_2 =2308	48	2.08	2.05
	W_3 =2340	W_3 =2386	46	1.93	
	W_1 =2180	W_1 =2258	78	3.45	

10% CSA	W_2 =2140	W_2 =2214	74	3.34	3.41
	W_3 =2240	W_3 =2320	80	3.44	
	W_1 =2189	W_1 =2273	84	3.69	
15% CSA	W_2 =2274	W_2 =2360	86	3.64	3.67
	W_3 =2245	W_3 =2331	86	3.69	
10 CSA+2% PRA	W_1 =2230	W_1 =2266	36	1.33	
	W_2 =2430	W_2 =2466	36	1.46	1.49
	W_3 =2380	W_3 =2418	38	1.57	
	W_1 =2210	W_1 =2258	48	2.13	
15 CSA+2% PRA	W_2 =2230	W_2 =2278	48	2.11	2.08
	W_3 =2345	W_3 =2393	48	2.00	

Appendix H.2 : Absorption Capacity of Samples Specimens at 56days (24HRS)

SAMPLE	**56days**				
	Weight Oven Dry	**Weight At SSD**	**Difference**	**%**	**Average %**
	W_1 =2320	W_1 =2420	100	4.13	
Control 100%CMT	W_2 =2180	W_2 =2310	110	5.62	4.6
	W_3 =2360	W_3 =2460	100	4.06	
	W_1 =2280	W_1 =2319	39	1.68	
Control+ 2% PRA	W_2 =2080	W_2 =2120	40	1.89	1.75
	W_3 =2222	W_3 =2270	38	1.68	
	W_1 =2340	W_1 =2406	66	2.73	
10% CSA	W_2 =2080	W_2 =2138	58	2.71	2.92
	W_3 =2200	W_3 =2265	65	2.86	

	W_1 =2280	W_1 =2340	60	2.63	
15% CSA	W_2 =2200	W_2 =2269	69	3.04	3.0
	W_3 =2280	W_3 =2360	80	3.38	
10 CSA+2% PRA	W_1 =2280	W_1 =2309	29	1.25	
	W_2 =2260	W_2 =2298	38	1.61	1.45
	W_3 =2268	W_3 =2303	35	1.5	
	W_1 =2420	W_1 =2456	37	1.51	
15 CSA+2% PRA	W_2 =2340	W_2 =2372	32	1.34	1.48
	W_2 =2200	W_3 =2236	36	1.61	

Appendix H.3 : Absorption Capacity of Samples Specimens at 90days (24HRS)

SAMPLE	**90days**				
	Weight Oven Dry	**Weight At SSD**	**Difference**	**%**	**Average %**
	W_1 =2327	W_1 =2422	95	3.92	
Control 100%CMT	W_2 =2166	W_2 =2266	100	4.13	4.02
	W_3 =2343	W_3 =2441	98	4.02	
	W_1 =2233	W_1 =2265	32	1.41	
Control+ 2% PRA	W_2 =2259	W_2 =2291	32	1.39	1.43
	W_3 =2190	W_3 =2223	33	1.48	
	W_1 =2192	W_1 =2224	32	1.44	
10% CSA	W_2 =2293	W_2 =2330	34	1.45	1.45
	W_3 =2275	W_3 =2309	34	1.47	

	W_1 =2270	W_1 =2335	65	2.78	
15% CSA	W_2 =2266	W_2 =2325	59	2.53	2.56
	W_3 =2194	W_3 =2247	53	2.35	
10 CSA+2% PRA	W_1 =2274	W_1 =2294	20	0.87	
	W_2 =2354	W_2 =2374	20	0.84	0.87
	W_3 =2194	W_3 =2214	20	0.90	
	W_1 =2363	W_1 =2391	28	1.17	
15 CSA+2% PRA	W_2 =2212	W_2 =2240	28	1.25	1.19
	W_3 =2287	W_3 =2314	27	1.17	

Appendix I: Sorptivity of Samples Specimens

Appendix I.1.1: Sorptivity Capacity of Samples Specimens at 28days (3HRS)

SAMPLE	**28days**				
	Oven dried Weight W_1	**SSD after 3hrs W_2**	**Difference $W_2 - W_1$**	**Sorptivity Index $x10^{-5}$**	**Average Sorptivity Index $x10^{-5}$**
Control 100% CMT	W_1= 2363	W_1=2385	22	16.39	
	W_2= 2284	W_2=2306	22	16.39	16.64
	W_3= 2238	W_3=2261	23	17.14	
2% PRA	W_1=2142	W_1=2153	8	5.96	
	W_2=2217	W_2=2228	8	5.96	5.71
	W_3=2305	W_3=2316	7	5.22	

10% CSA	W_1= 2269	W_1=2285	16	11.92	
	W_2= 2217	W_2=2267	17	12.66	11.91
	W_3= 2320	W_3=2335	15	11.17	
15% CSA	W_1= 2154	W_1=2171	17	12.67	
	W_2= 2075	W_2=2092	17	12.67	12.42
	W_3= 2240	W_3=2256	16	11.92	
10 CSA+2% PRA	W_1= 2227	W_1=2236	5	3.73	
	W_2= 2196	W_2=2205	6	4.47	4.22
	W_3= 2240	W_2=2220	6	4.47	
15 CSA+2% PRA	W_1= 2158	W_1=2168	7	5.21	
	W_2= 2210	W_2=2218	8	5.96	5.46
	W_3= 2248	W_3=2260	7	5.21	

Appendix I.1.2: Sorptivity Capacity of Samples Specimens at 28days (6HRS)

SAMPLES	**28days**				
	Oven dried Weight W_1	**SSD after 6hrs W_2**	**Difference $W_2 - W_1$**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100%CMT	W_1= 2363	W_1=2392	29	15.27	
	W_2= 2284	W_2=2312	28	14.75	15.44
	W_3= 2238	W_3=2269	31	16.32	
2% PRA	W_1= 2142	W_1=2157	15	7.91	
	W_2= 2217	W_2=2231	14	7.38	7.38
	W_3= 2305	W_3=2318	13	6.85	
10% CSA	W_1= 2269	W_1=2290	21	11.10	
	W_2= 2217	W_2=2237	20	10.54	11.08

	W_3= 2320	W_3=2342	22	11.59	
15% CSA	W_1= 2154	W_1=2176	22	11.59	
	W_2= 2075	W_2=2098	23	12.12	12.12
	W_3= 2240	W_3=2262	24	12.65	
10 CSA+2% PRA	W_1= 2227	W_1=2239	12	6.33	
	W_2= 2196	W_2=2209	14	7.38	6.68
	W_3= 2240	W_2=2252	12	6.33	
15 CSA+2% PRA	W_1= 2158	W_1=2175	17	8.96	
	W_2= 2210	W_2=2228	18	9.49	8.96
	W_3= 2245	W_3=2261	16	8.43	

Appendix I.1.3: Sorptivity Capacity of Samples Specimens at 28days (24HRS)

SAMPLE	**28days**				
	Oven dried Weight W_1	**SSD after 24hrs W_2**	**Difference W_2-W_1**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100%CMT	W_1= 2363	W_1=2451	88	23.18	
	W_2= 2284	W_2=2385	101	26.61	25.20
	W_3= 2238	W_3=2336	98	25.82	
2% PRA	W_1= 2142	W_1=2190	48	12.64	
	W_2= 2217	W_2=2264	47	12.38	12.47
	W_3= 2305	W_3=2352	47	12.38	
10% CSA	W_1= 2269	W_1=2327	58	15.28	
	W_2= 2217	W_2=2275	58	15.28	15.54
	W_3= 2320	W_3=2381	61	16.07	

15% CSA	W_1= 2154	W_1=2219	65	17.13	
	W_2= 2075	W_2=2142	67	17.65	17.48
	W_3= 2240	W_3=2307	67	17.65	
10 CSA+2% PRA	W_1= 2227	W_1=2261	34	8.95	
	W_2= 2196	W_2=2232	36	9.47	9.48
	W_3= 2240	W_2=2278	38	10.01	
15 CSA+2% PRA	W_1= 2158	W_1=2198	40	10.54	
	W_2= 2210	W_2=2252	42	11.08	11.14
	W_3= 2245	W_3=2284	41	10.80	

Appendix I.1.4: Sorptivity Capacity of Samples Specimens at 28days (48HRS)

SAMPLE	**28days**				
	Oven dried Weight W_1	**SSD after 6hrs W_2**	**Difference W_2-W_1**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100%CMT	W_1= 2363	W_1=2487	124	23.10	
	W_2= 2284	W_2=2413	129	24.04	23.10
	W_3= 2238	W_3=2357	119	22.17	
2% PRA	W_1= 2142	W_1=2184	42	7.83	
	W_2= 2217	W_2=2259	42	7.83	7.77
	W_3= 2305	W_3=2346	41	7.64	
10% CSA	W_1= 2269	W_1=2341	72	13.41	
	W_2= 2217	W_2=2287	70	13.04	13.16
	W_3= 2320	W_3=2390	70	13.04	

15% CSA	W_1= 2154	W_1=2232	78	14.53	
	W_2= 2075	W_2=2150	75	13.97	14.09
	W_3= 2240	W_3=2314	74	13.79	
10 CSA+2% PRA	W_1= 2227	W_1=2255	28	5.21	
	W_2= 2196	W_2=2223	27	5.03	5.21
	W_3= 2240	W_2=2269	29	5.40	
15 CSA+2% PRA	W_1= 2158	W_1=2193	35	6.52	
	W_2= 2210	W_2=2245	35	6.52	6.39
	W_3= 2245	W_3=2278	33	6.14	

Appendix I.2 : Sorptivity Capacity of Samples Specimens at 56days (3HRS)

Appendix I.2.1 : Sorptivity Capacity of Samples Specimens at 56days (3HRS)

SAMPLE	**Oven dried weight**	**SSD after 3hrs**	**56days Difference**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100% CMT	W_1= 2321	W_1=2344	19	14.15	
	W_2= 2175	W_2=2195	17	12.67	13.66
	W_3= 2350	W_3=2380	19	14.16	
2% PRA	W_1= 2294	W_1=2301	7	5.21	
	W_2= 2104	W_2=2110	6	4.47	4.96
	W_3= 2225	W_3=2232	7	5.21	
10% CSA	W_1= 2135	W_1=2148	13	9.69	

	W_2= 2265	W_2=2280	15	11.18	10.43
	W_3= 2188	W_3=2202	14	10.43	
15% CSA	W_1= 2276	W_1=2292	16	11.92	
	W_2= 2200	W_2=2216	16	11.92	12.17
	W_3=2278	W_3=2295	17	12.67	
10 CSA+2% PRA	W_1= 2322	W_1=2327	5	3.73	
	W_2= 2307	W_2=2312	5	3.73	3.43
	W_3= 2388	W_2=2392	4	2.98	
15 CSA+2% PRA	W_1= 2396	W_1=2402	6	4.47	
	W_2= 2332	W_2=2337	5	3.73	4.22
	W_3= 2189	W_3=2195	6	4.47	

Appendix I.2.2 : Sorptivity Capacity of Samples Specimens at 56days (6HRS)

SAMPLE	**56days**				
	Oven dried weight	**SSD after 6hrs**	**Difference**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100%CMT	W_1= 2321	W_1=2365	44	23.19	
	W_2= 2175	W_2=2221	46	24.24	24.06
	W_3= 2350	W_3=2397	47	24.77	
2% PRA	W_1= 2294	W_1=2317	23	12.12	
	W_2= 2104	W_2=2130	26	13.71	12.28
	W_3= 2225	W_3=2246	21	11.01	
10% CSA	W_1= 2135	W_1=2163	28	14.76	
	W_2= 2265	W_2=2291	26	13.71	14.23
	W_3= 2188	W_3=2215	27	14.23	

15% CSA	W_1= 2276	W_1=2306	30	15.81	
	W_2= 2200	W_2=2229	29	15.29	15.81
	W_3= 2278	W_3=2309	31	16.34	
10 CSA+2% PRA	W_1= 2322	W_1=2338	16	8.43	
	W_2= 2307	W_2=2321	14	7.38	8.08
	W_3= 2388	W_2=2404	16	8.43	
15 CSA+2% PRA	W_1= 2396	W_1=2415	19	10.01	
	W_2= 2332	W_2=2352	20	10.55	10.19
	W_3= 2189	W_3=2208	19	10.01	

Appendix I.2.3 : Sorptivity Capacity of Samples Specimens at 56days (24HRS)

SAMPLE	**56days**				
	Oven dried weight	**SSD after 24hrs**	**Difference**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100%CMT	W_1= 2321	W_1=2401	80	21.08	
	W_2= 2175	W_2=2255	80	21.08	21.66
	W_3= 2350	W_3=2436	86	22.66	
2% PRA	W_1= 2294	W_1=2333	39	10.27	
	W_2= 2104	W_2=2142	38	10.01	10.01
	W_3= 2225	W_3=2262	37	9.75	
10% CSA	W_1= 2135	W_1=2185	50	13.17	
	W_2= 2265	W_2=2314	49	12.91	12.99
	W_3= 2188	W_3=2237	49	12.91	

15% CSA	W_1= 2278	W_1=2331	53	13.96	
	W_2= 2200	W_2=2252	52	13.70	13.87
	W_3= 2278	W_3=2331	53	13.96	
10 CSA+2% PRA	W_1= 2332	W_1=2362	30	7.91	
	W_2= 2307	W_2=2338	31	8.17	7.91
	W_3= 2388	W_2=2417	29	7.64	
15 CSA+2% PRA	W_1= 2430	W_1=2464	34	8.96	
	W_2= 2342	W_2=2376	34	8.96	8.96
	W_3= 2215	W_3=2248	33	8.69	

Appendix I.2.4 : Sorptivity Capacity of Samples Specimens at 56days (48HRS)

SAMPLE	**56days**				
	Oven dried weight	**SSD after 24hrs**	**Difference**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100%CMT	W_1= 2321	W_1=2425	104	19.36	
	W_2= 2175	W_2=2280	105	19.56	19.68
	W_3= 2350	W_3=2458	108	20.13	
2% PRA	W_1= 2294	W_1=2328	34	6.34	
	W_2= 2104	W_2=2137	33	6.15	6.28
	W_3= 2225	W_3=2258	33	6.15	
10% CSA	W_1= 2135	W_1=2196	61	11.37	
	W_2= 2265	W_2=2323	58	10.81	11.37

	W_3= 2188	W_3=2252	64	11.93	
15% CSA	W_1= 2278	W_1=2344	66	12.29	
	W_2= 2200	W_2=2267	67	12.49	12.55
	W_3= 2278	W_3=2347	69	12.86	
10 CSA+2% PRA	W_1= 2332	W_1=2355	23	4.29	
	W_2= 2307	W_2=2330	23	4.29	4.22
	W_3= 2388	W_2=2410	22	4.09	
15 CSA+2% PRA	W_1= 2430	W_1=2470	29	5.40	
	W_2= 2342	W_2=2381	29	5.40	5.34
	W_3= 2215	W_3=2256	28	5.22	

Appendix I.3 : Sorptivity Capacity of Samples Specimens at 90days

AppendixI.3.1 : Sorptivity Capacity of Samples Specimens at 90days (3HRS)

SAMPLE	**Oven dried weight**	**SSD after 3hrs**	**90days Difference**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100%CMT	W_1= 2325	W_1=2310	15	11.17	
	W_2= 2165	W_2=2308	17	12.67	11.92
	W_3= 2359	W_3=2343	16	11.92	
2% PRA	W_1= 2256	W_1=2262	6	4.47	
	W_2= 2218	W_2=2224	6	4.47	4.22

	W_3= 2290	W_3=2295	5	3.73	
10% CSA	W_1= 2214	W_1=2223	9	6.71	
	W_2= 2306	W_2=2315	9	6.71	6.72
	W_3= 2304	W_3=2314	10	6.74	
15% CSA	W_1= 2253	W_1=2264	11	8.19	
	W_2= 2282	W_2=2293	11	8.19	7.94
	W_3= 2173	W_3=2183	10	7.45	
10 CSA+2% PRA	W_1= 2277	W_1=2281	4	2.98	
	W_2= 2358	W_2=2362	4	2.98	3.23
	W_3= 2233	W_2=2248	5	3.73	
15 CSA+2% PRA	W_1= 2213	W_1=2218	5	3.73	
	W_2= 2257	W_2=2263	5	3.73	3.73
	W_3= 2782	W_3=2787	5	3.73	

Appendix I.3.2 : Sorptivity Capacity of Samples Specimens at 90days (6HRS)

SAMPLE	**90days**				
	Oven dried weight	**SSD after 6hrs**	**Difference**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100%CMT	W_1= 2325	W_1=2358	33	17.4	
	W_2= 2165	W_2=2195	30	15.81	16.87
	W_3= 2359	W_3=2392	33	17.4	
2% PRA	W_1= 2256	W_1=2272	16	8.43	
	W_2= 2218	W_2=2235	17	8.96	8.61
	W_3= 2218	W_3=2234	16	8.43	

10% CSA	W_1= 2214	W_1=2233	19	10.01	
	W_2= 2306	W_2=2326	20	10.54	10.36
	W_3= 2304	W_3=2324	20	10.54	
15% CSA	W_1= 2253	W_1=2275	22	11.60	
	W_2= 2282	W_2=2302	20	10.54	12.47
	W_3= 2173	W_3=2195	22	11.60	
10 CSA+2% PRA	W_1= 2173	W_1=2185	12	6.33	
	W_2= 2173	W_2=2184	11	5.80	6.33
	W_3= 2233	W_2=2246	13	6.85	
15 CSA+2% PRA	W_1= 2213	W_1=2232	19	10.02	
	W_2= 2257	W_2=2277	20	10.54	10.01
	W_3= 2782	W_3=2800	18	9.48	

Appendix I.3.3 : Sorptivity Capacity of Samples Specimens at 90days (24HRS)

SAMPLE	**90days**				
	Oven dried weight	**SSD after 6hrs**	**Difference**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100% CMT	W_1= 2325	W_1=2373	48	12.65	
	W_2= 2165	W_2=2221	56	14.76	13.96
	W_3= 2359	W_3=2414	55	14.49	
2% PRA	W_1= 2256	W_1=2280	24	6.36	
	W_2= 2218	W_2=2242	24	6.32	6.25
	W_3= 2218	W_3=2241	23	6.06	

10% CSA	W_1= 2214	W_1=2247	33	8.70	
	W_2= 2306	W_2=2339	33	8.79	8.82
	W_3= 2304	W_3=2338	34	8.96	
15% CSA	W_1= 2253	W_1=2289	36	9.47	
	W_2= 2282	W_2=2319	37	9.75	9.48
	W_3= 2173	W_3=2208	35	9.22	
10 CSA+2% PRA	W_1= 2173	W_1=2191	18	4.74	
	W_2= 2173	W_2=2192	19	5.00	4.92
	W_3= 2233	W_2=2252	19	5.00	
15 CSA+2% PRA	W_1= 2213	W_1=2235	22	5.79	
	W_2= 2257	W_2=2280	23	6.10	5.89
	W_3= 2782	W_3=2804	22	5.79	

Appendix I.3.4 : Sorptivity Capacity of Samples Specimens at 90days (48HRS)

SAMPLE	**90days**				
	Oven dried weight	**SSD after 48hrs**	**Difference**	**Sorptivity Index x10^{-5}**	**Average Sorptivity Index x10^{-5}**
Control 100%CMT	W_1= 2325	W_1=2444	119	63.86	
	W_2= 2165	W_2=2263	98	52.50	56.14
	W_3= 2359	W_3=2456	97	52.05	
2% PRA	W_1= 2256	W_1=2276	20	7.60	
	W_2= 2218	W_2=2238	20	7.60	7.47

	W_3= 2218	W_3=2237	19	7.21	
10% CSA	W_1= 2214	W_1=2271	57	30.58	
	W_2= 2306	W_2=2365	59	31.66	29.15
	W_3= 2304	W_3=2351	47	25.22	
15% CSA	W_1= 2253	W_1=2316	63	33.81	
	W_2= 2282	W_2=2344	62	33.26	33.44
	W_3= 2173	W_3=2235	62	33.26	
10 CSA+2% PRA	W_1= 2173	W_1=2186	13	6.45	
	W_2= 2173	W_2=2187	14	5.31	5.69
	W_3= 2233	W_2=2275	14	5.31	
15 CSA+2% PRA	W_1= 2213	W_1=2230	17	6.45	
	W_2= 2257	W_2=2275	18	6.83	6.57
	W_3= 2258	W_3=2275	17	6.45	

AppendixJ: Abrasion Resistance of Samples Specimen

Appendix J.1:Abrasion Resistance of Samples Specimens at 28days

SAMPLE	**28days**				
	Weight Before Brushing	**Weight After Brushing**	**Difference**	**%**	**Average %**
	W_1 =2322	W_1=2316	3	0.25	
Control	W_2 =2345	W_2=2340	3	0.21	0.13

100%CMT					
	W_3 =2358	W_3=2252	3	0.25	
	W_1 =2300	W_1=2296	6	0.26	
Control+ 2% PRA	W_2 =2320	W_2=2314	6	0.26	0.23
	W_3 =2280	W_3=2276	4	0.18	
	W_1 =2328	W_1=2255	3	0.13	
10% CSA	W_2 =2280	W_2=2276	4	0.18	0.16
	W_3 =2290	W_3=2286	4	0.18	
	W_1 =2295	W_1=2290	5	0.22	
15% CSA	W_2 =2265	W_2=2260	5	0.22	0.21
	W_3 =2232	W_3=2228	4	0.18	
10 CSA+2% PRA	W_1 =2320	W_1=2317	3	0.13	
	W_2 =2230	W_2=2226	4	0.18	0.16
	W_3 =2342	W_3=2338	4	0.17	
	W_1 =2321	W_1=2316	4	0.17	
15 CSA+2% PRA	W_2 =2208	W_2=2203	3	0.23	0.16
	W_3 =2289	W_3=2284	4	0.22	

Appendix J.2:Abrasion Resistance of Samples Specimens at 56days

SAMPLE	**56days**				
	Weight Before Brushing	**Weight After Brushing**	**Difference**	**%**	**Average %**
	W_1 =2326	W_1=2323	2	0.085	
Control	W_2 =2310	W_2=2307	3	0.13	0.12
100%CMT					
	W_3 =2258	W_3=2254	4	0.18	

	W_1 =2280	W_1=2277	3	0.13	
Control+ 2% PRA	W_2 =2290	W_2=2287	3	0.13	0.15
	W_3 =2280	W_3=2276	4	0.18	
	W_1 =2328	W_1=2326	2	0.08	
10% CSA	W_2 =2280	W_2=2278	2	0.09	0.09
	W_3 =2310	W_3=2308	2	0.09	
	W_1 =2250	W_1=2247	3	0.13	
15% CSA	W_2 =2240	W_2=2238	2	0.09	0.12
	W_3 =2232	W_3=2229	3	0.13	
10 CSA+2% PRA	W_1 =2320	W_1=2318	2	0.09	
	W_2 =2240	W_2=2239	2	0.09	0.09
	W_3 =2242	W_3=2240	2	0.09	
	W_1 =2345	W_1=2343	2	0.09	
15 CSA+2% PRA	W_2 =2318	W_2=2316	2	0.09	0.10
	W_3 =2289	W_3=2286	3	0.13	

Appendix J.3 Abrasion Resistance of Samples Specimens at 90days

SAMPLE	**90days**				
	Weight Before Brushing	**Weight After Brushing**	**Difference**	**%**	**Average %**
	W_1 =2391	W_1=2389	2	0.084	
Control 100%CMT	W_2 =2410	W_2=2409	2	0.084	0.085

	W_3 =2232	W_3=2230	2	0.084	
	W_1 =2285	W_1=2284	1	0.044	
Control+ 2% PRA	W_2 =2245	W_2=2244	0	0	0.0445
	W_3 =2239	W_3=2338	1	0.045	
	W_1 =2256	W_1=2255	1	0.044	
10% CSA	W_2 =2339	W_2=2339	1	0.043	0.042
	W_3 =2356	W_3=2355	1	0.042	
	W_1 =2295	W_1=2294	1	0.044	
15% CSA	W_2 =2315	W_2=2314	1	0.043	0.044
	W_3 =2232	W_3=2231	1	0.045	
10 CSA+2% PRA	W_1 =2320	W_1=2320	1	0.043	
	W_2 =2430	W_2=2430	1	0.043	0.043
	W_3 =2379	W_3=2379	1	0.042	
	W_1 =2251	W_1=2250	1	0.044	
15 CSA+2% PRA	W_2 =2308	W_2=2308	1	0.043	0.043
	W_3 =2319	W_3=2318	1	0.043	