DURABILITY CHARACTERISTICS OF PORTLAND CEMENT/VOLCANIC ASH CONCRETE EXPOSED TO CHEMICALLY AGGRESSIVE ENVIRONMENTS

BY

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SEPTEMBER, 2015

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(M.Sc/ENV-DESIGN/41693/2012-2013)

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER DEGREE IN CONSTRUCTION TECHNOLOGY.

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DECLARATION

I declare that the work in this thesis entitled "DURABILITY CHARACTERISTICS OF PORTLAND CEMENT/VOLCANIC ASH CONCRETE EXPOSED TO CHEMICALLY AGGRESSIVE ENVIRONMENTS" has been carried out by me in the Department of Building, under the supervision of Dr. D. D. Danwata and Mal. M. Mamman. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

Mudasiru Ibrahim
(M.Sc/ENV-DESIGN/41693/2012-2013) ______________ ________________

Signature Date

CERTIFICATION

This thesis entitle "DURABILITY CHARACTERISTICS OF PORTLAND CEMENT/VOLCANIC ASH CONCRETE EXPOSED TO CHEMICALLY AGGRESSIVE ENVIRONMENTS" by Mudasiru Ibrahim meets the regulations governing the award of the degree of Master of Science in Construction Technology of the Ahmadu Bello University, and is approved for its contribution to Knowledge and literary presentation.

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DEDICATION

I dedicate this thesis to my late beloved father Alhaji Ibrahim Isma,il Na,akiyya Isa, late brother Alhaji Kabiru A. Ibrahim Isa and late sister Malama Yuhanazu Umar Filin bugu Katsina. May their gentle souls continue to rest in perfect peace amen.

ACKNOWLEDGEMENT

All praise be to the almighty ALLAH (SWT) the most gracious, the most merciful, the One and the only One that spare our lives up to this moment and gives us courage and ability to carried out this thesis from inception to successful completion. With absolute reverence, I wish to express my infinite gratefulness to my parents and relatives for their kindness, advices, and prayers upon me from the time I start this programme till date.

My mammoth appreciation goes to my supervisors; Dr. Dauda Dahiru Danwata and Mal. M. Mamman that are always there for me throughout the time I carried out this thesis research work. I wish to sincerely show my profound gratitude to our Head of Department Dr. Dikko Kado and also to Prof. Kabir Bala, Prof. M. M. Garba, Prof. I. K. Zubairu, Prof. O. G. Okoli, Prof. I. Mbamali, Dr. I. Mshelgaru, Dr. D. W. Dadu, Dr. Engr. A. D. Abdul Azeez, Dr. Stanley Mhya, Dr. D. Abdul Salam, Mal. I. M. Khalil, Mal. A. M. Makarfi, Mal. I. M. Mustapha, Mal. Mansir Dodo, Mal. M. Z. Muhammad, Mal. M. Buhari, Mal. A. Mua,wiyyah, for the knowledge, advices and support they gave to us, May the almighty ALLAH (SWT) continue to bless you and your families immensely amen. I am also indebted to my special friend Muhammad Najib Adam (Jiga) for his assistance, Building Department concrete laboratory technicians, Mal. Abdul azeez, Mal. Sa, idu, Mal. Alh. Audi and all others that are not mention for your help during my experiments. Also to Chemical Engineering lab technician Alhaji Jibrin and my entire M. Sc (2012–2013) class mates thank you so much for your friendliness and tolerance.

ABSTRACT

Current trend in concrete research is towards finding materials that can partially or fully replace cement. However, too much emphasis is given to compressive strength as the quality index; with little or no consideration given to durability property. The concrete can be strong but not durable especially when it is subjected to chemical aggressive environments. This research therefore assessed the durability characteristics of Portland/cement volcanic ash concrete exposed to chemically aggressive environments. Preliminary tests of the different properties of materials used for this research were carried out. The concrete samples were prepared using 5% and 10% volcanic ash replacements and nominal mix of 1:2:4 with a 0.5 w/c ratio. Cube mould of size 100mm x 100mm x100mm and cylinder mould of size 200mm x 100mm were used to cast a total of 405 concrete samples. Out of the 405 samples, 162 cubes were used to assess compressive strength test while 162 cylinders were used to determine the tensile strength by the split tensile method. The specimens were cured in H_2O, $MgSO_4$ and H_2SO_4 and tested at 7, 14, 21, 28, 56 and 90 days. Another set of 81 concrete cube samples were also produced and cured in the same curing media for test on abrasion resistance and water absorption test at 28, 56 and 90 days of age. The results show increase in compressive strength of about 8.68% for concrete samples with 10% volcanic ash replacements than 0% replacements cured in normal environment (H_2O) at 28 days. A decrease in compressive strength of about 15.02% was observed for concrete samples with 0% volcanic ash replacements than 10% replacements cured in $MgSO_4$ at 28 days. Also concrete samples with 0% volcanic ash replacements cured in H_2SO_4 withstood the medium better than the samples with 10% volcanic ash replacements as indicated by 12.78% increase in compressive strength at 28 days. Concrete samples made with 10% volcanic ash replacements have high resistance to abrasion and less sorptivity than 0% volcanic ash replacements in both normal and chemically aggressive environments at 90 days. In conclusion Miango JP 3 is a pozzolanic material having satisfied the requirement of ASTM C618-05. Therefore it was recommended to be used to produce a strong, dense and durable concrete which can be used both in normal and chemically aggressive environments.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Concrete was first used as a structural material during the nineteenth century when Portland cement was discovered in Portland England (Yasin *et al.,* 2012). According to Lappiatt and Ahmad (2004) in Shoubi *et al.,* (2013) it was estimated that the concrete industries throughout the world produces annually about 12 billion tons of concrete and uses about 1.6 billion tons of Portland cement. Thus on average, approximately 1 ton of concrete is produced each year for every human being in the world. Harley (2007) noted that the amount of concrete used in construction industries around the world is more than double that of the total of all other building materials, including wood, steel, plastic and aluminium. For this reason, concrete is the most widely used construction material and it is the second only to water as the most utilized substance all over the world. It has become most widely used due to the availability of its constituents, flexibility, strength, durability, impermeability etc. As a composite material it is commonly used in the construction of buildings and infrastructures. Merrit and Ricketts (2001) defined concrete as a mixture of Portland cement or any other hydraulic cement, fine aggregate, coarse aggregate and water, with or without admixtures.

According to Mohammad (2010) cement is one of the essential ingredients of concrete that both contributes to the construction industries and environmental problem. However, the production of cement emits carbon dioxide to the surroundings which result to environmental pollutions. It is expensive to buy when compared to other concrete materials such as gravel, sand, water etc. The problems of pollution and cost have led to researches on cement alternatives or substitutes that will fully or partially replace cement in the construction industry (Ogunbode and Hassan, 2011). Dadu (2011) reported that the global move currently is to reduce the amount of Portland cement contents used in the concrete mixtures with cheaper Supplementary Cementitious Material (SCM)/pozzolans to improve certain durability properties of concrete.

The American Society for Testing and Material (ASTM C125-06) defined pozzolan as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Shetty (2009) classified pozzolans as either natural or artificial pozzolan. Natural pozzolans include; clay and shales, opalinc cherts, diatomaceous earth, volcanic ash, volcanic tuffs and pumicites, Artificial pozzolans include; fly ash, blast furnance slag, silica fume, rice husk ash, metakaoline and surkhi. Volcanic ash, being one of the classifications of natural pozzolans, is environmentally friendly, economical and accessible than artificial pozzolan. According to Ogunbode and Hassan (2011), volcanic ash are formed as a result of volcanic eruption which can be found in volcanic areas around the world e.g. Japan, USA, Iranian plateau, Adamawa Highlands extending to Cameroonian Highlands, some Local Government Areas in Jos, Plateau State, Mkomon District of Kwande Local Government Area of Benue State etc. Dadu (2011) and Olawuyi *et al*., (2012) carried out researches on natural pozzolan (Jos Plateau volcanic ash) to replace Ordinary Portland Cement (OPC) in concrete, their results showed that the material can be used to partially replace OPC. This can lead to reactions between major constituents of OPC and that of the volcanic ash known as pozzolanic reaction. Pozzolanic reactions are silica reactions that take place in the presence of calcium hydroxide and water to produce calcium silicate hydrates(C-S-H). This C-S-H creates a denser microstructure that increases strength, reduces the permeability of concrete and improves its resistance to chemical attack (Osei and Jackson, 2012). According to Joergensen (2014) use of pozzolan to replace OPC in concrete lower heat development during hardening and improve durability of the final concrete structures. Concrete can be proportionally made strong but not durable. Currently concrete structures are being built in highly polluted urban and industrial areas, aggressive marine environments, harmful sub soil, water in coastal areas and many other hostile conditions where other materials of construction are found to be non durable (Shetty, 2009). Nagesh (2012) considered long service life as synonymous with durability and further stated that durability of concrete is the ability to perform satisfactorily in the exposure condition to which it's subjected over an intended period of time with minimum of maintenance.

Shetty (2009) stated that in the past, concrete researchers and designers paid too much attention on compressive strength neglecting other properties of concrete like durability. However it has now been recognized that compressive strength of concrete alone is not sufficient to judge the quality of concrete, the degree of aggressiveness of the environment to which the concrete is subjected to, is equally important to look upon. Therefore, both strength and durability have to be considered thoroughly at both the research and design stage (Shetty, 2009). This research work therefore assesses the durability properties of Portland cement/volcanic ash concrete subjected to chemically aggressive environments.

1.2 Statement of Research Problem

Cement as an important constituent of concrete is becoming gradually expensive compared to other ingredients of concrete. The mining of its raw materials leads to depletion of natural resources and degradation of environment. Its production pollutes the environment due to the emission of CO_2. The emission of CO_2 is such that for every ton of cement produced almost a ton of CO_2 is emitted Shoubi *et al.*, (2013); (Dahiru, 2010). In view of this and other problems associated with production and use of cement, a lot of research efforts were made to find an alternative material that will partially or fully replace cement in concrete production. As part of such efforts Dadu (2011); Olawuyi *et al*., (2012) carried out a research on Jos Plateau volcanic ash were the results showed that the volcanic ash possessed pozzolanic characteristics of natural pozzolans and recommend that it can be use to partially replaced cement in concrete. However durability properties such as exposing such volcanic ash concrete to aggressive or hostile environment like sulphate attack, acid attack, fire resistance etc. were not assessed. In addition, Shetty (2009) stated that earlier concrete was deemed to be very durable material which demands less or no maintenance but at later age it was discovered that when exposed to aggressive environment where there is presence of chemicals, failures would occur and this can cost huge amount of money to renovate the affected concrete structure. Therefore, the impression that concrete is a very durable material is being threatened and hence the durability properties need to be considered. Therefore this research was undertaken to assess the durability characteristics of Portland/cement volcanic ash concrete subjected to chemically aggressive environments.

1.3 Justification of the Study

The results of this research could provide information that may encourage the use of Jos Plateau volcanic deposits as a partial replacement of OPC in concrete in the chemically aggressive environments. This may lead to the reduction of the use of cement in concrete, pollution and depletion of natural resources. International Energy Agency in Sunku (2006) stated that the use of volcanic ash as supplementary cementitious material to replace OPC in concrete production reduces Green House Gas (GHG) emissions such as carbon dioxide which alone accounts for 7% of total global CO_2 emissions from cement industries. According to Cement Concrete and Aggregate Australia (CCAA, 2011) exposing concrete to chemically aggressive environments caused chemical reaction with the cement matrix (ettringite formation) which eventually caused expansion, cracking and loss of strength of concrete structures. Accordingly, this result to repair, replacement or deconstruction of the affected concrete structures which amount to about 40% of the total resources allocated to construction industry (Gambo, 2014).

1.4 Aim and Objectives

1.4.1 Aim

The aim of this research is to assess the durability characteristics of Portland cement/volcanic ash concrete with a view to determining the feasibility of its usage in chemically aggressive environments.

1.4.2 Objectives

The aforementioned aim was pursued through the following objectives:

1. To determine the properties of individual constituents of Portland cement volcanic ash concrete.

2. To assess the properties of Portland cement/volcanic ash concrete at fresh stage.
3. To determine the mechanical properties of Portland cement/volcanic ash concrete exposed to chemically aggressive environments.
4. To evaluate the durability properties of Portland cement/volcanic ash concrete.
5. To determine the suitability of using volcanic ash in the chemically aggressive environments.

1.5 Scope and Limitations

1.5.1 Scope

Although durability has many parameters, this study has confined itself to, only the following durability properties; assessment of the behaviour of Portland cement/volcanic ash concrete under chemically aggressive environments, abrasion resistance and water absorption. Besides, the mechanical properties such as compressive strength and split tensile strength were assessed. Workability and density properties were also evaluated.

1.5.2 Limitations

Non availability of some equipment served as constraints to the evaluation of durability properties such as shrinkage, creep, fire resistance, carbonation and alkali aggregate reaction. Hence they were not assessed. In addition, due to the non availability of mechanical vibrator manual method was employed to compact the concrete samples.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concrete as Construction Material

2.1.1 General

The word “concrete” as opined by Li (2011) is derived from the Latin, concretus, meaning “to grow together.” The ASTM C125-06 defines concrete as a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate; in hydraulic-cement concrete, the binder is formed from a mixture of hydraulic cement and water. It is a relatively new construction material when compared to stone, timber, steel etc. and the most widely used building and civil engineering construction material (Garba, 2008). This has made it to be the fundamental building material use to fulfill the housing and infrastructure needs for the public.

Reed (2008) stated that concrete as a manufactured material has various properties that are determined not only by the component materials, but also by the manufacturing process of the cement, the design of the structure to be build and the construction procedures followed on site. As a versatile material, concrete can be cast in any desired shape and hence can be applied for most building purposes. As a composite material concrete does not rot, rust or decay and is resistant to wind, water, rodents and insects. It is a non-combustible material, making it fire resistant and able to withstand high temperatures, so it is strength, durability and low maintenance features add to its versatility and popularity.

2.1.2 Classification of concrete

Concrete as a construction material can be made based on the binding materials that are available or manufactured within an area (e.g. pozzolanic, cement etc.) or based on contractors specifications. Contractor can specify the concrete required either by its perspective, performance, density or method of casting. Hence Duggal (2008) classified concrete as follows:

1. Based on Cementing Material: This class of concrete depend on cementing material that would be use to bind the aggregates together and it is classified as lime concrete, gypsum concrete and cement concrete.

2. Based on Perspective Specification: The cement concrete is specified by proportions of various constituents, e.g., 1 (cement) : 1.5 (fine aggregate) : 3 (coarse aggregate). It is believed that by obeying such perspective specifications satisfactory performance may be achieved. The usual mix proportions of cement concrete are given in table 2.1.

Table 2.1 Mix Proportion of Cement Concrete

Grade of concrete	M10	M15	M20	M25
Mix proportion	1:3:6	1:2:4	1:1$^1/_2$:3	1:1:2
Perspective characteristic strength	10	15	20	25

Source: Duggal (2008)

Where M refers to the mix and this type of concrete mix is also known as nominal mix.

3. Based on Performance Oriented Specifications: For a concrete that is specified based on performance, the required concrete properties such as strength, water-cement ratio, compaction factor, slump, etc., are specified by the contractor. For a design mix concrete the mix is designed to produce the grade of concrete having the required workability and a characteristic strength not less than the appropriate values as specified in the table 2.2.

4. Based on Grade of Cement Concrete: This class of concrete is specified depending upon the strength (N/mm^2) of the concrete cubes (150 mm) at 28 days required. The

strength specification can be low strength concrete (< 20 N/mm^2), medium strength concrete (20–40 N/mm^2) and high strength concrete (>40 N/mm^2).

This can also be shown in the table 2.2.

Table 2.2 Grades of Cement Concrete

Grade	M5	M7.5	M10	M20	M25	M30	M35	M40	M45	M50	M55
Characteristic Strength	5	7.5	10	15	20	25	30	40	45	50	55

Source: Duggal (2008)

5. Based on Bulk Density: Density of concrete is consider for this classification as super heavy (over 2500kg/m^3), dense (1800-2500 kg/m^3), light weight (500–1800 kg/m^3) and extra light weight concrete (below 500 kg/m^3).

6. Based on Place of Casting: This class of concrete are; in-situ concrete and precast concrete. When concrete is made and placed in position at the site it is known as in-situ concrete and when used as a material for making prefabricated units in a factory is known as precast concrete.

Cement Concrete and Aggregate Australia, CCAA, (2004) opined that concrete properties are its characteristics which entails; workability, cohesiveness, strength and durability. Concrete has various properties at fresh state; when it's wet and at hardened state when it's completely dry. The variation of these properties tends to affects its end use or functional requirements.

2.1.3 Properties of concrete

2.1.3.1 Properties of fresh concrete

Workability: workability as described by Lyon (2007) is the ability of the concrete mix to be placed within the formwork, around any reinforcement, and to be successfully compacted by hand or mechanical means to remove trapped air pockets. Workability of fresh concrete as opined by (Neville and brooks, 2010) can be defined as the amount of useful internal work (physical property of concrete and work or energy required to overcome the internal friction between the individual particles in the concrete) necessary to produce full compaction. But according to Garba (2008) fluidity of concrete is known as workability which can be defined as the ease with which a given set of materials can be mixed into concrete and subsequently handled, transported and placed with minimum loss of homogeneity. Therefore the term workability means flexibility, compatibility, mobility and stability.

Shetty (2009); Li (2011) stated that workability of fresh concrete can be affected by any of following factors:

1. Water cement ratio
2. Mix proportions
3. Size of aggregates
4. Shape of aggregates
5. Grading of aggregates
6. Use of admixtures

Duggal (2008) stated that workability of fresh concrete can be measured by; slump test method, compacting factor test, vee-bee consistometre method. Other methods that can be use to assess the workability of fresh concrete are; k-slump tester, flow test and Kelly ball test (Shetty, 2009). Neville and Brooks (2010) opined that slump test method of workability of concrete can be assess as; very low (0-25mm), low (25-50mm), medium (20-100mm) and high (100-175mm) degree of workability.

Consistency: consistency is the firmness of form of a substance or the ease with which it will flow. It is also mean the degree of wetness (Neville and brooks, 2010).

Segregation: segregation can be defined as the separation of the constituent materials of concrete and therefore their distribution is no longer consistent. A good concrete is one in which all the ingredients are properly distributed to make homogeneous mixture (Shetty, 2009). It is a state of concrete at which the constituents will be separated with one another and therefore the goal will not be achieved.

Bleeding: bleeding also known as water gain; is a form of segregation in which some of the water in the mix tends to rise to the surface of freshly placed concrete. Inability of the solid constituents of the mix to hold all of the mixing water when they settle downwards is the main factor that caused bleeding of concrete as stated by (Neville and brooks, 2010).

Setting time: setting time of concrete depends on; w/c ratio, temperature conditions, type of cement, use of mineral admixture, use of plasticizers in particular retarding plasticizer (Shetty, 2009).

2.1.3.2 Density property of concrete

Density is a very important factor as it affects many important properties of concrete including its durability. Density of concrete can be defined as mass per unit volume. According to Kazjonovs *et al.,* (2010); Pandit and Parameswari (2014) concrete with density higher than 2600 kg/m^3 is called high density concrete. The density of concrete samples can be increased by using high-weight aggregates, such as barite, hematite, iron ore and steel shot with densities is over 4000 kg/m^3. On the other hand

Mortazavi *et al.*, (2007) suggested that the density for ordinary concrete is about 2350 kg/m^3.

2.1.3.3 Strength properties of concrete

According to Khan (2009) performance of concrete subjected to its environment is judged by strength and durability properties. For this reason a strong and durable concrete can perform well in both normal and chemical environment. Concrete strength is majorly deemed to be one of the most important properties that need to be satisfied for any concrete structure Mehta and Monteiro (2006). It is the property most valued by designers and quality control engineers which can be defined as the ability to resist stress without failure which manifest by the appearance of cracks. Strength of concrete is assess in the concrete laboratory using cubes, cylinders or beams of different sizes which needs to conform to appropriate standard. Shetty (2009) stated that strength of concrete is it is resistance to rupture that may be measured in number of ways such as, strength in compression, in tension, in shear or in flexure.

Compressive strength: compressive strength of concrete as stated by Garba (2008) is a major property as it directly related to many other properties, thus is the most widely used in concrete practice. It can be determine on 150mm or 100mm cubes, 150mm diametre by 300mm or 100mm diametre by 200mm cylinders. It has been found that cylinders fail at lower compressive stress than cubes of the same quality concrete where the ratio of cube strength to cylinder strength is about 4:3. Factors that influenced compressive strength of concrete are; type, quantity and quality of cement, degree of compaction, water/cement ratio, age, curing conditions etc.

Tensile strength: tensile strength of concrete is very small as compared to it is compressive strength. It is about 1/12 to 1/13 of compressive strength responsible for reducing formation of cracks in concrete. Three different methods that can be use in finding the tensile strength of concrete; direct tensile test, flexural (bending) test on beam and indirect tensile test (split tensile test) but flexural and splitting tests are the most usual methods used as asserted by (Garba, 2008).

2.1.3.4 Durability properties of concrete

No material on itself is durable or non-durable; it is determine by the interaction of the material with its in-service environment (Olar, Anonymous). Shetty (2009) asserted that concrete in those days was deemed to be a very durable material demanding little or no maintenance. This assumption is perfect except when it is expose to chemically aggressive or harsh environment where other construction materials are found to be non durable e.g. steel, aluminium etc. As the population of the world growth the demand for construction of buildings and infrastructural facilities in harsh environments increases and so the desired service lives of the concrete structures in such environment also increases. Concrete structures are designed to perform, with minimal maintenance of 50 to 100 years Kurtis *et al.*, (Anonymous). Durability has gained worldwide concern as asserted by Maroliya (2012) because experts believe that the expenditure in rehabilitation and restore of concrete structure in near future going to be equal to the expenditure of new construction.

Durability according Sarja and Vesikari (2005) is the capability of a building, assembly, component, structure or product to maintain minimum performance over at least a specified time under the influence of degradation factors. According to American Concrete Institute (ACI, Committee 201) in Mehta and Monteiro (2006) durability of Portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. This means that a concrete that is durable will maintain it is shape, value and provide the intended service to the environment on which it is subjected to. A material is considered to reach the end of service life when its properties, under given conditions of use, have deteriorated to an extent that its continued use is ruled either unsafe or uneconomical.

Lack of durability: Neville and Brooks (2010) stated that lack of durability can be caused by either one of the following:

1. External agents arising from the environment
2. Internal agents within concrete

These causes can be also be categorized as:

1. Physical
2. Mechanical
3. Chemical

1. Physical causes include wetting and drying as a result of rainfall, expansion and contraction caused by sunlight and frost effect by freezing and thawing.

2. Mechanical causes include abrasion, erosion and cavitation.

Richardson (2004) stated that abrasion, erosion and cavitation are;

i. Abrasion: abrasion of concrete surfaces tends to occur as results of friction, which may cause wear or tear by repetitive impact and overloading of the concrete element. The sources of friction include; pedestrian or vehicular traffic, materials dragged across floors or pavements, and wind-borne particles impacting on facades.

ii. Erosion: Erosion is caused by heavy particles suspended in water flowing across concrete surfaces or by wind-borne sand particles impacting on building surfaces. The damage caused by water-borne is influenced by the velocity of flow of the water. The amount of particles being transported contributes as does the size and shape.

iii. Cavitations: Pitting of surfaces developed where local pressure changes in flowing water leads to the collapse of vapour bubbles. This phenomenon known as cavitations may occur in the same direction over a piece of concrete due to the layout of a hydraulic channel or pipe. A liquid flowing at high velocity creates a zone of sub-atmospheric pressure immediately downstream of an abrupt change in velocity or direction.

3. Chemical causes include attack by sulphates, acids, sea water, and also by chlorides, which induce electro-chemical corrosion of steel reinforcement (Neville and Brooks, 2010). Sea water contains about 2.71% sulphate (SO_4) as reported by (Zacarias, 2007). According to ACI Committee Report 201 (2001) in Turkel *et al.,* (2007) chemical attacks can be classified into; acidic attack, alkali attack, carbonation, chloride attack, leaching and sulphate attack. Ytterdal (2014) opined that external sulphates influence both the chemical and physical binding capacities, while sulphate from the cement mainly influences the type and the quantity of calcium aluminate hydrates that are produced, chemical binding capacity which in turn influence the binding capacity.

American Concrete Institute report 2R (ACI, 2001) specified the rate at which chemicals attack concrete and its effects at immediate environment. The chemicals classified into; inorganic acids, organic acids, alkaline solutions and salt solutions, this can be given in Table 2.3.

Table 2.3 Effect of commonly used chemicals on concrete

Rate of attack at ambient temperature	Inorganic acids	Organic acids	Alkaline solutions	Salt solutions	Miscellaneous
Rapid	Hydrochloric Nitric Sulphuric	Acetic Formic Lactic	_____	Aluminium chloride	_____
Moderate	Phosphoric	Tannic	Sodium hydroxide >20%	Ammonium nitrate Ammonium sulphate Sodium sulphate Magnesium sulphate Calcium sulphate	Bromine (gas) Sulphate liquor
Slow	Carbonic	___	Sodium hydroxide 10 to 20%	Ammonium chloride Magnesium chloride Sodium Cyanide	Chlorine (gas) Sea water Soft water
Negligible	___	Oxalic Tartaric	Sodium hydroxide >10% Sodium hypochlorite Ammonium hydroxide	Calcium chloride Sodium chloride Zinc nitrate Sodium chromate	Ammonia (liquid)

Source: ACI 201.2R (2001)

Concrete can be guide against or exposed to chemicals by factors that aggravate or delay the attacks as reported by ACI 201.2R (2001). This can be presented in Table 2.4.

Table 2.4 Factors influencing chemical attack on concrete

Factors that accelerate or aggravate attack	Factors that mitigate or delay attack
1. High porousity due to: i. High water absorption ii. Permeability iii. Voids	1. Dense concrete achieved by: i. Proper mixture proportioning ii. Reduced unit water content iii. Increase cementitious material content iv. Air entrainment v. Adequate consolidation vi. Effective curing
2.Cracks and separations due to: i. Stress concentration ii. Thermal shock	2. Reduced tensile stress in concrete by: i. Using tensile reinforcement of adequate size, correctly located ii. Inclusion of pozzolan (to reduce temperature rise) iii. Provision of adequate contraction joints content
3. Leaching and liquid penetration due to: i. Flowing liquid ii. Ponding iii. Hydraulic pressure	3. Structural design: i. To minimize areas of contact and turbulence ii. Provision of membranes and protective-barrier system to reduce penetration

Source: ACI 201.2R (2001)

Sulphate Attack: Neville (2004) asserted that sulphate ions are deleterious to concrete which results to physical and chemical sulphate attack. Sulphate attack is a chemical process between sulphate ions and the components of hardened concrete which results in it is degradation and deterioration (Antonio *et al.,* 2007). Corral-Higuera *et al.,* (2011) stated that concrete exposed to sulphate solutions can be attacked and suffered deterioration by expansion which can cause an increase in the internal tension and finally cause micro cracking. Calcium hydroxide and alumina-bearing phases of hydrated Portland cement are more vulnerable to attack by sulphate ions (Monteiro, Anonymous). Sulphate attack on concrete as found by Antonio *et al.,* (2007) occurs either from the external sources or from the internal sources. External sources are from the sea water, soil, atmospheric pollution and ground water while the internal sources are from the cement, admixtures, mixing water and aggregate (e.g. pyrite). Other sources as stated by CCAA (2002) include mining industry, industrial effluents and waste where chemicals, batteries, aluminium are manufactured. Shetty (2009) stated that most soils contain some sulphate either in the form of calcium, sodium, potassium or magnesium. Attack on concrete by sulphate caused cracking, spalling, increase permeability and strength loss. Resistance of concrete by this attack is paramount for a concrete structure to satisfy it is required performance. When sulphate attack concrete a characteristic whitish appearance, damage will emanate starting at the edges and corners followed by cracking and spalling of the concrete. The whitish appearance will lead to formation of calcium sulphate (gypsum) and calcium sulphoaluminate (ettringite), both products occupy greater volume than the compounds which they replace so that expansion and disruption of hardened concrete can take place (Neville and Brooks, 2010). In addition, CCAA (2002) asserted that two chemical reactions develop when sulphate attack concrete were; reaction of the sulphate with calcium hydroxide liberated during the hydration of the cement, forming calcium sulphate (gypsum), and reaction of the calcium sulphate with the hydrated calcium aluminate, forming calcium sulphoaluminate (ettringite). Both of these reactions caused an increase in the volume of solids which results to expansion and disruption of concretes exposed to sulphate solutions.

Magnesium sulphate attack: sulphates are many and varied, for this reason CCAA (2002) stated that magnesium and ammonium sulphates are the most damaging type of sulphate to concrete. Lee *et al.*, (Anonymous) opined that magnesium sulphate is recognized to be a corrosive agent in sulphate attacks, and magnesium ions can be found in large quantity in groundwater. Magnesium sulphate when attack cement paste substituted Mg^{2+} ions for Ca^{2+} ions in portlandite as well as the process of the disintegration of C-S-H gel to M-S-H gel, which is non cementitious material.

$$MgSO_4 + Ca(OH)_2 + 2H_2O \longrightarrow CaSO_4 \,.\, 2H_2O + Mg(OH)_2 \quad - \quad - \quad - \quad (2.1)$$

$$3MgSO_4 + 3CaO.2SiO_2.3H_2O + 8H_2O \longrightarrow 3CaSO_4.2H_2O + 3Mg(OH)_2 + 2SiO_2.H_2O \ -(2.2)$$

Equations 2.1 and 2.2 show the reactions between major compound of cement and water in a chemical environment with magnesium sulphate which formed minor compound of cement and water.

The conversion of calcium hydroxide to gypsum is accompanied by the simultaneous formation of relatively insoluble magnesium hydroxide. In the absence of hydroxyl ions in the solution C-S-H is no longer stable and is also attacked by the sulphate solution. The magnesium sulphate attack is therefore more severe on concrete. Factors influencing sulphate attack include; amount and nature of the sulphate present, level of the water table and its seasonal variation, flow of groundwater and soil porosity, form of construction, quality of concrete. The velocity of sulphate attack increases with increase in strength of solution, saturated solution of magnesium sulphate with higher water cement ratio can cause severe damage to concrete within short period of time (Shetty, 2009).

According to ACI Building Code 318 recommendation, the scale that can be use to judge the level of concentration or solutions of sulphate attack on concrete can be classified into:

1. Negligible attack: when the sulphate content is under 0.1 percent in soil, or under 150 part per million (ppm) (mg/litre) in water, there shall be no restriction on the cement type and water/cement ratio.

2. Moderate attack: when the sulphate content is 0.1 to 0.2 percent in soil, or 150 to 1500 ppm in water, ASTM Type II Portland cement or Portland pozzolan or Portland slag cement shall be used, with less than 0.5 water/cement ratio for normal-weight concrete.

3. Severe attack: when the sulphate content is 0.2 to 2.0 percent in soil, or 1500 to 10,000 ppm in water, ASTM Type V Portland cement, with less than 0.45 water/cement ratio, shall be used.

4. Very severe attack: when the sulphate content is over 2.0 percent in soil, or over 10,000 ppm in water, ASTM Type V cement plus a pozzolanic admixture shall be used, with less than 0.45 water/cement ratio (Monteiro, Anonymous).

Shetty (2009) suggested that sulphate attack on concrete can be controlled through the following methods; quality concrete, use of air entrainment, use of sulphate resisting cement, use of pozzolan, high pressure steam curing and use of high alumina cement.

Acid attack: American Concrete Institute (ACI committee report, 2001) stated that Portland cement concrete does not have good resistance when exposed to strong acids (e.g. sulphuric, hydrochloric, acetic, formic etc.) but it can withstand some weak acids (e.g. carbonic, oxalic, tartaric etc.) if the exposure is not severe. Bisschop (Anonymous) further stated that when these strong acids attack concrete, it can cause damage to the concrete structure. Sulphuric acid is one of the deteriorating agents that are harmful to the durability of concrete. It's the product of sulphur trioxide (SO_3) gas reacting with water (H_2O) (Nirmalkumar and Sivakumar, 2009). Bisschop (Anonymous) found that Sulphuric acid is very injurious to concrete as it causes both acid and sulphate attack. It first attack and destroy exterior surface of cement paste, before the interior surface of the concrete specimen (Nirmalkumar and Sivakumar, 2009). Other corrosive solutions that can cause damage as asserted by Bisschop (Anonymous) to concrete are ammonium sulphate, sodium sulphate, magnesium sulphate, sodium nitrate, calcium dichloride, magnesium dichloride, and sodium chloride.

ACI committee (2001) report that acids formed from different sources and attack concrete, some of the sources include; combustion of many fuels from industries emits sulphurous gases which when in contact with moisture form sulphuric acids. When organic matter decay in marshes, shallow lakes, mining pits and sewer pipes it often leads to the formation of Hydrogen Sulphide (H_2S), which can be transformed into sulphuric acid by bacterial action and attack concrete which can results to degradation and deterioration of the concrete structure Monteiro (Anonymous). Peat soils, clay soils, and alum shale contain iron sulphide (pyrite) which, upon oxidation, produces sulphuric acid. Some mineral waters containing large amounts of either dissolved carbon dioxide or hydrogen sulphide, or both, can seriously damage any concrete. Organic acids from farm silage, or from manufacturing or processing industries such as breweries, dairies, canneries, and wood-pulp mills, can cause surface damage to concrete (ACI committee report, 2001).

Recent researches on pozzolanic concrete exposed to chemicals concentrations: exposure to chemically aggressive environment is one of the major durability problems that concrete structures encountered in recent years including Nigeria. Among the major chemicals that concrete structures are exposed to, include sulphuric acid and magnesium sulphate. For this reason, Job and Adole (2011) investigated the effects of chemicals on the properties of millet husk ash blended cement concrete were 15% concentration of $MgSO_4$, 15% concentration of NaCl and 5% concentration of H_2SO_4 used to cure the concrete specimens. Also 0% concentration of chemical (normal water) was used as a control. The results showed that OPC/MHA concrete performed better in all the chemicals at 28 days hydration periods than OPC (control) concrete samples. Abalaka (2007) studied the effects of sulphuric acid on compressive strength of concrete produced with OPC were 0.2%, 0.4% and 0.6% used as a concentration of H_2SO_4. The results showed that there is loss in strength of concrete samples at 28 days curing days. In addition, Usman (2010) assessed the effects of some environmental conditions on the durability of lateritic concrete were various concrete samples immersed in magnesium sulphate solutions of 0.2%, 0.5%, 1.0%, 1.2% concentrations, and sulphuric acid solution of pH-4 for 28 and 56 days. It was observed that both the lateritic and granitic concrete showed no decrease in strength when exposed to magnesium sulphate solutions. Gambo (2014) also assessed the durability properties of ternary cementitious matrix concrete containing rice husk ash and sawdust ash as partial replacement of cement where the concrete samples were exposed to 1% concentration of $MgSO_4$. The results showed that there is insignificant effect of magnesium sulphate on the concrete samples.

Abrasion Resistance: Lamond and Pielart (2006) suggested that abrasion refers to a wear or tear due to hard particles or hard protrusions forced against and moving along a solid surface. Abrasion resistance is the ability of a surface to resist being worn away by using, rubbing and friction.

Wear of concrete surface can be classified as follows:

1. Wear on concrete floors.
2. Wear on concrete road surfaces due to heavy trucking, and automobiles, with and without studded snow tires or chains (attrition, plus scraping and percussion).

3. Wear on hydraulic structures such as dams, spillways, bridge piers, and abutments due to the action of abrasive materials carried by flowing water (erosion).
4. Wear on concrete dams, spillways, tunnels, and other water- carrying systems where high velocities and negative pressure are present. This is generally known as cavitation erosion (cavitation).

The following factors needs to be considered in the design and construction of concrete surfaces to withstand abrasion due to rubbing, scouring, sliding, impact, scraping, attrition, percussion, gouging, or cutting from mechanical or hydraulic forces. Failure of concrete surfaces to resist abrasion can be linked to collective effects such as soft aggregate, inadequate compressive strength, improper curing or finishing, or over manipulation during finishing of concrete surface.

Water Absorption: Castro *et al.,* (2011) stated that water absorption is an important factor for quantifying the durability of cementitious systems. It is being used by specifiers and in scientific studies to provide a parameter that can describe an aspect of concrete durability. The durability of concrete exposed to harsh environments depends largely on transport properties, which are influenced by the pore system. Water absorption mainly depends on the total volume of pores, filler type, density and permeation mechanisms of the concrete as found by (Nambiar and Ramamurthy, 2007). Castro *et al.,* (2011) described water absorption as the ability of concrete samples to take in water by means of capillary suction. Concrete of low water absorption will afford better protection to reinforcement design within it (Nwaubani and Poutos, 2013). Pitroda and Shah (2014) stated that the average absorption of the concrete test specimens shall not be greater than 5% and individual unit not greater than 7%.

2.2 Cementitious Materials

Assyrians and Babylonians were possibly the first people to use clay as cementing material while their counterpart Egyptians used lime and gypsum as cementing materials in constructing the famous pyramids. Also Romans used calcareous cements which is either lime stones burned in kilns or were mixtures of lime and pozzolanic materials (volcanic ash, tuff) combining into a hard concrete (Duggal, 2008). Merrit and Ricketts (2001) defines cementitious materials as any material which when mix with either water or some other liquid or both form a cementing paste that may be formed or molded while plastic but will set into a rigid shape. When sand is added to this paste, mortar is formed and when coarse aggregate (crushed stone) and fine aggregate (sand) added to the paste forms the concrete. Use of cementitious material increases the chemical and the physical binding capacity, influence the pore system as well as the composition of cement pastes (Ytterdal, 2014).

Duggal (2008) stated that Vitruvius, a Roman scientist was the first to know how about the chemistry of the cementitious lime followed by the researches made by M. Vicat of France. Joseph Aspedin of Yorkshire (U.K.) was the first to introduce Portland cement in 1824 formed by heating a mixture of limestone and finely divided clay in a furnace to a temperature high enough to drive off the carbonic acid gas. In 1845, another researcher Issac C. Johnson invented the cement by increasing the temperature at which the mixture of limestone and clay were burned to form clinker which was the sample of the modern Portland cement. From then onwards, a gradual improvement in the properties and qualities of cement has been made possible by researchers in U.S.A., U.K., France and Germany. Cement as one of the construction materials may be define as adhesive or sticky substances capable of adhering fragments or masses of solid matter to a compact whole. It is derived from the latin word cementum, which means stone chippings which were used in Roman mortar, now the binding material used. It can be made from a mixture of elements that are found in natural materials such as limestone, clay, sand and shale Mays (2003); (Isah, 2014); Oluwatuyi and Olayemi (2012). According to Mays (2003) cement generally are artificial chemicals which, when mixed with water, undergo a chemical reaction that is given the special name ‘hydration’. The mass hydration products together with the unhydrated parts of cement age granules are called the ‘cement paste’ and this paste maintains this name in dry, aged hardened concrete. Shetty (2009) stated that Ordinary Portland Cement (OPC) is by far the most important type of cement and recognized as the major construction material throughout the world.

2.2.1 Ordinary portland cement

Ordinary Portland Cement or Portland cement is the name given to a cement obtained by intimately mixing together calcareous and argillaceous, or other silica, alumina, and iron oxide bearing materials, burning them at a clinkering temperature up to about 1400^0C (2550^0F) and grinding the resulting clinker (Neville and Brooks, 2010). The raw materials according to Merritt and Ricketts (2001) used for the manufactured of Portland cement consist of four major compounds; lime (CaO), iron (Fe_2O_3), silica (SiO_2), and alumina (Al_2O_3) and two minor compounds; gypsum ($CaSO_4 . 2H_2O$) and magnesia (MgO). The calcareous (CaO) materials can be found from limestone, calcite, marl, or shale and the argillaceous (SiO_2 and Al_2O_3) materials found from clay, shale, and sand. The rate of production of this material (OPC) in the world is approximately 2.1 billion tons/year, and is expected to grow to about 3.5 billion tons/year by 2015 (Fernanda *et al.*, 2008).

ASTM C150-00 defines Portland cement as hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulphate as an interground addition. Mehta and Monteiro (2006) stated that cement pulverizing clinkers are 5 to 25mm diametre nodules of a sintered material that is produced when a raw mixture of predetermined composition is heated to high temperatures.

2.2.1.1 Characteristics of Portland Cement

Cement paste is an important part in concrete and thus; Rasa *et al.,* (2009) stated that the mechanical properties of concrete are highly influenced by the density and compressive strength of concrete cement paste. The density and compressive strength of concrete cement paste are affected by several parameters; water cementitious materials ratio, pozzolan contents, percentage of super-plasticizer, curing, cement type, etc. Strength and durability of any building to be constructed depends solely on the characteristics of cement to be use, and for this reason Garba (2008) described the characteristics of Portland cement as:

Fineness: fineness of cement as one of it is characteristics influences the rate of reaction with water because of the fact that finely ground cement has more exposed surface area than a coarsely ground one. If the rate of reaction of cement is affected the rate of setting and hardening of that cement will also be affected and therefore this characteristic facilitate in completing the chemical reaction between cement and water within short time. When cement ground too finely the particles may become pre-hydrated by moisture (water vapour) from air and result to loosing it is cementitious power (bad cement). This characteristic of cement can be measured from specific surface of the cement which can be determined in an air permeability apparatus where the typical value of OPC specific surface is 300m^2/kg. Sieving an estimated amount of 0.11kg of cement sample through no. 170 sieve (0.09 mm) in 15 minutes and the residue should not exceed 10% is another method that can be use for measuring the fineness of cement. For a material of similar features with cement like pozzolanic material the second method can also be use to determine the fineness of that material.

Chemical composition: this is the basis of characterization of cement which can affects all properties of cement except the fineness of cement. High content of certain cement constituents compound in proportion to others may lead to retardation or acceleration of the rate of setting and hardening, thus the constituents need to conform to standard specification. Excess of any compound could affect the rate of heat evolution as the cement hydrates and to guide against this the ratios of lime, silica, alumina, iron oxide, alkali and sulphur contents should be maintained base on the standard specification. Calcium chloride and calcium sulphate (gypsum) are used as additives to accelerate or retard the rate of setting of cement paste. Some of the methods that can be use for checking the chemical composition of cement are; Energy Dispersive X-Ray Fluorescence test (EDXRF), wet chemistry method, Neutron Activation Analysis (NAA) etc.

Soundness: a mixture of cement and water also known as cement paste. When it sets and hardens without any cracking or disintegrating such cement is said to be sound cement. Hydration of free lime (CaO), magnesia (MgO) and sulphates (SO_4) surrounded by cement particles caused unsoundness of cement by preventing easy hydration of free lime (uncombined lime) and other materials during the normal setting period. For a cement to be free from unsoundness it should be thoroughly mixed, burnt and ground. Selecting too much lime which may combine with acidic oxides during manufacture, too much magnesia and too much sulphate were the errors usually made responsible for the production of defective (unsound) cement. Le chartelier apparatus is the instrument widely used for checking the unsoundness of cement in the laboratory.

Hydration: the chemical reaction that occurred between cement and water is called hydration of cement which is an exothermic process and the heat liberated is known as heat of hydration. OPC can liberated heat as high as 85-100 cal./g. and low heat cement liberated up to about 60-70 cal./g. When this heat is release in large amount it could be harmful but at times could be useful for a huge concrete structure (e.g. dam, bridge etc.). It causes cracking and disintegration of the structure due to the high insulation properties of concrete and does not allow heat to dissipate easily thereby causing restrained thermal expansion.

Setting and Hardening: setting is the state of rigidity of cement paste over time and the process after final setting is the hardening of cement paste. When water poured onto cement, hydration of cement begins as the same time cement starts to stiffen loosing it is plasticity to become a bit rigid and hence the cement paste is said to have set. Setting time of cement can be determined in the laboratory by the use of Vicat apparatus, cylindrical mould, initial and final setting time needle to check the initial and final setting time of cement paste. Setting times of cement paste is a highly variable property of cement which should neither be too slow nor too fast and it does depend on the type of cement used. It should be long enough (not less than 45 minutes and not more than 10 hours for initial and final setting time) to enable mixing, transporting, placing and compaction of concrete or mortar to be completed before final setting starts.

Strength development: cement develops strength as a result of interweaving of cement gel (C-S-H) during hydration process. CCAA (2006) reported that concrete achieved about 80 - 100% of it is compressive strength at 28 days. Parametres that could be use for testing the strength development of cement concrete, mortar cube or cylinder are; compressive strength, tension test and flexural test, the data obtained are then compared with standard values as given in the appropriate standard.

2.2.1.2 Blended ordinary portland cement

The advancement and use of blended cements in the world is booming rapidly in the construction industries. This is due to considerations of cost saving, energy saving, environmental protection and conservation of resources (Khan, 2009). According to Joergensen (2014) blended cement is a mixture of ground or interground cement clinker, gypsum and mineral admixture. The mineral admixture, clinker replacement materials, will be one or more of the following materials:

1. Granulated Blast furnace Slag (GBS)
2. Natural Pozzolans
3. Fly Ash (PFA)
4. Limestone

2.2.1.3 Production of ordinary portland cement and environ

According to Mishra *et al*., (2013) environmental pollution caused by cement industry pollutes water, air and land through its various activities. It is a continuous source of cement dust and their constituent gases such as SO_2, CO_2, CO, and SiO_2 adversely affect source of drinking water like wells, ponds and mine pits. The presence of total solids in the form of salts of Ca, Na, K, Mg, Al as hydroxides sulphates and silicates leads to hardness of water which causes gastro intestinal disorders.

Major environmental problems associated with mining of cement:

1. Pollution of ground and surface water.
2. Loss of productive land due to open cast/underground mining.
3. Loss of land and property by surface subsidence.
4. Loss of property and injuries caused by rocks and ground vibrations during blasting.
5. Air pollution.
6. Deforestation.
7. Erosion of top soil.
8. Leaching effect from overburden.
9. Disappearance of fauna and flora.
10. Socio economic aspects.

Persistence of these problems will cause degradation and deterioration of our surroundings, thus they can be solve by the use of pozzolanic material as suggested by (Li, 2011; Shetty, 2009; Neville and Brooks, 2010).

2.2.2 Pozzolanic materials

The advances of concrete technology has shown that the use of pozzolanas also known as Supplementary Cementitious Material (SCM) such as rice hull ash (rice husk ash) , millet husk ash, meta kaolin, volcanic ash, silica fume, blast-furnace slag, fly ash etc. is necessary and essential for producing durable concrete (Lee *et al.,* Anonymous). Duggal (2008) stated that the term pozzolana is derived from Pozzouli, a town in Italy on the Bay of

Naples near Mount Vesuvious. The sand (volcanic dust) around this town when mixed with hydrated lime was found to possess hydraulic properties. In those days before the arrival of cement, pozzolan was used with lime to make concrete but contemporary it is use to replace a proportion in cement when making concrete. In addition, Hewlett (2006) stated that pozzolana has two distinct meanings. The first one indicates the pyroclastic rocks, essentially glassy and sometimes zeolitised, which occur either in the neighbourhood of Pozzuoli (the ancient Puteoli of the Roman times) or around Rome. The second meaning includes all those inorganic materials, either natural or artificial, which harden in water when mixed with calcium hydroxide (lime) or with materials that can release calcium hydroxide (Portland cement clinker). All pozzolanas both natural and artificial are rich in silica and alumina and contain only a small quantity of alkalis (Duggal, 2008). According to Newmann and Choo (2003) pozzolanas must separated into finer particles in order to expose a large surface area to the alkali solutions for the reaction to take place. It’s often required as partial cement replacement for large projects to lower the heat of hydration and improve durability. Some examples of pozzolanic materials are volcanic ash, pumice, opaline shales, burnt clay and fly ash. The silica in a pozzolana has to be amorphous, or glassy, to be reactive. Volcanic ash when touch is hard, can be red, brown or black in colour, insoluble in water, extremely abrasive, mildly corrosive and it can conduct electricity when in contact with water Olawuyi *et al.,* (2012).

2.2.2.1 Classification of pozzolanas

Ramezanianpour (2014) classified pozzolan based on their origin:

1. Natural pozzolan

2. Artificial pozzolan

1. Natural pozzolans are those materials which do not require any further treatment apart from grinding or pulverizing to react with lime. Natural pozzolan as opined by Yasin *et al.*, (2012) can be obtained from many parts of the world and have been used to produce concrete for over 2,300 years. According to Parhizkar *et al.*, (2010) Natural pozzolans can also be defined as natural materials containing reactive silica or alumina, which, alone, have little or no binding property, but when mixed with Portland cement, react with lime in the presence of water will set and harden like cement. Natural pozzolans are classified in four categories based on the principal lime reactive constituent present Ramezanianpour (2014). They are:

i. Volcanic tuff and pumicites

ii. Unaltered volcanic glass

iii. Calcined clay or shale

iv. Raw or calcined opaline silica

2. Artificial pozzolans are the materials with low pozzolanic activity and need further treatments to achieve pozzolanic activity; it results from chemical or structural modifications of materials originally having no or only weak pozzolanic properties (Ramezanianpour, 2014). Examples of artificial pozzolans as stated by (Shetty, 2009) are;

i. Fly ash

ii. Blast furnace slag

iii. Silica Fume

iv. Rice Husk ash

v. Matakaoline

vi. Surkhi

2.2.2.2 Standard specifications and test of pozzolans

ASTM C618-05 classified pozzolans into different classes which are;

1. Class N: this include raw or calcined natural pozzolans such as some diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes or pumicites, calcined or uncalcined; and various materials requiring calcinations to induce satisfactory properties, such as some clays and shales.

2. Class F: this class includes fly ash which is normally produced by burning anthracite or bituminous coal and it has pozzolanic properties.

3. Class C: this is another class of fly ash pozzolan but it is normally produced from lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some cementitious properties.

For a material to be a pozzolanic material it needs to satisfy ASTM C618-05 standard chemical and physical requirements as given in Table 2.5 and 2.6.

2.5 Chemical Requirements

Material contents	Mineral Admixture Class		
	N	F	C
$\sum SiO_2 + Al_2O_3 + Fe_2O_3$ min, %	70.0	70.0	50.0
SO_3 max, %	4.0	5.0	5.0
Moisture content, max, %	3.0	3.0	3.0
Loss on ignition, max, %	10.0	6.0	6.0

Source: ASTM C618-05

Table 2.6 Physical Requirements

Material contents	Mineral Admixture Class		
	N	F	C
Fineness: Amount retained when wet-sieved on 45 μm (No. 325) sieve, max, %	34	34	34
Strength activity index: With Portland cement, at 7 days, min, percent of control	75[C]	75[C]	75[C]
With Portland cement, at 28 days, min, percent of control	75[C]	75[C]	75[C]
Water requirement, max, percent of control	115	105	105
Soundness: Autoclave expansion or contraction, max, %	0.8	0.8	0.8
Uniformity requirements: The density and fineness of individual samples shall not vary from the average established by the ten preceding tests, or by all preceding tests if the number is less than ten, by more than: Density, max variation from average, %	5	5	5
Percent retained on 45-μm (No. 325), max variation, percentage points from average	5	5	5

Source: ASTM C618-05

2.2.2.3 Activity of pozzolanas

According to Duggal (2008) pozzolan when mixed with ordinary Portland cement, the silica that is present in the pozzolan combines with the free lime released during the hydration of cement and this is called pozzolanic action. The pozzolanic activity occur due to the presence of finely divided glassy silica and lime which produces calcium silicate hydrate similar to one as produced during hydration of Portland cement. The silica in the pozzolan reacts with the lime produced during hydration of Portland cement and contributes to development of strength. Slowly and gradually additional calcium silicate hydrate is formed which is a binder and fills up the space, gives impermeability, durability and ever increasing strength.

Hydration of Portland cement may be expressed as given in equation 2.3

$$\underset{}{C_3S + H_2O} \longrightarrow \underset{\text{(Calcium silicate hydrate)}}{\text{C-S-H}} + \underset{\text{(Lime)}}{Ca(OH)_2} \quad - \quad -(2.3)$$

Lime produced from equation 2.3 combines with silica of pozzolana to produce calcium silicate hydrate as shown in equation 2.4

$$Ca(OH)_2 + \underset{\text{(Silica)}}{SiO_2} \longrightarrow \text{C-S-H} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad (2.4)$$

Silica of amorphous form react with lime readily than those of crystalline form and this constitutes the difference between active pozzolanas and materials of similar chemical composition which exhibit little pozzolanic activity. Since pozzolanic action can develop only in the presence of water, enough moisture has to be made available for a long time to complete pozzolanic action. It is commonly thought that lime-silica reaction is the main or the only one that takes place, but recent information indicates that alumina and iron if present also take part in the chemical reaction. The optimum amount of pozzolana, as replacement for cement, may normally range between 10-30% and may be as low as 4-6% for natural pozzolanas. It may be somewhat higher for some artificial pozzolan e.g. fly ashes (Duggal, 2008).

2.2.2.4 Recent researches on OPC replacement with pozzolanas

Pozzolanas as a replaceable material of OPC in concrete is economical and environmental friendly compared with cement and thus; Dadu, (2011) is one out of many researchers that carried out a research on Jos Plateau volcanic ash to replaced OPC with 5%, 10%, 15%, 20%, 30% and 40% the results showed that 5% and 10% were the best replacement by achieving highest compressive strength. Olawuyi *et al*., (2012) used volcanic ash from Kerang of Mangu Local Government Area of Plateau State to replaced OPC with 10%, 20% and 30% the results showed that 20% was the optimum replacement level with greatest compressive strength. Other researchers that carry out similar researches were; Murkherjee *et al*., (2012) whose carry out a research on the replacement of OPC with fly ash at 20%, 30%, 40%, 50%, 60% and 70% replacements. The results showed that the compressive strength decreases at 3, 7 and 28 days as the replacement of fly ash approach 30% replacement. Groundnut shell ash was used by Mahmoud *et al*., (2012) at 10%, 20%, 30%, 40% and 50% as a partial replacements of cement in sandcrete blocks production. The optimum replacement achieved at 20% with a corresponding strength of 3.58 N/mm^2.

2.2.2.5 Effects of incorporating pozzolans into cement concrete

Duggal (2008) stated that incorporating pozzolans as a fine aggregate into the cement cause various effects which includes;

1. Effects heat of hydration cause by pozzolans is same as that of low heat cement.

2. When pozzolans are used in addition of an air entraining agent (e.g natural wood resins, animal and vegetable fats and oils such as tallow, olive oil etc.) may cause the reduction of the amount of water than if the air entraining agent was added to concrete containing Portland cement only. This may result to an increase in strength and thus less cement may be allowed for the same strength.

3. Pozzolan has greater influence on shrinkage and moisture movement in concrete structures in the same way as it effects by Portland cement.

2.2.2.6 Applications of pozzolans

In most recent times pozzolans as a cementitious material have been extensively used in Europe, USA, China, India and Japan to partially replace OPC in concrete structures for the construction of dams, bridges, roads and high rise buildings Dadu (2011); Duggal (2008). Furthermore optimum proportions of pozzolans when mixes with Portland cement enhance many qualities of concrete which are;

1. Lower the heat of hydration and thermal shrinkage
2. Increase the water tightness
3. Reduce the alkali aggregate reaction
4. Improve resistance to attack by sulphate soils and sea water
5. Improve extensibility
6. Lower susceptibility to dissolution and leaching
7. Improve workability
8. Lower cost
9. Lower excessive increase of water requirement or drying shrinkage

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The materials used for this research work were; Jos Plateau volcanic ash, Dangote Portland cement, sharp river sand, crushed granite stone and curing media. Each of the materials used for this research was obtained from a single source; this has helped to limit the likely discrepancies that might occur in the characteristics of the materials. Materials preparation and testing of concrete samples were done in adherence to appropriate B.S. standard. The chemical composition tests of the Jos Plateau volcanic ash was conducted at National Geological Survey Agency, Barnawa Kaduna. The Milling of Jos Plateau volcanic ash was carried out in the Department of Chemical Engineering ABU Zaria, while all other experimental work was conducted in the concrete laboratory of the Department of Building ABU Zaria.

3.1.1 Jos plateau volcanic ash

The Jos Plateau volcanic ash used in this research was obtained from Miango Twin Conical Hills (JP 3) in Bassa Local Government Area in Plateau State. The material was first ground using metal mortar and pestle to fine particles. The material was then carried to Chemical Engineering Department for milling using electronic balls milling machine and sieved through 75µm sieve aperture. Volcanic ash sieved to 75µm can be shown in Plate I.

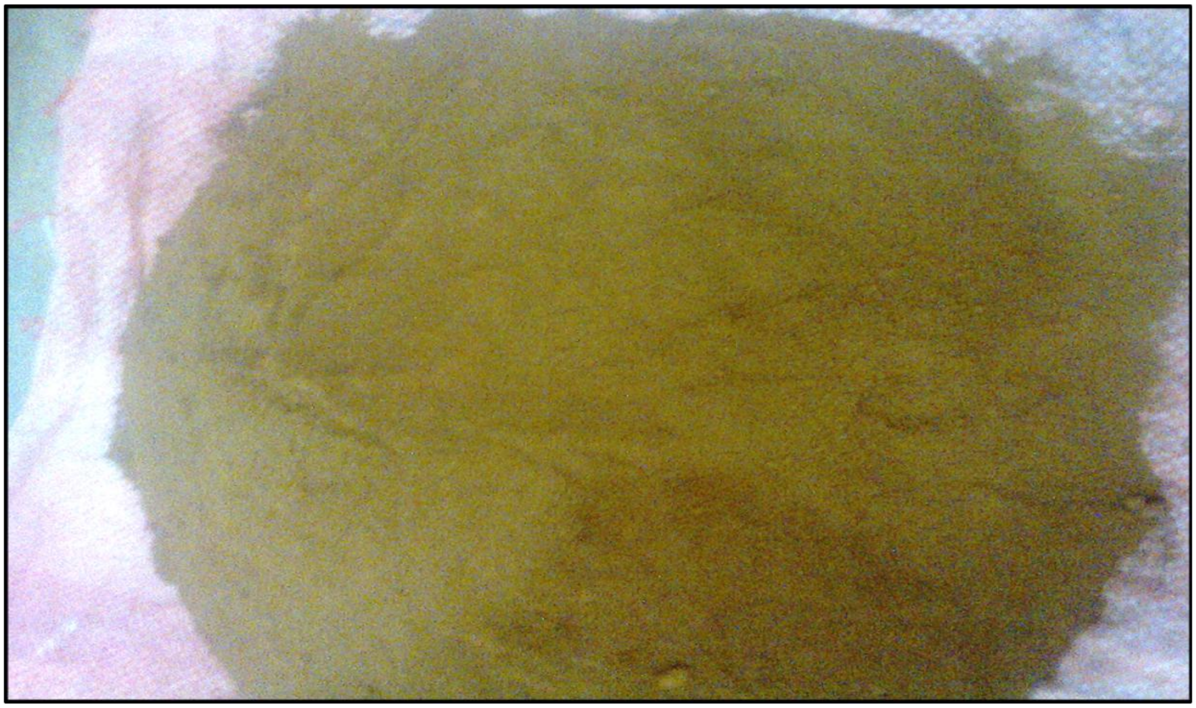

Plate I: Volcanic ash sieved to 75μm

3.1.2 Cement

Ordinary Portland Cement of Dangote brand obtained from Sabon Gari Market of Sabon Gari Local Government Area was used for this research.

3.1.3 Fine aggregates

The fine aggregates used in this research was clean and saturated surface dried sharp river sand obtained from Samaru Zaria. It was sieved through 5mm sieve to take away any impurities and larger size aggregates in accordance to BS EN 933-1 (1997).

3.1.4 Coarse aggregates

Totally crushed granite stone that conformed to BS EN 933-5 (1998) was used for this research and it was obtained from quarrying area along Zaria – Sokoto road. It was also sieved passing through 20mm sieve and retained on 10mm sieve.

3.1.5 Concrete mix details

Optimum water cement ratio (w/c) was determined by producing four different types of concrete samples with different w/c; 0.40, 0.45, 0.50 and 0.55. The test shows that 0.50 w/c is the most suitable and was used for this research. Also four different types of replacement of Portland cement volcanic ash concrete were produced; 5%, 10%, 15% and 20% with 0% as control to determine the most appropriate replacement. The results show that 5% and 10% volcanic ash replacement are the best and were used for the research. Batching and mixing of fresh concrete was conducted using 1:2:4 nominal mix ratios in accordance to BS 1881-125 (1986) and dry room temperature was recorded.

Table: 3.1 Mix details for cube samples

Percentage replacement (%)	Mass of materials/cube (kg)				
	Volcanic ash	Cement	Sand	Crushed granite	Water
0%	0.00	0.39	0.84	1.61	0.20
5%	0.02	0.37	0.84	1.61	0.20
10%	0.04	0.35	0.84	1.61	0.20

Source: Laboratory Research Work (2014)

Table 3.1 shows the details of mixing of materials of Portland cement/volcanic ash concrete cubes samples.

Table: 3.2 Mix details for cylinder samples

Percentage replacement (%)	Mass of materials/cylinder (kg)				
	Volcanic ash	Cement	Sand	Crushed granite	Water
0%	0.00	0.61	1.31	2.52	0.31
5%	0.03	0.58	1.31	2.52	0.31
10%	0.06	0.55	1.31	2.52	0.31

Source: Laboratory Research Work (2014)

Table 3.2 shows the details of mixing of materials of Portland cement/volcanic ash concrete cylinder samples.

3.1.6 Mixing and curing water

Clean tap water fit for drinking supplied from ABU water board was used for the production and curing of concrete samples. The water conforms to BS EN 1008-2 (2002).

3.1.7 Curing method

The Portland cement volcanic ash concrete samples were cured by completely immersing into the curing media. Three types of curing media were used which were; 0% concentration of H_2O, 1.2% concentration of $MgSO_4$ and 1.2% concentration of H_2SO_4. 1.2% concentration of $MgSO_4$ and H_2SO_4 used for this research were severe concentration range Monteiro (Anonymous). Suphuric acid (H_2SO_4) was procured in liquid form and magnesium sulphate ($MgSO_4$) in powdered form from chemicals vendor near Emanto guest inn along Sokoto road Sabon Gari Local Government. The chemicals were prepared based on the instruction given by chemistry laboratory technician. A bowl was used that have the capacity up to 100 litres of water to cure concrete samples, but only 50 litres was poured. This was done to allow the specimens to be placed and cured properly without overflow. The calculation was done in this way:

50 litres of water is equivalent to 50000g by weight

50000g of water to 100% concentration of chemical

Unknown gram of chemical to 1.2% concentration of chemical

Therefore mathematically:

$$50000 = 100\%$$

$$x = 1.2\%$$

$$x = \frac{50000 \times 1.2}{100} = 600\text{g} \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (3.1)$$

Therefore from equation 3.1 for every 50000g capacity container of clean tap water, 600g of chemical was poured as 1.2% concentration.

3.2 Tests Method

The tests conducted in this research can be categorized into:

3.2.1 Preliminary tests of materials

The preliminary tests of materials that were carried out were; determination of chemical composition of Jos Plateau volcanic ash using Energy Dispersive X-Ray Fluorescence method (EDXRF), specific gravity and bulk density test for Jos Plateau volcanic ash, OPC, sharp sand and crushed granite stone. Also sieve analysis, and moisture content for sharp sand and crushed granite stones, setting time and soundness test for Jos Plateau volcanic ash and OPC were carried out.

3.2.1.1 Chemical composition of materials

The chemical composition test of Jos Plateau volcanic ash was carried out at National Geological Survey Agency Barnawa Kaduna using EDXRF method. The machine used to carry out this test was Minipal 4 Energy Dispersive X-Ray Fluorescence. The primary filter used was kapton, x-ray current was 14kv, air as the current gas medium, and the time used to measure the sample was 100seconds. Fresh portion of the Jos Plateau volcanic ash was crushed and ground to pass through 100 micro mesh sieve. 10g of the powdered sample (Miango JP 3) was weighed into a given sample cup and was carefully placed on the sample charger of the x-ray fluorescence machine. The major oxides, minor oxides and Lost on Ignition (LoI) were measured and recorded.

3.2.1.2 Bulk density of materials

Bulk density of aggregates was determined in accordance to BS 812-2 (1995). The apparatus used were density wooden cube, trowel, rammer and weighing balance. The bulk density for aggregate sample was computed using the equation 3.2.

$$D = \frac{m}{v} \qquad (3.2)$$

Where D is the density of the aggregate specimen in kg/m^3

m is the mass of the aggregate specimen in kg

v is the volume of the aggregate specimen in m^3

Also mass of the aggregates sample was determined by subtracting the weight of empty container from the weight of container plus aggregate sample using equation 3.3.

$$m = B - A \qquad (3.3)$$

Where m is the mass of the aggregate specimen in kg

A is the weight of the empty container in kg

B is the weight of container plus aggregate sample in kg

3.2.1.3 Specific gravity of materials

Specific gravity of the fine and coarse aggregates were determined using pyknometre method, the procedure used was in accordance with BS 812-2 (1995). The apparatus used during the test include density bottle and stopper, funnel, spatula and weighing balance.

The specific gravity of aggregates was calculated using equation 3.4.

$$G_S = \frac{C - A}{(B - A) - (D - C)} \qquad (3.4)$$

Where: A is the weight of empty density bottle and it is stopper which it was clean and dried

B is the weight of empty density bottle plus water

C is the weight of empty density bottle plus aggregate sample

D is the weight of empty density bottle plus water plus aggregate sample

3.2.1.4 Sieve analysis of materials

In accordance to BS EN 933-1 (1995) 6kg of coarse aggregates was weighed and then poured on different sizes of sieves passing through 20mm, 13.2mm, and 9.50mm. Weight of aggregates retained and passing on each sieve was taken down and percentage passing was calculated. Also the same procedure was used for fine aggregates of 6kg passing through sieve sizes 4.75mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm and pan. Fineness modulus of fine and coarse aggregates were determined as sum of cumulative percentage of aggregates retained on each of a series of sieves (each sieve having a clear opening that is half of the preceding one) and the total divided by 100.

3.2.1.5 Moisture content of materials

1kg of coarse aggregates was weighed as (A) using weighing balance, the material was then poured on wide metal container, spread and put inside an electric oven for 24hours at 105^{0}C. After 24hours the aggregates was removed from the oven and allowed to cool down at room temperature, and then the aggregates was weighed again as (B). The same procedures was applied for 0.5kg of fine aggregates and finally the moisture content were determined in accordance to BS 812-109 (1990) using equation 3.5.

$$\text{Moisture content} = \frac{A - B}{B} \times 100\% \qquad (3.5)$$

3.2.1.6 Setting time and soundness of materials

As described in BS EN 196-3 (1995) setting time and soundness test were conducted in which consistency, initial setting time and final setting time were carried out using Vicat apparatus plunge, needle and le chartelier apparatus. Three different mix; 0%, 5% and 10% replacement of Portland cement volcanic ash paste was prepared for both setting time and soundness.

3.2.1.7 Consistency

Consistency was determined using equation 3.6.

$$\text{Consistency} = \frac{\text{Water consumed}}{\text{Weight of cement sample}} \times 100\% \qquad (3.6)$$

3.2.2 Testing of fresh Portland cement volcanic/ash concrete

Fresh property of Portland cement volcanic ash concrete was assessed to test its level of fluidity and mobility using slump test method as;

3.2.2.1 Slump test

Slump test method was used to test the workability of the fresh Portland cement volcanic ash concrete as provided in BS 1881-102 (1983). The apparatus used to carrying out this test consist of mould, scoop, sampling tray, trowel, tamping rod, and rule. The internal surface of the mould was clean and damp free from unneeded moisture then placed on sampling tray and hold firmly against the surface below. The fresh concrete was poured into the mould in three layers, approximately one third of the height of the mould where each layer was tamped 25 strokes and the mould was removed gently vertically upward. The slump was measured (nearest 5mm) to determine the difference between the height of the mould and the height of slump concrete. The slump/cone test method can be shown in Plate II.

Plate II: Slump/cone test method

3.2.3 Testing of hardened concrete samples

The concrete samples produced were cured in three curing media which were; 0% concentration of H_2O (control), 1.2% concentration of $MgSO_4$ and 1.2% concentration of H_2SO_4. The concrete specimens were crushed after 7, 14, 21, 28, 56, and 90 days. The tests carried out were;

3.2.3.1 Density test

The concrete specimens were removed from the curing container and placed outside to surface dried, then weighed using weighing balance to determine the mass of the samples in accordance to BS EN 12390-7 (2000). The density of concrete specimens was calculated, using equation 3.7.

$$D = \frac{m}{v} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad (3.7)$$

Where D is the density of the concrete specimen in kg/m^3

m is the mass of the concrete specimen in kg

V is the volume of the concrete specimen in m^3

The density test can be shown in Plate III.

Plate III: Density test

3.2.3.2 Compressive strength test

The concrete samples (cubes) were removed from the curing basin and placed outside to surface dried, weighed and positioned at the centre of hydraulic manual compression machine for crushing. Packing was not use in this type of testing and the force was applied at the specimen by swinging the handle of the crushing machine till it failed. The force exerted on the specimen was recorded and compressive strength was computed in conformity with BS EN 12390-3 (2002) using equation 3.8.

$$f = \frac{F}{A} \qquad (3.8)$$

Where f is the compressive strength, in KN/m^2

F is the maximum load at failure, in KN

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

The compressive strength test can be shown in Plate IV.

Plate IV: Compressive strength test

3.2.3.3 Split tensile test

The concrete samples (cylinders) were removed from the curing vessel and placed outside to surface dried, weighed and positioned at the centre of hydraulic manual compression machine for splitting. In this type of testing two strips packing were applied at the bottom and top of the cylinder and the force was applied at the specimen by swinging the handle of the crushing machine till it failed. The force exerted on the specimen was recorded and split tensile strength was computed in conformity with BS EN 12390-6 (2000) using equation 3.9.

$$f_{ct} = \frac{2 X F}{\pi X L X d} \qquad (3.9)$$

Where f_{ct} is the tensile splitting strength, in KN/m^2

F is the maximum load, in KN

L is the length of the line of contact of the specimen, in m

d is the designated cross-sectional dimension, in m

The split tensile test can be shown in Plate V.

Plate V: Split tensile test

3.2.3.4 Abrasion resistance test

The concrete samples (cubes) were removed from the container and allowed to surface dried, weighed and the values were recorded as W_1. A weight of 3.5kg was mounted and tightly fixed to the wire brush and stroke the specimen surface for 60 times at equal speed, then the specimen was re-weighed and the value was recorded as W_2. Final weight was deducted from the initial weight to determine the lost in weight of each sample as stated by Gambo (2014) using equation 3.10.

$$\text{Abrasion resistance test} = \frac{w_1 - w_2}{w_2} \times 100\% \quad - \quad - \quad - \quad - \quad - \quad (3.10)$$

The abrasion resistance test can be shown in Plate VI.

Plate VI: Abrasion resistance test

3.2.3.5 Water absorption test

The concrete samples (cubes) were removed from the curing tank and allowed to dried, then placed in the electronic oven to oven dried at 105^0C for 72 hours. The samples were removed from the oven and allowed to cool at room temperature then weighed to determine the initial weights. The final weights were determine after immersing the concrete samples in the curing medium for 30 minutes then removed to cloth dried and re-weighed again. The values obtained were recorded and the results were calculated to assess the rate of absorption of the concrete specimens in accordance to BS 1881-122 (1983).

The water absorption concrete samples before weighing can be shown in Plate VII.

Plate VII: Absorbed concrete samples before weighing

3.3 Method of Data Analysis

The results obtained for different tests carried out in this research work were analysed using simple statiscal tools (mean and percentage). According to Tavakoli (2012) mean also called arithmetic mean, represented by M or X is the most commonly used measure of central tendency which is the sum of scores divided by the total number of scores, often represented by equation 3.11.

$$X = \frac{\sum X}{N} \qquad (3.11)$$

Where: X (read as *X*-bar) is the symbol for the mean

A percent or percentage is a proportion multiplied by hundred. It is used in this research to analyse the results of abrasion resistance test and water absorption.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSIONS

4.1 Presentation of Results of Preliminary Test

The results of preliminary tests conducted for this research work were; chemical composition of Miango (JP 3) Jos Plateau volcanic ash, trial test of water cementitious materials (w/c) and Portland cement volcanic ash replacement. Others were; specific gravity and bulk density, moisture content, sieve analysis of the aggregates, setting time and soundness test and slump test of fresh Portland cement/volcanic ash concrete.

Table 4.1: Energy Dispersive X-Ray Fluorescence (EDXRF) Method of Miango (JP 3) Volcanic Ash in Comparison with Dadu (2011) and ASTM Requirement.

Elements	% Composition	% Composition Dadu (2011)	ASTM C618-05 limits
Aluminum Oxide (Al_2O_3)	18.00	35.50	Al_2O_3
Silicon Oxide (SiO_2)	28.10	41.10	+
Iron Oxide (Fe_2O_3)	35.11	13.52	SiO_2
Potassium Oxide (K_2O)	0.26	ND	+
Calcium Oxide (CaO)	0.29	0.16	Fe_2O_3
Titanium Oxide(TiO_2)	1.76	5.46	=
Vanadium Oxide (V_2O_5)	0.21	-	70.0% min
Chromium Oxide (Cr_2O_3)	0.05	0.12	
Manganese Oxide (MnO)	0.03	ND	
Magnesium Oxide (MgO)	0.26	0.05	
Nickel Oxide (NiO)	0.03	0.01	
Sodium Oxide (Na_2O)	0.02	ND	
Sulphur trioxide (SO_3)	-	ND	4.0% max
Loss On Ignition (LOI)	15.87	14.00	10.0% max

Source: Laboratory Research Work (2014) ND Not Detected

Table 4.1 presents the chemical composition carried out by Dadu (2011) and this study on the same sample of twin conical hill Miango (JP 3) volcanic ash. The results satisfied the ASTM C618-05 requirement which stated that for a material to be a pozzolan the summation of Aluminum Oxide (Al_2O_3), Silicon Oxide (SiO_2) and Iron Oxide (Fe_2O_3) must be 70.0 % minimum. Dadu (2011) and this research achieved 90.12% and 81.21% for the summation of the chemicals composition which agrees to ASTM C618-05 requirements.

Table 4.2: Trial Test of Portland Cement Volcanic Ash Concrete Replacement

Replacement	Density (kg/m^3)	Average Compressive Strength (N/mm^2)
0%	2310	15.00
5%	2290	15.25
10%	2290	15.75
15%	2320	13.50
20%	2320	12.50

Source: Laboratory Research Work (2014)

Table 4.2 presents the results of trial test for determining the most suitable replacement of Portland cement volcanic ash. The compressive strength tested after seven days show that 5% and 10% are higher than 0%, 15% and 20% which tally with the literature reviewed (Dadu, 2011). Therefore 5% and 10% replacement were used for this research.

Table 4.3: Trial Test of Water Cementitious Materials Ratio (w/c)

w/c	Density (kg/m^3)	Average Compressive Strength (N/mm^2)
0.40	1980	1.90
0.45	1860	7.80
0.50	1960	13.80
0.55	1960	8.00

Source: Laboratory Research Work (2014)

Table 4.3 shows the trial test of water cementitious material ratio (w/c) for the research work. It presents that 0.50 w/c was the best with average compressive strength of 13.80N/mm^2 at seven days. It achieved high compressive strength than the other w/c and hence it was used for the research.

Table 4.4: Physical properties: Specific Gravity and Bulk Density of Materials

No	Materials	Specific Gravity (kg)	Bulk Density (kg/m^3)
1.	Crush granite stone	2.83	1363
2.	Sand	2.78	1385
3.	Portland cement	3.43	1278
4.	Volcanic ash	2.33	1310

Source: Laboratory Research Work (2014)

Table 4.4 presents specific gravity and bulk density of materials used for the research. The results obtained satisfied the requirements of ACI E1-99 which specified the range for normal weight aggregates between 2.30 to 2.90 kg for specific gravity and 1280 to 1920 kg/m^3 for bulk density.

Table 4.5: Physical properties of Portland Cement Volcanic Ash Paste

Portland cement/volcanic ash paste	0%	5%	10%
Soundness	2mm	0	0
Setting time			
Initial	169mins	196mins	200mins
Final	260mins	293mins	307mins
Consistency	33%	33.3%	33.5%

Source: Laboratory Research Work (2014)

Table 4.5 show soundness and setting time of Portland cement volcanic ash paste. The setting time for Portland cement volcanic ash paste tally with the literature reviewed. The soundness test of Portland cement volcanic ash concrete were correspond to the requirement of BS EN 197-01 (2000) which specified that it should be ≤ 10mm otherwise the cement is unsoundness.

Table 4.6: Physical properties: Moisture Content of the Research Materials

No	Materials	Weight of material before oven dry (kg)	Weight of material after oven dry (kg)	Mc Percentage (%)
1.	Crushed granite stone	1.000	0.995	0.50
2.	Sand	1.000	0.948	5.49
3.	Portland cement	0.500	0.499	0.20
4.	Volcanic ash	0.500	0.473	5.71

Source: Laboratory Research Work (2014)

Table 4.6 presents results of moisture content test for the research materials. According to ACI E1-99 moisture content for coarse aggregates should be within 0 to 2% and for fine aggregates should be within 0 to 10% which denote that the test on the aggregates has conformed to the standard.

Table 4.7: Sieve Analysis of Fine Aggregates

BS Sieve Size	Weight Retained (kg)	Weight Passing (kg)	Percentage Passing (%)
4.75mm	0.36	5.64	94
2.36mm	0.54	5.10	85
1.18mm	3.28	1.82	30
600μm	1.40	0.42	7
300μm	0.12	0.30	5
150μm	0.00	0.00	0
Pan	0.00	0.00	0

Source: Laboratory Research Work (2014)

Table 4.7 show results of sieve analysis of fine aggregates which was used to determine the fineness modulus and calculated as 2.92. The fineness modulus of fine aggregates should be within the range of 2.0 – 3.5 (± 0.2) and hence it has satisfied the literature reviewed Garba (2008).

Table 4.8: Sieve Analysis of Coarse Aggregates

BS Sieve Size	Weight Retained (kg)	Weight Passing (kg)	Percentage Passing (%)
19.00mm	0.32	5.68	95
13.20mm	1.94	3.74	62
9.50mm	1.50	2.24	37
4.75mm	1.88	0.36	6
2.36mm	0.24	0.12	2
1.18mm	0.04	0.08	1.3
600μm	0.02	0.06	1
300μm	0.007	0.053	0.88
150μm	0.000	0.053	0.88
Pan	0.000	0.053	0.88

Source: Laboratory Research Work (2014)

Table 4.8 presents results of sieve analysis of coarse aggregates which has been used to determine the fineness modulus calculated as 6.01. The fineness modulus of coarse aggregates should fell within the range of 5.5 – 8.0 (± 0.2) and therefore the coarse aggregates used for this research was in conformity with the literature reviewed Garba (2008).

Table: 4.9: Slump Test of Portland Cement Volcanic Ash Concrete Samples

Concrete sample	Slump (mm)	Room temperature (^0C)
0%	10	25.5
5%	15	25.5
10%	23	25.5

Source: Laboratory Research Work (2014)

Table 4.9 show slump test results of Portland/cement volcanic ash concrete were shear slump with room temperature recorded at 25.5^0C. From the values of the three mixes, the degree of workability of this Portland cement volcanic ash concrete was very low category fell within 0-25mm Neville and Brooks (2010). Mixes with 5% and 10% volcanic ash replacement were more workable than mix with 0% replacement (control). The slump test value of Portland cement/volcanic ash concrete increase with increase in percentage of volcanic ash content in the mix.

4.2 Presentation of Results of Tests on Hardened Concrete

4.2.1 Visual observation

There was no significant wear or tear observed for concrete samples cured in 1.2% concentration of $MgSO_4$ and 1.2% concentration of H_2SO_4 at 90 curing days. But change of colour was noticed which increase with increase in curing periods. Concrete samples that were cured in $MgSO_4$ discoloured to white and those cured in H_2SO_4 discoloured to light milk. Loss of weight of the concrete samples was also noted which can results not to serve it is functional requirement. The concrete samples cured in chemicals can be shown in Plate VIII:

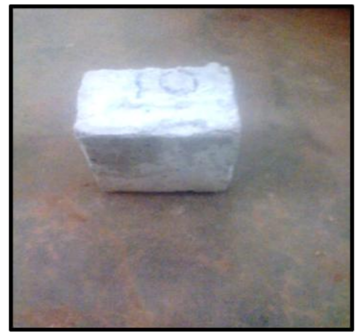

Plate VIII: Concrete samples cured in chemicals at 90 days

4.2.2 Density of hardened concrete samples

Table 4.10: Average Density of Concrete Samples Cured in H_2O

Replacements	7 days	14 days	21 days	28 days	56 days	90 days
0%	2360	2480	2540	2527	2500	2507
5%	2420	2447	2373	2593	2533	2513
10%	2660	2447	2420	2447	2587	2527

Source: Laboratory Research Work (2014)

Table 4.10 presents the average density of Portland cement volcanic ash concrete samples cured in normal water (H_2O) and weighed at 7, 14, 21, 28, 56 and 90 curing days. The density of concrete cube samples varies from 2360 kg/m^3 to 2660 kg/m^3 and it increase with increase in curing periods. Concrete samples with density higher than 2600kg/m^3 are called as higher density concrete samples (Kazjonovs *et al.*, 2010). Therefore, Portland cement volcanic ash concrete is a concrete with ordinary density, though samples with pozzolanic material replacements were denser than the control samples.

Table 4.11: Average Density of Concrete Samples Cured in 1.2% Concentration of $MgSO_4$

Replacements	7 days	14 days	21 days	28 days	56 days	90 days
0%	2500	2407	2387	2333	2393	2310
5%	2440	2387	2387	2493	2453	2467
10%	2507	2613	2573	2547	2453	2487

Source: Laboratory Research Work (2014)

Table 4.11 shows the average density of Portland cement volcanic ash concrete samples cured in $MgSO_4$ and weighed at 7, 14, 21, 28, 56 and 90 curing days. The density of concrete cube samples varies from 2333 kg/m^3 to 2613 kg/m^3 and it decrease with increase in curing periods. There was more loss of density in control concrete samples than in volcanic ash replacement concrete samples of about 7.66% at 90 curing days which can results to failed from it is required function.

Table 4.12: Average Density of Concrete Samples Cured in 1.2% Concentration of H_2SO_4

Replacements	7 days	14 days	21 days	28 days	56 days	90 days
0%	2347	2520	2453	2460	2487	2307
5%	2353	2600	2470	2467	2387	2330
10%	2560	2607	2520	2540	2487	2493

Source: Laboratory Research Work (2014)

Table 4.12 presents the average density of Portland cement volcanic ash concrete samples cured in H_2SO_4 and weighed at 7, 14, 21, 28, 56 and 90 hydration periods. The density of concrete cube samples varies from 2327 kg/m^3 to 2607 kg/m^3 and it decrease with increase in curing periods. From the results H_2SO_4 curing medium has great effect on concrete samples than $MgSO_4$ curing medium and this could be due to attack by both acid and sulphate concurrently Bisschop (Anonymous). There was also more loss of density in control concrete samples than in volcanic ash replacement concrete samples to about 8.06% at 90 hydration periods.

4.2.3 Compressive strength test of hardened concrete samples

Details of all the figures used to present the results for compressive, split tensile, abrasion resistance and water absorption test were attached at appendices. Compressive strength is an important property of concrete and thus, Cement Concrete and Aggregate Australia (CCAA, 2006) stated that concrete achieved about 80 - 100% of it is compressive strength at 28 days. For this reason 28 days compressive and split tensile strength results were picked and discussed while all other curing days were analysed and presented.

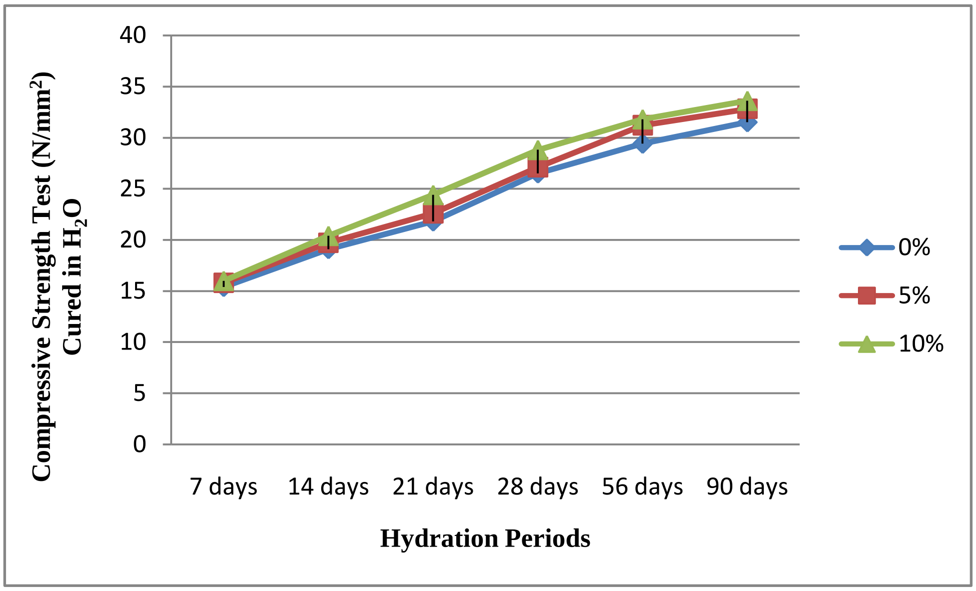

Figure 4.1 Compressive Strength of OPC and OPC/VA Concrete Specimens Cured in H_2O

Figure 4.1 show compressive strength of Portland cement/volcanic ash concrete specimens cured in normal water (H_2O) and crushed at 7, 14, 21, 28, 56 and 90 hydration periods. Concrete samples with 5% and 10% replacement of Portland cement volcanic ash achieved 27.1 N/mm^2 and 28.8 N/mm^2 while 0% replacement achieved 26.5 N/mm^2 at 28 days. This represents 8.68% increase of 10% over 0% volcanic ash replacements in compressive strength. The compressive strength achieved for both control and volcanic ash replacement were below the BS EN 197-01 (2000) requirement which stated that concrete sample should achieved 32.5 N/mm^2 at 28 days. This could be due to the method of compaction applied (manual compaction) during the concrete production. However, the standard requires the use of mechanical compaction to achieve this result.

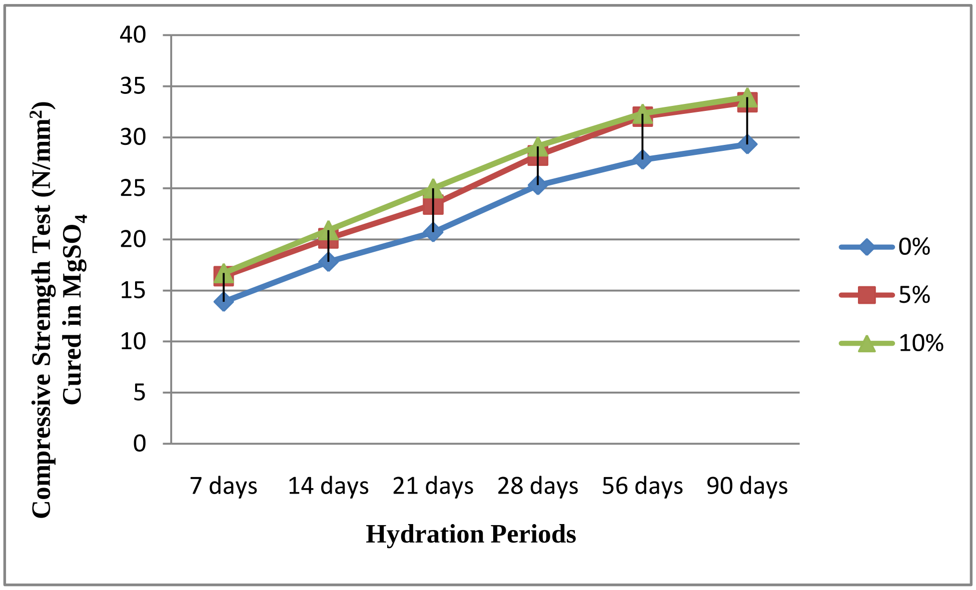

Figure 4.2 Compressive Strength of OPC and OPC/VA Concrete Specimens Cured in 1.2% Concentration of $MgSO_4$

Figure 4.2 presents compressive strength of Portland cement/volcanic ash concrete specimens cured in $MgSO_4$ and crushed at 7, 14, 21, 28, 56 and 90 hydration periods. Concrete samples with 0% replacement (control) encountered great loss in strength. Concrete specimens with 0% volcanic ash replacement achieved only 25.3 N/mm^2 while 5% and 10% replacement of Portland cement volcanic ash achieved 28.2 N/mm^2 and 29.1 N/mm^2 at 28 days. This represents 15.02% decrease of 0% from 10% volcanic ash replacements in compressive strength. The results also show that 5% and 10% replacement can withstand exposure to magnesium sulphates compared to 0% volcanic ash replacement. Also the compressive strength obtained for Portland cement volcanic ash concrete when exposed to this medium were more than the compressive strength obtained in normal curing medium (normal water). This may be as a result of the addition of pozzolanic materials which tally with the assertion made by Osei and Jackson (2012); Duggal (2008); ACI 201.2R (2001).

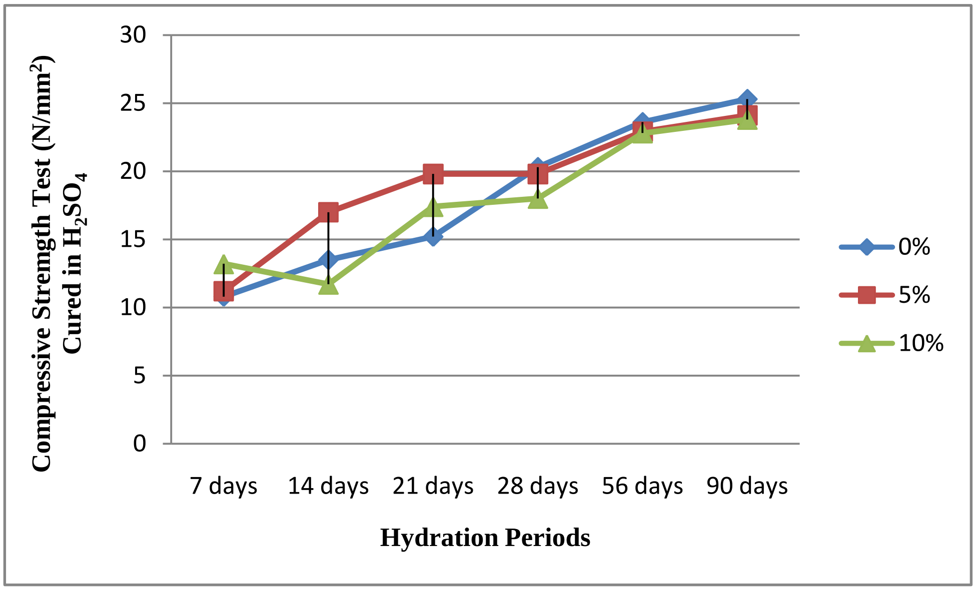

Figure 4.3 Compressive Strength of OPC and OPC/VA Concrete Specimens Cured in 1.2% Concentration of H_2SO_4

Figure 4.3 show compressive strength of Portland cement/volcanic ash concrete specimens cured in H_2SO_4 and crushed at 7, 14, 21, 28, 56 and 90 hydration periods. Concrete samples with 0% volcanic ash replacement withstand sulphuric acid medium better than 5% and 10% replacement. It achieved 20.3 N/mm^2 against 19.8 N/mm^2 and 18.0 N/mm^2 at 28 days. This represents 12.78% decrease of 10% from 0% volcanic ash replacements in compressive strength. This means that H_2SO_4 curing medium are more injurious to concrete samples with volcanic ash replacement than control samples. This has occurred being the curing medium (H_2SO_4) is one of the strong acids that can damage the concrete rapidly depending on the concentration. It damage concrete both in acid and sulphate attack Bisschop (Anonymous).

4.2.4 Split tensile strength test of hardened concrete samples

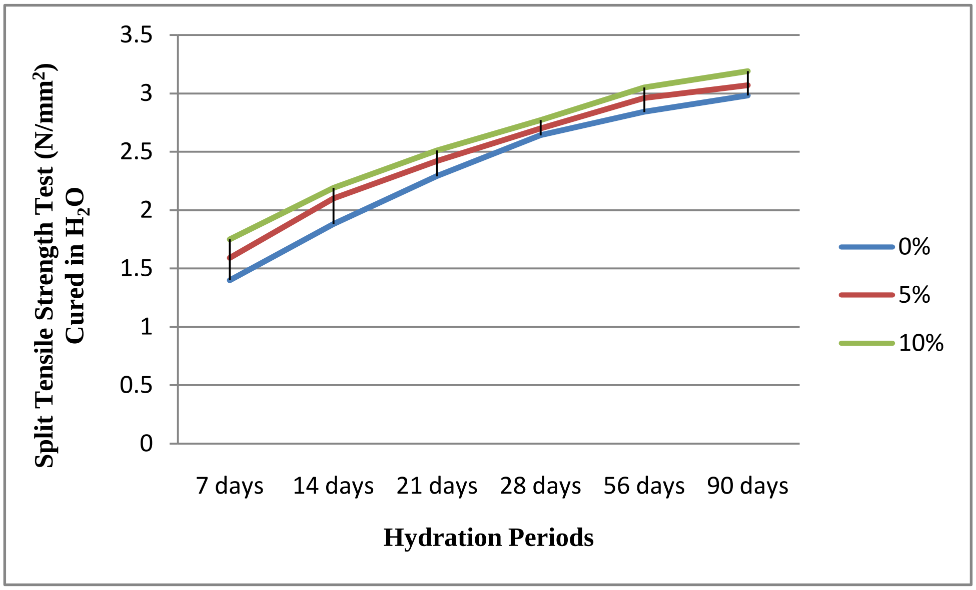

Figure 4.4 Split Tensile Strength of OPC and OPC/VA Concrete Specimens Cured in H_2O

Figure 4.4 show split tensile strength of Portland cement volcanic ash concrete specimens cured in normal water (H_2O) crushed at 7, 14, 21, 28, 56 and 90 curing days. From the results it shows that 0% replacement was the lowest against 5% and 10% replacement attaining 2.64 N/mm^2 against 2.70 N/mm^2 and 2.77 N/mm^2. This means that 10% replacement has higher tensile strength than 0% replacement with about 4.92% increase. The split tensile strength of concrete specimen should be 1/12 to 1/13 of compressive strength Garba (2008). Both the results of control concrete samples and volcanic ash replacement concrete samples were conformed to this.

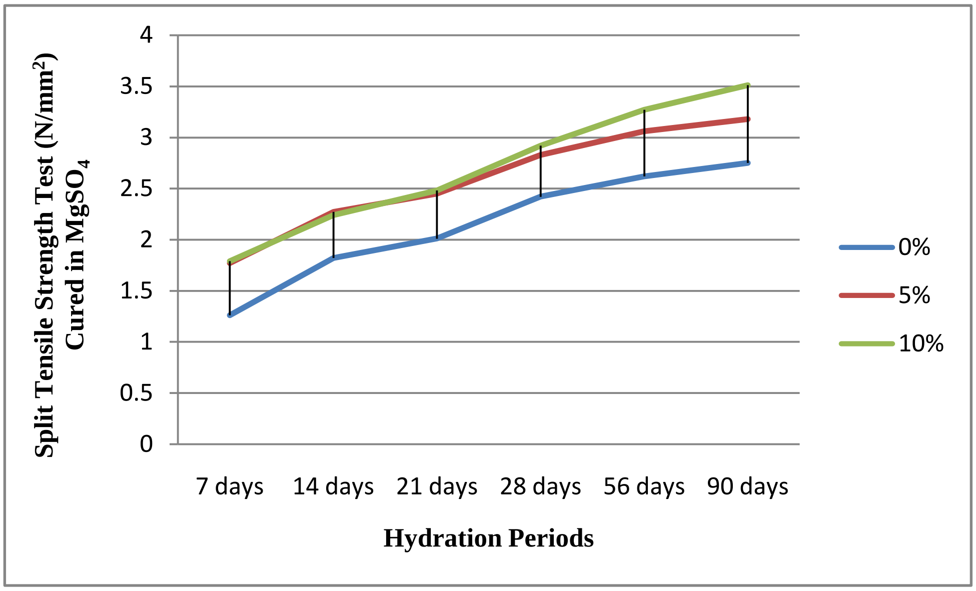

Figure 4.5 Split Tensile Strength of OPC and OPC/VA Concrete Specimens Cured in 1.2% Concentration of $MgSO_4$

Figure 4.5 presents split tensile strength of Portland cement volcanic ash concrete specimens cured in $MgSO_4$ and crushed at 7, 14, 21, 28, 56 and 90 curing days. Concrete samples with 5% and 10% replacement of Portland cement volcanic ash concrete were better, achieving 2.83 N/mm^2 and 2.92 N/mm^2 than 0% replacement which achieved 2.42 N/mm^2 at 28 days. This means that 10% replacement has higher tensile strength than 0% replacement with 20.66% increase. Exposing Portland cement volcanic ash concrete samples to $MgSO_4$ does not have negative effect to split tensile test as the reduction in strength is still within the recommended limit 1/12 to 1/13 Garba (2008).

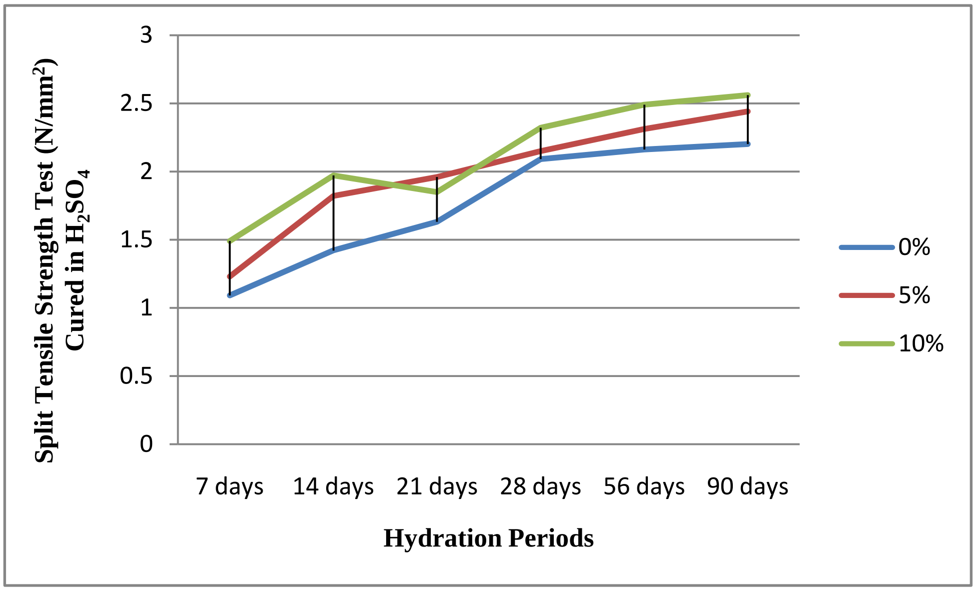

Figure 4.6 Split Tensile Strength of OPC and OPC/VA Concrete Specimens Cured in 1.2% Concentration of H_2SO_4

Figure 4.6 show split tensile strength of Portland cement volcanic ash concrete specimens cured in H_2SO_4 and crushed at 7, 14, 21, 28, 56 and 90 curing days. Concrete samples with 0% replacement cured in this media dropped to 2.09 N/mm^2 while 5% and 10% replacement achieved 2.15 N/mm^2 and 2.32 N/mm^2 at 28 days. This show that 5% and 10% replacement can withstand exposure to sulphuric acids with 11.00% increase than 0% replacement in tensile strength without affecting the 1/12 to 1/13 split tensile strength requirement.

4.2.5 Abrasion resistance test of hardened concrete samples

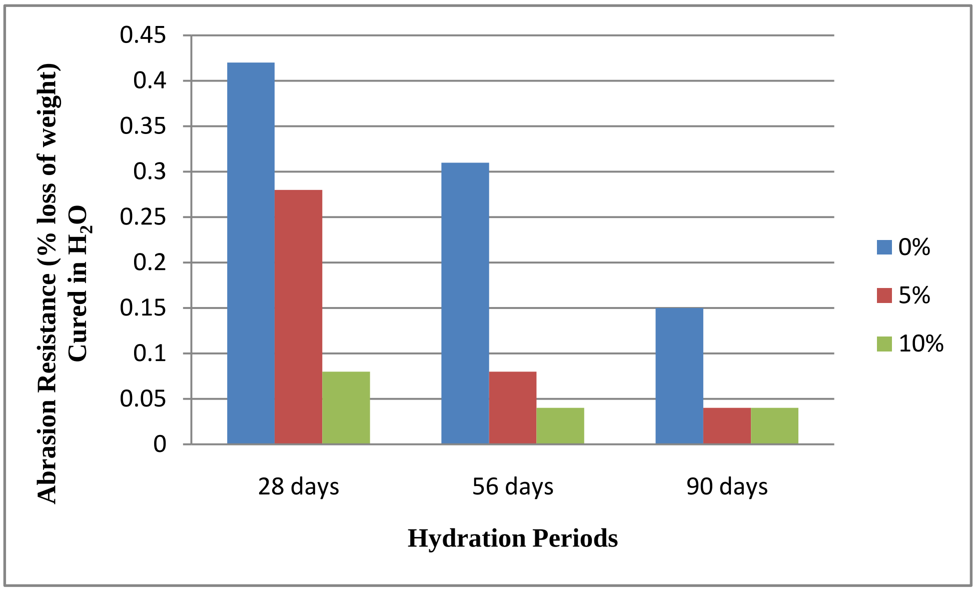

Figure 4.7 Abrasion Resistance Tests of OPC and OPC/VA Concrete Specimens Cured in H_2O

Figure 4.7 presents the abrasion resistance of Portland cement volcanic ash concrete specimens cured in normal (H_2O) and tested at 28, 56 and 90 hydration periods. There was loss of weight of the concrete samples were 0% replacement has high loss of weight as 0.15% than 5% and 10% replacement which both have 0.04% respectively at 90 days. Thus 5% and 10% replacement resist abrasion impact than 0% replacement.

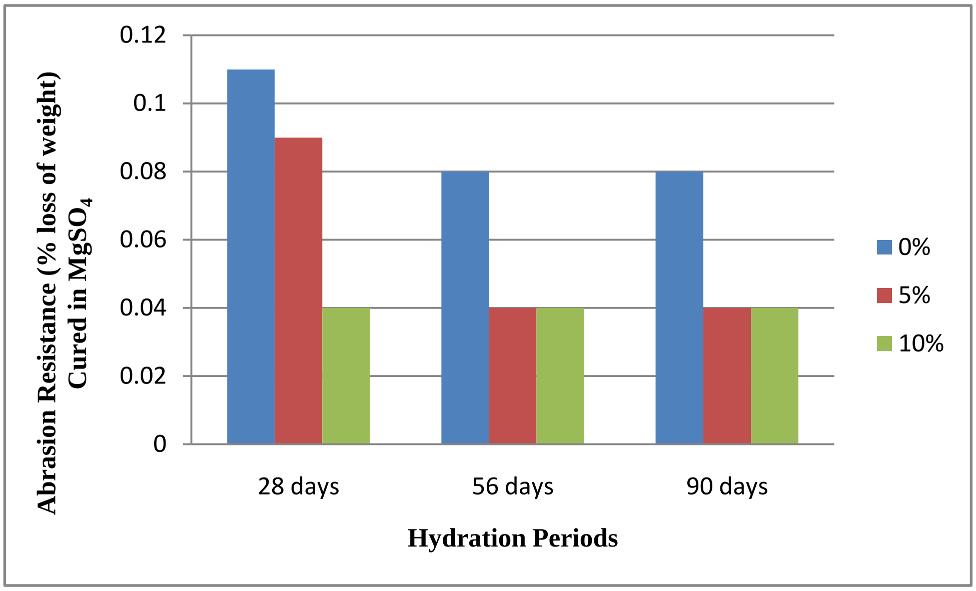

Figure 4.8 Abrasion Resistance Tests of OPC and OPC/VA Concrete Specimens Cured in 1.2 Concentration of $MgSO_4$

Figure 4.8 show the abrasion resistance of Portland cement volcanic ash concrete specimens cured in $MgSO_4$ and tested at 28, 56 and 90 hydration periods. Loss of weight for the concrete samples cured in $MgSO_4$ was not as high as their counterparts that were cured in normal water (H_2O). Concrete samples with 0% replacement loss 0.08% while 5% and 10% replacement loss equal 0.04% respectively at 90 days. This means that 5% and 10% replacement were more resistance to abrasion than 0% replacement when subjected to magnesium sulphate curing medium.

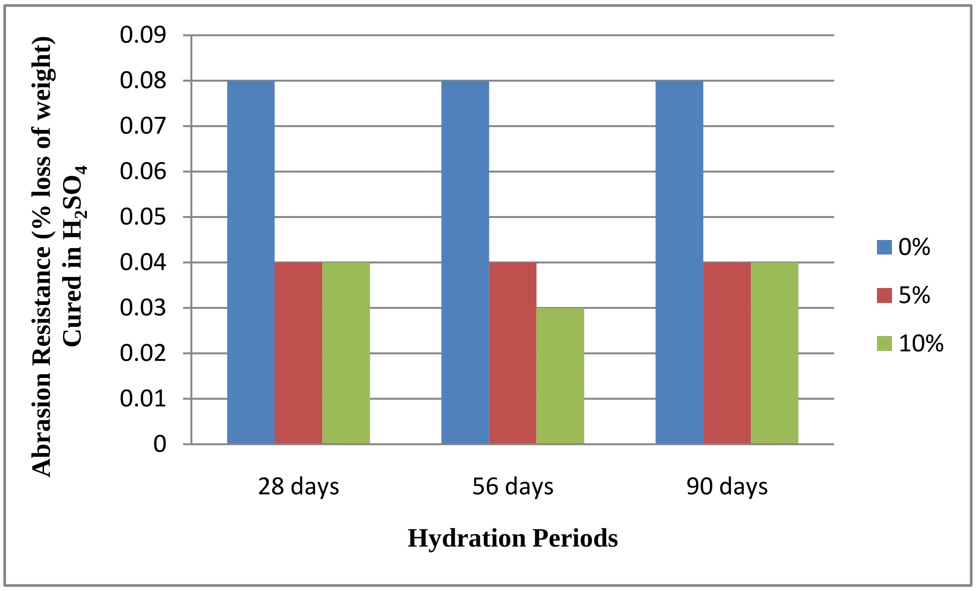

Figure 4.9 Abrasion Resistance Tests of OPC and OPC/VA Concrete Specimens Cured in 1.2% Concentration of H_2SO_4

Figure 4.8 presents the abrasion resistance of Portland cement volcanic ash concrete specimens cured in H_2SO_4 and tested at 28, 56 and 90 hydration periods. Concrete samples with 5% and 10% replacement loss equal weight of 0.04% and 0% replacement loss weight of 0.08% at 90 days. This shows that 5% and 10% replacements withstand abrasion impact when cured in sulphuric acid than 0% replacement.

4.2.6 Water absorption test of hardened concrete samples

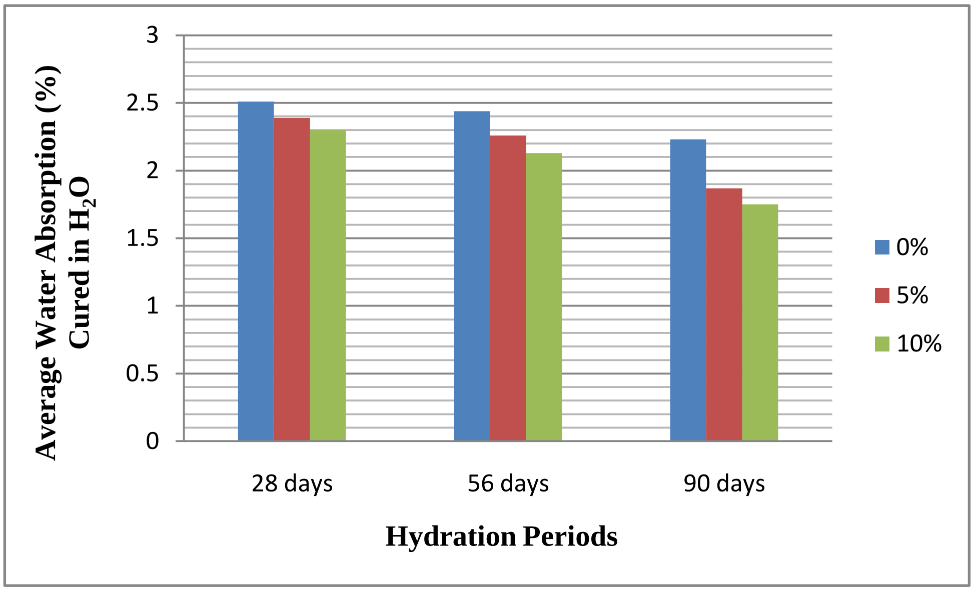

Figure 4.10 Water Absorption Tests of OPC and OPC/VA Concrete Specimens Cured in H_2O

Figure 4.10 show water absorption test of Portland cement volcanic ash concrete specimens cured and tested at 28, 56 and 90 curing days. The degree of sorption of Portland cement volcanic ash concrete in the three curing media has tally with Pitroda and Shah (2014) which stated that the average absorption of the concrete test specimens shall not be greater than 5%. The level of sorptivity of concrete samples reduced with increase in curing days where 0% replacement absorbed more curing agent than 5% and 10% replacement. Concrete samples with 0% replacement absorbed 2.23% while 5% and 10% replacement absorbed 1.87% and 1.75% at 90 days. This means that 5% and 10% replacement absorbed less amount of curing agent than 0% replacement.

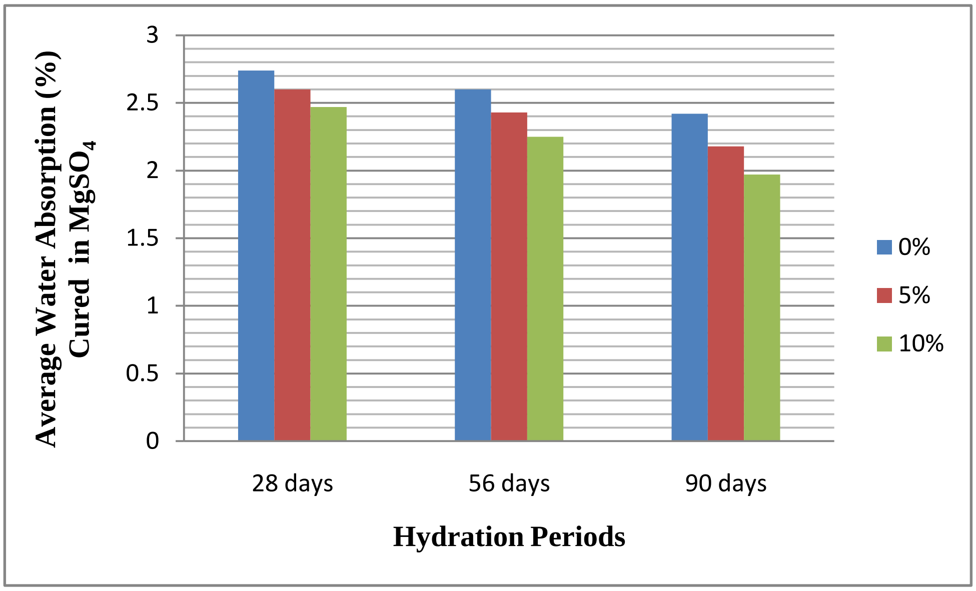

Figure 4.11 Water Absorption Tests of OPC and OPC/VA Concrete Specimens Cured in 1.2% Concentration of $MgSO_4$

Figure 4.11 show water absorption test of Portland cement volcanic ash concrete specimens cured and tested at 28, 56 and 90 curing days. The degree of sorptivity of concrete samples cured in $MgSO_4$ were higher than concrete samples cured in normal water (H_2O). Concrete samples with 0% replacement absorbed 2.42% while 5% and 10% replacement absorbed 2.18% and 1.97% at 90 days. This means that 5% and 10% replacement absorbed less chemical agent than 0% replacement. Hence attack by sulphate may not affect the Portland cement volcanic ash concrete.

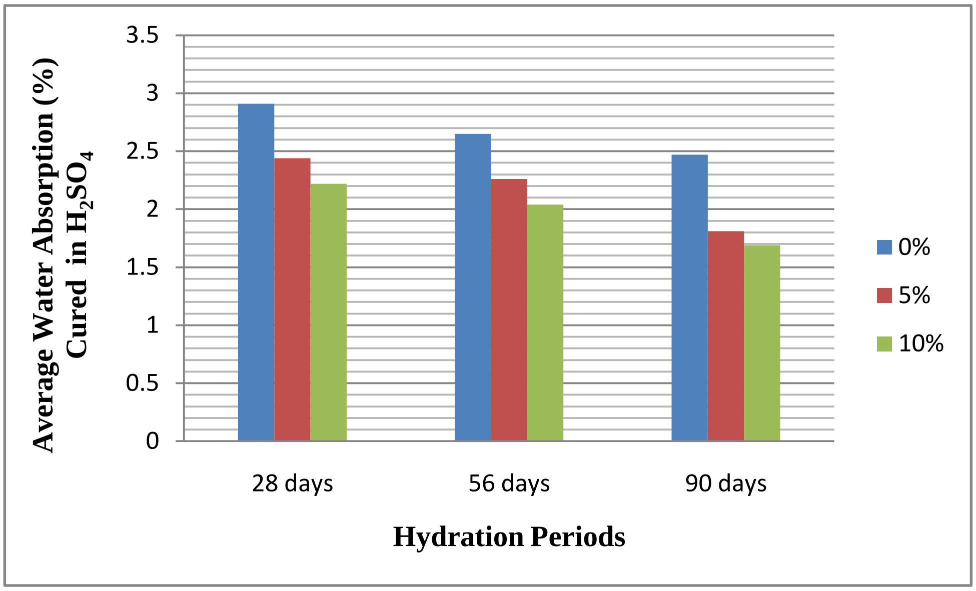

Figure 4.12 Water Absorption Tests of OPC and OPC/VA Concrete Specimens Cured in 1.2% Concentration of H_2SO_4

Figure 4.12 presents water absorption test of Portland cement volcanic ash concrete specimens cured and tested at 28, 56 and 90 curing days. Concrete samples with 0% replacement absorbed 2.47% while 5% and 10% replacement absorbed 1.81% and 1.69% at 90 days. Thus 5% and 10% replacement absorbed less curing medium than 0% replacement when exposed to chemical agent.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Findings

In this research individual properties of constituents of Portland cement/volcanic ash concrete were determined. Durability properties of Portland cement/volcanic ash concrete were evaluated so as to investigate the feasibility of its usage in the chemically aggressive environment. Density and strength properties were also assessed. The highlights of the major findings are as follows:

1. The summation of Aluminium Oxide (Al_2O_3), Silicon Oxide (SiO_2) and Iron Oxide (Fe_2O_3) for Miango JP 3 volcanic ash gave 81.21%. It has high Loss on Ignition (LoI) of 15.87, high moisture content of 5.71 and absence of sulphur trioxide (SO_3).

2. Concrete produced with 10% replacement of Portland cement/volcanic ash was more workable than 0% replacement.

3. 5% and 10% replacement of Portland cement/volcanic ash paste retard setting time than 0% replacement.

4. There were no significant wear or tear observed for concrete samples cured in $MgSO_4$ and H_2SO_4 though the concrete samples cured in $MgSO_4$ discoloured to white and those cured in H_2SO_4 turned to light milk.

5. There was loss of density for 0% volcanic ash replacements (control) concrete samples from 10% volcanic ash replacements exposed to $MgSO_4$ of about 7.66% and 8.06% for concrete samples cured in H_2SO_4 at 90 days.

6. Concrete samples with 10% OPC/VA replacement leads to the increase of compressive strength by 8.68% at 28 days in normal environment. Also concrete samples with 0%

volcanic ash replacements (control) suffered great loss of strength in chemicals media than 5% and 10% replacement.

7. Concrete samples with 10% OPC/VA replacements also leads to the increase in split tensile strength by 4.92% at 28 days in normal environment. There were no significant changes of tensile strength results for concrete samples cured in chemicals media.

8. Portland cement/volcanic ash concrete have high resistance to abrasion and less sorptivity than OPC concrete (control) specimens in both normal and chemically aggressive environments at 90 days.

5.2 Conclusions

Based on the results of the research the following conclusions were drawn:

1. The EDXRF chemical analysis of Miango (JP 3) shows that it has satisfied the ASTM C618-05 requirement as a pozzolanic material.

2. The physical properties such as bulk density, specific gravity and moisture content of volcanic ash were found to be in conformity with ACI E1-99. Setting time and soundness test of Portland cement volcanic ash satisfied the BS EN 197-1 (2000) requirements.

3. Concrete samples with volcanic ash replacements have higher strength both in normal and chemically aggressive environments than control concrete samples.

4. Concrete samples made with pozzolanic material have high resistance to abrasion and less sorptivity in normal and chemically aggressive environments than control concrete samples.

5.3 Recommendations

5.3.1 Recommendations

From the results of this research, the following recommendations were made:

1. The research recommends the use of Miango (JP 3) as a volcanic ash to replace OPC in concrete production to save cost and environment.

2. The use of 10% Miango (JP 3) is the optimum OPC/VA replacement level that can be used to produce durable concrete for construction purposes in both normal and chemically aggressive environment.

3. Use of Miango (JP 3) volcanic ash as an admixture to retard initial and final setting time of OPC/VA concrete is recommended.

5.3.2 Recommendations for further research

1. It is recommended that testing of Portland cement/volcanic ash concrete produced with 5% and 10% replacement be extended to 180, 360 or possibly 720 days to further determine the pozzolanic ability of the concrete both in normal and chemically aggressive environments.

2. It is recommended that the concentration of the chemical curing media for Portland cement/volcanic ash concrete samples be increase to more than 2.0% and tested up to 90 curing days to further assess the severity of the deterioration on the concrete samples.

3. Durability properties are many and varied; therefore further research should be carried out to assess the suitability of this material on fire resistance, shrinkage, creep etc.

4. Detailed cost analysis should be carried out to determine the level of savings possible from the use of Miango JP 3 volcanic ash in concrete.

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APPENDIX ONE

Table 1: Average Compressive Strength of Concrete Samples Cured in H_2O

Replacements	7 days	14 days	21 days	28 days	56 days	90 days
0%	15.4	19.1	21.8	26.5	29.4	31.5
5%	15.8	19.7	22.6	27.1	31.2	32.8
10%	16.0	20.4	24.4	28.8	31.8	33.6

Source: Laboratory Research Work (2014)

Table 2: Average Compressive Strength of Concrete Samples Cured in 1.2% Concentration of $MgSO_4$

Replacements	7 days	14 days	21 days	28 days	56 days	90 days
0%	13.9	17.8	20.7	25.3	27.8	29.3
5%	16.4	20.1	23.4	28.2	32.0	33.4
10%	16.7	20.9	25.0	29.1	32.3	33.9

Source: Laboratory Research Work (2014)

Table 3: Average Compressive Strength of Concrete Samples Cured in 1.2% Concentration of H_2SO_4

Replacements	7 days	14 days	21 days	28 days	56 days	90 days
0%	10.8	13.5	15.2	20.3	23.6	25.3
5%	11.2	17.0	19.8	19.8	22.9	24.1
10%	13.2	11.7	17.4	18.0	22.8	23.8

Source: Laboratory Research Work (2014)

APPENDIX TWO

Table 4: Average Split Tensile Strength of Concrete Samples Cured in H_2O

Replacements	7 days	14 days	21 days	28 days	56 days	90 days
0%	1.40	1.88	2.29	2.64	2.84	2.98
5%	1.59	2.10	2.42	2.70	2.96	3.07
10%	1.75	2.19	2.51	2.77	3.05	3.19

Source: Laboratory Research Work (2014)

Table 5: Average Split Tensile Strength of Concrete Samples Cured in 1.2% Concentration of $MgSO_4$

Replacements	7 days	14 days	21 days	28 days	56 days	90 days
0%	1.26	1.82	2.01	2.42	2.62	2.75
5%	1.77	2.27	2.45	2.83	3.06	3.18
10%	1.79	2.24	2.48	2.92	3.27	3.51

Source: Laboratory Research Work (2014)

Table 6: Average Split Tensile Strength of Concrete Samples Cured in 1.2% Concentration of H_2SO_4

Replacements	7 days	14 days	21 days	28 days	56 days	90 days
0%	1.09	1.42	1.63	2.09	2.16	2.20
5%	1.23	1.82	1.96	2.15	2.31	2.44
10%	1.49	1.97	1.85	2.32	2.49	2.56

Source: Laboratory Research Work (2014)

APPENDIX THREE

Table 7: Average Abrasion Resistance of Concrete Samples Cured in H_2O

Replacements	28 days % loss	56 days % loss	90 days % loss
0%	0.42	0.31	0.15
5%	0.28	0.08	0.04
10%	0.08	0.04	0.04

Source: Laboratory Research Work (2014)

Table 8: Average Abrasion Resistance of Concrete Samples Cured in 1.2% Concentration of $MgSO_4$

Replacements	28 days % loss	56 days % loss	90 days % loss
0%	0.11	0.08	0.08
5%	0.09	0.04	0.04
10%	0.04	0.04	0.04

Source: Laboratory Research Work (2014)

Table 9: Average Abrasion Resistance of Concrete Samples Cured in 1.2% Concentration of H_2SO_4

Replacements	28 days % loss	56 days % loss	90 days % loss
0%	0.08	0.08	0.08
5%	0.08	0.04	0.04
10%	0.04	0.03	0.04

Source: Laboratory Research Work (2014)

APPENDIX FOUR

Table 10: Average Water Absorption Test of Concrete Samples Cured in H_2O

Replacements	28 days % absorbed	56 days % absorbed	90 days % absorbed
0%	2.51	2.44	2.23
5%	2.39	2.26	1.87
10%	2.30	2.13	1.75

Source: Laboratory Research Work (2014)

Table 11: Average Water Absorption Test of Concrete Samples Cured in 1.2% Concentration of $MgSO_4$

Replacements	28 days % absorbed	56 days % absorbed	90 days % absorbed
	2.74	2.60	2.42
	2.60	2.43	2.18
	2.47	2.25	1.97

Source: Laboratory Research Work (2014)

Table 12: Average Water Absorption Test of Concrete Samples Cured in 1.2% Concentration of H_2SO_4

Replacements	28 days % absorbed	56 days % absorbed	90 days % absorbed
0%	2.91	2.65	2.47
5%	2.44	2.26	1.81
10%	2.22	2.04	1.69

Source: Laboratory Research Work (2014)