INFLUENCE OF SUPERPLASTICIZER ON CONCRETES MADE WITH DIFFERENT BRANDS OF PORTLAND CEMENTS IN NIGERIA

BY

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DECLARATION

I declare that the work in the dissertation report entitled "INFLUENCE OF SUPERPLASTICIZER ON CONCRETES MADE WITH DIFFERENT BRANDS OF PORTLAND CEMENT IN NIGERIA" has been done by me in the Department of Building, under the supervision of Prof. M. M. Garba. 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.

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CERTIFICATION

This is to certify that this dissertation entitled" INFLUENCE OF SUPERPLASTICIZER ON CONCRETES MADE WITH DIFFERENT BRANDS OF PORTLAND CEMENT IN NIGERIA" by Bashir Iliyasu Umar, has been duly supervised, corrected, hereby approved and meets the regulations governing the award of the Mastres 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

This Dissertation is dedicated, first and foremost, to my parents, members of my family, brothers and sisters and to those set of people that help their fellow human beings irrespective of their tribe, religion, race, ideology or social status.

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ABSTRACT

The rate of strength development of concrete depends mainly on cement type, water-cement ratio, and sometimes the use of admixtures or super plasticizer (SP). SPs are indispensable in modern concretes, providing high workable concrete at low water to cement ratios, and resulting in the production of high strength, durable and sustainable concrete. However, the issues of cement-SPs incompatibility, when wrong combination is used, have been identified by some researchers. This research therefore aimed at assessing the influence of Rheobuild-600 on concretes made with different brands of Portland cements manufactured in Nigeria. Optimum dosage of SP for the research was established by weight of cement A. Building Research Establishment (BRE), method of concrete mix design was used to design a grade 30 concrete that was used in the research. 30% of the quantity of mixing water was deducted from the design water content in order to determine the effect of SP on workability. Concrete samples were prepared using five brands of cements. A set of 320 100mm x 100mm x 100mm concrete cube specimens were cured by complete immersion in water. Another set of 320 cubes were exposed to 1% concentration of $MgSO_4$ solution. The samples were then, tested for compressive and tensile strengths at the ends of 3, 7, 28 and 56 days of curing. Furthermore, the quantity of cement saving was determined when the dosage of SP was increased from 0.2 to 1.5%. The research established that the workability of the concrete mixes were found to fall between medium and high workability when 1% SP was used. Compressive strength increased for the super-plasticized concrete over the non-super-plasticized concrete which were found to be 40.31%, 37.65%, 51.62%, 52.08%, and 65.32% for cements A, B, C, D, and E respectively. Also, the quantity of cement saving was found to be up to 25.05% when 1% Rheobuild-600 is used. It was concluded that the cement brands investigated

were all compatible with Rheobuild-600 in terms of higher performance on strength, workability, and durability of concrete. Cement E was found to be the most compatible brand because of the higher strength obtained. The research recommends that though the five brands of cements studied were found to be compatible with Rheobuild-600, the optimum dosage of the Rheobuild-600 should be determined for any selected cement before used.

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INTRODUCTION

1.0 Background of the Study

Concrete is a composite material made out of water, aggregates ensconce in a hard matrix of material that fills the space between the aggregate particles and glues them together. The mixing water according to Gupta and Gupta (2012), Shetty (2009), MacCarthy (2010), Sabraini (2010) and Garba (2014),induces hydration process in concrete production (which is responsible for strength development) and assist in workability. The hard matrix of material that glues the aggregate particles (sand and gravel etc) is either ordinary Portland cement (OPC) or Portland Pozzolana cement (PPC). In order to perform its intended functions, concrete is made with different types of cements and sometimes contains admixtures (Neville and Brooks, 2000).

Portland cement, according to Neville and Brooks (2000), is the name given to a cement obtained by initially mixing together calcareous and argillaceous, or other silica, alumina and iron oxide-bearing materials, burning them at a clinkering temperature and grinding the resulting clinker. Houst *et al.* (2010) opined that Portland cement composed of roughly five mineralogical phases; Alite (C_3S), Belite (C_2S), Celite (C_3A), Felite (C_4AF), and gypsum, which according to Matawal (2013), are responsible for early cement strength, strength development at 28 days, setting time and heat of hydration and cement coloration respectively. The gypsum added during grinding of clinker adjusts setting time and improves cement soundness (Matawal, 2013).

Qualities of cement may differ based on the production origin. In the study carried out by Yahya (2009) on the Physico-Chemical classification of Nigerian cement, the result indicated that only two indigenous Portland cement brands conform, in their chemical composition, with the set of standards and the majority of the Portland cements sold in Nigeria are better used for structures involved with low loading. However, according to Omoniyi and Okunola (2015) the physical tests on five brands of Portland cements (Dangote, Ibeto, Unicem, Elephant and Atlas) sold in Umuahia, Nigeria revealed that the respective fineness of 2%, 0.34%, 0.17%, 0.3% and 0.35% obtained for Dangote, Elephant, Ibeto, Unicem and Atlas cements are in conformity with the standard specification of 10% maximum but the average specific gravity obtained for the samples was below the standard value of 3.1 minimum. Thus, the mechanical properties of cement depend on the progressive maturation of hydrated porous phases due to continuous reaction of water with cement. The hydration process, according to Chiang *et al*. (2013), can last for several years and is strongly affected by admixtures.

Nowadays, the need for quality and timely completion of projects has given rise to the use of admixtures. An admixture is a material other than water, aggregate or hydraulic cement that is used as an ingredient of concrete or mortar, and is added to the batch immediately before or during mixing (Ganiron, 2013).Due to multiple purposes of the concrete structures and various restrictions on the construction environment, the use of both mineral admixtures (fly ash, silica fume, blast furnance, slag) and chemical admixtures (retarders, accelerators, plasticizers and superplasticizers) have become more pronounced, and more specific for every construction.

Superplasticizers (SP), also known as high range water-reducers, constitute a relatively new category and improved version of plasticizers (water- reducing admixtures) and are chemically different from each other. Generally, there are four main categories of SPs:

sulfonated melamine-formaldehyde condensates (SMF), sulfonated naphthalene-formaldehyde condensates (SNF), modified lignosulfonates (MLS) and others such as sulfonic acid, esters and carbohydrate esters (Alasady, 2013). Superplsticizers (when use in concrete mix) mainly affect the yield stress by minimizing attractive forces between the particles of the concrete (Schmidt, 2015). Yield stress is the minimum stress, which has to be applied before viscous flow is initiated. Since Portland cement flocculates in wet concrete and the flocculation, according to Shetty (2009) entraps certain amount of water used in the mix thereby all the water is not freely available to fluidify the mix. Neville and Brooks (2000) confirmed that when plasticizers or SP are used in the mix they cause the cement to disperse by being adsorbed on the surface of the cement particles, causing them to become negatively charged and thus mutually repulsive, this increase the workability at a given w/c ratio. The dispersing ability of water reducing admixtures (plasticizers) and high range water reducers (SPs) therefore, results in a greater surface area of cement exposed to hydration, and for this reason there is increase in strength at early ages. The dispersion of particles takes place either by electrostatic or steric repulsion, or a combination of both effects (Schmidt, 2015). However, according to Bassioni (2015) large amount of SP is adsorbed on C_3A of OPC in the relationship between them, which do not significantly affect the setting of concrete except in the case of cements with a very low C_3A content.

Furthermore, Shetty (2009) summarised the properties affected by plasticizers and Sps in the fresh concrete environment as: inducing electrostatic repulsion between particles of cement, reduction in the surface tension of water, lubricating film between cement particles, dispersion of cement grains by releasing water trapped within cement flocs, inhibition of surface hydration reaction of the cement particles leaving more water to fluidify the mix, change in the morphology of the hydration process, and inducing steric hindrance preventing particles-to-particles contact.

According to Evangeline and Neelamegan (2013) the use of SP permits reduction of water to an extent of up to 30% without reducing the workability in contrast to the possible reduction up to 15% in case of plasticizers. However, Ran *et al.* (2006) opined that the water reduction can reach up to 22.2% at a rate of 0.20% by weight of cement. This perhaps explain the reason why Collepardi *et al.* (2006) delineated the purposes of using SP in concrete mixtures as; (a) to increase workability, at a given mix composition, in order to enhance placing characteristics of concrete, (b) to reduce mixing water, at a given cement content and workability, in order to reduce the water-cement ratio (w/c) and therefore to increase strength and improve durability and (c) to reduce both water and cement, at a given workability and strength, in order to save cement and reduce creep, shrinkage, and thermal strains caused by heat of cement hydration.

Few studies have been done on the impact of SPs on fresh and hardened concrete. It was generally observed by virtually all the researchers such as; Ahmad *et al.* (2005), Santhanam (2013), Kapelco and Kapelco (2007), Mohammed *et al.* (2014), Bassioni (2015), Malagavelli and Paturu (2012), etc that with a very low water/cement ratio SPs significantly influence concrete mixture fluidity. The reduction of water cement ratio improves the durability of concrete (Shetty, 2009). Neville and Brooks (2010) opined that the influence of SP on strength and durability of concrete is greater with cements which have low C_3A or low alkali content. However, these benefits of SPs, as asserted by Santhanam (2013) and Bassioni (2015), come at some cost in chemical complexity and possible interaction problems when incompatibilities with certain cement types, common incompatibilities among a few chemical admixtures, or incompatibilities with other concrete components arise.

Santhanam (2013) and Bassioni (2015) pointed out that cement-superplasticizer incompatibilities are regularly seen in field application. This explains the reason why Diamond and Matsukawa (1993) carried out an extensive research on quantitative analysis of interaction between brands of Portland cements available in Northern America and some selected SPs. They discovered that in all cases, the presence of the SPs modifies the early pattern of ettringite development but when excessive amount of alkali hydroxides were added to superplasticized white cement, premature stiffening of a variant kind was developed. Aitchin (2004) affirms that the C_3A content, the soluble (alkali) sulphate content, and the fineness of cement, which influence the adsorption rate of the SP on the cement particles, are among the key factors that control the compatibility and robustness of cement-SP combination, especially for polysulfonated admixtures. Neville and Brooks (2010) reiterated that C_3A content, C_3S/C_2S ratio, fineness of cement, alkali content and gypsum content are responsible for lack of compatibility with a particular type of SP and their performance in concrete. Since certain brands of cement may not be compatible with SPs as clarified by Bakash and Reddy (2013) the type of cement to be used should be properly selected and sufficient trial mixes be carried out to ensure production of sustainable superplasticized concrete.

Shah *et al.* (2014)identified the behaviour of normal strength concrete using SP under different curing regimes and concluded that the compressive strength of concrete is enhanced with addition of SP up to an optimum limit of 0.50% by weight of cement (subject to maintainance of water/cement ratio). According to Alsady (2015) the dosage of

SP is between 1-3L/m^{3}which can be increased to as high as 5-20L/m^3 depending on the concentration of the SP. Ahmad *et al.* (2005) used 0.8% SPs to determine their effect on workability and strength of concrete. Thus, the effectiveness of a given dosage largely depends on the water/cement ratio (i.e. the effectiveness increases with decrease in water/cement ratio). And although increment in dosage will enhance the compressive strength but when the dosages go beyond the specified limit, the compressive strength will only get reduced as confirmed by Alsady, (2015). However, Santhanam (2013) proved that the concretes made with Portland Pozzolana Cement (PPC) require higher SP dosages for the same workability as compared to the concrete made with Ordinary Portland Cement (OPC).

1.2 Statement of Research Problem

The workability of a concrete influences the strength and durability of a hardened concrete which could be enhanced by increasing the quantity of mixing water among many other ways. Neville and Brooks (2010) defined workability as the property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. The modern method of increasing workability of a concrete is by using an optimum dosage of SP during the concrete production while the water/cement ratio is kept constant. SPs are essential components in modern concretes, providing workability enhancement at low water to cement ratio and resulting in the production of durable and sustainable concrete (Santhanam, 2013). Although the relevance of SP have long being established, its (SP) effects on different brands of OPC is still been studied.

Many researchers such as Kapelko and Kapelko (2007), Ahmad *et al.* (2005), Zingg (2008), Houst*et al*. (2010) and Santhanam (2012) emphasised that although the mechanisms leading to SP performance are well understood, issues of cement-superplasticizer incompatibility are regularly seen in field applications. Santhanam (2013) enumerated the common problems that arise as a result of incompatibility between some types of cements and SPs as: rapid loss of workability, excessive quickening or retardation of setting, and low rate of strength gain. Shetty (2009) also, listed some site problems in the use of SPs which includes; selection of SPs, sequence of addition of SPs, problem with crusher dust, problem with crushed sand, determination of dosage, slump loss, how to reduce slump loss, segregation, bleeding, and compatibility with cement. In addition, economic benefits, as opined by Ahmad *et al*. (2013) may be possible through reduced cement content and less labour intensive concrete placement in the field could be achieved. This research intends to assess how SP (Rheobuild-600) affects the qualities of concretes produced with different brands of OPC in Nigeria.

1.3 Justification of the Study

With the increase in the demand for larger structures that can withstand heavier loads, the strength of the concrete has to be increased in order to meet the demands. Increased strength requirements of the concrete will require concrete of lesser water cement ratio (low workable mixes). Thus, methods of increasing workability without reducing the strength and quality have to be explored in order to meet the demand. This research will focus specifically on a type of super plasticizer (Reobuild-600), which is considered as the most available SP in the Nigerian markets, and the different brands of Portland cements that are available in the Nigerian market, particularly the northern part of the country.

If the research is successfully completed, the cement brand that is most compatible to Rheobuild-600 will be identified. And the use of the admixture in construction with the appropriate cement will as opined by Bassiani, (2012) minimise cement production (which causes CO_2 emission). Results of this work would therefore assist in ensuring that building and construction sector is moved towards a better performance in terms of sustainability. The construction industry, according to Bakash and Reddy, (2013) roughly accounts for 40% of global energy consumption and waste generation and 50% of CO_2 emission.

1.4 Aim and Objectives

1.4.1 Aim

The aim of this research is to assess the influence of Rheobuild-600 on concretes made with different brands of Portland cements in Nigeria; this is with a view to determining the most compatible cement type for the production of durable concrete.

1.4.2 Objectives

The objectives are:

1. To ascertain the elemental and chemical composition of different brands of Portland cement to be used.
2. To design grade C30 Concrete using BRE method for available materials.
3. To investigate the effect of SP on the fresh and hardened properties of concrete.
4. To determine the effect of SP on cement- saving.
5. To evaluate the durability properties of the concretes produced.

1.5 Scope and Limitations

1.5.1 Scope

In view of the fact that there exist different brands of Ordinary Portland Cements and different varieties of SPs in the Nigerian markets, the scope of this research therefore focussed on the influence of Rheobuild-600 on the physical, mechanical and durability properties of concrete made with Ashaka, Bua, Elephant, Dangote, and Sokoto cements.

1.5.2 Limitations

Compressive strength is the most important property of concrete at hardened stage. Thus, the research focussed on compressive strength of concretes made with the selected materials for assessing the cements-SP compatibility. The research did not carry out tests on Drying shrinkage, Flexural strength, Porosity, Modulus of Elasticity, and Permeability.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concrete as a Structural Material

Concrete is the most commonly used material for building and civil engineering constructions in the world. It is basically composed of two components: paste and aggregate. The paste, which binds the aggregate together, contains cement and water and sometimes other admixtures (e.g Super plasticizers), whereas the aggregate contains sand and gravel or crushed stone. The aggregates are relatively inert filler materials which occupy 60to 75% of the concrete volume and can therefore be expected to have influence on its properties (Gupta and Gupta, 2012 and Garba, 2014).

The word concrete comes from a Latin word concretus which means to grow together (Diamond *et al,* 1993) which implies that it is a composite of different materials. It is composed of coarse granular material called aggregate or filler which is embedded in a hard matrix of material (cement or binder with water) binding the aggregates together and filling the space formed between them. When the constituents are mixed with water the concrete solidifies and hardens due to a chemical reaction between the water and the cement called hydration, which finally forms a stone like material by binding the aggregates together.

Concrete is a relatively new construction material when compared to earth, stone, timber and steel. However it is now the most widely used material for building and civil engineering constructions. In 2011 alone, over 27 billion tons was used (in comparison to only about 0.7 billion used in 1993) (Garba, 2014).

Besides, if a concrete is to be suitable for a particular purpose, it is necessary to select the constituent materials and combine them in such a manner as to develop the special qualities required as economical as possible. Therefore the selection of constituents of concrete depends on the quality and economy of the particular concrete required.

2.1.1 Composition of Concrete

It is very essential to understand the fundamental composition of a concrete mix before exploring the mechanism of super plasticizer for concrete. Besides, concrete has been said to be a composite material made by mixing three essential ingredients; cement, water and fragments of aggregate (sand or stone and gravel or crushed stone) and some times, admixtures are added to improve some qualities of the concrete.

2.1.1.1 Cement

Cement is considered as the main constituent of concrete in terms strength development. Gupta and Gupta (2012) define cement as a material having adhesive and cohesive properties which makes it capable of bonding material fragments into a compact mass. Cement and water constituents of concrete chemically react to form a binding medium (Garba, 2014). When cement paste hardens, it binds the aggregate into an artificial stone-like material called concrete.

2.1.1.2 Water

Water is one of the most important ingredients of concrete as it actively participates in the chemical reaction with cement. This is why Neville and Brooks (2000) reiterates that the quality of water is important because impurities in it may interfere with the setting of cement, may adversely affect the strength of the concrete or cause staining of its surface, and may also lead to corrosion of reinforcement.

However, according to Shetty (2009), MacCarthy (2010), Sabraini (2010) and Garba *et al* (2014), mixing water induce hydration process in concrete production (which is responsible for strength development) and assist in workability (which enables concrete to be easily mixed, transported placed and compacted). The reaction between cement and water is as follows;

$$2Ca_3Si0_5 + 6H_20 \rightarrow 3Ca\,(OH)_2 + Ca_3Si_2O_7 \cdot 3H_2O \text{------------------} (2.1)$$

$$Ca_3\,(AlO_3)_2 + 6H_20 \rightarrow Ca_6\,(AlO_3)_2 \cdot 6H_2O \text{--------------------} (2.2)$$

Numerous studies have been carried out on the effect of water quality on the strength and durability characteristics of Portland cement concrete. It was generally observed by virtually all the researchers such as McCarthy (2010), Sabraini (2010), Gupta and Gupta (2012) and Garba (2014) that the quality of mixing water for concrete production should be as good as drinking water. However, this statement was not agreed by Shetty (2009), he argues that some water containing small amount of sugar could be suitable for mixing concrete and conversely water suitable for mixing concrete may not necessary be fit for drinking. He emphasizes that the best course to find out whether a particular type of water is suitable for concrete making or not, is, to make concrete with this water and compare its 7 day's and 28 day's strength with comparison cubes made with distilled water. If the compressive strength is up to 90%, the source of water may be accepted.

Besides that, there is relationship between the quality of mixing waters used in the construction of a structure with the setting time strength, stability, safety and serviceability of that structure. Noruzman *et al* (2012) carried out a research in which they noted that the initial setting time of cement paste and the compressive strength tests are the two methods by which questionable water may be tested with respect to its suitability for concrete production. Also, the presence of harmful oxides, such as MgO, SO_3 and other alkalis, in mixing water affects the quality of the hardened concrete (Reddy, 2013). Since water may contain some impurities such as clay, sugar, oil, salt etc, which may not be within the tolerable concentration as clarified by Shetty (2009), the quality of water is to be critically monitored and controlled during the process of concrete making.

2.1.1.3 Aggregate

Aggregates constitute the skeleton of concrete. Approximately three-quarters of the volume of conventional concrete are 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 (Neville and Brooks, 2000).

2.1.2 Admixtures

Prior to discussing SP and its performance in concrete, some of the literatures on admixtures and additives are reviewed to properly understand the differences between them. Shetty (2009) and Ganiron (2013) defined admixture as a material other than water, aggregate or hydraulic cement that is used as an ingredient of concrete or mortar, and is added to the batch immediately before or during mixing. Admixtures are however, used in concrete to improve or modify some or several properties of Portland cement concrete or to compensate for some deficiencies (Nemati, 2015).

Cement additives are used to bring special properties to the fresh or hardened concrete; these special properties are related to the reduction of water consumption, increased resistance to compression or extension of the setting time, and others, they also can improve the durability, workability and strength of a concrete mixture and also is used to overcome difficult situations construction such as casts in hot or cold weather, pumping requirements, early strength requirements or specifications of a water/cement ratio very low (Ocampo and Zea, 2014).Grinding assistants are the most common additives for cement and they can consist of glycols, alkanolamines and phenolic compound sand can be tentatively qualified according to the properties that they modify in fresh or harden concrete. However, additives work or function through one or more mechanisms according to Ocampo and Zea (2014).

1. Chemical interaction in cement hydration processes; typically causing acceleration or deceleration of the reaction speed of one or more clinker phases or cement.
2. Cement surface adsorption; typically causing better particle dispersion (plasticizing effect).
3. Modifiying water superficial tension; causing an increase of air present in the mixture, affecting rheology; causing an increase in plastic viscosity or mixture cohesion

It should be noted that the term '*admixture*' and '*additive*' are used synonymously. However, Navill and Brooks (2010) argued that Admixture refers to a substance which is added at the cement manufacturing stage, while Additives are substance added at the mixing stage. Ganiron (2013) opined that admixtures are grouped into Mineral admixtures and Chemical admixture. The admixtures mostly used in the construction industries among others are; Retaining plasticizers and Retarders, accelerating plasticizers, damp-proofing and water proofing admixtures, corrosion inhibiting admixtures and colouring admixtures (Shetty, 2013).

However, Neville and Brooks (2000) and Gupta and Gupta (2012) classified admixtures according to their characteristic effect as chemical and mineral admixtures.

2.1.2.1 Chemical Admixtures

They are used in concrete to generally serve as water reducers, accelerators, set retarders, or a combination, AST C494.

Water-reducing admixtures: Decrease water requirements for a concrete mix by chemically reacting with early hydration products to form a monomolecular layer at the cement-water interface that lubricates the mix and exposes more cement particles for hydration.

Superplasticizers: They are high-range water-reducing admixtures that meet the requirements of ASTM C494 Type F or G. They are often used to achieve high-strength concrete from mixes with a low water-cement ratio with good workability and low segregation.

Air-entraining agents: Increase the resistance of concrete to frost action by introducing numerous tiny air bubbles into the hardened cement paste.

Set-accelerating admixtures: They are used to decrease the time from the start of addition of water to cement to initial set and to increase the rate of strength gain of concrete. The most commonly used set-accelerating admixture is calcium chloride.

*Retarding admixtures***:** They are used to retard the initial set of concrete. A Type B or D admixture will allow transport of concrete for a longer time before initial set occurs. Final set also is delayed. Hence, precautions should be taken if retarded concrete is to be used in walls

2.1.2.2 Mineral Admixtures

These include fly ashes, pozzolans, and micro silicates. Natural cement is sometimes used as an admixture ;

Corrosion Inhibitors: They are sometimes added to a concrete mix to protect reinforcing steel. The steel usually is protected against corrosion by the high alkalinity of the concrete, which creates a passivation layer at the steel surface

*Damp proofing admixtures***:** They may be a waterproofing or a damp proofing compound or an agent that creates an organic film around the reinforcing steel, supplementing the passivation layer. The latter type of admixture may be added at a fixed rate regardless of expected chloride exposure.

*Gas-forming admixtures***:** They are used to form lightweight concrete. They are also used in masonry grout where it is desirable for the grout to expand and bond to the concrete masonry unit. They are typically an aluminium powder.

Colouring admixtures: They may be mineral oxides or manufactured pigments. Colouring requires careful control of materials, batching, and water addition in order to maintain a consistent colour at the jobsite. Note that raw carbon black, commonly used for black colour, greatly reduces the amount of entrained air in a mix.

*Miscellaneous Admixtures***:** They are organic polymer emulsions (sometimes called latexes). They usually increase the air content of mortars or concretes. The principal organic polymer emulsions used in these admixtures are polyvinyl acetate, acrylic or styrene-butadiene. The polyvinyl acetate types may or may not be re-emulsifiable. The re-emulsifiable polyvinyl acetate types should be restricted to interior or other areas not subjected to immersion. Bonding admixtures tend to render plastic concretes sticky and more difficult to place and finish. Part of this characteristic is due to their air-entrainment and part to the nature of the latex itself (Gamiron,2013).

2.1.2.2 Functions of Admixtures

Generally, admixtures are used for the following purposes according to Gupta and Gupta (2012); to retard the initial setting of concrete, to increase the strength of concrete, to improve the workability of fresh concrete, to improve the durability of concrete, to reduce the heat of evaluation, to control the alkali aggregate expansion, to promote pozzolanic properties in concrete, to aid in curing of concrete, to promote wear resistance to concrete, to reduce shrinkage during setting of concrete, to reduce bleeding of concrete, to impart colour to concrete, to aerate concrete or mortar to produce light weight concrete, to reduce segregation in grout mixes, to produce fungal, insects, etc. resistant concrete, to produce non skid surface concrete, to increase resistance to chemical attack, to decrease the permeability of concrete, to check the corrosion of concrete reinforcement and to increase the bond between the old and new surface and also between concrete and reinforcement.

2.2 Properties of Concrete

Compressive strength is the most valuable property of concrete (Dahiru, 2013). Although in many practical cases other characteristics, such as durability, imperviousness, hardness and mould ability etc, may be more important (Neville and Brooks, 2000).

2.2.1 Properties of Fresh Concrete

Fresh or plastic concrete is a freshly mixed material which can be moulded into any shape. The quality of hardened concrete can be said to be dependent on the properties at its fresh stage. It is therefore, important that fresh concrete is checked and satisfied adequately before use.

2.2.1.1 Workability

The term workability can be defined as the amount of useful internal work necessary to produce full compaction. However, the term workability has been considered very difficult to define as opines by Peurifoy *et al*. (2011). Workability of concrete is also 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). Anonymous *et al.* (2003) defined the workability of fresh concrete as "the amount of mechanical work, or energy, required to produce full compaction of the concrete without segregation.

Tests for Workability

According to Garba (2004) workability cannot be measured but can only be assessed indirectly by measuring the slump or the compacting factor.

Slump Test

This is the most commonly used method of measuring consistency of concrete which can be employed either in the laboratory or at site work (Shetty, 2009). 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, see Figure 2.2. To conduct a slump test, first moisten the slump test mould and place it on a flat, non-absorbent, moist, and rigid surface. Then hold it firmly to the ground by foot supports.

Next, fill 1/3 of the mould with the fresh concrete and ram it 25 times uniformly over the cross section. Likewise fill 2/3 of the mould and ram the layer 25 times, then fill the mould completely and ram it 25 times. If the concrete settles below the top of the mould, add more. Strike off any excessive concrete. Remove the mould immediately in one move (Zongjin, 2011).

The differences between the initial and final heights represent the slump (which approximately gives the degree of workability). Using the slump test a mix could have these three different slumps as shown in figure 2.3:

1. Trueslump; represent mix with low workability
2. Shear slump: represent harsh mix, low cement context and poor aggregate grading texture.
3. Collapse slump; represent mix with high workability.

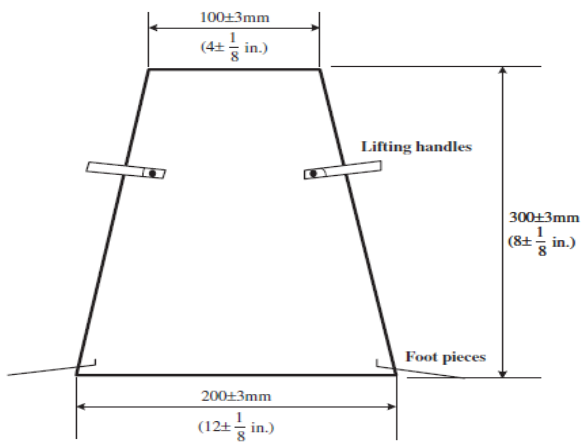


Figure 2.7 Truncated Cone for the Slump Test

Source: Naville and Brooks, (2000)

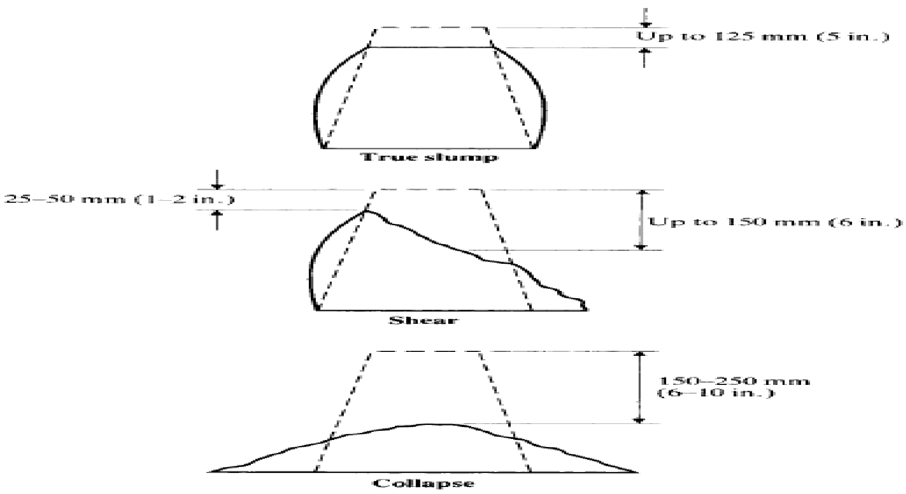


Figure 2.8: Slumps; True, Shear and Collapse
Source: Neville and Brooks, (2000)

Compacting Factor Test

Shetty (2009) and Gupta and Gupta (2012) considers compacting factor test as the most sensitive and précised test and is particularly useful for concrete mixes of very low workability as are normally used for concrete to be compacted by vibrationsuch concrete may fail to slump.

The compacting factor for concrete is then computed using the relationship below;

$$Compacting\ factor = \frac{\text{Weight of prtially compacted concrete}}{\text{Weight of fully compacted concrete}} - - - - - - - - - - - -(2.3)$$

Figure 2.4 shows the apparatus while table 2.5 gives the values of slump and compacting factor for different workability

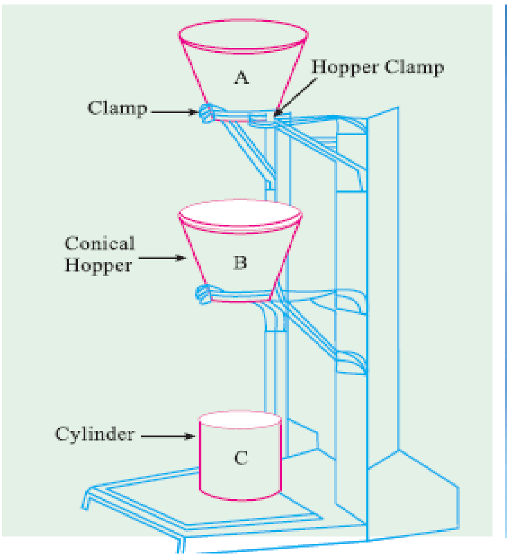


Figure 2.9 Compacting Factor Apparatus

Source: Shetty (2009)

Table 2.5: Workability, Slump and Compacting factor of concretes with 19 or 38mm maximum size of aggregate 21

Degree of workability	Slump mm	Slump in.	Compacting factor	Use for which concrete is suitable
Very low	0–25	0–1	0.78	Roads vibrated by power-operated machines. At the more 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 machines. At the more 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 aggregates. 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)

2.2.2 Properties of Hardened Concrete

A chemical reaction known as hydration of cement takes place when water is added to cement and a large quantity of heat liberates. On hydration of cement, gel is formed which binds the aggregate particles together and provides strength and water tightness to concrete on hardening.. In the hardened state, concrete is ready to support external loads as a structural material. The most important properties of hardened concrete include various strengths, complete stress–strain relationship, various moduli and Poisson's ratio, and durability (Baba, 2012).

1) ***Compressive Strength***

Concrete is used mainly so as to exploit its good compressive strength. The compressive strength of concrete is the load applied on hardened concrete per unit area of the specimen symbolized by N/mm^2. Neville and Brooks (2000) consider the fracture mechanics approach for concrete under bi-and triaaxial stresses and under uniaxial compression. The fracture criteria are represented graphically in figure 2.5.

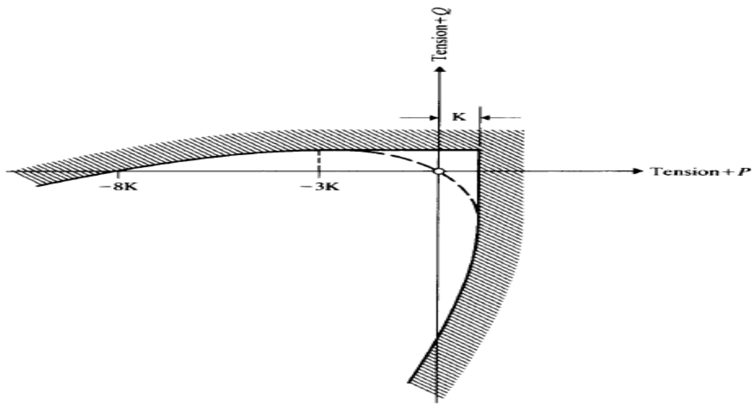


Figure 2.10: Orowon's criteria of fracture under biaxial stress

Source: Neville and Brooks, (2000)

The letter K represents the tensile strength in direct tension. Thus, the fracture occurs under the combination of P and Q such that the point representing the state of stress crosses the curve outwards onto the shaded side.

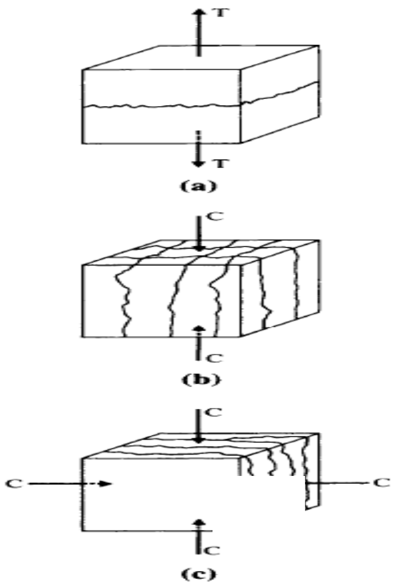


Figure 2.11: Fracture pattern of concrete under: (a) uniaxial tension, (b) uniaxial compression, and (c) biaxial compression.

Source: Neville and Brooks, (2000)

*2) **Tensile Strength***

Tensile strength is responsible for reducing formation of cracks in concrete (Gupta and Gupta, 2012). This could be the reason why Neville and Brooks (2000) states that according to fracture theory, failure is initiated by the largest crack which is oriented in the direction normal to the applied loac' 24 ' hus the problem is one of the statistical probability of the occurrence of such a crack. This means that size and, possibly, shape of the specimen are factors in strength.

In view of the fact that strength is the most important property of concrete at hardened stage; which gives overall picture of concrete quality, it is therefore, important to establish the relationship between compressive and tensile strength.

According to Shetty, (2009) the strength of concrete in compression and tension (both direct tension and flexural tension) are closely related, but the relationship is not the type of proportionality. The compressive strength of concrete is eight times larger than its tensile strength (Gupta and Gupta, 2012). Thus, the ratio of tensile to compressive strength is lower for higher compressive strengths. Figures 2.7 and 2.8 illustrate the relationships.

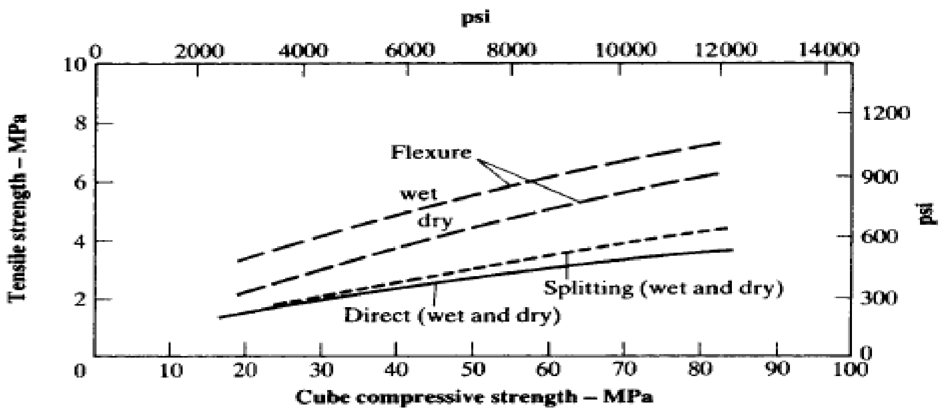


Figure 2.12: Relationship between compressive and tensile strength.

Source: Neville and Brooks, (2000)

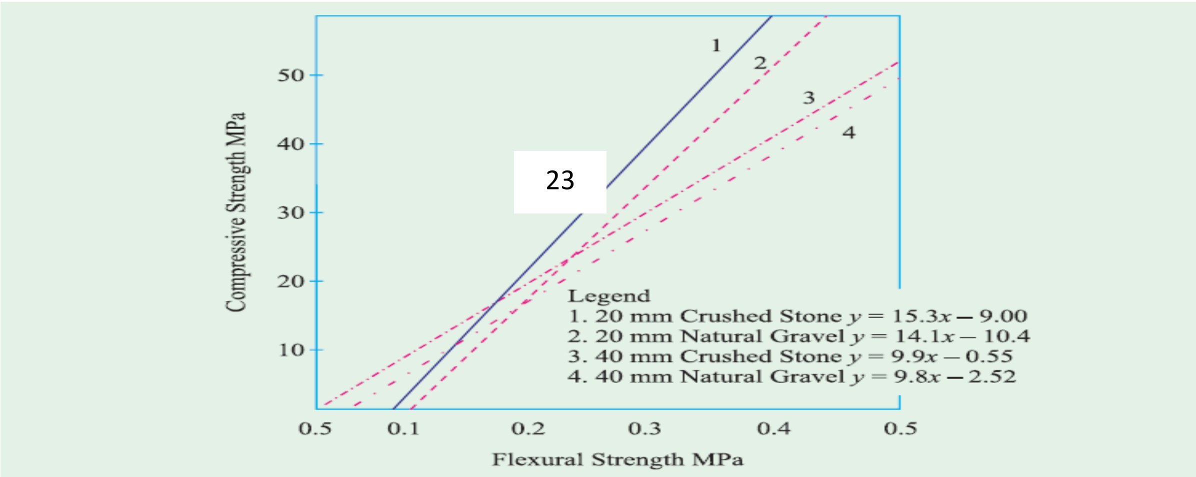


Figure 2.13: Relationship between flexural and compressive

Source: Shetty, (2009)

2.3 Durability of Concrete

Concrete has been considered as a material that can bear both internal and external exposure conditions requiring little or no maintenance. This assumption proved valid except when it is subjected to severe or aggressive environment. A durable concrete is one that serves the purpose for which it was designed for, for the specified service condition and the lifespan. Gambo (2014) defines durability of cement concrete as its resistance to deteriorating agencies to which it may be exposed during its service life or which may inadvertently reside inside the concrete itself.

The durability of concrete is affected by physical, mechanical and chemical causes but is mostly affected by chemical causes, which result in volume change, cracking of concrete and ultimately leading to deterioration of concrete. This is the reason why Gupta and Gupta (2012) discussed the effect of chemical causes on the durability of concrete under the following headings:

1. Sulphate attack
2. Acid attack
3. Sea water attack
4. Alkali aggregate reaction
5. Deicing salts effect
6. Carbonation

Shetty, (2009) summarises the types and causes of cracks in concrete in figure 2.9. These cause deterioration of concrete and ultimately cause collapse of structural elements.

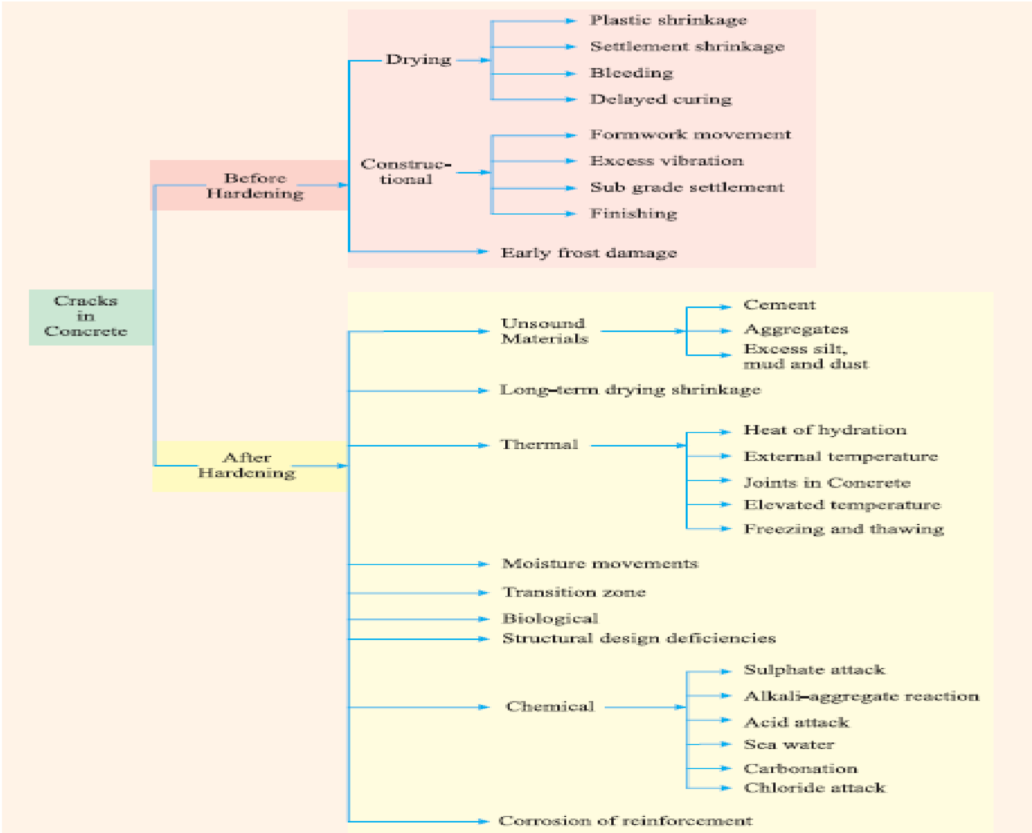


Figure 2.14: Various types and causes of cracks in concrete.

Source: Shett, (2009)

2.3.1 Effect of Sulphate Attack on Concrete

Sulphates are chemical salts, which dissolve in water forming solution. Sulphates are found in most of the soils as calcium, potassium, sodium and magnesium sulphates (Shetty, 2009 and Gupta and Gupta, 2012). Concrete attacked by sulphates has a characteristic whitish appearance. The reason for this appearance, according to Neville and Brooks (2000), is that the essence of sulphate attack is the formation of calcium sulphate (gypsum) and calcium sulfoaluminate (ettringite), both products occupying a greater volume than the compounds which they replace so that expansion and disruption of hardened concrete take place. Tables 2.6 and 2.7 explain the requirements of ACI and BS EN for concrete exposed to sulphate attack.

Table 2.6: Requirements of ACI 318-05 for concrete exposed to sulphate attack

Sulfate exposure	Water-soluble sulfate (SO_4) in soil	Sulfate (SO_4) in water	ASTM cement type	Maximum free w/c*, normal-weight aggregate concrete	Minimum compressive strength, normal weight and lightweight concrete
	% by mass	ppm or mg/litre			MPa (psi)
Negligible	0 to 0.1	0 to 150	–	–	–
Moderate (seawater)	0.1 to 0.2	150 to 1500	II, IP(MS), IS(MS), P(MS), I(PM)(MS), I(SM)(MS)	0.50	28 (4000)
Severe	0.2 to 2	1500 to 10,000	V	0.45	31 (4500)
Very severe	Over 2	Over 10,000	V plus pozzolan	0.45	31 (4500)

Source; Naville and Brooks (2000)

Table 2.7: Requirements of BS EN 206-1: 2000 for concrete exposed to sulphate attack in groundwater

Exposure class	Sulfate concentration	pH	Maximum w/c	Minimum cement content	Minimum strength class*
	mg/l			kg/m^3 (lb/yd^3)	
Slightly aggressive	$\geq 200 \leq 600$	≤ 6.5 ≥ 5.5	0.55	300 (505)	C30/37
Moderately aggressive	$> 600 \leq 3000$	< 5.5 ≥ 4.5	0.50	320 (540)	C30/37
Highly aggressive	> 3000 ≤ 6000	< 4.5 ≥ 4.0	0.45	360 (605)	C35/45

Source; Naville and Brooks (2000)

2.4 Cement

Cement is a fine grey powder which when reacted with water hardens to form a rigid chemical mineral structure which gives concrete its high strengths. Cement functions by forming a plastic paste when mixed with water, which develops rigidity (sets) and steadily increases in compressive strength (hardness) by chemical reaction with the water (hydration). When a material increases in strength even when stored under water after setting it, the material is said to be hydraulic Neville and Brooks (2000). According to Chudley (2005), cements used in construction are sometimes named for their commonly reported place of origin, like Roman cement, or for their resemblance to other materials, such as Portland cement, which produces a concrete resembling the Portland stone used for building in England.

2.4.1Classification of Cement

Cement can be classified into two groups: Natural and Artificial cement.

2.4.1.1 Natural Cement

This type of cement can be obtained by burning lime stone containing 20-40% of clay and crushing in to powder. It is brown in colure and set very quickly when mixed with water; it is very akin to eminate hydraulic lime. The only difference between hydraulic lime and Natural cement is that lime start to slake un-mixing with water (Gupta and Gupta, 2012).

2.4.1.2 Artificial or Portland Cement

This is classified and presented in Figure 2.10 as Portland Cement and Special Cement. The Portland cement is further divided into Ordinary PC, Rapid hardening and Low Heat cement. Types of Special cement are Quick setting, High alumina, Blast furnace cement among others.

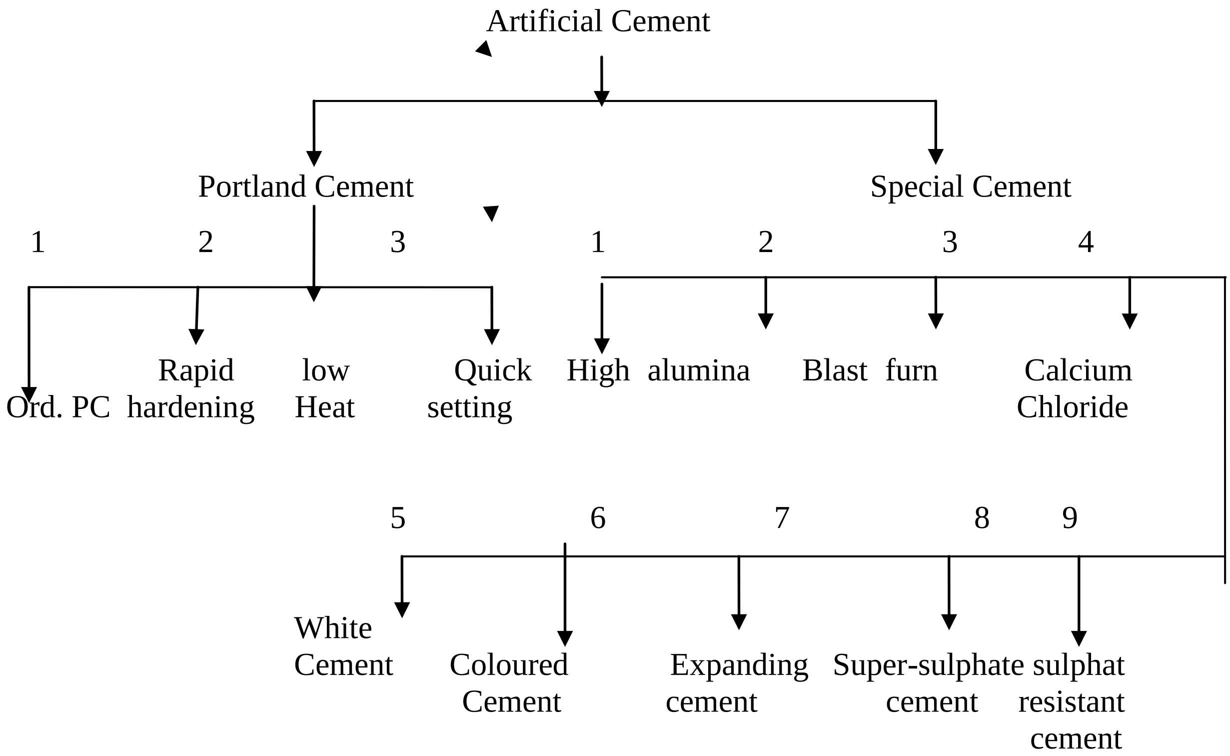


Figure 2.15: Classification of Artificial Cement.

Source: Gupta & Gupta (2012)

2.5 Portland Cement

Portland cement is currently defined, according to Neville and Brooks (2010), as a mixture of argillaceous (i.e. clay-like) and calcaneous (i.e. containing $CaCO_3$ or other insoluble calcium salts) materials mixed with gypsum ($CaSO_4 \cdot 2H_2O$) sintered and then pulverised into a fine powder. Portland cement is the most common type of cement in general use around the world, used as a basic ingredient of concrete, mortar, stucco, and most non-specialty grout. It usually originates from limestone.

2.5.1 Chemical and Elemental Composition of Portland Cement

The constituents of cement mainly lime, silica, alumina and iron oxide interact with each other in the kiln and form complex product of definite molecular structure

(Shetty, 2009 and Gupta and Gupta, 2012). Data presented in table 2.12 shows the composition in percentage of all the oxides present in cement. Lime is ranked highest with an average of 63% whereas alkalis' of potassium and sodium are ranked lowest with an average of 1% content in OPC. This data implies that poor quality concrete will result if the average values are exceeded or reduced.

Table 2.8: Composition of Oxide in OPC

	Name of Constituent Oxides		Percentage by weight Range	Average	Value of Compounds in %
1.	Lime	Cao	60 – 67	63	C_3S = 54.1
2.	Silica	Sio_2	18 – 25	20	C_2S = 16.6
3.	Alumina	Al_2O_3	3 – 8	6	C_3A = 10.8
4.	Iron	Fe_2O_2	0.5 – 6	3	C_4AF = 9.1
5.	Magnesia	MgO	0.1 – 4	1.5	
6.	Sulphur-trioxide	SO_3	1 – 3	2	
7.	Alkalis' etc	K_2O & Na_2O	0.2 –	1	
8.	Calcium sulphate (Gypsum) ($CaSO_4$)		1.3 3 – 5	4	

Source: Singh and Singh, (2006)

However, the excess of any compound could affect the rate of heat of evolution (Ibrahim, 2015). This is the reason why Garba (2014) states that high content of SO_3 affect the initial and long term strength of cement. Four compounds are regarded as the major constituents of cement as shown in table 2.10.

Table 2.9: Compound Composition of Portland Cement

Compound Composition	Chemical Formula	Simple Formula	Mineral Name
Tricalcium silicate	$3CaO.SiO_2$	C_3S	Alite
Dicalciumsilicate	$2CaO.SiO_2$	C_2S	Belite
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	Celite
Tetracalciunaluminoferrite	$4CaO.Al_2O.Fe_2O_3$	C_4AF	Felite

Source: Naville and Brooks (2010) and Garba (2014)

2.5.2 Types of Portland Cement

Portland cement is the most common type of cement in general use around the world. The main types of Portland cement, according to Shetty (2009) and Gupta and Gupta (2012), are; Ordinary Portland cement, Portland pozzolana cement, Rapid hardening portland cement, Modified Portland cement, Low heat Portland cement, Blast furnance Portland cement, Sulphur resisting Portland cement, White cement, Coloured cement and White cement.

2.5.3 Phase Chemistry of Portland cement

The phase chemistry of cement has been studied for decades and a lot of research is still going on to improve its technology.Portland cement composed of roughly five mineralogical phases; Alite (C_3S), Belite (C_2S), Celite (C_3A), Felite (C_4AF), and gypsum (Houst *et al*, 2010).

2.5.4.1 Alite

Alite (C_3S) also known as Tricalcium silicate, is the most important clinker mineral because it is the major contributor to the development of compressive strength in the final application. Alite in its pure form ($Ca_3SiO_5(s)$) is found in three different crystal structures (triclinic, monoclinic and rhombohedral) (Hokfors, 2014). In addition, as many as seven different phases are known to exist at various temperatures. However, Taylor (1997) states that Alite is not a pure phase in clinker and it contains substituent oxides of MgO, Al_2O_3, Fe_2O_3, K_2O, Na_2O, P_2O_5 and SO_3

2.5.4.2 Belite

This is also known as dicalcium silicate (C_2S) responsible for strength development as 28 days (Matawal, 2013). Belite (C_2S) is the name for the five polymorphs of calcium silicate (Ca_2SiO_4). There are belite phases in their stoichiometric forms and as solution species. StoichiometricbeliteaC$_2$S (gamma-olivine) and the belite solution phasesA$_9$C$_2$S and AC$_2$S may potentially form) (Hokfors, 2014). The belite solutions according to Hokfrs (2014) are composed of calcium silicate (Ca_2SiO_4), iron silicate (Fe_2SiO_4) and magnesium silicate (Mg_2SiO_4). In A_9C_2S, zinc silicate (Zn_2SiO_4) is also a possible component.

2.5.4.3Celite

The Tricalcium aluminate (C_3A) which is known celite, is responsible for setting time and heat of hydration as reiterated by Matawal, (2013). The amount of C_3A in most cements is comparatively very small, but its behavior is very important (Gupta and Gupta, 2012). However C_3A, according to Hokfors (2014), is modified by substitution of ions to three different crystal systems. Both C3A and C4AF replace aluminium oxide with iron oxide and vice versa, and normally contain some sodium oxide, potassium oxide and magnesium oxide (Taylor, 1997).

2.5.4.3 Felite

This is also known as Tetra-calcium aluminu ferrite (C_4AF) responsible for cement colouration. According to Gupta and Gupta (2012) C_4AF acts as a flux and if is not present, the reaction in the kiln would progress much more slowly and would probably be incomplete. However, Gypsum with C_4AF forms calcium sulpho ferrite as well as calcium sulpho aluminate and its presence accelerates the hydration of silicates.

2.5.4 Brands of Cement in Nigeria

The production of Portland cement has played a vital role as a construction material throughout the history of civilization. Every year a large quantity of Portland cement is produced for general construction purposes. Nigeria has been blessed with many cement producing companies located across the country. These companies, among others are: Ashaka, Bua, Dangote, Elephant and Sokoto cements. Figure 2.11 shows the locations of the companies across the country.

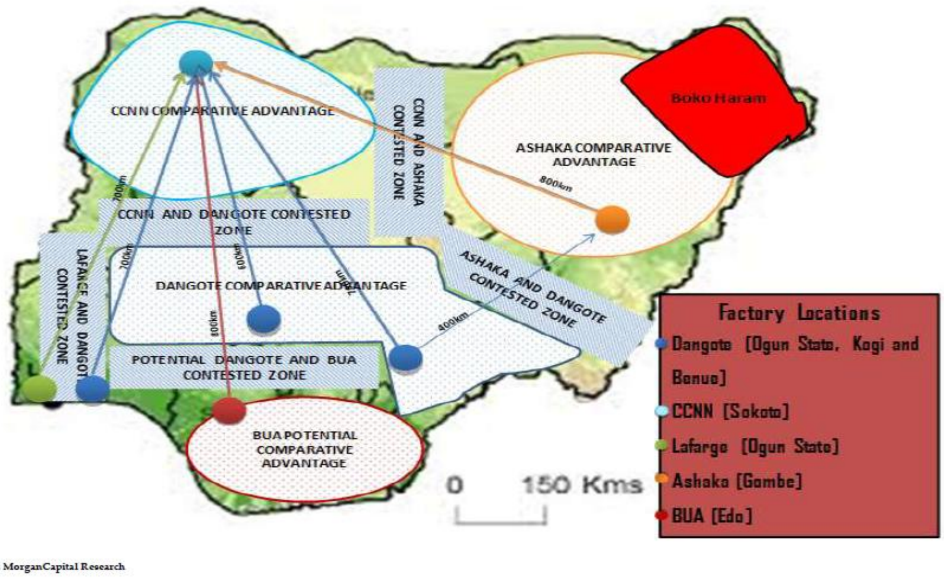


Figure 2.16: Different Brands of Portland Cement in Nigeria

Source: Morgan Capital Group (2014)

2.5.4.1 Properties of Nigerian Cement

The characterization and classification of cement is based on the determination of its chemical composition and physico-mechanical properties (Yahaya, 2009). The use of low quality cement in structural and constructional works may cause loss of lives and properties. So, the quality assurance of cement is therefore becoming important and critical factor especially if the quality of the cement, at the construction stage, is to be improved in order to derive some advantages through the use of SPs. Thus, the properties of the cement must be ascertained to ensure its compatibility with the particular SP to be used.

1) Fineness

This is one of the important characteristics of cement that influences the rate of cement reaction with water (Ibrahim, 2015). However, if cement is ground too finely, the extreme fine particles may, become pre-hydrated by moisture (water vapour) from making otherwise good cement bad (by losing it cementing power) (Garba, 2014).

Fineness of cement is determined by the specific surface of the cement, which is expressed in m^2/kg (Neville and Brooks, 2010). It could also be estimated by sieving 0.11kg of the cement sample through no. 170 sieve (0.09mm) for 15 minutes, the residue should not exceed 10% (Garba, 2014).

According to Kurtis (Anonymous) fineness of cement affects the properties of cement such as: rate of hydration, rate of setting, rate of hardening, rate of carbonation during storage, rate of gypsum addition, durability, cost, and bleeding. This perhaps, is the reason why Gupta and Gupta (2012) summarized the advantages and disadvantages of finer cements as follows:

Advantages

1. The finer the cement, the greater the rate of hydration.
2. The finer the cement, the rapid and greater the strength development.
3. The finer the cement, the lesser they bleed.
4. The finer the cement, the better the workability.
5. The coarser the cement, the greater the period of hydration and complete hydration is not possible.

Disadvantages

1. Finer the cement, higher the cost of grinding.
2. Finer the cement, more rapid it deteriorates on exposure to atmosphere.
3. Finer the cement, stronger the reaction with alkali reactive aggregate.
4. Finer the cement, stronger the shrinkage and the proneness to cracking.
5. Finer the cement, greater amount of C_3A they possess and more amount of gypsum they require for proper retardation of setting time.
6. For standard consistency paste, finer the cement, greater the amount of water needed.

2) Soundness and Consistency

A mixture of cement and water (cement paste) when sets and hardens without any cracking or disintegration, such cement is said to be sound cement (Ibrahim, 2015).Such expansion or cracking occurs due to the reaction of free lime, magnesia, and calcium suplhate (Naville and Brooks, 2010). The equation below shows the reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2 \text{------------------------------} (2.4)$$

$$MgO + H_2O \rightarrow Mg(OH)_2 \text{------------------------------} (2.5)$$

Unsound cement is assessed in the laboratory using many methods but the accelerated test devised by Le Chatelier that uses boiling water and the autoclave test (ASTM 151-93a) are the most widely used (Garba, 2014).

3) Chemical Composition

Portland cements are dependent on the chemical and morphological composition of clinker, gypsum and other additives introduced during the process of grinding (Yahya, 2009). The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. Ibrahim, (2015) reiterates that the chemical composition of cement affects all its properties apart from the fineness. BS 12 states the basic requirements in relation to the ratio of the chemical composition of any Portland cement. This is why Shetty (2010) enumerate the chemical requirements that the result of a test should comply with as:

1. Ratio of percentage of lime to the percentage of silica, alumina, and iron oxide; known as Lime Saturation Factor, when calculated by the formula,

   $$\frac{\mathrm{CaO} - 0.7\ \mathrm{SO_3}}{2.8\ SiO_2 + 1.2\ Al_2\ O_3 + 0.65\ Fe_2O_3} - (2.6)$$

   should not be greater than 1.02 and less than 0.66

2. Ratio of percentage of alumina to that of iron oxide should not be less than 0.66
3. Weight of insoluble residue should not be more than 2%
4. Weight of magnesia should not exceed 6%
5. Total sulphur content calculated as sulphuric anhydrite (SO_3) should not exceed 2.5%, C_3A is 5% or less. Not more than 3%, when C_3A is more than 5%
6. Total loss on ignition should not be more than 5%.

However, several research works have been carried out on the quality of Nigerian cement such as that conducted by Yahaya (2009) on the Physico-Chemical Classification of Nigerian Cement. He concluded that the indigenous Portland cement brands, Ashaka and Elephant, conform in their chemical composition with the set of standards but their physico-mechanical analysis assessments shows considerable deviation from ASTM (1986) and BSI (1978). Similarly, based on his investigation and experimental results, it was discovered that the chemical and physico-mechanical properties of Dangote cement did not conform to any of the international standards. Tables 2.11(a), 2.11(b) and 2.12 show the chemical composition of some Nigerian cements.

Table 2.10a: Composition of major constituents of some indigenous cements (ANOVA)

Test Samples	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)
Ashaka	60.00±0.58	20.65+1.33	3.83±1.17	2.20±0.12
Burham	56.17±1.0l	19.07±0.88	5.30±0.45a	3.15±0.60
Dangote	51.67±3.84	8.02±0.66	1.25±0.25b	10.5±0.76
Elephant	58.83±2.09	17.33±l.76	5.07±1.48	2.50±0.29
Sem	±2.26	±1.23	±0.54	±0.25

Source: Yahaya (2009)

Table 2.10b: Composition of minor constituents of some indigenous cements (ANOVA)

Test Samples	LOl (%)	IR (%)	Free CaO (%)	SO_3 (%)	MgO (%)
Ashaka	2.27±0.11	2.76±0.02	1.50±0.12	1.70±0.04	0.75±0.10
Burham	3.16+0.02	3.9±0.38	1.83±0.04	1.14±0.06	0.74±0.12
Dangote	3.27±0.38	2.03±0.15	2.15±0.03	1.40±0.02	1.45±0.03
Elephant	1.50±0.01	3.02±0.04	2.60+0.47	0.32±0.04	2.30±0.72
Sem	±0.20	±0.19	0.24	±0.04	±0.04

Source: Yahaya (2009)

Table 2.10c: Calculated Mineral Percentage Composition of Portland cement

Test Samples	C_3S	C_2S	C_3A	C_4AF	Total sum
Ashaka	22.55	46.41	12.51	6.08	87.55
Burham	22.91	42.94	12.51	6.08	84.44
Dangote	33.33	26.47	14.33	4.77	78.90
Elephant	20.58	41.83	6.36	7.62	76.36

Source: Yahaya (2009)

4) Setting and Hardening

Setting simply means the transition phase between a fluid and a rigid state while the process after final setting is called hardening. According to Marar (2011) setting period starts when concrete lose its plasticity, becoming workable, and it is complete when it possesses enough strength to support loads with acceptable stable deformation. Setting time of cement can be determined in the laboratory by the use of Vicat Apparatus etc (Shetty, 2010). The period of setting is divided into two parts as: initial and final setting time. The initial setting time starts from the moment water is added until paste ceases to be fluid and plastic, while the final setting start from the moment water is added for the paste to acquire certain degree of hardness (Kurtis, Anonymous).

Similarly, the Nigerian cement have been reported by Yahaya (2011) to have the following properties, as summarised in Table 2.13

Table 2.11: Analysis of Variance on Physical and Mechanical Properties of Some Nigerian Cements

Test Samples	Consistency (%)	Setting time (mins)	Soundness (mm)	Compressive strength (N/mm_2)
Ashaka	31.00±0.58	20.50±0.29	3.43±0.35	21.96±0.15
Burham	31.07±0.58	31.00±0.58	1.01±0.07	23.92±0.15
Dangote	31.15±0.08	11.34±0.60	1.17±0.16	22.00±0.40
Elephant	28.73±0.33	25.00±0.58	3.00±0.01	17.04±0.65
Sem	±0.35	±1.03	±0.19	±0.39

Source: Yahaya (2009)

2.6 Super plasticizer

Superplasticizers are essential components in modern concretes, providing workability enhancement at low water to cement ratios, and resulting in the production of durable and sustainable concrete. A number of research works have been carried out on the use of superplasticizer in concrete production such as; Ahmad *et al* (2005), Santhanam (2013), Kapelco and Kapelco (2007), Mohammed *et al* (2014), Bassioni (2015), Malagavelli and Paturu (2012), etc. The advantages derived in the usage as opined by Callepardi *et al* (2006) are: (a) increase in workability, at a given mix composition, which enhance placing characteristics of concrete, (b) reduction of mixing water, at a given cement content and workability, which reduce the water-cement ratio (w/c) and therefore to increase strength and improve durability and (c) reduction of both water and cement, at a given workability and strength, which in turn save cement and reduce creep, shrinkage, and thermal strains caused heat of cement hydration.

Gupta and Gupta (2012) identifies the use of SP for the production of high strength and high performance concrete which could be produced with the water/cement ratio as low as 0.25 or even less. The strength of such concrete could be up to 120MPa or more.

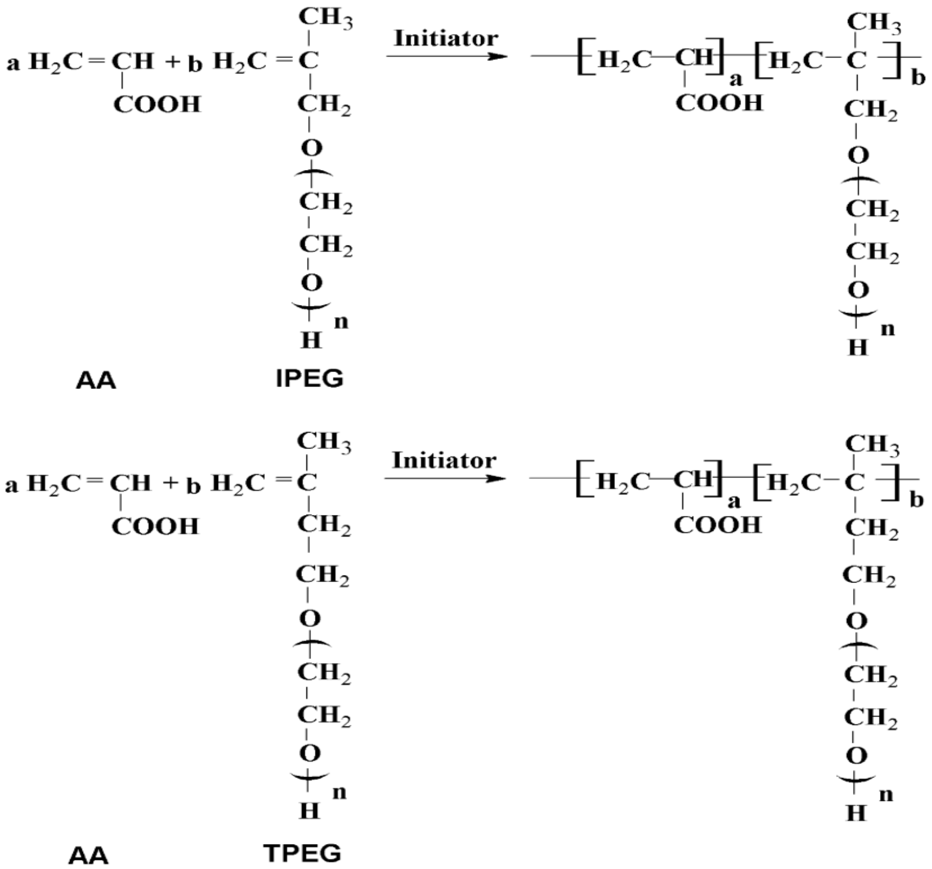
2.6.1 Characteristics and Chemical Composition of Super plasticizer

The two most popular Sp types are naphthalene sulfonate and melamine solfonate (Liu *et al*, 2014).The characteristics of different types of SPs are summarised in table 2.12. Figure 2.17 shows the schematic diagram of polycarboxylate SP

Table 2.12: Chemical and Physical Data on SP

	Chemical Analysis Data (%)		
	Naphthalene Sulfonate		Melamine Sulfonate
Superplasticizer	A	B	M
Solid Component (%)			
Monomer	8.18	-	-
Nonadsorbables&trimer	10.49	-	-
High polymers	68.03	-	
Na_2SO_4	13.3	-	-
Inorganic Composition (by analysis) (%)			
Na	11.6	8.6	9.5
K	0.0	0.1	0.2
Ca	0.2	0.7	0.1
OH	-	-	1.6
SO_4	3.2	0.7	2.5
NaOH estimated	-	-	3.7
Na_2SO_4estimated	4.7	1.0	3.7
Organic Composition (by subtraction (%)	85.0	89.9	86.1
Organic Charge density (meq/g)	5.26	4.45	3.24

Source: Diamond *et al* (1993)



Figue 2.17: Schematic diagram of Polycarboxylate SP

Source: Liu *et al*, (2014).

2.6.2 Mechanism of Superplasticizer Adsorption

When SPs are used in concrete they get adsorbed on the cement particles (Neville, 2010). The adsorption of charged polymers on the particles of cement creates particles-to-particles repulsive forces which overcome the attractive forces. This repulsive force is called Zeta potential, which depends on the base, solid content, and quantity of SP used. The overall result is that the cement particles are deflocculated and dispersed. When cement particles are deflocculated, the water trapped inside the flocs get released and now available to fluidify the mix. (Shetty, 2009).

However, in the case of retarding effect of plasticizers and SPs, Shetty (2009) also explained that when they get adsorbed on the surface of cement particles, they form a thin sheath. This thin sheath inhibits the surface hydration reaction between water and cement as long as sufficient plasticizer or SP is available at the particle/solution interface. The quantity of Plasticizer or SP will progressively decrease as the polymers become enrapped in hydration products.

2.6.3 Effect of Superplasticizers on Fresh Concrete

2.6.3.1 Slump

The utilization of SP has positive effects on properties of fresh and hardened concrete. The rate of slump loss in concrete containing SP can be affected by the following factors as reported by ACI 212.4R-93: the type of SP used, the dosage used, type and brand of cement, the class of concrete and the temperature. Generally, the higher the dosage rate of SP in concrete, the lower the rate of slump (Neville, 2010) However, each product has an operating range beyond which other properties of the concrete may be affected. If the dosage rate is increased beyond this range as a means of further lowering the rate of slump loss, the results may include changes in initial setting characteristics, segregation, or bleeding.

The chemical composition of cement can also affect the performance characteristics of concrete containing SP. This is not to say that SP will not work with a certain type of cement, but that slump loss and other characteristics may be different. However, dosage rates may also vary from brand to brand for different types of cement. Similarly, temperature is another important factor that should be considered when using SP as with all concrete, the higher the concrete temperature the more rapid the slump loss.

Dramatic improvement in workability is not showing up when SPs are added to zero slump concrete at nominal dosage (Shetty, 2009). The influence of SP on workability can by seen in figure 2.15.

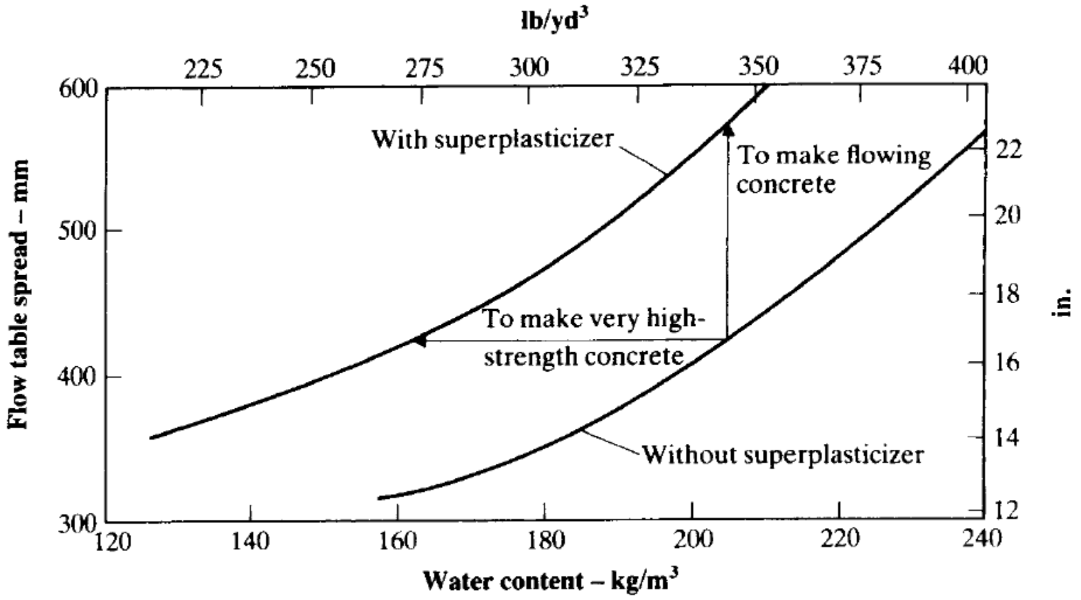


Figure 2.18: Influence of SP on workability
Source: Shetty, (2009)

2.6.3.2 *Reduction in water content*

When the high strength concrete at a given workability is needed, the use of SP results in reduction of water up to 30% as asserted by Evangeline and Neelamegan (2013).

2.6.3.3 Decreased water and cement contents

Superplasticizers may be used to reduce both water and cement contents, thus permitting the use of less cement without reducing strength. The use of SP to achieve cement saving have been justified by several researchers. For example, Ahmad *et al* (2005) checked the effect of water reduction on SP added concrete where the water content was gradually increased, keeping all other ingredients of the mix constant. The dosages of the SP was increased to compensate for the lost of workability. Similarly, the cement content was kept constant and water content was reduced keeping w/c ratio and workability constant.

Kapelco (2006) investigates the possibility of cement content reduction in concretes with SP by using varying dosages from 0.8 to 2.0% by weight of cement. His research has concludes that the admixture in the amount of 1.5% according to cement mass allows cement saving and reduction of water at the same time.

2.6.4 Effect of Superplasticizers on Hardened Concrete

2.6.4.1 Effect of Superplaticizer on Compressive Strength of Concrete

A number of researchers such as Ahmad *et al.* (2005), Kapelco and Kapelco (2007), Malagavelli *et al*, (2012), Alasadey (2012), Santhanam (2013), Mohammed *et al.* (2014) and Bassioni (2015) have investigated the effect of SP on the compressive strength of concrete and concluded that the compressive strength of concrete is improved by SP compared with control.

However, the research carried out by Dumne (2014) indicated that the compressive strength of concrete made with 0.35% SP and 10% Fly Ash was increased by 17.43% and 18.01% at 7^{th} and 28^{th} days of curing respectively. The average compressive strength of grade 30 concrete by using SP is increased by 11.69% compared to concrete without the admixture (Malagavelli *et al*, (2012). According to Muhit (2013) the addition of SP up to a specific limit (1.0%) increases the compressive strength of SP by about $13N/mm^2$. However, the research carried out by Dubey and Kumar (2012) on the effect of SP dosages on compressive strength of self-compacting concrete concluded that the compressive strength is increased with increase in SP dosage but beyond 2% the compressive strength decrease with increase in dosage of SP.

CHAPTER THREE

3.0 EXPERIMENTAL PROGRAMME

3.1 Research Materials and Methods

3.1.1 Materials

To achieve the desired objectives, previous research works were studied. This was followed by the selection of good materials that complied to some standards. The materials used for the study were; coarse aggregate, fine aggregate, Ordinary Portland Cement (OPC), Superplasticizer (Rheobuild-600), Magnisium sulphate ($MgSO_4$) and portable water. Details of the materials used are as follows;

3.1.1.1 Coarse Aggregate: The coarse aggregate used was crushed granite (20mm maximum size and retained on a 10mm sieve) obtained from a single quarry site along Zaria-Sokoto road, opposite school of Aviation Zaria. It was sieved in accordance to BS 933 part 1 (1997).

3.1.1.2 Fine Aggregate: Clean and air-dried river sand sourced from Samara, Zaria was used. The range of sizes of sand/fine aggregate was from 600 micron – 4.75m on the B.S test sieve. A 5mm BS 112 (1971) sieve was used to remove larger aggregate sizes and impurities.

3.1.1.3 Ordinary Portland cement (OPC): Five brands of OPC, mostly used across the country were used, they were; A, B, C, D, E, and F cements. The cement brands complied with the requirements of BS EN (1995) and were obtained from local dealers in Zaria and Kaduna.

3.1.1.4 Water: Water pumped from the Ahmadu Bello University water works was used throughout the research. The quality of water conformed to the specification of BS 1008, (2002) which specifies that water to be used must be safe for drinking, free from odour, colour, taste and impurities, thus satisfying the specification requirement for water to be used for concrete production.

3.1.1.5 Super plasticizer: The SP used in this study, because of its availability, was Rheobuild-600 from Melvyn Nickson Nigeria Limited Abuja branch and it complied with ASTM C494 Type D & G and BS 5075 requirements for high range water-reducing admixtures.

3.2 Tools/Apparatus Used

The apparatus used in carrying out the various tests in the laboratory includes: head pan, hand scoop, weighing scale, shovel, wheel barrow, trowel, wire brush, tapping rod, mixing board, standard sieved, Vicat apparatus, Le Charteliers apparatus and mould cube etc.

The equipments used in the course of carrying out the various experiments were:

i. Concrete mixing machine
ii. Compressive strength testing machine (STYE-2000)
iii. Tensile strength testing machine (STYE-2000)
iv. Weighing machine
v. Ovum

3.3 Methods

The research was carried out through the following processes;

3.3.1 Literature review

Relevant literatures were reviewed from different text books, journals, conference proceedings, seminars, published and unpublished research works, lecture notes, etc so as to articulate existing knowledge on the topic of research.

3.3.2 Experimental Program

The experiments were conducted in two stages as follows:

A) Preliminary Investigations: In this experiment, preliminary test on the individual constituent of the concrete were carried out such as; Chemical analysis of different brands of cement used, sieve analysis and bulk density of aggregate. Nominal mix design was used in order to estimate the quantity of materials needed for the research. Other tests conducted were; Soundness test base on ASTMC151-93a, Fineness test base on BS EN 196-9: 1992,and Setting time base on BS 12.

1. Bulk Density of Aggregate

Density is defined as weight per unit volume of both solid material and the pores volume inside a single aggregate: The bulk density of aggregate was determined in accordance to BS 812-2 (1995) using the formula below:

$$BD = \frac{M}{V} ---------------------------------(3.1)$$

Where:
BD = density of the aggregate in Kg/m^3
M = mass of the aggregate in Kg
V = volume of the aggregate in m^3

2. Percentage of Fine Aggregate Passing Through 600μm BS Sieve

This was determined as described in accordance with BS 812-103.1 [1985]. 2kg sample of the fine aggregate was weighed and poured gently into the 600μm BS sieve. The sieving operation was carried out by shaking the 600μm BS sieve. The weight retained on the pan was recorded and the percentage passing was determined.

$$\%\ \text{Passing} = \frac{\text{Weight Passing (g)}}{\text{Weight of Sample (g)}}\ X\ 100 ---------------------(3.2)$$

3. Concrete Mix Design Using BRE Method

This method was introduced in 1997 and was previously called the 1988 Department of Environment (DoE) method. According to Garba (2014) the BRE method is an upgrade of the 1988 DoE method and were all originated from the Road Note 4 that was published in 1950.

Grade C30 concrete was designed from where the mix proportion and w/c ratio were computed. 30 percent of the quantity of water obtained from the design was deducted and the result was used for the production of the sample specimens in order to determine the effect of SP on each cement brands.

4. ***Chemical test***

The test was undertaken at the Defence Industries Corporation of Nigeria (DICON), Kakuri Industrial Layout, Kaduna. Five brands of cement namely; A, B, C, D, E and F cements were subjected to both elemental and compound composition using the X-ray fluorescence Spectrometry. The XRF test Mini Pal which is a compact energy dispersive X-ray Spectrometry designed for such test was used. The system is controlled by a PC running the dedicated Mini Pal analytical software. The result of test is presented in table 4.1

5. ***Setting Time, Soundness and Consistency of Cement***:

The values obtained were compared with the limits set out in BS EN 196-3 (1995). The setting time procedure is shown in plate I below: However, the consistency was determined using the formula:

$$\text{Consistency} = \frac{\text{Water used for mixing}}{\text{weight of cement sample}} \text{ X } 100 ------------------(3.3)$$

Plate I: Determination of setting time

B) Tests Undertaken on Hardened Concrete Samples:

The following were the tests carried out**:**

1. Compressive Strength
2. Split Tensile Strength
3. Abrasion Resistance
4. Water Absorption

All concrete samples were cured at different periods (3, 7, 28 and 56days) in two curing media namely; water and magnesium sulphate solution. However, the samples produced for determination of optimum dosage of SP and percentage cement-saving were cured in water and tested for 3, 7, and 28 hydration periods only. Details of the type of concrete specimens and curing days are as presented in tables 3.1 to 3

Table 3.1: Production of Concrete Cubes using five brands of OPC

Type of Tests	Sample Specimen				Control Specimen			
Curing Period (Days)	**3**	**7**	**28**	**56**	**3**	**7**	**28**	**56**
Compressive Strength	5	5	5	5	5	5	5	5
Tensile Strength	5	5	5	5	5	5	5	5
Abrasion Resistance	-	-	5	5	-	-	5	5
Water Absorption Test	-	-	5	5	-	-	5	5

Source: Laboratory Research Work (2016)

Table 3.2: Production of Concrete Cubes for Determination of Optimum Dosage of SP and Percentage Cement Saving

Rheobuild-600	Sample Specimen		
Curing Period (Days)	**3**	**7**	**28**
0.20%	5	5	5
0.40%	5	5	5
0.60%	5	5	5
0.80%	5	5	5
1.00%	5	5	5
1.20%	5	5	5
1.50%	5	5	5

Source: Laboratory Research Work (2016)

Thus a total of 808 numbers of specimens were produced out of which 320 specimens were produced with the five brands of OPC and a fixed dosage of SP (0.1% by weight of cement) was used. The quantity of water was reduced by 30% .The control specimens were also 320 numbers. Similarly, 168 numbers of specimens were produced with the use of cement A and varying dosages of SP (0.2%, 0.4%, 0.6%, 0.8%, 1.0%, 1.2% and 1.5%by weight of cement) so as to determine the optimum dosage of SP and the percentage cement saving derived. The samples were subjected to compressive strength only. The various water/cement ratio used were comprehensively discussed in chapter four.

3.4 Production and Testing of Concrete Specimens

3.4.1 Trial Mix

Trial mixes were prepared in order to test the appropriateness of the water/cement ratio obtain from the concrete mix design and to determine the suitability of reducing the quantity of water by 30 percent with the help of SP at different dosages. However, the main objective of producing trial mixes is to check whether or not the particular aggregates or cement selected for use will behave as anticipated. Cement A was used for the trial test.

3.4.2 Final Mix Design

Grade C30 concrete was designed and the result was used for the production of the concrete samples. The quantity of water obtained from the design was reduced by 30%). The reduced water was maintained throughout this research work in order to study the influence of SP on various properties of concrete at a constant water/cement ratio. However, in order to determine the optimum dosage of SP, cement A was used to prepare seven different mixes containing SP with0.2%, 0.4%, 0.6%, 0.8%, 1.0%, 1.2% and 1.5% by weight of cement and compressive strength was tested at 7 days hydration period. The percentage dosage that gives the highest compressive strength was 1.0% hence; it was adopted for all the cement brands.

The preparation of the concrete samples and assessed was carried out in accordance to the appropriate British Standard such as BS 1881 (1986), BS 1881 (1988) and BS 812 (1990).

3.4.3 Test on Fresh Properties of Concrete

At fresh stage, the concrete samples were tested for workability using compacting factor and slump tests/methods. The tests were carried out in accordance with the relevant standard such as BS 1881 Part 102 (1983).

3.4.3.1 Slump and Compacting factor tests

Slump test was carried out immediately after the mixture is thoroughly mixed to determine the workability of the sample produced. The apparatus for carrying out the slump test includes steel tamping rod, base plate, hand scoop, trowel and metal cone

Apparatus

1. A standard mould which is a frustum of a cone complying with BS 1881 – 102: 1983
2. A standard flat base plate preferably steel.
3. A standard tamping rod.
4. Standard graduated steel rule from 0 to 300mm at 5mm intervals.
5. A scoop approximately 100mm wide.

Workability of the concrete samples was also assessed using compacting factor testing accordance to BS EN 12350-2 (2009) as in Plate II.

Plate II: Slump and Compacting factor tests.

3.4.4 Casting of Superplasticized Concrete Samples

Oil was applied on the inner surface of the moulds prior to casting in order to prevent bond between the moulds and the concrete. The fresh superplasticized concrete was placed in 100mm x100mm x 100mm cube moulds in three layers and each layer was compacted by giving 25 blows with a tapping rod. The moulds were filled to overflowing and excess concrete removed by sawing action of steel rule. Surface finishing was done by means of a trowel. The test specimens was then left in the moulds undisturbed for 24 hours and protected against vibration, dehydration and shock. Plate III shows the casting process.

Plate III: Casting of Concrete Cubes

3.4.5 Curing of Superplasticized Concrete Specimens

After casting, the specimens were kept in rest period at room temperature for 24hours, after which they were de-moulded and placed in water and magnesium sulphate solution and allowed for the required hydration period before testing.

The concentration of $MgSO_4$used was 1.0% categorised as moderate attack by Gambo (2014). The quantity of $MgSO_4$used to achieve this concentration was based on the relationship adopted by Ibrahim (2015).

50 litres of water = 5000g by weight
5000g of water = 100% concentration
Using 1.0% concentration, the quantity of water = Xg

Therefore, mathematically,

$$Xg = \frac{5000\text{g x } 1.0}{100} ------------------------------(3.4)$$

Therefore, for every 5000g of water, 50g of $MgSO_4$was dissolved in the water.

3.5 Testing of Hardened Concrete

The concrete cubes produced were subjected to compressive strength, tensile strength, abrasion resistance and water absorption tests at the end of 3, 7, 28 and 56 days of curing. The details of various test and results are presented as follows:

3.5.1 Compressive Strength Test

Cube samples were crushed at 3, 7, 28 and 56 days curing periods in ambient temperature. Compressive strength was determined in the laboratory with the aid of a crushing machine. This was carried out in accordance to BS 1881, part 116 (1983).

$$Compressive\ strength = \frac{\mathrm{F}}{\mathrm{A}} - (3.5)$$

Where;

F = Load at failure (KN)

A= cross-sectional area of the specimen on which compressive force acts.

The compressive strength test can be shown below:

Plate IV: Compressive strength test

3.5.2 Split Tensile strength test

The test specimens after curing for the required age were removed and surface dried. The specimens were then weighed and placed diagonally at the centering jig with loading pieces carefully positioned along the top and bottom of the plate of the loading system. The tensile strength was calculated as in Gambo (2014).

$$Tensile\ stength \quad = \frac{0.518 \text{ x P}}{S^2} \text{ X } 1000 ------------------(3.6)$$

Where: P = failure Load in KN

S^2 = area of cube in mm^2

The tensile strength test can be shown below:

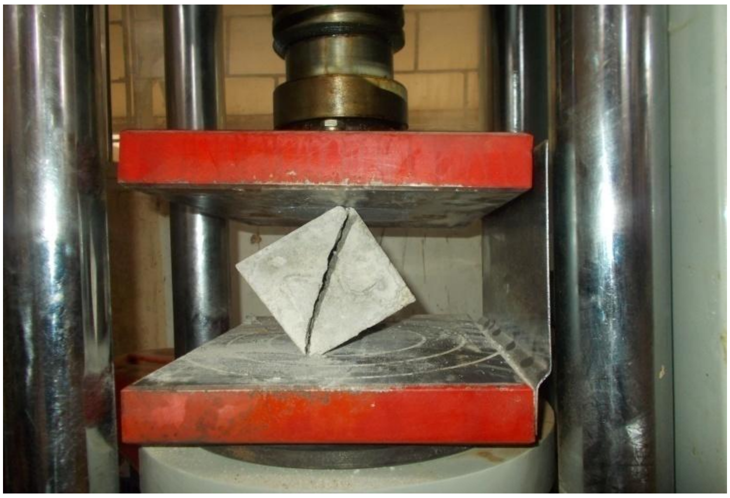


Plate V: Split tensile strength test

3.5.3 Abrasive Strength Test

This is aimed at determining the abrasion resistance of a material through sliding or scraping thus causing attrition, which is characterised by the loss in initial weight per $1cm^2$ of the surface being abraded. Each specimen was weighed and the values recorded as W_1 before brushing its surface with a wire brush. Wire brush attached with 3.5kg weight was used to stroke the surface of each specimen up to 60 times at uniform speed. The specimens re-weighed again and the value recorded as W_2. The loss in weight was calculated by subtracting the final weight from the initial weight ($W_1 - W_2$).

Abrasion resistance is calculated, according to Ibrahim (2015), using the formula:

$$\%\ abraded\ material = \frac{\mathrm{W1} - \mathrm{W2}}{\mathrm{W2}}\ \mathrm{X}\ 100 - - - - - - - - - - - - - - - -(3.7)$$

3.5.4 Water Absorption Test

This is the ability of concrete to absorb and retain water. It is described by the amount of water absorbed by an initially dry material fully immersed in water. This was carried out in accordance to BS 1881-122 (1983).

The specimens were oven-dried at 105^0C for 24 hours then removed from the oven and allowed to cool at room temperature to determine the initial weight and recorded as W_1.The final weights were determined after the specimens were immersed in water for 24 hours then removed and surface dried, re-weighed and recorded as W_2. The percentage of water absorption was calculated as:

$$Water\ absorption\ (\%) = \frac{\mathrm{W2} - \mathrm{W1}}{\mathrm{W1}}\ \mathrm{X}\ 100 - - - - - - - - - - - - - - - - - (3.8)$$

3.6 Method of Data Analysis

In view of the fact that compressive strength is the most important single property of concrete that is not only quantitatively related to most other properties, but also serve as quality index for concrete, the results of various test conducted were analysed by relating them to compressive strength

The results of the conducted tests were analyzed using percentage and mean to determine the relationship between the superplasticized concrete test results made with different brands of OPC and the conventional concrete. The arithmetic mean is the central tendency of collection of numbers taken as the sum of numbers divided by the size of the collection. The mean were used to analyze the result of the compressive and tensile strength at different curing period by summing the strength of the cubes for sample concrete and control specimen for a particular day and divided it by the numbers of cubes. Percentage was also used to analyze the results of abrasion resistance and absorption test by calculating the percentage of water absorption for the entire concrete specimen and the percentage of weight loss. Graphs and tables were also used to present some results.

The result of above tests are presented and analyzed in chapter four of this research work.

CHAPTER FOUR

4.0 DATA PRESENTATION, ANALYSIS AND DISCUSSIONS

The results presented in this chapter are based on the tests carried out on the different brands of cement manufactured in Nigeria and SP (Rheobuild-600). The result for the influence of the SP on the cement brands are also presented and discussed in this chapter.

4.1 Presentation of Results of Preliminary Test

Table 4.1 presents the percentage of elements in each brand of cement. Cements A, B, C, D, and E have elemental sum of 99.91%, 98.9%, 100%, 100% and 97.68% respectively. The result shows that the XRF machine was able to detect almost all the elements.

Table 4.1: Elemental Composition of Ordinary Portland Cement

Element		Brands of Cements Manufactured in Nigeria				
		A (%)	**B (%)**	**C (%)**	**D (%)**	**E (%)**
Aluminium	Al	3.80	5.4	3.90	3.70	4.2
Silicon	Si	9.24	11.10	8.71	10.00	10.70
Sulphur	S	1.44	1.36	1.57	2.02	1.46
Potassium	K	ND	1.07	0.32	0.01	0.47
Calcium	Ca	78.25	72.67	77.07	74.54	71.19
Titanium	Ti	0.26	0.34	0.23	0.29	0.22
Vanadium	V	0.03	0.02	0.02	0.03	0.02
Chromium	Cr	0.03	0.01	0.01	0.03	0.01
Manganese	Mn	0.08	0.31	0.09	0.20	0.07
Iron	Fe	4.57	5.52	5.45	6.39	7.44
Rubidium	Rb	0.03	ND	0.01	0.06	ND
Yttrium	Y	0.20	0.10	0.20	0.53	0.20
Indium	In	1.45	0.84	1.70	I.40	0.95
Barium	Ba	0.11	0.16	0.15	0.12	0.16
Europium	Eu	ND	ND	0.02	ND	0.05
Lutetium	Lu	0.06	0.06	0.05	0.07	ND
Mercury	Hg	0.47	ND	0.50	0.61	0.54
Silver	Ag	ND	1.01	ND	ND	ND
Neodymium	Nd	ND	0.02	ND	ND	ND

Source: Laboratory Research Work (2016)
ND Not Detected

Table 4.2 presents the chemical composition of the cement brands used for the research. The major oxides detected were Al_2O_3, CaO, SiO_2, Fe_2O_3, SO_3 and K_2O and their percentages for each cement are within the limit set by IS 269-1967 and 1976. However, the percentages of Silicon oxide in cements A, C and D were 15.70%, 15% and 15.75 respectively. These are not within the specified range of 18-25; hence, the phase composition of the cements may change as a result. Similarly, the percentage of lime (CaO) in cement C is 70.77% which could lead to appreciable increase in C_3S and Decrease in C_2S as stated by Gupta and Gupta (2012).

Table 4.2: Chemical Composition of Ordinary Portland Cement

Oxide		**Brands of Cements Manufactured in Nigeria**					**IS 296**
		A (%)	**B (%)**	**C (%)**	**D (%)**	**E (%)**	**Range**
Aluminium oxide	Al_2O_3	5.30	7.20	5.90	5.60	6.00	3-8
Silicon oxide	SiO_2	15.00	20.10	15.70	15.70	18.30	18-25
Sulphur trioxide	SO_3	2.55	2.44	3.01	3.30	2.99	1-3
Potassium oxide	K_2O	0.01	0.73	0.22	0.04	0.33	0.2-1.3
Calcium oxide	CaO	70.77	61.82	69.00	66.30	64.36	60-67
Titanium oxide	TiO_2	0.29	0.51	0.23	0.27	0.24	----
Vanadium oxide	V_2O_5	0.03	0.03	0.02	0.03	0.02	----
Chromium trioxide	Cr_2O_3	0.03	0.01	ND	0.02	0.01	----
Manganese oxide	MnO	0.05	0.21	0.06	0.13	0.05	----
Iron trioxide	Fe_2O_3	3.39	3.93	3.98	4.71	5.75	0.5-6
Rubidium oxide	Rb_2O	ND	0.90	ND	ND	ND	----
Yttrium oxide	Y_2O_3	0.54	0.50	0.20	0.64	0.20	----
Indium oxide	In_2O_3	0.67	1.20	1.30	0.72	1.30	----
Barium oxide	BaO	0.06	0.11	0.10	0.06	0.11	----
Europium oxide	Eu_2O_3	ND	0.01	ND	0.02	0.01	----
Lutetium oxide	Lu_2O_3	0.04	0.02	0.02	0.05	0.02	----
Mercury oxide	HgO	0.31	0.28	0.28	0.00	0.37	----
Silver oxide	Ag_2O	1.00	ND	ND	ND	ND	----
Copper oxide	CuO	ND	ND	0.01	ND	ND	----
Germanium oxide	GeO2	ND	ND	ND	0.07	ND	----
Palladium oxide	PdO	ND	ND	ND	2.32	ND	----

Source: Laboratory Research Work (2016)
ND Not Detected

Table 4.3 presents the compound composition and the fineness of the cements. The percentages of celites and felites of all the cements had satisfied the limit according to Garba, (2014) However, only cement E, having 65.81% Alite content, complied with the limit. This perhaps could be due to the presence of higher percentage of iron oxide. As a result, earlier strength development of concrete is possible. Hence, its compatibility with SP could be more pronounced. It should be noted that the high content of Alite and negative values of Belite in cements A, C and D may not be true. This is because the cement used possibly contain excessive amount of free lime because of the blending of clinker with limestone that is the practice in Nigerian cement factories. Thus Boque's equation may be unsuitable in establishing the Alite and Belite content of Nigerian cements. Even though Boque's equation has been modified by Taylor (1997), the modified equation cannot be used because the actual free lime is unknown. Similarly, the percentages of fines passing through 600mmµ BS Sieve of all the cements are in accordance with the 10% limit except cement C that has 13.62%.Concrete made with cement sample C could be rapidly deteriorated on exposure to atmosphere (Gupta and Gupta, 2012). Details of the calculations are presented in appendix A1.

Table 4.3: Boque's Potential Phase Mass Fraction and Fineness of OPC

Compound		Brands of Cements Manufactured in Nigeria					
		A (%)	**B(%)**	**C (%)**	**D (%)**	**E (%)**	**Limit according to Garba (2014)**
Alite	C_3S	126.29	37.90	107.59	96.74	65.81	45-65
Belite	C_2S	-52.17	29.11	-36.06	-27.88	2.90	15-35
Celite	C_3A	8.32	12.44	9.08	2.24	6.18	04-14
Felite	C_4AF	10.31	11.95	12.10	14.32	17.48	10-18
Fineness		13.62	8.18	3.60	3.62	0.91	10%

Source: Laboratory Research Work (2016)

Table 4.4 presents the summary of the Concrete Mix Design using BRE method. The quantities per cubic metre of cement, fine aggregate, course aggregate and water were 360kg, 805.2kg, 1024.8kg and 210kg respectively. Details of the mix design calculations are presented in Appendix A2.

Table 4.4: Summary of the Result of Concrete Mix Design Using BRE Method

STAGE	**ITEM**	**REFERENCE/CALCULATION**	**VALUES**
1.	1.1 Characteristic strength	Specified	30N/mm^{2}at 28 days, Proportion defective = 5%
	1.2 Standard deviation	Figure 2.2	4N/mm^2
	1.3 Margin	Ks	(k = 1.64, s = 4) = 6.56N/mm^2
	1.4Target mean strength	$f_m = f_c + ks$	30 + 6.56 = 36.56N/mm^2
	1.5Cement strength class	Specified	42.5
	1.6Aggregate type: Coarse and Fine		Crushed
	1.7Free-water/cement ratio	Table2.6, Fig 2.4	0.63
	1.8Max. free-W/C ratio	Specified	0.60 } use this lower value
2.	2.1Slump test	Specified	50mm
	2.2Max. aggregate size	Specified	20mm
	2.3 Free water content (WC)	Table 2.8	210kg/m^3
3.	3.1 Cement content (CC)	$\frac{water\ content}{w/c}$	350kg/m^3
	3.2 Maximum cement content	Specified	350kg/m^3
	3.3 Minimum cement content	Specified	360kg/m^3
		Use 3.1 if ≤ 3.2 *Use 3.3 if □ 3.1*	360kg/m^3
4.	4.1 Relative density of aggregate (SSD)		2.70
	4.2Concrete density (CD)	Fig 2.5	2400kg/m^3
	4.3 Total aggregate content (TAC)	CD-CC-WC	2400– 360-210 = 1830kg/m^3
5.	5.1 Grading of fine aggregate	% passing 600µm sieve	42%
	5.2 Proportion of fine aggregate (PFA)	Fig 2.6	44%
	5.3 Fine aggregate content (FAC)	TAC x PFA	1830x $\frac{44}{100}$ = 805.20kg/m^3
	5.4Coarse aggregate content (CAC)	TAC-FAC	1830– 805.20 = 1024.80kg/m^3

Source: Laboratory Research Work (2016).

Looking at table 4.5, it can be observed that the highest value of the compressive strength at 28th day of curing is 32.33N/mm^2 which was produced using 1.0% SP by weight of cement. However, when 1.50% SP was used, 21.73N/mm^2 was achieved which is 27.29% less than the control sample. Therefore, 1.0% SP is the optimum dosage and was selected throughout the experiment.

Table 4.5: Determination of Optimum Dosage of SP Using Cement A

Dosage of SP (%)	**W/C Ratio**	**Compressive Strength (N/mm^2)**		
		3 Days	**7 Days**	**28 Days**
0.00	0.60	8.83	13.70	27.66
0.20	0.60	14.50	17.00	28.33
0.40	0.60	18.75	19.00	28.50
0.60	0.60	12.00	19.65	29.97
0.80	0.60	15.75	24.00	31.80
1.00	0.60	13.25	25.00	32.33
1.20	0.60	12.25	20.33	28.67
1.50	0.60	10.67	15.50	21.73

Source: Laboratory Research Work (2016)

Table 4.6 shows setting time, soundness and consistency of the cement brands. The setting time of the super plasticized cements and their control samples were all within the BS 12 standard which states that the initial setting should not be less than 45 minutes and not more than 600 minutes for the final setting. Also, the soundness tests of the cements corresponded to the requirement of BS EN 197-1 (2000) which specifies that it should not be less than 10mm

Table 4.6: Effect of SP on Setting time, Soundness and Consistency

Cement Brands	SP (%)	Setting time (mins)		Soundness (mm)	Consistency (%)
		Initial	Final		
A	0.0	121	184	2	30
A	1.0	285	395	0	31.25
B	0.0	136	186	1	33
B	1.0	338	443	1	30
C	0.0	120	181	4	30.5
C	1.0	105	163	2	26
D	0.0	165	233	1	36.75
D	1.0	47	149	2	30
E	0.0	158	202	1	35
E	1.0	256	464	0	32

Source: Laboratory Research Work (2016)

4.2 Presentation of Results of Tests on Fresh Concrete

4.2.1 Influence of Super Plasticizer on Workability

Table 4.7 presents the slump and compacting factor tests of the concretes produced with different cement brands. The slump test results were essential in determining the workability of the concrete design. The workability of the control samples fell between medium (25-100mm slump) and high workability (100-175mm slump) (BRE, 1997). Similarly, since Compacting factor test is more precise and is particularly useful for concrete mixes of very low workability, as stated by Shetty, (2009) the values obtained for both the super-plasticized concrete and the control samples fell between medium and high workability (0.92-0.95). This indicates that the 30% reduction in water for the super plasticized concrete did not render the concrete unworkable.

Table 4.7: W/C Ratio, Slump and Compacting Factor Tests.

Cement Brands	SP (%)	W/C Ratio	Water Reduction (%)	Slump (mm)	Compacting factor
A	0.0	0.60	--	135	0.96
A	1.0	0.60	30	10	0.94
B	0.0	0.60	--	90	0.97
B	1.0	0.60	30	22	0.95
C	0.0	0.60	--	110	0.97
C	1.0	0.60	30	06	0.95
D	0.0	0.60	--	70	0.98
D	1.0	0.60	30	04	0.91
E	0.0	0.60	--	94	0.96
E	1.0	0.60	30	25	0.94

Source: Laboratory Research Work (2016)

4.3 Presentation of Results of Tests on Hardened Concrete

4.3.1 Influence of Super Plasticizer on Cement-Saving

Table 4.8 shows the prospect of saving the quantity of cement with the use of different dosages of SP. The result indicates that it is possible to save up to 25.05% of cement when 1.0% SP is used. However, beyond 25.05% cement reduction, the concrete samples fails during hydration period which indicate that it is not possible to achieve cement saving using over 1.0% SP. The calculation of the water reduction and the quantity of material used were presented in Appendices A4 and A5.

Table 4.8: Percentage of Cement Saving Using Cement A

SP Used Rheobuid-600 (%)	W/C Ratio	Slump (mm)	Compacting factor	Amount of Cement (kg)	Cement Saving (%)	Compressive Strength (N/mm^2)		
						3 Days	7 Days	28 Days
0.00	0.60	135	0.96	4.75	---	8.83	13.70	27.66
0.20	0.53	66	0.97	4.17	12.21	12.75	18.50	27.55
0.40	0.51	15	0.94	4.02	15.37	16.00	19.00	27.12
0.60	0.49	12	0.90	3.87	18.53	16.50	20.46	29.19
0.80	0.47	4	0.92	3.72	21.89	17.00	17.25	28.87
1.00	0.46	3	0.89	3.56	25.05	13.75	16.65	28.75
1.20	0.44	0	0.89	3.41	28.21	0.70	8.75	0.00
1.50	0.42	0	0.80	3.26	31.37	0.00	0.00	0.00

Source: Laboratory Research Work (2016).

4.3.2 Influence of Super Plasticizer on Strength of Concrete

Figure 4.1 presents the average compressive strength of concrete specimen produced with different brands of cement cured in normal water for 3, 7, 28, and 56 days prior to crushing. The control specimens are indicated by 0%SP while 1%SP denotes the sample specimens. It can be seen that there is a gap between the strengths of concrete produced with addition of SP and the control specimens in all the cement brands. This could be due to the compatibility of SP with the cement brands. However, there was about 65.32%increases in compressive strength when 1% SP was added to cement E. This could be due to the higher dispersing ability of SP in the cement which resulted in greater surface area exposed to hydration, and for this reason strength development was greater. The strengths determined are presented in appendix A6.

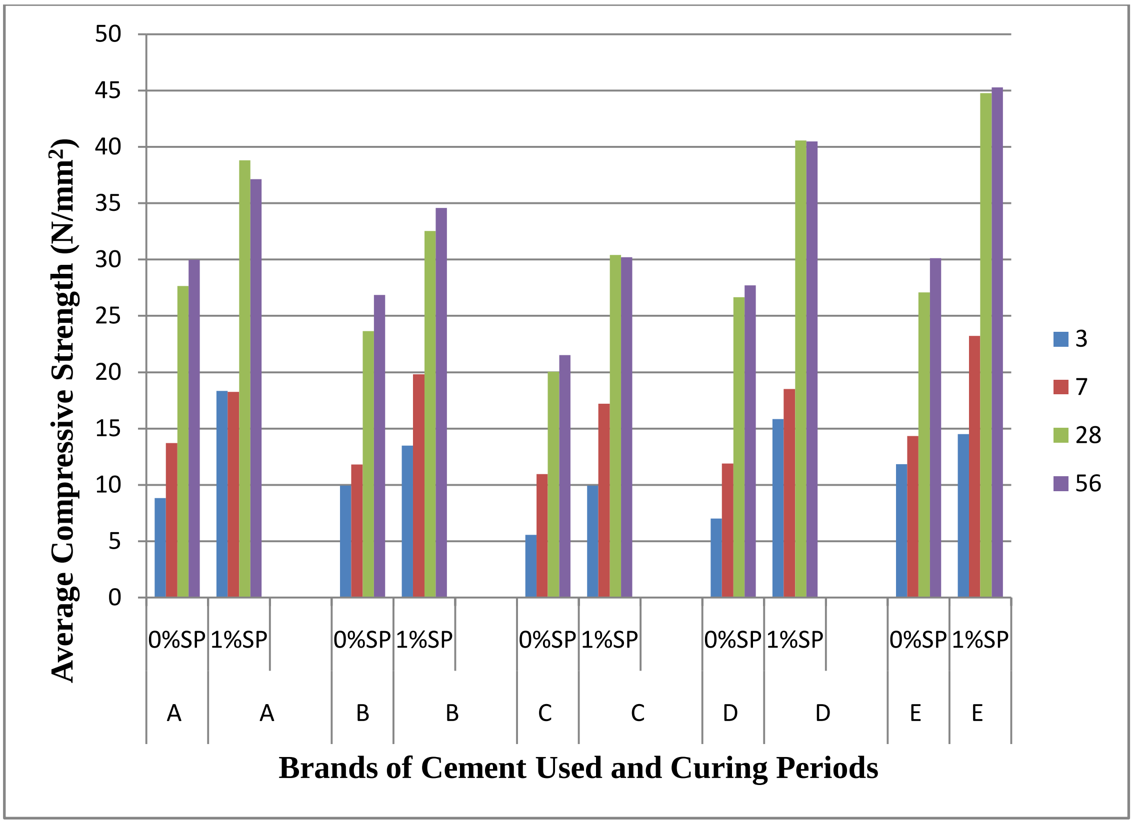


Figure 4.1: Relationship between Compressive Strength of Concretes and Age for Different Brands of Cement Cured in Water

From figure 4.2, it can be observed that magnesium sulphate solution comparatively affects the strength development of the control specimens signifying that the super-plasticized concrete was not affected by the salt solution. However, cement C shows about 3.66% reduction in compressive strength when exposed to the salt solution for 56 days of curing. The reason for this is because $MgSO_4$ reacts comparatively more with the belite phase of the cement and affects the concrete strength at later age. The strengths determined are presented in appendix A7.

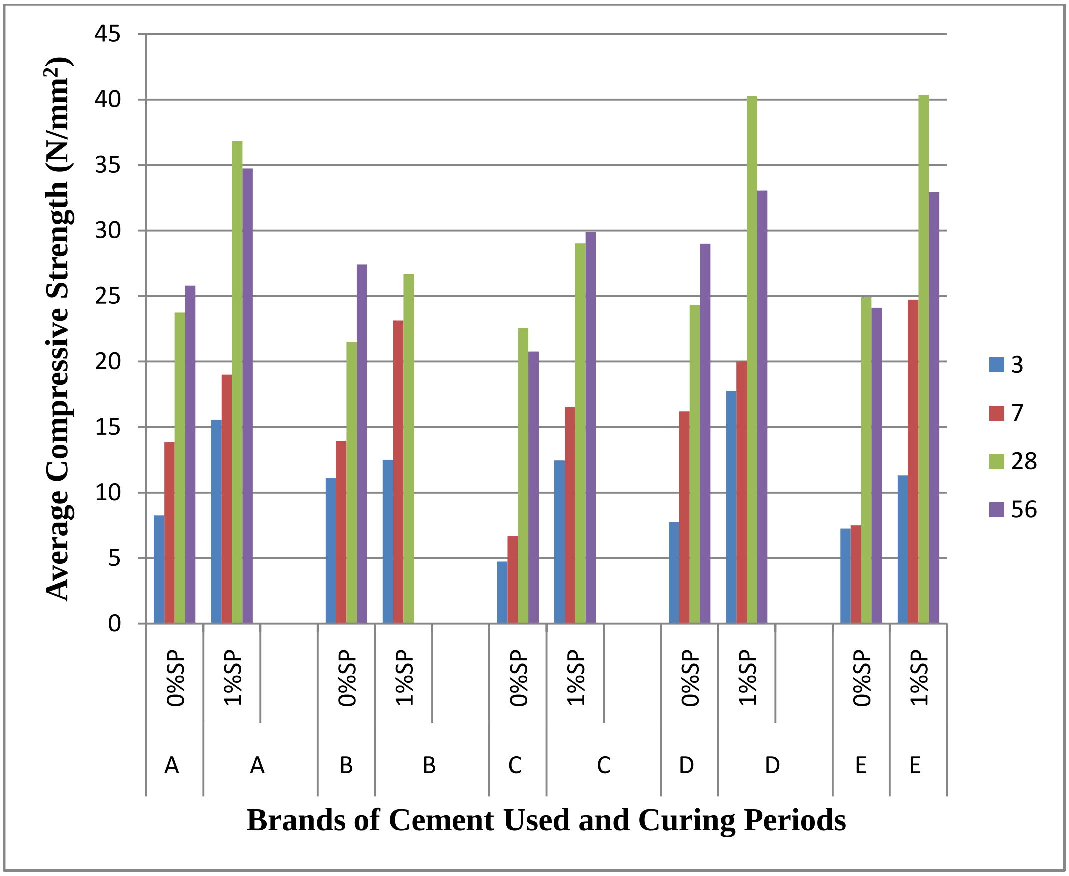


Figure 4.2: Compressive Strength of Concrete Exposed to $MgSO_4$

Figurer 4.3 shows the residual strength of specimens exposed to $MgSO_4$ and water. The letters AW and AM represents cements A cured in water and magnesium sulphate curing media respectively. It can be observed that each of the five charts for the different cement brands used have comparatively similar compressive strengths with their corresponding curing media. However, cement B concrete had the highest reduction of 21.96% while cement D concrete had the lowest reduction of 0.75%. This could be as a result of difference in the level of reaction of the salt solution with the cement brands. The strengths determined are shown in appendices A6 and A7.

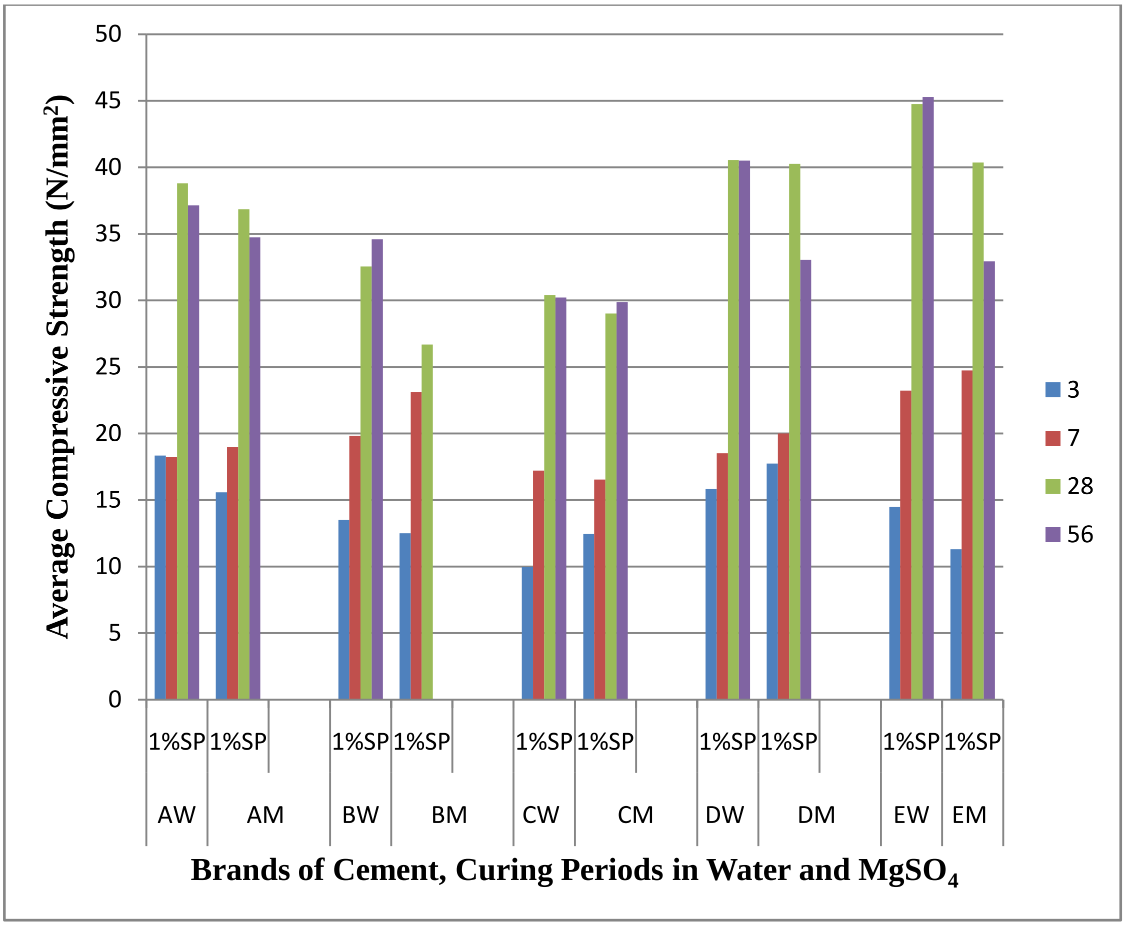


Figure 4.3: Residual Strength of Specimens Exposed to $MgSO_4$ and Water

Figure 4.4 presents the average tensile strength of superplasticized concrete produced with different cement brands and their control specimens. It can be observed that at the later periods of curing, the tensile strength of the superplasticized concretes produced with cements D and E recorded the highest strength of 3.74 and 3.76N/mm^2 respectively. This therefore, justified the results of the compressive strength of the specimens. The strength determined is presented in appendix A8.

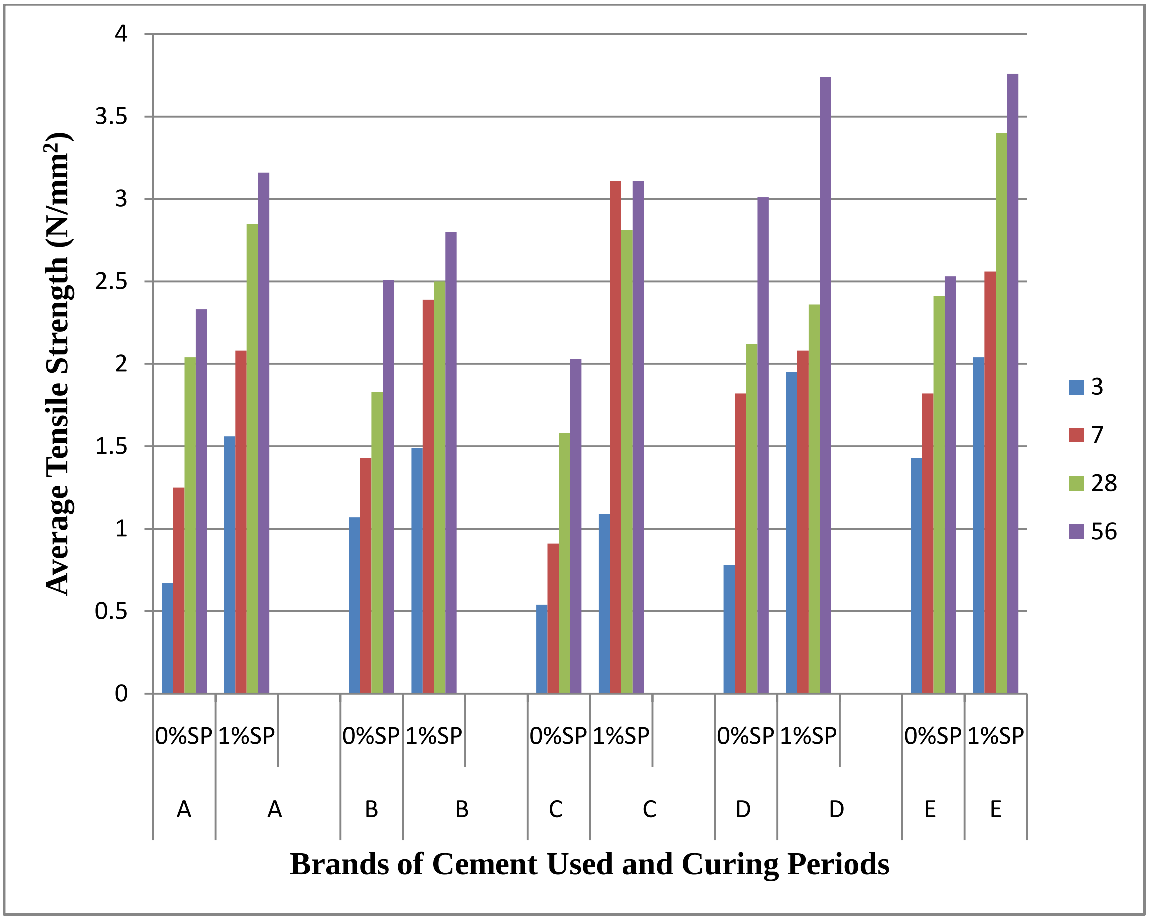


Figure 4.4: Tensile Strength Values of Concretes Cured in Water

From figure 4.5, it can be noted that there is wide gap between the sample specimens at the 28th day curing and their respective control. This is not surprising because the super-plasticized concrete attains early strength as reiterated by Neville and Brooks, (2000). The result of the experiment shows that cement E concrete has the least loss in weight of about 0% at 56th day of curing. This perhaps could be due to the high strength of the specimens. The detail results of the tensile strength are presented in appendices A9 to A10.

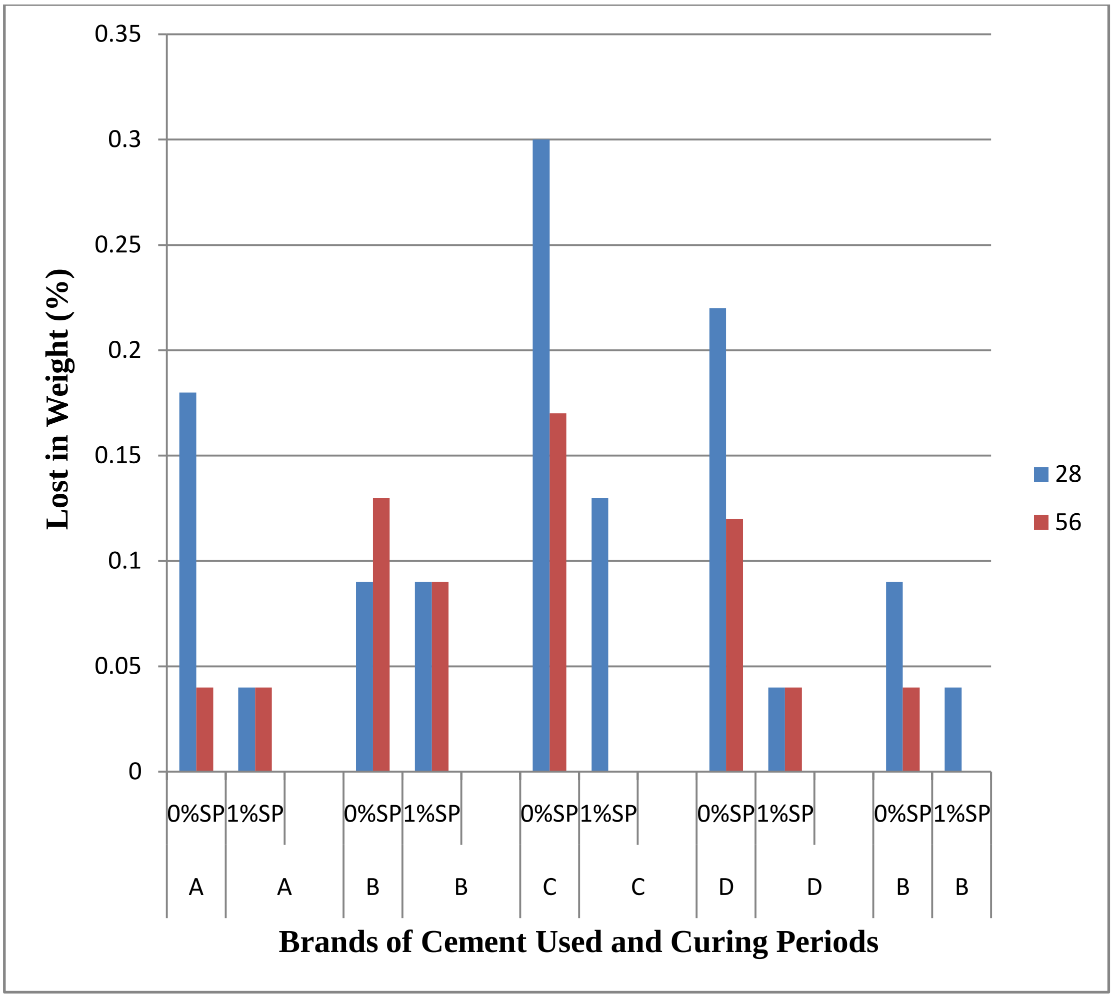


Figure 4.5: Abrasion Resistance of Concretes Cured in Water

Figure 4.6 shows the abrasion resistance of the concrete samples exposed to magnesium sulphate solution. It can be observed that cement A concrete sample shows the highest loss in weight of about 0.38%. This could be as a result of the impact of the salt solution at the surface of the specimens. The detail results of the abrasion test are shown in appendices A11 to A12.

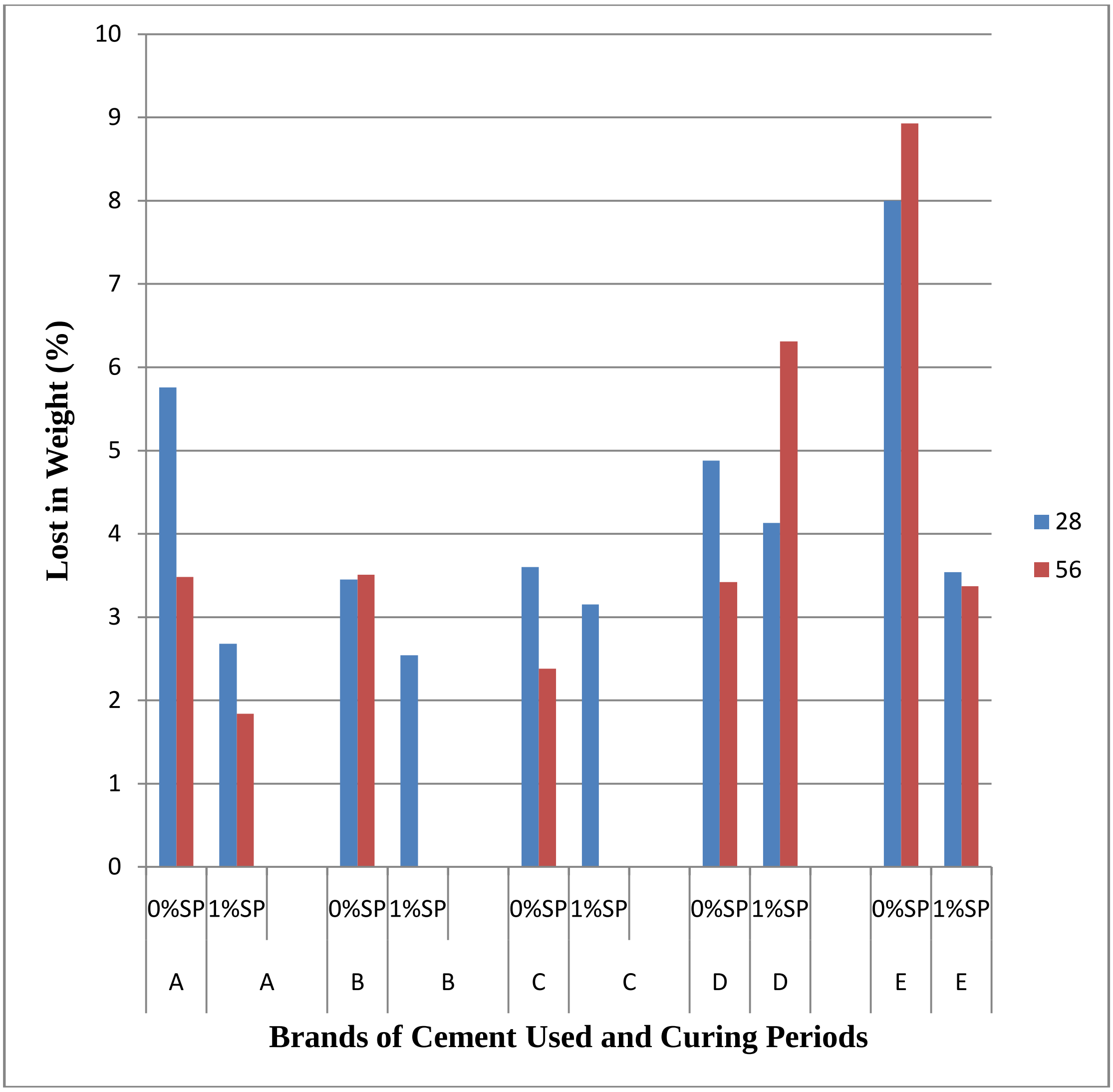


Figure 4.6: Abrasion Resistance of Concretes Exposed to $MgSO_4$Solution

Figure 4.7 shows the absorption capacity of the concrete specimens. The control specimen of cement C concrete had the highest absorption capacity of 6.80% at 56th day of curing. This could be as a result of the effect of SP on rheology (the science of flow and deformation) of the concrete specimens. The detail results of the abrasion test are shown in appendices A13 to A14.

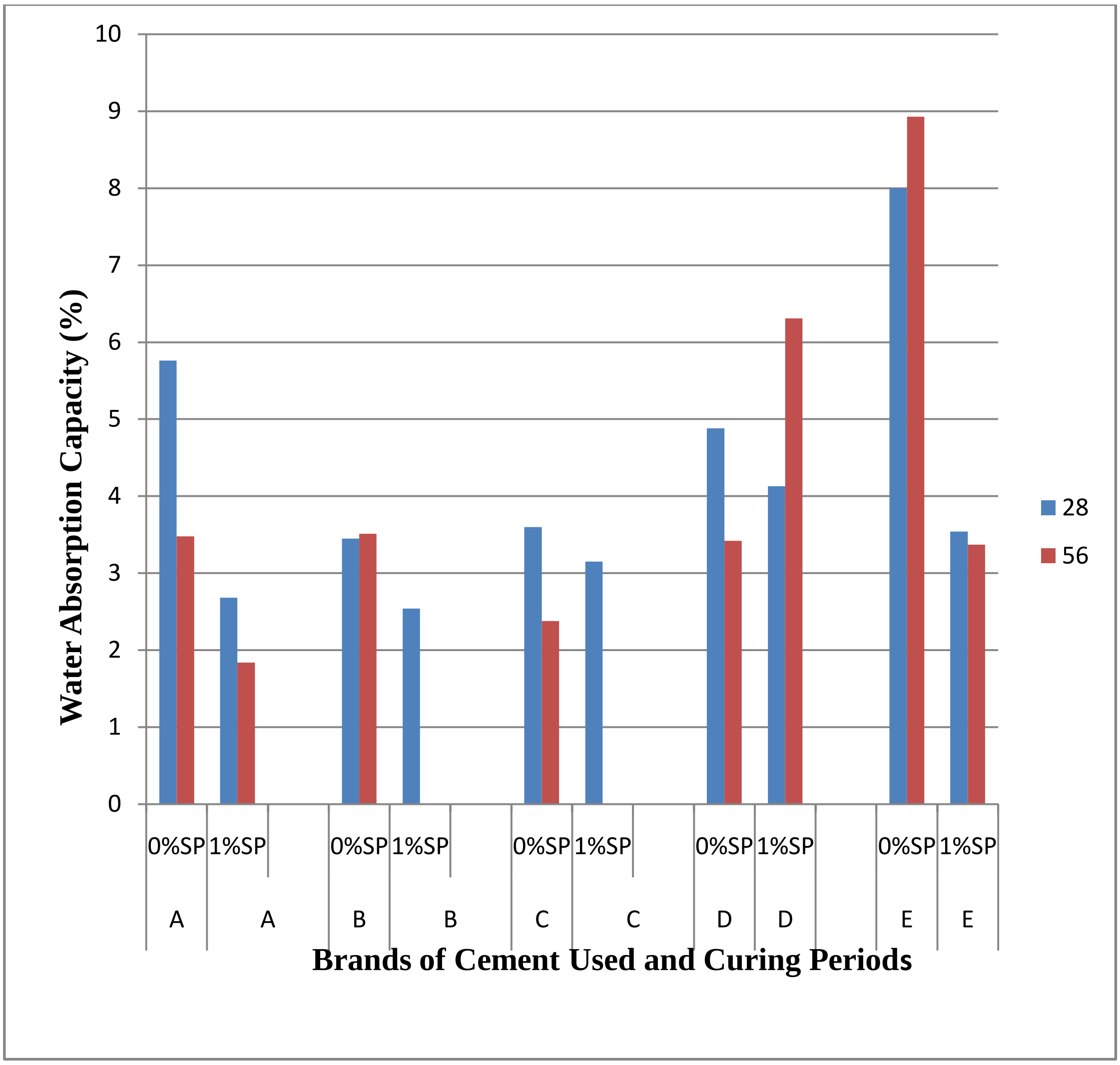


Figure 4.7: Water Absorption Capacity of Specimens Cured in Water

Figure 4.8 presents the absorption capacity of concrete samples exposed to magnesium sulphate solution.

However, the degree of absorption capacity of all the sample specimens in both figure 4.6 and 4.7 agree with the assertion made by Pitroda and Shah (2014) in Ibrahim (2015) which states that the average absorption capacity of concrete specimen should not be greater than 5%.

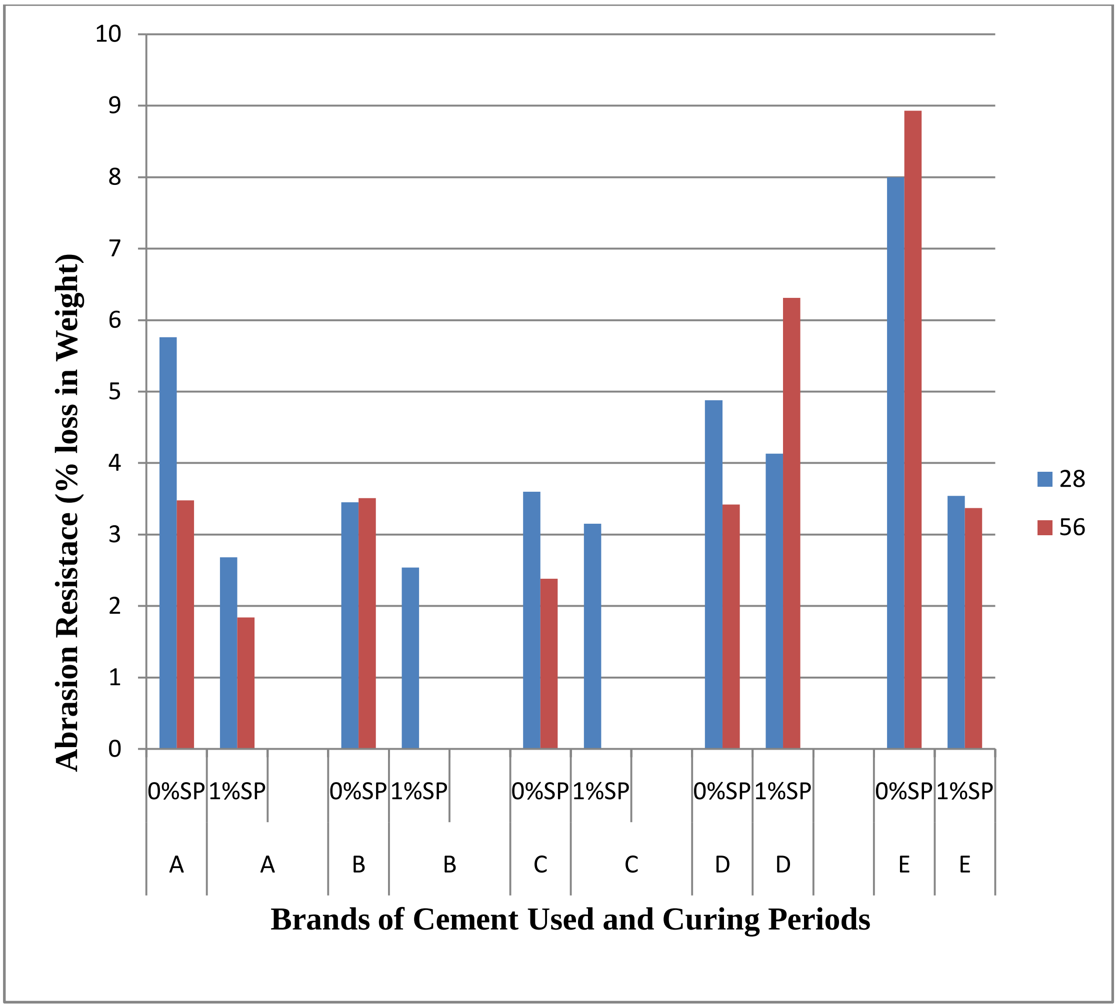


Figure 4.7:Water Absorption Test of Concrete Specimens Exposed to $MgSO_4$Solution.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the Major Findings

This study aimed at assessing the influence of SP on concrete made with different brands of Portland cement available in Nigeria. In this study a number of tests were carried out so as examine the compatibility of Rheobuild-600 with the cement brands. The highlight of the major findings are summarised as follows:

1. The summation of elements found in cement A, B, C, D and E were 99.91%, 98.9%, 100%, 100%and 97.68%, respectively. However, cement C has the highest percent of CaO (70.77%) and lowest percent of SiO_2 (15.0%).
2. The fineness of the cements A, B, C, D, and E were found to be 3.60%, 8.18%, 13.62%, 3.62% and 0.19%,respectively.
3. The optimum dosage of SP using cement A was found to be 1.0% by weight of cement.
4. The initial and final setting times of all the cement brands were less than 45 and 60 minutes respectively. Similarly, the soundness test indicates that both the super plasticized cement pastes and their respective control samples were less than 10mm.
5. The workability of the control specimens for cements B, D and E fell within the BS limit of medium slump (i.e 25-100mm) while cements A, and C fell within high slump (i.e 100-175mm). However, the workability of the super-plasticized concrete specimens using compacting factor test ranges between 0.91- 0.98.
6. The highest percentage cement saving for concrete produced using different dosages of SP was 25.05% while the water reduction was up to 41%.

7. The increase in compressive strength of the sample specimens to their respective control specimens for all the cement brands cured in water were found to be 40.31% for cement A, 37.65% for cement B, 51.62% for cement C, 52.08% for cement D, and 65.32% for cement E. Nevertheless, for the samples exposed to $MgSO_4$ solution the increase in compressive strength were: 55.22% for cement A, 24.27% for cement B, 28.38% for cement C, 65.48% for cement D, and 63.93% for cement E
8. The residual strength of sample specimens exposed to $MgSO_4$solution shows that cement D concrete has the least reduction in compressive strength of 0.75% while cement B concrete has 21.96%.

5.2 Conclusions

After carrying out the experiments, observations, analysis and discussions, on the influence of SP on concrete made with five brands of Portland cements manufactured in Nigeria, the following conclusions were drawn:

1. The Alite, Belite, Celite, and Felite content calculated using Boque's equation have shown that all the cement brands comply with the standard limit of 0.14 – 14% and 10-18% in terms of Celite and Felite respectively, while only cement E, with 65.81% Alite content was within the specified limit 45.65% but not in compliance with 15-35% Belite content.
2. The locally available concrete ingredients were used to design Grade 30 concrete using BRE method for the locally available materials. However, the maximum compressive strength obtained was 27.66N/mm^2.
3. Rheobuild-600 SP was used to produce the specimens with 30% reduction of water. The workability of the fresh concrete specimens was found to fell

between medium and high workability when 1% SP was used. The cement brands used were all compatible with Rheobuild-600 in terms of increase in compressive strengths of the concrete specimens, with cement E being the most compatible brand. However, the dosage of SP beyond 1.0% by weight of cement A only decreased the compressive strength rather than increasing it.

4. The use of Rheobuild-600 in the production of concrete specimens saved about 25% of cement and 41% of water quantities.
5. The exposure of the super-plasticized concrete samples to 1.0% concentration of $MgSO_4$ solution had mild effect on the compressive strength and abrasion resistance.
6. Concrete made with Rheobuild-600 performed better than conventional concrete in terms of workability, strength and durability.

5.3 Recommendations

1. The research recommends that the cement quality manufactured in Nigeria should be improved to meet the international standards such as BS 12 (1996).

2. The Rheobuild-600 could be used to increase compressive strength of concrete using cements A, B, C, D, and E.

3. The Rheobuild -600 could be used when high early strength is needed.

4. Although the five brands of cements investigated were found to be compatible with Rheobuild-600, the research recommends that trial mixes should be performed with job materials to determine the optimum dosage required for a specified setting time and a given strength requirement.

5.4 Recommendations for Further Studies

1. Research should be carried out on the study of the chemical reactivity between Rheobuild-600 and the different cement brands manufactured in Nigeria.

2. The optimum dosages of Rheobuild-600 should be determined when cements B, C, D and E are to be used.

3. Different brands of SP other than Rheobuild-600 should also be used to find out the influence on the cement brands.

5.5 Contributions to Knowledge

The research established that:

1. the optimum dosage of Rheobuild-600 when cement A is used is 1.0% beyond which the concrete would only starts reducing in strength.

2. it is possible to save about 25% cement quantity when Rheobuild-600 is used for the production of concrete.

3. the compatibility of Nigerian Cement with Rheobuild-600 varies with the cement brands investigated. However, cement E concrete which gives about 65% increase in compressive strength is the most compatible cement brand.

REFERENCES

Aggarwal, P., Siddique, R., Aggarwal, Y. and Gupta, S. M. (2008). Self-Compacting Concrete-procedure for Mix Design. *Leonardo Electronic Journal of Practices and Technologies*, 1(12), 15-24. http://lejpt.academicdirect.org

Ahmad, S., Nawaz, M. and E liha, A. (2005). Effect of Superplasticizer on Workability and strength of Concrete, *Our World in Concrete & Structures*. Paper presentedat the 30th Annual Conference, Singapore. Retrieved from http://cipremier.com/100030014

Aitcin, P.C. (2004). Cement and Superplasticizer: Compatibility and Robustness. *ATM International*, 26(02), 1-7. doi: 10.1520/CCA 12329.

Alsady, S. (2015).Effect of Superplasticizer on Fresh and Hardened Properties of Concrete. *Journal of Agricultural Science and Engineering*, 1(2), 70-74. Retrieved fromhttp://www.publicscienceframework.org/journaj/jase

Alsady, S. (2013, December). Effect of Superplasticizing and Retarding Admixtures on Properties of Concrete. *International Conference on Innovations in Engineering and Technolog, 1*(2), 271-273.. Retrieved from http:/dx.doi.org/10.15242/IIE.E1213607

Alsady, S. (2012). Influence of Superplasticizer on strength of Concrete. *International Conference on Innovations in Engineering and Technolog, 1*(3), 2277-4378.

American Society for Testing and Matrials (2004) “Standard Specification for Chemical Admixtures, American Society for Testing and Materials, West Conshohoccken, Pa, C494/C494M.

Baba, M. T. (2012). The Characteristics of High Strength Light Weight and Medium Weight Concrete**.** *An Unpublished BSc Project*, Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria.

Bassioni, G. (2015). The Influence of Cement Composition on Superplasticizers’Efficiency. *International Journal of Engineering*, 3(6), 577 587.Retrieved fromhttp://journals.ru.iv/index.php/ETR article/view/1013

Bakash, S.A., and Reddy, K.B. (2013). Increasing the Sustainability of Concrete by Using Superplasticizers-A Study. *International Journal of Advanced Structures and Geotechnical Engineering*, 2(01), 36-39. Retrieved from http://schorlar.google.co.in/citation?user=IJTFEMAAAAJ&hl=en

British Standard 812:109 (1990).Method for Determination of Moisture Content of Aggregate.BSILinfordwood, Milton Keynes MK14 6LE, UK.

British Standard 812 part 2 (1995).Testing aggregate part 2.Methods of determination of density. BSI Publication British Standard Institution, London

British Standard, BS 112 (1971): "Determination of Properties of Fine Aggregate" BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

British Standard European Norm, (1997). Testing for geometrical properties of aggregate; Determination of particle size distribution-Test sieves, nominal size of apertures. BS EN 933-2, BSI, Milton Keynes MK14 6LE, U.K

British Standard 5075-1, (1982). Concrete Admixtures Specification for Accelerating Admixtures, Retarding Admixtures and Water Reducing Admixtures, BSI, Linfordwood, Milton Keynes MK14 6LE, U.S

British Standard European Norm, 1008, (2002).Mixing Water for Concrete. Specification for Sampling, Testing and Assessing the Suitability of Water, Including Water Recovered from Processes in the Concrete Industry, as Mixing Water in Concrete.

British Standard European Norm, 12350-2 (2009).Testing fresh concrete slump
.

British Standard European Norm,(1995). Method of testing cement; Chemical analysis of cement. BS EN 196-2, BSI, Linfordwood, Milton Keynes MK14 6LE, U.S

British Standard, (1983).Testing fresh concrete.Method for determination of water absorption. BS 1881-122, BSI, Linfordwood, Milton Keynes MK14 6LE, U.S

British Standard, (1986).Testing Concrete; Method for mixing and sampling fresh concrete in the laboratory.BS 1881-125, BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

British Standard, BS 1881:124 (1988). "Methods of Analysis of Hardened Concrete" BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

Chiang, W., Fratini, E., Ridi, F., Lim, S., Yeh, Y., Baglioni, P., Choi, S., Jeng, U. and Chen, S. (2013). Microstructural Changes of Globules in Calcium-Silicate Hydrates Gels with and without Additives and X-ray Scattering. *Journal of Colloidal and InterfaceScience*, 398(2013), 67-73. Retrieved from http://www.elsevier.com/locate/jcis

Chudley, R. and Greeno, R. (2005). *Buliding Construction Handbook*. Butterworth Heinemann Publication, Burlington, USA.

Collepardi, M., Borsoi,A., andCollepardi S. (2005). *Cement & Concrete Composites*, 27 (2005), 704–708.

Dahiru, D. (2013). Assessment of Non Destructive Testing in Concrete. *An Unpublished PhD Dissertation Work*, Department of Civil Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria.

Diamond, S., and Matsukawa, K. (1993). Quantitative Analysis of Interactions between Portland Cements and Superplasticizers. *Joint Transportation Research Program*, Purdue University, West Lafayette, Indiana.

Dubey, R., and Kumar, P. (2012). Effect of SP Dosage on Compressive Strength of Self-Compacting Concrete. *International Journal of Civil and Structural Engineering,* 3(2), 976-4399.

Dumre, S. M. (2014). Effect of Superplasticizer on Fresh and Hardened Properties of Self-Compacting Concrete Containing Fly Ash. *American Journal of Engineering Research (AJER*), 3(3), 205-211

Evangeline, K. and Neelamegam, M. (2013).Effect of Superplasticizer on Workability and Mechanical Properties of Self-Compacting Concrete. *Journal of Mechanical andCivil Engineering*, 18-29. Retrieved from http://www.iosrjournals.org

Eckert, W. C and Carrasquito, R. (1988). Guideliness for The Proper use of Superplasticizer in Concrete. Centre for Transport Research Bureau of Enginnering Research, University of Texas, Autin.

Gambo, S. (2014).Assessment of the Durability Properties of Ternary Cementitious Matrix Concrete Containing Rice Husk Ash and Sawdust Ash. *Unpublished M.Sc Thesis Work*, Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria.

Ganiron, T.U. (2013). Influence of Polymer Fibre on Strength of Concrete. *International Journal of Advanced Science and Technology*, 55(01), 53-66.

Garba, M.M. (2014, May). Concreting: Materials, Design, Production and Assembly. *Increasing the Core Practice Areas of Builders VI.* Paper presented at the 7th annual Mandatory Continuing Professional Development Programme for Builders, Lagos, Nigeria.

Gupta, B.I and Gupta, A. (2012) *Concrete Technolog*y. Standard Publishers Distributors

Hokfors, B. and Bostrom.D. (2014). On the Phase Chemistry of Portland Cement Klinker. *Research Gate*, 27(01), 50-60. Retrieved from http://dx.doi.org/10.1680/adcr.13.00071

Houst, Y.F., Bowen, P. and Siebold, H. (2010). *Some Basic Aspects of the Interaction of Cement-Superplasticizers.Swiss,* Federal Institute of Technology, Institute of Material Science, Power Technology Laboratory, Lausanne, Switzerland.

Ibrahim, M. (2015). An Assessment of Durabilities of Portland Volcanic Ash Concrete. *An Unpublished MSc Thesis Work*, Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria.

Kapelko, A. and Kapelko, R. (2007, May).The influence of new generation superplasticizer on the fluidity of concrete mixes. In *The 9th International Conference "Modern BuildingMaterials Structures and Techniques"* (76-82).

Kurtis, K. (Anonymous). Test on Portland Cements, School of Civil Engineering, Gorgia Institute of Technology, Altarta, Gorgia.

Liu, X., Wang, Z., Zhang, Y., Cui, S., Lan, M., Li, H., Zhu, J. and Liang, X. (2014). Preparation, Characterization and Performance of Powdered Polycarboxylate Superplasticizer with Bulk Polymerization. *Journal of Materials*, 7(9), 6169-6183.Doi: 10.3390/ma/7096169.

Malagavelli, V. and Paturu, N.R. (2012). Strength and Workability Characteristics of Concrete by Using Different Super plasticizers. *International Journal of Material Engineering*. 2(01), 7-11. DOI: 10.5923/j.ijme.20120201.02

Marar, K. and Eren, O. (2011). Effect of Cement Content and Water/Cement Ratio on Fresh Concrete Properties Without Admixtures. *International Journal of the Physical Science*, 6(24), 5752-5765. Doi: 10.5897/IJPSII.188.

Matawal, D. S. (2013).Nigerian General Specification for Civil Engineering Works, Forum on Concrete Specifications, Applications and Cement Standards. Nigerian Building and Road Research Institute, NBRRI

Mohammed, M.H, Pusch, R., Knutsson, S., and Jonasson, J. (2014). Performance of Cement-Poor Concrete With Different Superplasticizers. *International Journal of Research and Review in Applied Science*, 18(02), 163-172. Retrievedfrom http://www.arpapress.com/Volumes/Vol18Issue2/IJRRAS_18_2_07.pdf

McCarthy, L. M. (2010). Analysis of Alternative Water Sources for Use in the Manufacture of Concrete. Unpublished M.Sc Thesis Work. School of Physical and Chemical Sciences,Queensland University of Technology, Australia.

Muhit, I. B. (2013). Dosage Limit Determination of Superplasticizing Admixtures and Effect Evaluation on Properties of Concrete. *International Journal of Scientific & Engineering Research*, 4(3), 2299-5518.

Nemati, K.M. (2015). *Concrete Technology*: Admixtures in Concrete. University of Worshington.

Neville, A.M. and Brooks, J. J. (2000). *Concrete Technology*. 1st edition. Pearson education, Longman Group Essex, England.

Neville, A.M. and Brooks, J. J. (2010). *Concrete Technology*. 2nd edition. Pearson education, Longman Group Essex, England.

Noruzman, A. H., Muhammad, B., Ismail, M. and Abdul-majid, Z. (2012). Characteristics of Treated Effluents and Their Potential Applications for Producing Concrete. *Journal of Environmental Management*, 1(10), 27-32. Doi: 10.1016/j.jenvinan.2012.05.019.

Okampo, A. and Zea, H. (2014).Formulation and Evaluation of Ready Mix Concrete of Chemical Additives Based on Molasses, Carboxymethylcelloluse and Polynaphthalnesulphonate. *International Journal of Chemical Technology Research*, 6(01), 769-778. Retrieved from http://www.sphinxsai.com

Peurifoy, R. L. (2011). *Construction Planning ,Equipments and Methods*. 8th Edition, McCraw-Hill, New york.

Ran, Q., Miao, C., Liu, J., Wu, S. and Shen, J. (2006). Performance and Mechanism of a Multi-functional Superplasticizer for Concrete. *Journal of Material Transaction*, 47(6),1599-1604.Retrievedfrom http://joi.jlc.jst.go.jp/JST.JSTAGE/matertrans/47.1599

Reddy, S. (2013). Increasing the Sustainability of Concrete by Using Superplasticizers. *International Journal of Advanced Structures and Geotechnical Engineering*, 02(01), 36-39.

Sabriani, S. (2010). The Effect of Waste Wash Water on Concrete Properties. Unpublished M.Sc Thesis Work.Department of Civil Engineering, Faculty of Civil Engineering andEarth Resources, University of Malaysia, Pahang.

Santhanam, M. (2013). Evaluation of Superplasticizer Performance in Concrete.*The 3rd International Conference "Sustainable Constrution Materials and Technologies"*.76-82.Retrieved from http://www.claisse.info/proceedings.htm

Schmidt, W. (2015, June). Parameter Controlling Superplasticizers Cement Interraction During Casting and Hardening of Cement Based Systems. *1st International Symposium Knowledge Exchange for Young Scientists*.Retrieved from http://www.bam.de

Shah, S.N., Aslam, M., Shah, S.A., Ord, R. (2014). Behaviour of Normal Concrete Using SuperplasticizerUnder Different Curing Regimes. *Pakistan Journal of Engineering and Applied Science*, 15(01), 87-94.

Shetty, M. S. (2009). *Concrete Technology: Theory and Practice*. S. Chad & Company Ltd, Ram Nagar, New-Delhi 110055, India.

Taylor. H. F. W. (1997). *Cement Chemistry*, 2ndedn. Thomas Telford, London, UK.

Yahaya, M. D. (2009). Physico-Chemical Classification of Nigerian Cement. An Unpublished MSc Thesis Work, Department of Chemical Engineering, Federal University of Technology Minna.

Zing, A. (2008). Cement-SuperplasticizerInteraction:Link Between Microscopic Phenomina and Macrostructural Data of the Early Cement Hydration. A Dissertation submitted to the Swiss Federal University of Technology, Zurish

Zongjin, L. (2011). *Advanced Concrete Technology* “Department of Civil and Environmental Engineering”, Hong Kong University of Science and Technology, China, John Wiley & Sons.

APPENDICES

APPENDIX A1: BOQUE'S EQUATION FOR CALCULATION OF MAJOR COMPOUNDS OF ORDINARY PORTLAND CEMENT

From Boque's equation the C_3S for the different brands of cement are given as follows:

CEMENT A

$\mathbf{C_3S}$ = 4.07(CaO) – 7.60(SiO_2) – 6.72(Al_2O_3) – 1.42(F_e2O_3) - 2.55(SO_3)

= 4.07(69.00) –7.60(15.70) – 6.72(5.90) – 1.43(3.98) – 2.55(3.01)

= 107.59%

$\mathbf{C_2S}$ = 2.87(SiO_2) – 0.754(3Cao.SiO_2)

= 2.87(SiO_2) – 0.754(C_3S)

= 2.87(15.70) – 0.754(107.59)

= -36.06%

$\mathbf{C_3A}$ = 2.65(Al_2O_3) – 1.69(F_e2O_3)

= 2.65(5.90) – 1.69(3.98)

= 9.07%

$\mathbf{C_4AF}$ = 3.04(F_e2O_3)

= 3.04(3.98)

= 12.10%

CEMENT B

$\mathbf{C_3S}$ = 4.07(CaO) – 7.60(SiO_2) – 6.72(Al_2O_3) – 1.42(F_e2O_3) - 2.55(SO_3)

= 4.07(61.82) –7.60(20.10) – 6.72(7.20) – 1.43(3.93) – 2.55(2.44)

= 37.90%

$\mathbf{C_2S}$ = 2.87(SiO_2) – 0.754(3Cao.SiO_2)

= 2.87(SiO_2) – 0.754(C_3S)

= 2.87(20.10) – 0.754(37.90)

= 29.11%

C_3A = 2.65(Al_2O_3) – 1.69(F_e2O_3)

= 2.65(7.20) – 1.69(3.93)

= 12.44%

C_4AF = 3.04(F_e2O_3)

= 3.04(3.93)

= 11.95%

CEMENT C

C_3S = 4.07(CaO) – 7.60(SiO_2) – 6.72(Al_2O_3) – 1.42(F_e2O_3) - 2.55(SO_3)

= 4.07(70.77) –7.60(15.0) – 6.72(5.30) – 1.43(3.39) – 2.55(2.55)

= 126.29%

C_2S = 2.87(SiO_2) – 0.754(3Cao.SiO_2)

= 2.87(SiO_2) – 0.754(C_3S)

= 2.87(15.0) – 0.754(126.29)

= -52.17%

C_3A = 2.65(Al_2O_3) – 1.69(F_e2O_3)

= 2.65(5.30) – 1.69(3.39)

= 8.32%

C_4AF = 3.04(F_e2O_3)

= 3.04(3.39)

= 10.31%

CEMENT D

C_3S = 4.07(CaO) – 7.60(SiO_2) – 6.72(Al_2O_3) – 1.42(F_e2O_3) - 2.55(SO_3)

= 4.07(66.30) –7.60(15.70) – 6.72(5.60) – 1.43(4.71) – 2.55(3.30)

= 96.74%

C_2S = 2.87(SiO_2) – 0.754(3Cao.SiO_2)

= 2.87(SiO_2) – 0.754(C_3S)

= 2.87(15.70) – 0.754(96.74)

$= -27.88\%$

C_3A $= 2.65(Al_2O_3) – 1.69(F_e2O_3)$

$= 2.65(5.60) – 1.69(4.71)$

$= 7.24\%$

C_4AF $= 3.04(F_e2O_3)$

$= 3.04(4.71)$

$= 14.32\%$

CEMENT E

C_3S $= 4.07(CaO) – 7.60(SiO_2) – 6.72(Al_2O_3) – 1.42(F_e2O_3) - 2.55(SO_3)$

$= 4.07(64.36) –7.60(18.30) – 6.72(6.0) – 1.43(5.75) – 2.55(2.99)$

$= 65.81\%$

C_2S $= 2.87(SiO_2) – 0.754(3Cao.SiO_2)$

$= 2.87(SiO_2) – 0.754(C_3S)$

$= 2.87(18.30) – 0.754(65.81)$

$= 2.90\%$

C_3A $= 2.65(Al_2O_3) – 1.69(F_e2O_3)$

$= 2.65(6.0) – 1.69(5.75)$

$= 6.18\%$

C_4AF $= 3.04(F_e2O_3)$

$= 3.04(5.75)$

$= 17.48\%$

APPENDIX A2: Mix Design for Grade C30 Concrete Using Building Research Establishment Method (BRE)

Design Stipulations and Test data for Materials

Grade of cement =42.5

Type of concrete = Reinforced Concrete Hardstand

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

Coarse aggregate type = crushed granite

Maximum Size of Aggregate = 20mm

Fine aggregate = Natural sand with 42% of it passes through the 600µm BS sieve.

Condition of exposure = Alternate wetting and drying

Margin factor =5%

STEP 1:***COMPUTE MEAN TARGET STRENTH***

$f_m = f_c + ks$

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 figure 2.2 = select5% margin factor

From table 2.5, k = 1.64 and s =4

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

f_m =30+6.56

f_m= 36.56N/mm^2

<u>STEP 2</u>: ***INFORMATION ON MATERIALS***

a) Sieve analysis test for course aggregate = 20mm Max. size
b) Sieve analysis test for fine aggregate = 42% passes through 600µm sieve.
c) Specific gravity of coarse aggregate based on SSD = 2.70

<u>STEP 3</u>: ***DETERMINE THE REQUIRED WATER CEMENT RATIO***

Using cement grade 42.5 and crushed course aggregate at 28 day

From table 2.6

Anticipate strength = 49N/mm^2

Target strength = 36.56N/mm^2

Free water/cement ratio =0.5

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

From figure 2.4

Using the curve that is drawn from 0.5 free water/cement ratio and 49N/mm^{2}anticipated strength, trace the new water/cement ratio at target strength of 36.56N/mm^2

New free water/cement ratio = 0.63 □ 0.60 not ok

From table 2.8 Maximum water/cement ratio for alternate wetting and drying condition of exposure, plain concrete = 0.60

Therefore, water/cement ratio = 0.60

<u>STEP 4</u>: *DECIDE ON THE WORKABILITY (SLUMP)*

From table 2.9

Select low degree of workability with a slump ranging from 25 to 50mm.

<u>STEP 5</u>: *OBTAIN THE REQUIRED FREE WATER (kg/m^3)*

From table 2.7, based on the selected workability, maximum size and type of aggregate, the required free water content = 210kg/m^3

<u>STEP 6 :</u>*CALCULATE THE CEEMENT CONTENT BY USING THE W/C RATIO*

$$\text{Cement content (kg/m}^3\text{)} = \frac{Water\ content\ (kg/m3)}{w/c}$$

$$\text{Cement content (kg/m}^3\text{)} = \frac{210kg/m3}{0.60}$$

Cement = 350kg/m^3

<u>STEP 7:</u>*COMPARE THE AMOUNT OF THE CEMENT OBTAINED WITH THEMINIMUM ALLOWABLE CONTENT FOR DURABILITY*.

From table 2.8, the minimum cement content for reinforced concrete exposed to alternate wetting and drying = 360kg/m^3>350kg/m^3. Therefore, 360kg/m^3 is adequate.

<u>STEP 8</u>: *OBTAINE THE WET DENSITY OF THE CONCRETE*

From figure 2.5

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

Combined specific gravity of aggregate at SSD = 2.70

Therefore, Wet density (plastic density)= 2400kg/m^3

STEP 9: ***DETERMINE 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 = 42%

From figure 2.6: the proportion of fine aggregate = 44%

STEP 10:***COMPUTE THE QUANTITY OF AGGREGATE***

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

   $= 2400\text{kg/m}^3 – 360\text{kg/m}^3 - 210\text{kg/m}^3$

   $= 1830\text{kg/m}^3$

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

   $= 1830\text{kg/m}^3 \times \frac{44}{100}$

   $= 805.20\text{kg/m}^3$

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

   $= 1830\text{kg/m}^3 – 805.20\text{kg/m}^3$

   $= 1024.80\text{kg/m}^3$

STEP 11: ***DEDUCE MIX PROPORTION BY WEIGTH***

Cement Content = 360kg/m^3

Fine Aggregate Content = 805.20kg/m^3

Coarse Aggregate Content = 1024.80kg/m^3

Water Content = 210kg/m^3

Mix Proportion $=\frac{360}{360}:\frac{805.20}{360}:\frac{1024.80}{360}$ and $\frac{210}{360}$

$= 1: 2\frac{2}{25} : 2\frac{17}{20}$ and W/C = 0.60.

STEP 12:*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)*

STEP 13: ***Quantity of materials in kg per the required volume of concrete***

Compute the total volume of concrete required.

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

Add 10% waste, total volume = 0.0001+0.001 = 0.0011m^3

Number of cubes required = 808

Volume of 808 cubes = $0.0011m^3 \times 808 = 0.8888m^3$

Quantity of Material = Total volume of concrete (waste inclusive) x Quantity of material per m^3

Quantity of cement = 0.8888m^3x 360kg/m^3= 319.97kg

Quantity of F.A = $0.8888m^3$ x 805.20kg/m^3= 715.66kg

Quantity of C.A = $0.8888m^3$ x 1024.80kg/m^3= 910.84kg

Quantity of water = 0.8888m^3 x 210kg/m^3= 186.65kg

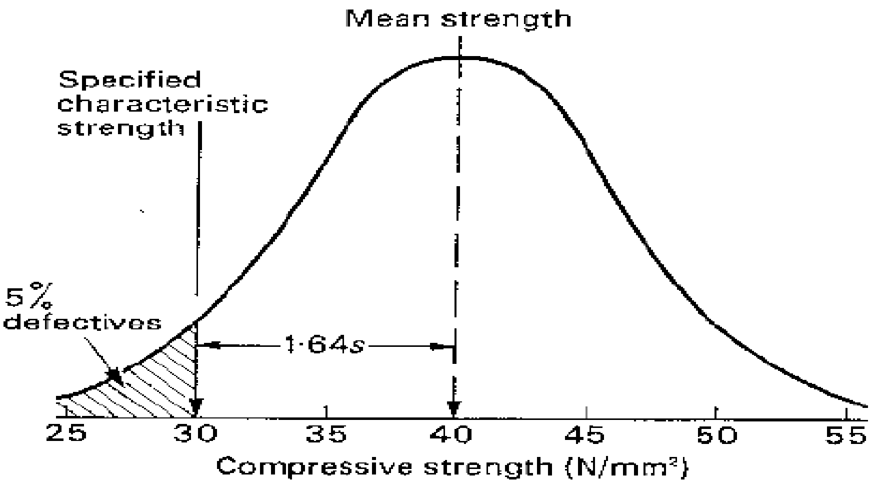


Figure 2.2: Normal Distribution of Concrete Strength

Source: Building Research Establishment (1997)

Table 2.1: 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)

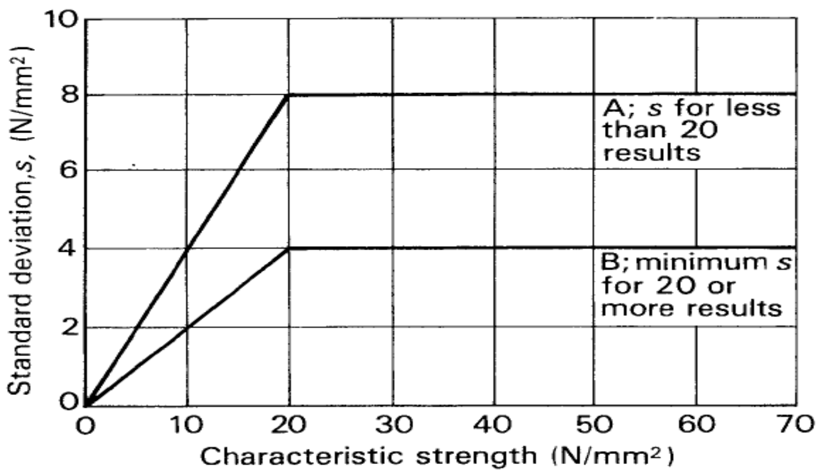


Figure 2.3: Characteristic Strength Versus Standard Deviation Relationship

Source: Building Research Establishment (1997)

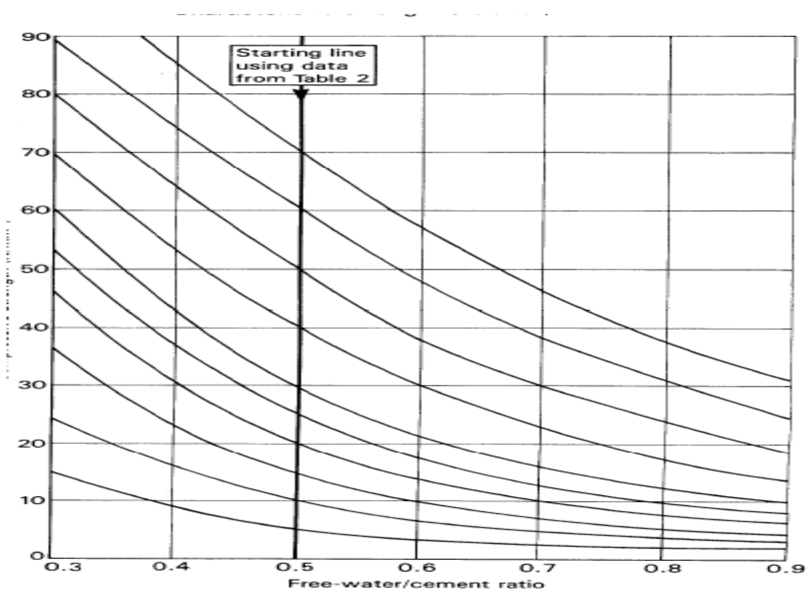


Figure 2.4: Relationship between Compressive Strength and Water/Cement Ratios

Source: Building Research Establishment (1997)

Table 2.2: 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 2.3: 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)

Table 2.4: 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)

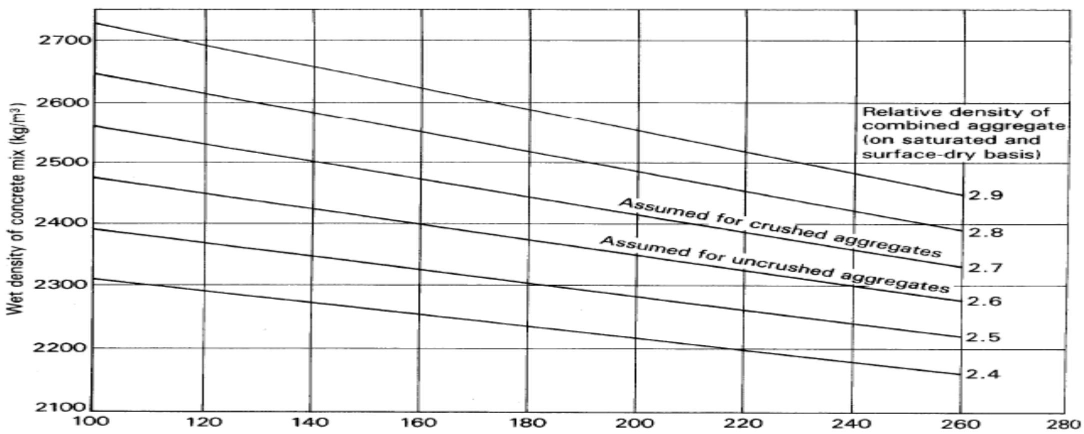


Figure 2.5: Relationship between free-water content and wet density of concrete

Source: Building Research Establishment (1997)

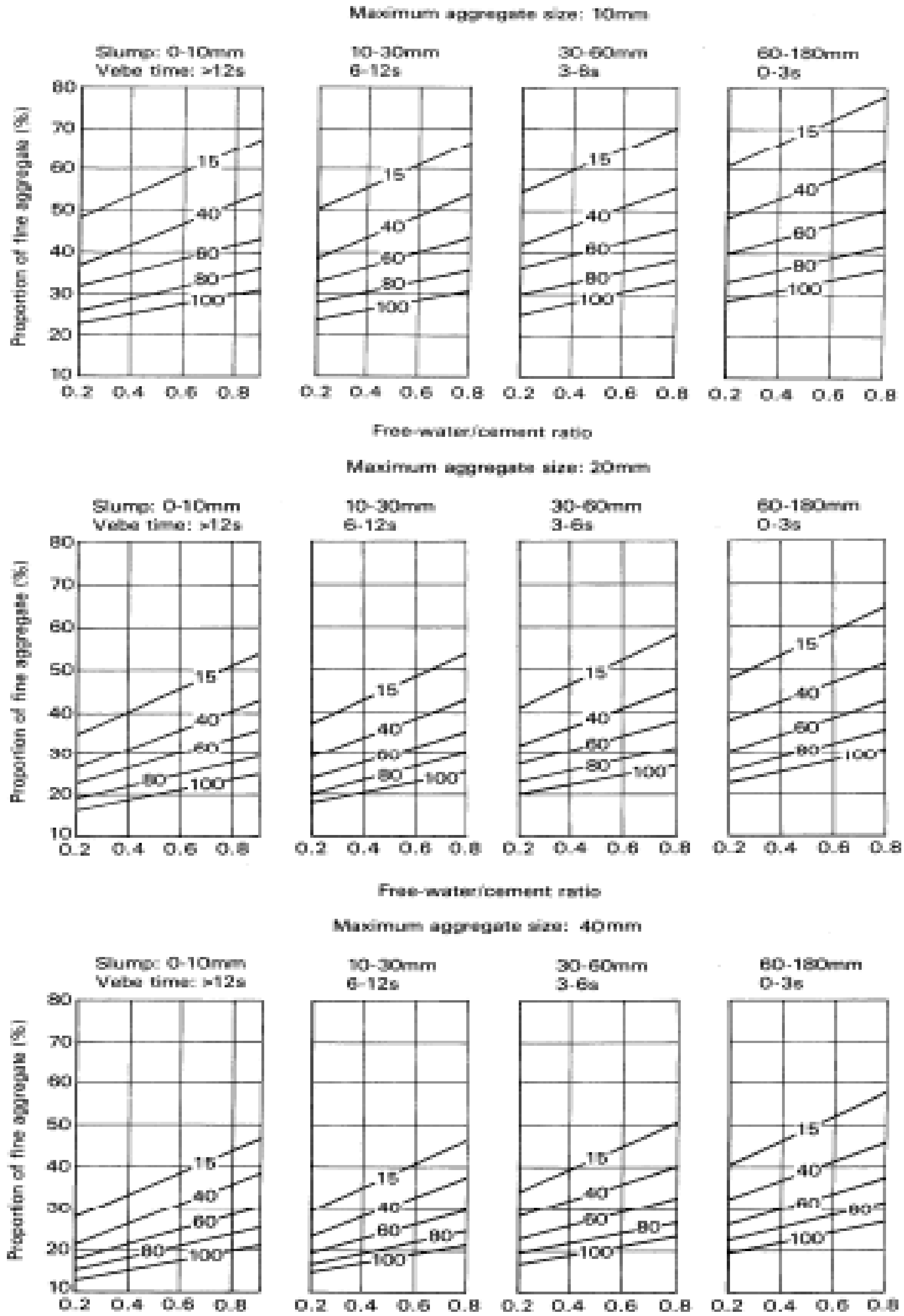


Figure 2.6: Recommended Percentages of fine aggregate in total aggregate as a function of free-water/cement ratio for values of workability and maximum size of aggregate

Source: Building Research Establishment (1997)

APPENDIX A3: Quantity of Materials per Dosage of SP for Grade C30 Concrete

Super plasticizer (SP)	Dosages (%)	Mix Proportion	Amount of Water (kg)	Amount of Cement (kg)	W/C	Amount of SP in kg (Cement x %)	Amount of FA (kg)	Amount of CA (kg)
	0.00	1:2.24:2.85	2.77	4.75	0.60	0.00	10.63	13.53
	0.20	1:2.24:2.85	2.77	4.75	0.60	0.01	10.63	13.53
	0.40	1:2.24:2.85	2.77	4.75	0.60	0.02	10.63	13.53
Rheobuild 600	0.60	1:2.24:2.85	2.77	4.75	0.60	0.03	10.63	13.53
	0.80	1:2.24:2.85	2.77	4.75	0.60	0.04	10.63	13.53
	1.00	1:2.24:2.85	2.77	4.75	0.60	0.05	10.63	13.53
	1.20	1:2.24:2.85	2.77	4.75	0.60	0.06	10.63	13.53
	1.50	1:2.24:2.85	2.77	4.75	0.60	0.07	10.63	13.53

APPENDIX A4: CALCULATION OF PERCENTAGE CEMENT SAVING USING SP

Assuming that F_C = $f_{cm=}\, f_{cm28=}\, f_{cm28sp}$ $----------------------(1)$

According to Kapelko, 2006

- For concrete mixture M (without SP)

$$f_{cm28} = A\left(\frac{\mathrm{C1}}{\mathrm{W1}} - 0.5\right) ----------------------------(2)$$

- For concrete mixture M_{SP} (with SP)

$$f_{cm28SP}=A\left(\frac{\mathrm{C1-\Delta C1sp+Ssp}}{\mathrm{W1-\Delta W1sp}} - 0.5\right)$$

$$=A\left(\frac{\mathrm{C1sp+Ssp}}{\mathrm{W1sp}} - 0.5\right) -----------------------(3)$$

The difference between cement contents (ΔC1sp) in both concretes can be calculated by comparing formulae (1) and (2)

$$\Delta\mathrm{C1sp}=\frac{\mathrm{C1}}{\mathrm{W1}} \text{ x } \Delta\mathrm{W1sp} + \mathrm{Ssp} ----------------------(4)$$

The quantity of cement used in the mixture with SP will equal to

$$\mathrm{C1sp = C1- \Delta C1sp} ---------------------------(5)$$

Also, the percentage Cement Reduction (Saving) will equal to

$$\text{\% Cement Saving} = \frac{\Delta\mathrm{C1sp}}{\mathrm{C1}} \text{ x } 100 ----------------------(6)$$

Where:

SP = Super plasticizer

f_{cm28} – the mean compressive strength after 28 days ofhardening of concrete formed from mixture withoutadmixture (control mixture), N/mm^2

f_{cm28SP} – the mean compressive strength after 28 daysof hardening of concrete formed from mixture with SP, N/mm^2

*C*1 – the quantity of cement in the mixture without SP (control mixture), kg,

*W*1 – the quantity of water in the mixture without SP (control mixture), kg,

$\Delta C1_{SP}$– the reduction of the cement quantity in themixture with SP

$\Delta W1_{SP}$– the reduction of the water quantity in themixture with SP

$C1_{SP}$– the quantity of cement in the mixture with SP, kg,

$W1_{SP}$– the quantity of water in the mixture with SP, kg

S_{SP}– the quantity of SP, kg.

From Table 4.8, the quantity cement saved is calculated thus:

FOR 0.2% DOSAGE OF SP

W/C ratio used = 12% reduction from the quantity obtained from the design

= (0.6 – 12% of 0.6)

= 0.53

Quantity of cement for control specimen (C1) = 4.75kg (From the design)

Quantity of water for control specimen (W1) = 2.77kg (From the design)

The reduction of the water quantity ($\Delta W1_{SP}$) = 12% of 2.77kg

= 0.33kg

Quantity of SP used (S*sp*) = $\frac{0.2}{100}$ x 4.77

= 0.01kg

The reduction in the quantity of cement ($\Delta C1_{SP}$) $=\frac{C1}{W1}$ x $\Delta W1sp + Ssp$

$= \frac{4.75}{2.77}$ x $0.33 + 0.01$

= 0.58kg

Quantity of cement used (C1sp) = C1- $\Delta C1sp$

= 4.75kg – 0.58

= 4.17kg

Quantity of water used (W1sp) = W/C x C1sp

= 0.53 x 4.17kg

= 2.21kg

Therefore, % Cement Saving = $\frac{\Delta C1sp}{C1}$ x 100

$\frac{0.58}{4.75}$ x 100

= 12.21%

Ditto to the remaining dosages of SP.

APPENDIX A5: Quantity of Materials for Determination of Cement-Saving

Dosage of SP (%)	Amount of SP (kg)	W/C Ratio	Amount of Cement (kg)	Amount of Water (kg)	Amount of FA (kg)	Amount of CA (kg)	Cement Reduction kg (ΔC)	Water Reduction kg (ΔW)
0.00	-	0.60	4.75	2.77	10.63	13.53	-	-
0.20	0.01	0.53	4.17	2.21	10.63	13.53	0.58	0.33
0.40	0.02	0.51	4.02	2.05	10.63	13.53	0.73	0.42
0.60	0.03	0.49	3.87	1.90	10.63	13.53	0.88	0.50
0.80	0.04	0.47	3.72	1.76	10.63	13.53	1.04	0.58
1.00	0.05	0.46	3.56	1.63	10.63	13.53	1.19	0.67
1.20	0.06	0.44	3.41	1.50	10.63	13.53	1.34	0.75
1.50	0.07	0.42	3.26	1.38	10.63	13.53	1.49	0.83

Source: Laboratory Research Work (2016)

APPENDIX A6: Compressive Strength Values of Concretes Cured in Water

Cement Brand	SP (%)	Average Compressive Strength (N/mm^2)			
		Curing Periods (Days)			
		3	**7**	**28**	**56**
A	0.0	8.83	13.70	27.66	29.98
A	1.0	18.33	18.25	38.81	37.15
B	0.0	9.93	11.80	23.64	26.85
B	1.0	13.50	19.82	32.54	34.59
C	0.0	5.56	10.97	20.05	21.53
C	1.0	9.95	17.21	30.40	30.21
D	0.0	7.00	11.90	26.67	27.71
D	1.0	15.83	18.50	40.56	40.50
E	0.0	11.83	14.33	27.08	30.13
E	1.0	14.50	23.23	44.77	45.29

Source: Laboratory Research Work (2016).

APPENDIX A7: Compressive Strength Values of Concrete Exposed to $MgSO_4$ Solution.

Cement Brand	SP (%)	Average Compressive Strength (N/mm^2)			
		Curing Periods (Days)			
		3	**7**	**28**	**56**
A	0.0	8.25	13.85	23.74	25.81
A	1.0	15.57	19.00	36.85	34.74
B	0.0	11.10	13.95	21.47	27.40
B	1.0	12.50	23.13	26.68	----
C	0.0	4.74	6.67	22.54	20.77
C	1.0	12.45	16.53	29.02	29.87
D	0.0	7.75	16.20	24.33	28.99
D	1.0	17.75	20.00	40.26	33.05
E	0.0	7.25	7.50	24.92	24.12
E	1.0	11.30	24.73	40.35	32.94

Source: Laboratory Research Work (2016)

APPENDIX A8: Tensile Strength Values of Concretes Cured in Water

Cement Brand	SP (%)	Average Tensile Strength (N/mm^2)			
		Curing Periods (Days)			
		3	**7**	**28**	**56**
A	0.0	0.67	1.25	2.04	2.33
A	1.0	1.56	2.08	2.85	3.16
B	0.0	1.07	1.43	1.83	2.51
B	1.0	1.49	2.39	2.50	2.80
C	0.0	0.54	0.91	1.58	2.03
C	1.0	1.09	3.11	2.81	3.11
D	0.0	0.78	1.82	2.12	3.01
D	1.0	1.95	2.08	2.36	3.74
E	0.0	1.43	1.82	2.41	2.53
E	1.0	2.04	2.56	3.40	3.76

Source: Laboratory Research Work (2016)

APPENDIX A9: Abrasion Resistance of Concretes Cured in Water for 28 Days

Concrete Type	SP (%)	Weight Before Brushing (g)	Weight After Brushing (g)	Difference (g)	Lost in Weight (%)
A	0.0	2224	2220	04	0.18
A	1.0	2311	2320	01	0.04
B	0.0	2296	2294	02	0.09
B	1.0	2335	2333	02	0.09
C	0.0	2340	2333	07	0.30
C	1.0	2382	2379	03	0.13
D	0.0	2264	2259	05	0.22
D	1.0	2468	2467	01	0.04
E	0.0	2237	2235	02	0.09
E	1.0	2297	2293	00	0.04

Source: Laboratory Research Work (2016)

APPENDIX A10: Abrasion Resistance of Concretes Cured in Water for 56 Days

Concrete Type	SP (%)	Weight Before Brushing (g)	Weight After Brushing (g)	Difference (g)	Lost in Weight (%)
A	0.0	2485	2484	01	0.04
A	1.0	2344	2343	01	0.04
B	0.0	2257	2254	03	0.13
B	1.0	2358	2356	02	0.09
C	0.0	2362	2358	04	0.17
C	1.0	---	----	---	---
D	0.0	2509	2506	03	0.12
D	1.0	2433	2434	01	0.04
E	0.0	2310	2309	01	0.04
E	1.0	2331	2330	01	0.00

Laboratory Research Work (2016)

APPENDIX A11: Abrasion Resistance of Concretes Exposed to $MgSO_4$ for 28 Days

Concrete Type	SP (%)	Weight Before Brushing (g)	Weight After Brushing (g)	Difference (g)	Lost in Weight (%)
A	0.0	2239	2236	03	0.13
A	1.0	2436	2435	01	0.04
B	0.0	2380	2376	04	0.17
B	1.0	2311	2310	01	0.04
C	0.0	2555	2552	03	0.12
C	1.0	2400	2398	02	0.08
D	0.0	2442	2438	04	0.16
D	1.0	2355	2354	01	0.04
E	0.0	2288	2286	02	0.09
E	1.0	2330	2328	02	0.09

Source: Laboratory Research Work (2016)

APPENDIX A12: Abrasion Resistance of Concretes Exposed to $MgSO_4$ for 56 Days

Concrete Type	SP (%)	Weight Before Brushing (g)	Weight After Brushing (g)	Difference (g)	Lost in Weight (%)
A	0.0	2127	2119	08	0.38
A	1.0	2213	2210	03	0.14
B	0.0	2373	2369	04	0.19
B	1.0	2390	2385	05	0.21
C	0.0	2631	2627	04	0.15
C	1.0	---	---	--	---
D	0.0	2435	2428	07	0.29
D	1.0	2342	2338	04	0.17
E	0.0	2356	2349	07	0.30
E	1.0	2200	2198	02	0.09

Source: Laboratory Research Work (2016)

APPENDIX A13: Water Absorption Test of Concrete Specimens Cured in Water for 28 Days

Concrete Type	SP (%)	Oven Dry Weight (Kg)	SSD (Kg)	Absorption Capacity (%)
A	0.0	2.34	2.50	6.80
A	1.0	2.24	2.30	3.13
B	0.0	2.20	2.30	4.55
B	1.0	2.16	2.22	2.78
C	0.0	2.42	2.54	5.00
C	1.0	2.32	2.38	2.59
D	0.0	2.54	2.66	4.72
D	1.0	2.48	2.56	3.23
E	0.0	2.10	2.22	5.71
E	1.0	2.20	2.28	3.64

Source: Laboratory Research Work (2016)

APPENDIX A14: Water Absorption Test of Concrete Specimens Cured in Water for 56 Days

Concrete Type	SP (%)	Oven Dry Weight (Kg)	SSD (Kg)	Absorption Capacity (%)
A	0.0	2.30	2.40	4.35
A	1.0	2.42	2.50	3.31
B	0.0	2.16	2.26	4.63
B	1.0	2.34	2.38	1.71
C	0.0	2.02	2.16	6.93
C	1.0	2.52	2.58	2.38
D	0.0	2.54	2.62	3.15
D	1.0	2.56	2.60	1.56
E	0.0	2.20	2.32	5.46
E	1.0	2.40	2.48	3.33

Source: Laboratory Research Work (2016)

APPENDIX A15: Water Absorption Test of Concrete Specimens Exposed to $MgSO_4$ for 28 Days

Concrete Type	SP (%)	Oven Dry Weight (Kg)	SSD (Kg)	Absorption Capacity (%)
A	0.0	2.08	2.20	5.76
A	1.0	2.24	2.30	2.68
B	0.0	2.32	2.40	3.45
B	1.0	2.36	2.42	2.54
C	0.0	2.22	2.30	3.60
C	1.0	2.54	2.62	3.15
D	0.0	2.46	2.58	4.88
D	1.0	2.42	2.52	4.13
E	0.0	2.00	2.16	8.00
E	1.0	2.26	2.34	3.54

Source: Laboratory Research Work (2016)

APPENDIX A16: Water Absorption Test of Concrete Specimens Exposed to $MgSO_4$ for 56 Days

Concrete Type	SP (%)	Oven Dry Weight (Kg)	SSD (Kg)	Absorption Capacity (%)
A	0.0	2.30	2.38	3.48
A	1.0	2.18	2.22	1.84
B	0.0	2.28	2.36	3.51
B	1.0	----	----	-----
C	0.0	2.52	2.58	2.38
C	1.0	---	----	----
D	0.0	2.34	2.42	3.42
D	1.0	2.22	2.36	6.31
E	0.0	2.24	2.44	8.93
E	1.0	2.30	2.38	3.37

Source: Laboratory Research Work (2016)