EFFECTS OF PUMICE AGGREGATE ON THE PROPERTIES OF CONCRETE SUBJECTED TO ELEVATED TEMPERATURE

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Declaration

I declare that the work in the dissertation entitled "EFFECTS OF PUMICE AGGREGATE ON THE PROPERTIES OF CONCRETE SUBJECTED TO ELEVATED TEMPERATURE" has been done by me in the Department of Building, under the supervision of Prof. M. M. Garba. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation report was previously presented for another degree at any university.

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Certification

This is to certify that this dissertation entitled "EFFECTS OF PUMICE AGGREGATE ON THE PROPERTIES OF CONCRETE SUBJECTED TO ELEVATED TEMPERATURE" by Munnir Tukur BABA, has been duly supervised, corrected, hereby approved and meets the regulations governing the award of the Masters Degree (MSc) in Construction Technology, Department of Building, Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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Dedication

This is dedicated, first and foremost, to my parents Alh. Tukur Baba and Haj.Rakiya Tukur Baba (may Janna be her final home) with my beloved wife and children(Muhammad and Fatima Munnir Baba), members of my family, brothers and sisters and to those set of people that help their fellow human beings irrespective of their tribe, religion, race, ideology or social status.

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Abstract

Heat is an aggression that weakens the concrete as a result of change in chemical and physical properties. One of the factors that affect elevated temperature resistance of concrete is the type of aggregate used. Concrete made with light weight aggregates show a better resistance to heat than the one made with siliceous aggregate. Pumice is a light weight aggregate obtained from volcanic action which has good insulation characteristic. This research evaluated the effect of pumice as coarse aggregate on properties of concrete with a view to establish the most suitable proportion of pumice aggregate for the production of concrete. Building Research Establishment (BRE) method of concrete mix design was used to design concrete of grade 25. Workability of the fresh concrete was assessed by slump test. Two set of concrete samples were produced for the study. The first set is the control which was produced using 100% granite aggregate. The second set is the specimens which were produced by replacing 25%, 50%, 75% and 100% of granite aggregate with pumice aggregate. Concrete cube samples of 100 × 100 × 100mm and concrete cylinders of 200 × 100mm were produced and cured in water for 28 days. After 28 days, the concrete samples were removed from curing tank and air dried for 1 hour. After wards, 100 cube samples were tested for compressive strength, tensile strength, abrasion resistance and Ultrasonic Pulse Velocity (UPV). In addition, 100 cubes were subjected to elevated temperatures of 200^{o}C, 400^{o}C, 600^{o}C and 800^{o}C and tested for compressive strength and ultrasonic pulse velocity (UPV). Results show that the density of 25% pumice concrete is in the range of normal weight concrete and 50% and 75% pumice concretes are in the range of medium weight concrete. The 100% pumice concrete is in the range of light weight concrete. The compressive strength decrease as the percentage of pumice aggregate increase in the concrete by a range of 7.68% to 31.14% of the control sample. The residual compressive strength of all the samples

decreases as the temperatures rises up. At 600^oC, the residual compressive strength of the control (0%), 25%, 50%, 75% and 100% pumice concrete are 36.44, 33.96, 39.30, 35.90 and 34.70% respectively. The research concludes that concrete made with 50% pumice showed better resistant to elevated temperatures than the control (0%) concrete sample and recommend that pumice aggregate should be used at 50% replacement of granite aggregate so as to improve the resistance of concrete to elevated temperatures.

Table of Contents

List of Tables

List of Figures

List of Plates

List of Appendices

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Concrete is one of the most versatile and widely produced construction materials in the world (Shetty, 2005). It is widely known as a primary structural material used in construction because of it numerous advantages which include strength, durability, ease of fabrication and non-combustibility properties it has over other construction materials (Venkatesh, 2014). The ever-increasing population, living standards, and economic development lead to an increasing demand for infrastructure development. Concrete is a composite material, it is composed of different graded aggregates embedded in hardened matrix of cementatious material. Concrete is a relatively new construction material when compared to earth, stone, timber and steel. However it is now the most widely used material for building and civil engineering construction. In 2011 alone, over 27 billion tons was used (in comparison to only about 0.7 billion used in 1993) (Garba, 2014). It is relatively strong and less maintained when compared with other construction material. The reasons are that, they neither decay, rot nor rust; they are resistant to wind, water, fire, insects and has the ability to withstand high and low temperatures depending on their strengths (Shetty, 2010).

Concrete strengths are considered important in concrete technology, as they represent the resistant of concrete to rupture (Kosmatka, Beatrix and William, 2003). As for reinforced concrete design theory, compressive strength is identified as an essential strength of concrete, for it is used qualitatively to measure all other properties such as flexural strength, tensile strength, modulus of elasticity, wear resistance, fire resistance, permeability of hardened concrete; it is also used to resist stresses due to compressive forces (Mosley and Bungey, 1992). As stated by

Zongjin (2011), the properties of major constituents of concrete mixtures, such as aggregates, cementation materials, admixtures, and water, should be understood first to better learn the properties and performance of concrete. Concretes are produced in various density classes such as heavy weight, normal weight, light weight and other classes.

Structural lightweight concrete has density in the order of 1440 kg/m^3 to 1840 kg/m^3 compare to normal weight concrete with a density in the range of 2200kg/m^3 to 2600kg/m^3 (Mehta & Monteiro, 2006). As presented by Gupta and Gupta (2012), for structural applications the lightweight concrete should have strength greater than 17 N/mm^2. Structural lightweight concrete can be made about 25% lighter than normal-weight concrete but with a compressive strength of up to 40 N/mm^2 (Shetty, 2005). The primary use of structural lightweight concrete is to reduce the dead load of a concrete structure, which then allows the structural designer to reduce the size of columns, footing and other load bearing elements (National Ready Mixed Concrete Association NRMCA, 2003). Studies indicated that light weight aggregates especially those manufactured in high temperature kiln or furnace have more resistance to high temperature.

Concrete has adequate fire resistance for various applications; but the strength and durability properties of concrete are significantly affected as a result of chemical and physical changes (Koksal, Gervel, Brostow and Hagg, 2012). One of the factors that affect the high temperature resistance of concrete is the properties of the aggregate which play an important role in the degradation process at high temperature. Porosity and mineralogy of the aggregate have significant effects also. Mehta and Monteiro (2006) stated that mineralogy of the aggregate determine differences in thermal expansivities between the aggregate and the cement paste and also bond strength at the interface.

Concrete has excellent properties when it comes to heat resistance compared to other materials and can be used to shield other structural materials such as steel (Sinha, 2013). Fire is one of the natural hazards that can attack building. When concrete is subjected to high temperature, it leads to severe deterioration and it undergoes a number of transformations and reactions, that cause progressive breakdown of cement past structure, reduced durability, increased tendency of drying shrinkage, structural cracking and the associated aggregate color change.

Concrete structural members when used in building have to satisfy appropriate fire safety requirement specified in building code (ACI 216 1, 2007). This is because fire represents one of the most severe environmental conditions that may be subjected (Venkatesh, 2014). According to John and Ban (2003) concrete that resist temperature of up to $1000^{o}C$ are considered as heat resistant concrete and that this temperature is not a fixed boundary but a convenient marker. Most heat resistant concrete are used at temperature below $1000^{o}C$ and sometimes above this temperature. The influence of elevated temperatures on mechanical properties of concrete is of very much importance for fire resistance studies and also for understanding the behavior of containment vessels, chimneys, nuclear reactor pressure vessels during service and ultimate conditions (Vasusmitha and Rao, 2012)

According to Sinha (2013) developments in 1990's have seen a marked increased in the number of structures exposed to elevated temperature which include; nuclear reactor pressure vessels, storage tank for hot crude oil and hot water, coal gasification and pavements subjected to jet engine blast. The extensive use of concrete structural materials in all the above mentioned structures and public utility building, multistory building exposed to element of terrorism necessitated the need to study the behavior of concrete at elevated temperature and its durability for the required needs (Srinivas, Potha and Raju, 2006). Apart from fire, other aggressive environments can compromise the efficiency and durability of concrete structures.

The absence of durability as stated by Gupta and Gupta (2012) may be caused by the environment to which the concrete is exposed to or internal causes within the concrete itself. The external causes can be physical, chemical, or mechanical; they may be due to weathering, extreme temperature, abrasion, electrolytic action and attack by natural or industrial liquids and gases. Shetty (2010) define durability of cement concrete as its ability to resist weathering action, chemical attack, abrasion or any other process of deterioration. It is important that concrete should withstand the condition for which it has been exposed to without deterioration over a period of years, such is called a durable concrete (Page and Page, 2007). The durability of concrete depends on its constituent material. The cement type, the aggregate type whether granite and pumice aggregates influence the durability of concrete made with them

As opine by Doran (1992), the early development in the use of pumice is known to have started during the Roman empire where it was imported from Italy and Greece and used in the construction of the dome of Colosseum and Pantheon in Rome. Pumice has been described as froth like volcanic glass which did not crystallize due to rapid cooling and frothed with sudden release of dissolved gases (Doran, 1992). Further research on pumice as a stone has revealed that it is highly honey-combed and porous. Neville and Brooks (2010) state that pumice stone has a density in the range of 500 kg/m^3-900 kg/m of high absorption and shrinkage level but posses good insulation characteristic.

1.2 Statement of Research Problem

Concrete can be exposed to elevated temperatures during fire or when it is closed to furnaces of reactors. The mechanical properties of concrete decrease remarkably upon heating resulting in a decrease in the structural quality of concrete. High temperature is a physical deterioration process that mostly affects the durability of concrete structure (Aydin, 2008) and this may result in undesirable structural failures.

The high temperature behavior of concrete is greatly affected by material properties such as the properties of aggregate, the cement paste and the aggregates-cement paste bond and also the thermal compatibility between the aggregate and cement paste (Bahar & Oguzhan, 2010)
Neville (1995) noted that at temperatures approximately above 430^{o}C concrete with siliceous aggregates show significant strength loss when compared to light weight aggregates. As already reported by Koksal *et al*. (2012) at temperature of about 600^{o}C, concrete can loss half of its strength while at above 800^{o}C, the loss of strength may reach up to 80% of its strength due to the loss of water bond in the hydrates.

Turker, Exdogdu and Erdo (2001) state that pumice aggregate mortar subjected to high temperature of up to 500^{o}C does not show compressive strength loss and is more resistant to high temperatures than quartzite or limestone. Concrete structural members when used in building have to satisfy appropriate fire safety requirement specified in building code (ACI 216 1, 2007). The influence of elevated temperatures on mechanical properties of concrete is of very much important for heat resistance concrete and also for understanding the behavior of containment vessels, chimneys, nuclear reactor, pressure vessels during the service and ultimate conditions (Vasusmitta and Rao, 2012). This research evaluates the properties of concrete made with varying proportions of pumice aggregate in concrete production when exposed to elevated temperatures.

1.3 Justification for the Study

The current evolvement of the human society and subsequent rising challenges in the construction of taller buildings in the construction industry make it imperative to consider the use of lighter materials that would reduce the total dead load of the structural elements be it on soil with the problem of bearing capacity

Concrete has an enduring capacity to high temperature and fire because of its low thermal conductivity and high specific heat (Morsy, Alsayed and Aqel, 2010). However, it does not mean that fire and high temperature do not affect the concrete. Properties such as compressive strength, color, concrete density, elasticity, surface appearance are all affected by high temperature (Morsy, Rashad and El-Nouhy, 2009).

Therefore, improving the concrete's fire resistance is a field of interest for many researchers. According to studies, it is possible to improve fire resistance of concrete by replacement of cement with pozzolans, addition of polypropylene fiber in concrete mix. However, Morsy *et al*. (2010) state that the attribution to thermal properties of concrete is provided by the type of aggregate.

Natural Light weight aggregates normally undergo heating process during its manufacture and it makes it possesses insulation properties. According to Sinha (2013) the physical compatibility between matrix and aggregate with regard to deformation and expansion characteristics are better in lightweight concrete than in dense concrete which result to less damage and internal stresses. It can also withstand cooling shock much better than gravel concrete.

Similar results were reported by Kong, Evans, Cohen and Roll (1983) and Abeles and Bardhan-Roy (1981) which state that concrete containing lightweight aggregate preserve strength up to 500^{o}C. As reported in volume 63 of the ASTM proceeding in Sinha (2013) work which indicated that aggregates with high porosity and high amount of moisture content has high temperature resistance. These facts made it worthwhile the application of pumice aggregate in construction and simultaneously heat isolation and sound absorption materials.

1.4 Aim and Objectives

1.4.1 Aim

The aim of this research is to evaluate the effect of pumice aggregates on properties of concrete subjected to temperature, this is with the view to produce a heat resistant concrete.

1.4.2 Objectives

The stated aim was pursed through the following objectives, to;

i. determine the properties of the pumice and crushed granite aggregates

ii. assess the workability and strength characteristics of pumice concrete

iii. assess the quality of concrete containing varying proportions of pumice subjected to elevated temperatures and abrasion

1.5 Scope and Limitation

1.5.1 Scope

The research focused on the compressive strength, tensile strength and durability properties of concrete containing varying proportions of pumice aggregate when exposed to temperatures. Concrete of grade 25 strength was maintained throughout the work.

1.5.2 Limitation

This study did not carry out durability properties such as carbonation, freezing and thawing resistance and chlorine absorption.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concrete

Concrete in the broadest sense is any product or mass consisting of fragments and bonded by the use of a cementing medium. Generally this medium is the product of reaction between hydraulic cement and water (Neville & Brooks, 2010). Concrete is heterogeneous in virtually all aspect, because it is a mixture of different materials each of which in itself is not homogenous in nature.

2.2 Classification of Concrete

As presented by Duggal (2008) which classified concrete based on the following:

I. **Cementing material;** Concretes are classified as lime concrete, gypsum concrete and cement concrete.

II. **Perspective Specification;** The cement concrete is specified by proportion of different materials used in making concrete. Example, one (1) cement: two (2) fine aggregate: three(3) coarse aggregate. That is; 1:2:3.

III. **Grading of Cement Concrete**; Concrete is also classified on the basis of grade of strength specified using a cube (150mm side) at 28days as shown in Table 2.1.

Table 2.1. Grade of Cement Concrete

Grade	M5	M7.5	M10	M20	M25	M30	M35	M40	M45	M50	M55
Characteristic Strength(N/mm^2)	5	7.5	10	20	25	30	35	40	45	50	55

Source; Duggal (2008)

IV. Strength as :

a. High strength concrete (strength greater than 30 N/mm^2)

b. Normal strength concrete (strength between 20-29 N/mm^2)

c. Low strength concrete (less than 20 N/mm^2)

V. Bulk density :

a. Super heavy weight (density greater than 2500 kg/m^3)

b. Heavy weight (density of 1899 to 2500 kg/m^3)

c. Light weight (density below 500 kg/m^3)

2.3 Properties of Fresh Concrete

Fresh or plastic concrete is a freshly mixed material which can be moulded into any shape (Gupta and Gupta, 2012). Zongjin (2011) defines fresh concrete as a fully mixed concrete in a rheological state that has not lost its plasticity. The performance requirement of hardened concrete is largely dependent on its properties at fresh stage (Jamilu, 2010). The strength and durability of concrete can be affected if it is deficient in some of its properties such as workability, bleeding and segregation at fresh stage.

2.3.1 Workability

The properties of fresh concrete affect the choice of handling, consolidation and construction sequence (Zongjin, 2011). Workability of concrete is defined in ASTM C125 (2005) as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity (uniform). Shetty (2010) defined the workability of fresh concrete as “the amount of mechanical work, or energy, required to produce full compaction of the concrete without segregation.”

2.3.1.1 Measurement of workability

Workability cannot be measured. It can only be assessed indirectly by measuring the slump or the compacting factor (Shetty, 2010). According to Zongjin (2011) the difficulty in measuring the mechanical work defined in terms of workability, the composite nature of the fresh concrete, and the dependence of the workability on the type and method of construction makes it impossible to develop a well-accepted test method to measure workability.

a) Slump Test

Using the slump test, a mix could have these three different slumps as shown in Figure 2.2.

i. True slump; represent mix with low workability

ii. Shear slump: represent harsh mix, low cement context poor aggregate grading texture.

iii. Collapse slump; represent mix with high workability.

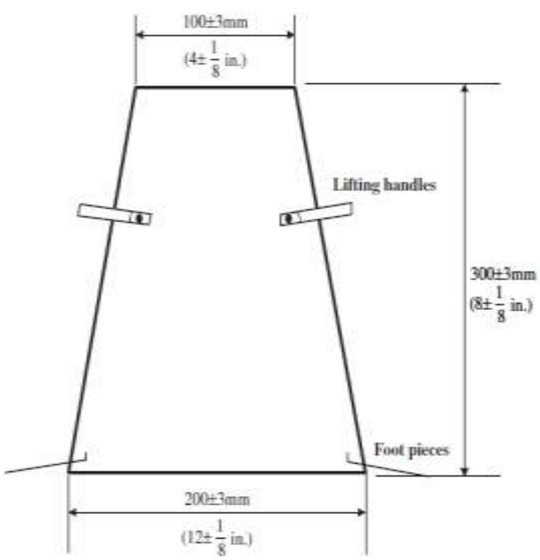

Figure 2.1 Truncated Cone for the Slump Test
Source: Neville and Brooks (2010)

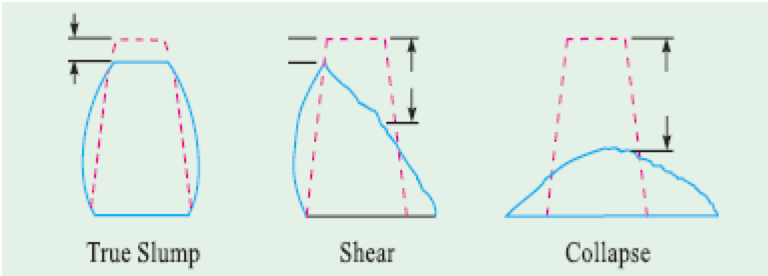

Figure 2.2: Slumps; True, Shear and Collapse
Source: Shetty (2005)

b) Compacting Factor Test

The compacting factor test is a method of measuring the degree of compaction obtained by doing a standard amount of work on the concrete and therefore bears a close relation to workability. The method of test is described fully in B.S 1881(1986)

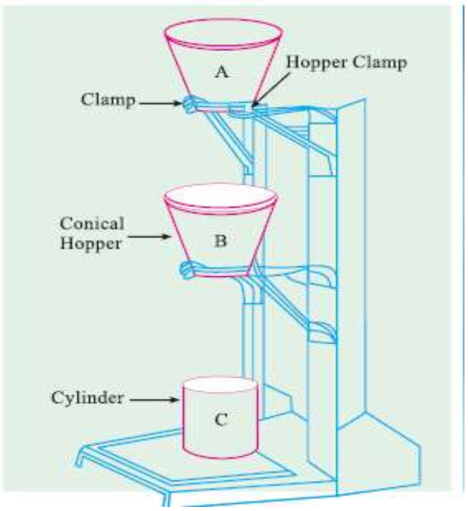

Figure 2.3 Compacting Factor Apparatus
Source: Shetty (2005)

2.3.2 Segregation

In discussing the workability of concrete, it has been pointed out that cohesiveness is an important characteristic of the workability. A proper cohesiveness can ensure concrete to hold all the ingredients in a homogeneous way without any concentration of a single component and even after the full compaction is achieved (Zongjin, 2011).Thus, segregation can be defined as concentration of individual constituents of a heterogeneous (no uniform) mixture so that their distribution is no longer uniform.

There are two (2) forms of segregation, the first one is whereby coarse particles tend to separate out because they tend to travel further along a slope or to settle more than finer particle aggregate materials. The second one occurs particularly in a wet mixes, by the separation of grout (cement plus water) from the mix. The first type of segregation may occur if the mix is too dry, so addition of water would improve the cohesion of the mix, but when the mix becomes too wet the second type of segregation will take place (Neville, 2003).

2.3.3 Bleeding

Bleeding is a form of local concentration of water in some special positions in concrete, usually the bottom of the coarse aggregates, the bottom of the reinforcement, and the top surface of the concrete member. Taylor (1997) defines bleeding as the exudation of water from unhardened concrete.

As a result of bleeding, an interface between aggregates and bulk cement paste is formed, and the top of every lift (layer of concrete placed) may become too wet. If the water is trapped by the superimposed concrete, a porous and weak layer of nondurable concrete may result. If the bleeding water is remixed during the finishing process of the surface, a weak wearing surface can be formed. This can be avoided by delaying the finishing operations until the bleeding water has evaporated, and also by the use of wood floats and avoidance of overworking the surface (Zongjin, 2011).

2.4 Aggregate for Concrete

Aggregates constitute the skeleton of concrete. Approximately three-quarters of the volume of conventional concrete are occupied by aggregate (Shetty, 2010). It is inevitable that a constituent occupying such a large percentage of the mass should contribute important properties to both the fresh and hardened product. Not only may the aggregate limit the strength of concrete but also it properties greatly affect the durability and structural performance of concrete (Neville and Brooks, 2010).

2.4.1 Classification of Aggregates

Aggregates can be divided into several categories according to different criteria, such as size, source and unit weight (Zongjin, 2011). As opined by Duggal (2008), it can also be classified based on geological origin and shape.

2.4.1.1 Classification of Aggregates in Accordance with Size

Coarse aggregate: Aggregates predominately retained on a No. 4 (4.75-mm) sieve are classified as coarse aggregate (Zongjin, 2011). Generally, the size of coarse aggregates range from 5 mm to 150 mm. For structural members such as beams and columns, the maximum size of coarse aggregate is about 25 mm while for mass concrete used for dams or deep foundations, the maximum size can be as large as 150 mm. Plate 2.1 shows some examples of coarse aggregates.

Fine aggregate (sand): Aggregates passing through a No. 4 (4.75 mm) sieve and predominately retained on a No. 200 (75µm) sieve are classified as fine aggregate. River sand is the most commonly used fine aggregate.. In addition, crushed rock fines can be used as fine aggregate. However, the concrete with crushed rock fines is not as good as that with river sand. Plate 2.1 showed the different sizes of aggregates.

5~10 mm 10~14 mm 14~20 mm 20 mm

Plate I : Different sizes of Coarse Aggregates
Source: Zongjin (2011)

2.4.1.2 Classification of Aggregate Based on Unit Weight

In this classification, aggregates are grouped based on their unit weight as normal weight, heavy weight and lightweight aggregates. Gambhir (2006) noted that normal weight aggregates are those which have specific gravities between 2.5 and 2.7 and produce concrete with unit weight ranging from 23 kg/m^3 to 26 kg/m^3 as normal-weight. Heavy-weight aggregates have specific gravities between 2.8 and 2.9 with concrete produce unit weight ranging from 28kg/m^3 to 29kg/m^3 and also lightweight have unit weight up to 12 kg/m^3. As opined by Duggal (2008) aggregates are classified based on unit weight as in Table 2.2.

Table 2.2 Classification of Aggregate based on Unit Weight

Aggregate	Sp. gr.	Unit weight (kN/m^3)	Bulk density (kg/m^3)	Examples
Normal-weight	2.5-2.7	23-26	1520-1680	Sand, gravel, granite sandstone, limestone
Heavy-weight	2.8-2.9	25-29	>2080	Magnetite (Fe_3O_4), Baryte (Ba_3SO_4), scrap iron
Light-weight		12	<1120	Dolomite, pumice, cinder, clay

Source: Duggal (2008)

2.4.1.3 Classification Based on Geological Origin

Aggregates under this category are usually derived from natural sources and may have been naturally reduced to size (e.g gravel) or may have to be reduced by crushing (Shetty, 2005). These aggregates can be further classified as natural aggregates and artificial aggregate.

i. **Natural aggregates**

These are aggregates formed from naturally occurring materials. As presented by Gambhir (2006) the natural aggregates such as gravel and sand are the products of weathering and action of running water. Almost all natural aggregate materials originate from bed rocks (Shetty, 2005). There are three kinds of rocks, namely; igneous, sedimentary and metamorphic rocks. Examples of natural aggregates are sand, crushed gravel, basalt, and sandstone.

ii. Artificial Aggregates

The artificial aggregates are normally produced for some special purposes as burned clay aggregates for making lightweight concrete (Shetty, 2005).

2.6 Properties of Aggregates

The properties to be considered while selecting aggregates for concrete are strength, particles shape, specific gravity, bulk density, voids, porosity, moisture content and bulking (Duggal, 2008). It is stated by Neville and Brooks (2010) that approximately three-quarter of the volume of concrete is occupied by aggregate. It is not surprising that its quality is of considerable importance, not only may the aggregate limit the strength of concrete but the aggregate properties greatly affect the durability and structural performance of concrete.

2.6.1 Physical Properties of Aggregate

The most important physical properties that affect compliance with British Standard and affect the performance of concrete as presented by Dewar and Anderson (1992) are grading, fineness modulus, particle shape and texture, gravity, moisture content, absorption and bulk density.

2.6.1.1 Shape and texture of Aggregate

The shape influences the properties of fresh concrete more than when it has hardened (Duggal, 2008). Rounded aggregate are highly workable but yield low strength concrete. Flaky aggregate require more cement paste, produce maximum voids and are not desirable. Angular shape is the best. Crushed and uncrushed aggregates generally give essentially the same strength for the same cement content. Plate 2.2 showed the different shapes and texture of aggregates we have.

Plate II; Shape and Texture of Aggregates
Source: Zongjin, (2011)

2.6.2 Mechanical Properties

When the mechanical properties of aggregate are being discussed, the strength of the aggregate has to be considered which influence the strength of concrete. The test for mechanical properties of aggregate is due to production of high strength and ultra high strength concrete. And also to manufacture aggregate by industrial process (Shetty, 2010)

2.6.2.1 Aggregate Impact Value

With respect to concrete aggregate toughness is usually considered the resistance of the material to failure by impact. Several attempts to develop a method of test for aggregate have been made. The most successful is the one in which a sample of standard aggregate kept in a moulds is subjected to fifteen blows of a metal hammer of weight 14kgs falling from a height of 38 cm. the quantity of finer material (passing through 2.36 mm) resulting from pounding will indicate the toughness of the sample aggregate. The ratio of the weight of the fines (finer than 2.36mm size) formed, to the weight of the total sample taken is in percentage. It is known as aggregate impact value. IS 283-1970 specifies that aggregate impact value shall not exceed 45 percent by weight for aggregate used for concrete other than wearing surface and 30 percent by weight for concrete for wearing surfaces such as runways, roads and pavements. Figure 2.4 shows a typical impact machine.

Figure 2.4: Aggregate Impact Value Apparatus
Source: Shetty (2010)

2.6.2.2 Aggregate Crushing Value

The compressive strength of parent rock does not exactly indicate the strength of aggregate in concrete (Shetty, 2010). Gupta and Gupta (2012) stated that it is not easy to determine the crushing strength of individual particles. It is the bulk aggregate crushing strength which is determined. For this reason, assessment of strength of the aggregate is made by using a sample of bulk aggregate in a standardized manner. This test is known as aggregate crushing value test. Aggregate crushing value gives a relative measure of the resistance of an aggregate sample to crushing under gradually applied compressive load generally; this test is made on single size aggregates passing 12.5mm and retained on 10mm sieve (Shetty, 2010).

The aggregate is placed in a cylinder mould of size 25mm diameter and 25mm height compressive stress load of 40tons is applied through a plunger. The material crushed to finer than 2.36mm is separated and expressed as percentage of the original weight taking in the mould. The percentage is referred as aggregate crushing value. The crushing value of aggregate is restricted to 30percent for concrete use for loads and pavements. And 45% may be permitted for other structures (Gupta & Gupta, 2012).

2.7 Pumice Aggregate

It is a rock of volcanic origin which occurs in many parts of the world. They are light in weight enough but have sufficient strength to be used as structural light weight aggregate. The light weight of these rocks is due to escaping of gas from the molten lava when erupted from beneath the earth's crest (Gupta and Gupta, 2012).

Pumice concrete is composed of Portland cement, pumice rock, pumice sand and water. It can be pumice rock, river sand and water. It is proportioned, mixed and placed in a similar manner as with conventional sand and gravel concrete. It is used in some application and is placed, screed, trawled and finished with the same equipment.

2.7.1 Properties of Pumice Aggregate Concrete

2.7.1.1 Lightweight Concrete

The most significant of the advantages of pumice concrete is its lightweight quality which is about one third lighter than conventional sand and gravel concrete (Gupta and Gupta, 2012). This contributes to a decrease of structural steel cost and consequently, job costs. Larger volumes of concrete can be handled by lighter equipment with less wear and tear on equipment. The reduction of dead load on structural supports, trusses, girder and slabs can allow extra stories on buildings where dead load is a governing factor. The lightweight pumice concrete also reduces the live load on formwork.

2.7.1.2 Low Conductivity

‘The lower thermal conductivity of pumice concrete provides less heat. Pumice concrete has $4\ times$ the R-value of regular aggregate concrete. This both slows heat transfer and eliminates or reduces moisture condensation on walls and ceilings. Pumice concrete delivers a higher fire rating than normal concrete and will not spall under contact with direct flame. Acoustical rating is higher for a pumice concrete (Shetty, 2009)

2.7.1.3 Durability

Pumice concrete has superior resistance to harsh weather conditions like freezing and thawing. This plus its R-value, makes pumice concrete suitable for colder climates and dramatic changes weather. Pumice concrete is more elastic, for reduced brittleness under earthquake conditions (Gupta & Gupta, 2012).

The superior water absorption/ desorption characteristics of pumice means that the moisture held in the interior of the pumice aggregate is not immediately available for chemical interaction with cement but is extremely beneficial in maintaining longer periods of curing, giving better strength and reduced permeability in the final concrete (ASTM C 127, 1993).

2.8 Durability of Concrete

A durable concrete is one that serve the purpose for which it was designed for, for the specified service condition and the lifespan. The durability of concrete as defined by Gupta and Gupta (2012) is its ability to resist weathering action, chemical attack, abrasion or any other process of deterioration. Durability is mostly related to long-term serviceability of concrete and concrete structures. Serviceability refers to the capability of the structure to perform the functions for which it has been designed and constructed after exposure to a specific environment (Zongjin, 2011).

2.8.1 Significance of Durability

Durability is the ability for a material to last a long time without significant deterioration. According to Jamilu (2010), a durable material helps the environment by conserving resource and reducing wastes and the environmental impacts of repair and replacement.

2.8.2 Causes of Non Durability of Concrete

The factors which cause non durability in concrete may be classified as internal and external factors

a) Internal Factors

These are factors of deterioration within the concrete itself. They can be prevented by careful selection of materials. According to Garba and Zubairu (2002), the internal factors are: Alkaline-aggregate reaction, type of aggregate, permeability of the concrete and thermal properties of the aggregate and cement paste.

b) External Factors

These are factors related to the condition to which the concrete is exposed to. They are factors that can be prevented by correct assessment of the environment where the concrete will be placed and also by application of appropriate protection technique (Jamilu, 2010)

The external causes can be physical, mechanical and chemical whereby these can be grouped in the following categories (Gupta and Gupta, 2012)

i. Environmental, such as occurrence of extreme temperature (fire), abrasion and electrostatic actions.
ii. Chemical attack by natural or industrial liquids and gases such as salts acids and alkali.

2.8.3 Effect of Water-Cement Ratio on Durability

The water-cement ratio has great impact on the durability of the concrete. The higher the water-cement ratio, the more the volume changes (Shetty, 2005). Therefore, the use of higher water-cement ratio leads to permeability which in turn brings about volume change that makes concrete to crack, disintegrate and failure of concrete.

2.8.4 Sulphate Attack on Concrete

Sulphate present in soil, sea water, decay organic matter and industrial effluence surrounding a concrete structure constitute a major threat to the long term durability of concrete exposed to this environment (Gupta and Gupta, 2012). Sulphate attack on concrete may lead to cracking, spalling, increase permeability and strength loss. Therefore, resistance of concrete to sulphate is integral to ensure satisfactory performance over long period

Most soils contain some sulphate in the form of calcium, sodium, potassium and magnesium but magnesium sulphate poses more attack than other sulphates because it decomposes the hydrated calcium silicate completely and make it friable mass (Shetty, 2005)

2.8.5 Abrasion Resistance of Concrete

Abrasion is defined by Taylor (1997) as the resistance to wear due to friction and in the context of concrete refers almost exclusively to floors usually without a surface topping or coating. However, if there is an increase in air entrainment of concrete, there will be low abrasion resistance of concrete.

2.9 Fire Resistance of Concrete

Human safety in the event of fire is one of the major considerations in the design of residential, public and industrial buildings. Therefore, there is the need for the use of materials that provide good service in this respect. Concrete unlike plastic and wood, being incombustible and which emits no toxic fumes on exposure to high temperature could be regarded as one of the best material suitable for the purpose. As stated by Mehta and Monterio (2006) concrete unlike the steel when subjected to temperatures of the order of 700^{o}C to 800^{o}C is able to retain sufficient strength for a reasonable long period.

Concrete structure exposed to fire may be completely destroyed or slightly damaged. The extent of damage depends on the duration of temperature experienced by the structure during the fire. The fire resistance of cement concrete is dependent on many factors. One of the most important of these is the structural characteristics of the aggregate used.

The effectiveness of aggregate to the resistance of fire depends on the voids (absorption) in the aggregate. Blast furnace slag is superior to natural aggregates with respect to this important physical characteristic because of its vesicular (non-interconnected) cell structure and higher absorption rate.

2.9.1 Effect of high temperature on hardened concrete

A number of factors influence the decision regarding the type of concrete to be used under conditions of elevated temperature. These include the following: length of exposure, rate of temperature rise, temperature of concrete at initiation of exposure to high temperature, degree of water saturation of the concrete, type of aggregate used, type of cement used, aggregate / cement ratio, and loading conditions at time of exposure (Eva and Gyorgy, 2009).

2.9.2 Impact of temperature effect on concrete microstructure

2.9.2.1 *Cement paste*

Naus (2006) stated concrete made with ordinary Portland cement and subjected to heat, a number of transformations and reactions occur, even if there is only a moderate increase in temperature. Hager (2013) stated that when cement paste is heated in moist sealed conditions, hydrothermal reactions may take place and the phenomenon called internal autoclaving may occur in large members, where due to heating, moisture is transformed into water vapour. In these conditions chemical and physical changes may take place. The process of simultaneously exposing the material to high pressures and temperature is a well-known technology in the prefabrication of concrete. This may well activate changes in the microstructure of hydrates and often increases cement paste strength (Hager, 2013). According to Hager (2013), the nature of the phase changes will depend upon the mineralogical composition of the cement, its calcium to silica ratio, the amount of fine particles (quartz or silica fume), and the temperature and pressure levels that have been reached. Heating the cement paste with calcium to silica ratio around 1.5 to temperature above 100^{o}C produces several forms of calcium silicates, in general highly porous and weak.

2.9.2.2 Aggregates

Aggregates occupy 70 – 80% of the volume of concrete and thus heavily influence its thermal behaviour. According to Hager (2013), thermal stability of aggregates is the term used to describe aggregates effect on concrete performance at high temperature and thermally stable aggregates are characterized by chemical and physical stability at high temperature, which is determined by dilatometric, thermo-gravimetric, and differential thermal tests. Mineralogical composition determines aggregate thermal strains, since all minerals differ in their thermal expansion properties. It therefore governs the chemical and physical changes that take place during heating (Hager, 2013). The melting temperature varies along the mineralogical composition, for most igneous rocks, it is above 1000◦C. The melting temperature of granites is 1210–1250◦C, while basalts melt at 1050◦C, which is accompanied by gas release and expansion. Limestone (carbonate aggregate) provides higher fire resistance and better spalling resistance than that of siliceous aggregate (predominantly quartz) because carbonate aggregate possesses substantially higher heat capacity (specific heat), it thereby gives benefit for mitigating spalling and also increasing fire resistance. This increase in specific heat is caused by an endothermic reaction occurring around 600^{o}C - 750^{o}C due to dissociation of dolomite in carbonate aggregate concrete. This endothermic reaction absorbs energy supplied by fire and enhances the specific heat of concrete in that temperature range. Generally speaking, aggregates that contain a comparatively high proportion of silica exhibit a higher coefficient of thermal expansion, therefore they should be avoided in concrete which is to be exposed to high temperatures. (Singh, Shivani & Rai, 2003)

2.9.3 Cement paste and aggregate interaction in concrete during heating

Heating of concrete makes its aggregate volume grow and also cause the contraction of the cement paste surrounding it. As a result, the cement paste-aggregate bond is the weakest point in heated cementious material. Damage to concrete to a large extent is caused by cracking, which occurs due to mismatched thermal strains between the coarse aggregates and the matrix (Hager, 2004).

2.10 Ultrasonic Pulse Velocity (UPV)

Non destructive test is now widely used in construction industry to study mechanical properties and integrity of concrete structures. These methods are simple to use and often economically advantageous. The velocity of ultrasonic pulse (UPV) in concrete is governed by its elastic properties and density and can be used to detect internal cracking, voids and variation of the physical properties in concrete due to severe chemical environment, freezing and thawing and heat resistance (Biagiotti, 1997).

The use of UPV test is prescribed in ASTM C 597 (2002). The UPV are affected by: Smoothness of contact surface under test; Moisture condition of concrete; Path length; Temperature; Presence of reinforcing steel ; Age of Concrete (Biagiotti, 1997). It was observed that the wave velocity *Vp*of is a function of the dynamic Young's modulus E, the Poisson's ratio , and the mass density and is given by:

$$V_p = \sqrt{\left(\frac{E(1-v)}{p(1+v)(1-2v)}\right)} \qquad (2.1)$$

Table 2.3 shows the ranges of concrete quality based on the value of UPV (km/s) provided by International Atomic Energy Agency (IAEA, 2002).

Table 2.3: Quality of concrete as a function of UPV

UPV(Km/s)	Concrete quality
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Doubtful
2.0 to 3.0	Poor
Below 2.0	Very poor

Source: Rehman, Ibrahim, Memon and Jameel (2016)

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Materials

Materials that were used in this research work include: cement, coarse aggregates (pumice and granite coarse aggregates), fine aggregate, and water.

3.1.1 Cement

Dangote brand of Ordinary Portland Cement was used for this research as the binder for the specimen and it satisfies the minimum requirement as provided by ASTM C150 (2017).

3.1.2 Pumice coarse aggregate (PCA)

The PCA was obtained from within Mangu market, Mangu Local Government Area of Plateau State. It was crushed manually with sledge hammer. Because it was crushed into various sizes, sieve analysis was carried out in line with BS 933 Parts 1(1997) to determine its particle size distribution. Aggregates that fall between 20 mm to 4.75 mm were used in its saturated surface dry condition (SSD). The result is shown in appendix A1.

3.1.3 Granite coarse aggregate (GCA)

The granite coarse aggregate was obtained from within Zaria, Kwari Quarry Industry, Palladan, Zaria, Kaduna State. Sieve analysis was carried out in accordance to BS 933 Part 1(1997) in order to determine the particle size distribution. The aggregate used comprise of 20mm as its maximum and 4.75mm as its minimum and were used in saturated surface dry (SSD) condition. The result of the sieve analysis is presented in appendix A2.

3.1.4 Fine aggregate

River sand was obtained from within Zaria, Ahmadu Bello University dam. Sieve analysis in accordance to BS EN 933-2(1997) was carried out in order to determine the particle size distribution. It was kept in saturated surface dry (SSD) condition prior to use. The result is presented in appendix A3.

3.1.5Water

Water fit for drinking with PH value of 7 was used for this research. It was used for mixing the concrete as well as for curing.

3.2 Tools and Apparatus Used

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

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

i. Concrete mixing machine
ii. Compressive strength testing machine
iii. Tensile strength testing machine
iv. Weighing machine
v. Oven
vi. Ultrasonic Pulse Velocity testing machine

3.3 Research Method

The research was carried out through the following processes;

3.3.1 Experimental Programme

The various experiments conducted are as follow:

3.3.1.1 Preliminary investigation

The tests that were carried out include the physical and mechanical properties of the materials used for the research and the results are presented in Table 4.1 and 4.2 respectively.

TESTS CARRIED OUT

Particle Size Distribution

The particle size distribution for both the pumice and crushed granite aggregates were determined using sieve analysis as described in accordance with BS 812-103 (1990). This was done in order to determine the grading of the aggregates. The results of the sieve analysis are presented in appendices A1 and A2.

Specific Gravity

The specific gravity of the pumice, granite and fine aggregate were determined by using pyconometer method.Apparatus used were Pyconometer, Oven**,** and BS sieves. The procedure was in accordance to ASTM C 127 (1993).

Bulk Density

This was determined in accordance to BS 812: Part 2 (1995) for the pumice, crushed granite and fine aggregates, at saturated surface dry condition and compacted. The result is presented in table 4.1 and the calculations are in Appendix D

Water Absorption Capacity

The Absorption capacity test was carried out on the aggregates (i.e. the coarse and fine aggregate). This was done as stipulated by BS 1881-122 (1983). The result is presented in table 4.1

Moisture Content.

The procedure specified by BS 812 (1995) was followed strictly during the determination of moisture content of coarse and fine aggregate. The results are shown in table 4.1 in chapter four.

Aggregate impact value and aggregate crushing value

Aggregate impact value test was carried out on the pumice and granite in order to determine their toughness under impact. This was done in accordance to BS 812-112, (1990). The crushing value was also determined to measure the resistance of the PCA, and GCA under applied compressive load. The calculation for the impact and crushing values are shown in Appendix D. Method presented by Shetty (2010) was used to determine the impact and crushing values. The results for both the pumice and granite aggregates impact and crushing values are presented in table 4.2

3.3.2 Production and Testing of concrete Specimen

3.3.2.1 Mix Design

Using Building Research Establishment (BRE) Method of mix design, grade of 25 N/mm^{2}was designed, which resulted to a mix ratio 1.00:2.065:2.85 with water cement ratio of 0.60. The details of the procedure of design are presented in Appendix B.

3.3.2.2 Testing of Fresh Concrete Specimens

Workability test

Before casting the fresh pumice and granite concretes specimens into moulds, workability of each mix of the fresh concretes was assessed by slump test. This was done as recommended by BS 1881-102 (1983).The apparatus that were used in carrying out the slump test includes; steel tamping rod, base plate, hand scoop, trowel and metal cone. It was assessed as shown on Plates 3.1 and 3.2 . the result is presented in table 4.3.

Plate IV: Slump Assessment
Laboratory research work (2018)

Plate V: Slump Assessment
Laboratory research work (2018)

3.3. Tests on Hardened Concrete Specimens:

The concrete samples produced were subjected to compressive strength, tensile strength, abrasion resistance, water absorption and exposure to elevated temperatures of 200^oC, 400^oC, 600^oC, and 800^oC at the end of 28 days of curing. Table 3.1 gives the breakdown of cubes produced. The details of various test conducted are described in the sections that follow:

Table 3.1: Breakdown of Concrete Specimens, Tests and Curing Days

Test	**Curing days**	**Varying Samples** 0%	25%	50%	75%	100%
Compressive Strength		5	5	5	5	5
Tensile Strength		5	5	5	5	5
Absorption Capacity	28	5	5	5	5	5
Abrasion Resistance		5	5	5	5	5
Elevated Temperature		20	20	20	20	20
Total no of Specimens	= 200					

Laboratory research work (2018)

3.3.1 Compressive Strength Test

The test was done in according to BS EN 12390:3 (2002). Cubes of 100 mm x100 mm x100 mm size were crushed at saturated surface dry condition. The crushing tests were carried out at 28 days using the hydraulic crushing machine of 1000 KN capacity. The compressive strength (f_{cu}) was determined using equation 3.1. The result is presented in Appendix C2

$$f_{cu} = \frac{P}{A} \qquad (3.1)$$

Where; P= Load from the test machine.

A= Area of the cube.

3.3.2 Tensile Strength Test

Tensile strength was carried out on the concrete cylinder specimen produced by applying load gradually.The test was carried out after 28 days curring using the hydraulic crushing machine of 1000 KN capacity. It was conducted in accordance with the BS EN 12390:6 (2000).

The tensile strength (f_y) was determined from equation 3.2. The result is presented in Appendix C3

$$f_y = \frac{2P}{\pi DL} \qquad (3.2)$$

Where P = Load at failure from machine

D = diameter of cylinder

L = length of cylinder

3.3.3 Water Absorption Test

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

The specimens were oven-dried at 105^0C for 24 hours then removed from the oven and allowed to cool at room temperature to determine the initial weight and recorded as W_1. The specimens were immersed in water for 24 hours then removed and surface dried, re-weighed and recorded as W_2. The percentage of water absorption was calculated using equation 3.3. The result is presented in Appendix C6

$$Water\ absorption\ (\%) = \frac{W2 - W1}{W1}\ X\ 100 \qquad (3.3)$$

3.3.4 Abrasion Resistance Test

The abrasion resistance test was conducted in accordance with African Regional Standard (ARS) 674 (1996). Three specimens at 28 days age of curing were used for the experiment. The surfaces of the concrete cubes were subjected to brushing by means of a wire brush. The brushing consisted of forward and backward motion per second for one minute. The mass of the cubes before brushing was measured and recorded as W1 and after brushing, the mass was recorded as W2. The loss in weight was calculated by subtracting the final weight from the initial weight ($W_1 - W_2$).

Abrasion resistance is calculated as presented by Ibrahim (2015), using the formula:

$$abraded\ material = \frac{W1 - W2}{W2}\ X\ 100 \qquad (3.4)$$

3.3.5 Elevated Temperature

An electrically heated furnace designed for a maximum temperature of 3000^0C shown in Plate 3.3 was used. At the age of 28 days, the concrete cubes were removed from water and dried in air for 24 hours under laboratory conditions. The cubes were then placed in a ventilated oven at 105^0C for 24 hours before subjecting them to high temperature. Surface drying and preheating was very necessary to avoid the explosion of the concrete cubes in the furnace due to the formation of steam when the concrete is subjected to elevated temperature (Chow hurry, 2014). Five (5) cubes from each of the concrete specimens produced with different proportions of pumice of 0%, 25%, 50% 75% and 100% replacement were exposed to elevated temperatures of 200^oC, 400^oC, 600^oC and 800^oC for 2 hours. The heating rate was maintained at 20^oC /min. The specimens were allowed to cool at the rate of 20^oC /min and stored in dry condition at room temperature for 2 hours until testing. Loss in weight, U.P.V test and residual compressive strength of the concrete were determined. The tests were carried out at Chemical Engineering laboratory of Ahmadu Bello University, Zaria. The results are shown in appendices C4 and C5

Plate VI; An electrically heated furnace
Laboratory research work (2018)

3.3.5.1 Ultrasonic Pulse Velocity Test

The test was conducted at curing age of 28 days which is in accordance to the requirement of BS EN 12504-4 (2004). It was carried out at Civil Engineering laboratory of the Ahmadu Bello University, Zaria to determine how well the particles of the concrete are packed under normal curing condition and when subjected to elevated temperature. The cubes were subjected to ultrasonic pulse and the transmitting time taken by the wave to pass through the cube was measured and recorded as shown in Plate 3.4. The pulse velocity was calculated using the following equation.

$$\text{Pulse Velocity} = \frac{Distance\ \ move\ \ by\ pulse}{Time\ \ taken} \qquad (3.5)$$

Plate VII: Ultrasonic Pulse Velocity Machine Laboratory research work (2018)

3.4 Method of Data Analysis

The results of the conducted tests were analyzed using simple descriptive statistical tools. The method of presentation adopted is by using tables, graphs and charts.

CHAPTER FOUR

4.0 DATA PRESENTATION, ANALYSIS AND DISCUSSION

4.1 Data Presentation and Analysis

This chapter presents the results of the laboratory experiment conducted on materials used for the research. Preliminaries tests were conducted on the aggregates used. Tests were carried out on concrete when fresh and hardened. Six (6) concrete properties were tested; these included workability, compressive strength, tensile strength, abrasion resistance, water absorption capacity and residual compressive strength after exposure to elevated temperatures.

4.2 Physical and Mechanical Properties of the Aggregates

4.2.1 Physical Properties

In determining the properties of crushed pumice, crushed granite and river sand aggregates in concrete, the results in Table 4.1 were obtained.

Table 4.1; Physical Properties of the Aggregates

Tests	Materials		
	Fine Aggregate	Pumice Aggregate	Granite Aggregate
Bulk Density(kg/m^3)	1450	589	1557
Specific Gravity	2.65	1.28	2.55
Moisture Content (%)	0.85	1.0	0.42
Absorption Capacity (%)	1.5	20	0.8

Laboratory research work (2018)

The bulk density of pumice from Table 4.1 indicated that the aggregate is a lightweight aggregate with a value of 589 kg/m^3 and the granite aggregate is a normal weight aggregate with value 1557 kg/m^3. The results are in line with what have been opined by Mehta and Monteiro (2006); Gupta and Gupta (2012). The specific gravity of the pumice and granite are 1.28 and

2.55 respectively and they are in the range of lightweight and normal weight aggregates (Duggal, 2008).

The results of moisture content of pumice and granite aggregates are 1.0% and 0.42% with absorption capacities of 20% and 0.80% respectively. The moisture content and absorption capacity of an aggregate is a measure of porosity and strength of that material (Mehta and Monteiro, 2006). The higher the moisture content and absorption capacity of material, the lesser the strength and more porous the aggregates. Therefore, the result indicated that granite aggregate is stronger than pumice aggregate. But the porosity of the pumice may be said to be good for high temperature resistance concrete (Sinha, 2013)

4.2.2 Mechanical Properties

The mechanical properties of the pumice and granite aggregates determined here are the impact and crushing values which indicate the strength of the aggregates used for concrete specimens.

Table 4.2: Result of Mechanical Properties of the Aggregates

Properties	Pumice Aggregate	Granite Aggregate
Impact Values	23.75%	10.33%
Crushing Values	43.00%	19.50%

Laboratory research work (2018)

Table 4.2 presents the results of impact and crushing values of the aggregates. The pumice aggregate has higher impact and crushing values of 23.75% and 43.00% respectively whereas granite aggregate has 10.33% and 19.50%. The results indicated pumice can only be used for concrete other than wearing surfaces as presented by Shetty (2005) that maximum impact and crushing values of 30% of aggregate for concrete use for wearing surfaces and 45% for other structural elements.

4.3 Properties of Fresh Concrete

Table 4.3 depicts the result of slump test conducted on concrete with varying proportion of pumice aggregate of 0%, 25%, 50%, 75%, and 100% replacement mixes at fresh stage.

Table 4.3: Workability Test Result of Concrete Mix

Pumice aggregate content (%)	W/C Ratio	Slump (mm)	Slump Type	Degree of Workability
0	0.60	68	True Slump	Medium
25	0.60	80	Shear	Medium
50	0.60	115	Shear	Medium
75	0.60	135	Shear	High
100	0.60	-	Collapse	High

Laboratory research work (2018)

It can be seen that the slump of the concrete mix increases with the increase of pumice replacement. This increase of the slump may be as a result of increased in moisture content of the pumice aggregate as presented by Gupta and Gupta (2012). The degree of workability of the mixes of the control, 25% pumice and 50% pumice replacement are in the range of what specified by Gambhir (2006) as 25mm – 125mm slump height.

4.4 Properties of Hardened Concrete

The hardened properties of concrete studied include; density, compressive strength, tensile strength, water absorption and abrasion resistance.

4.4.1 Density of Concrete Specimens

Figure 4.1 presents the result of density test of different concrete specimens. There is decrease in density as the percentage of pumice replacement increases. The values of density for 25%

pumice, 50% pumice, 75% pumice and 100% pumice concrete are 8.44%, 19.57%, 25.56% and 31.52% lesser than 0% pumice.

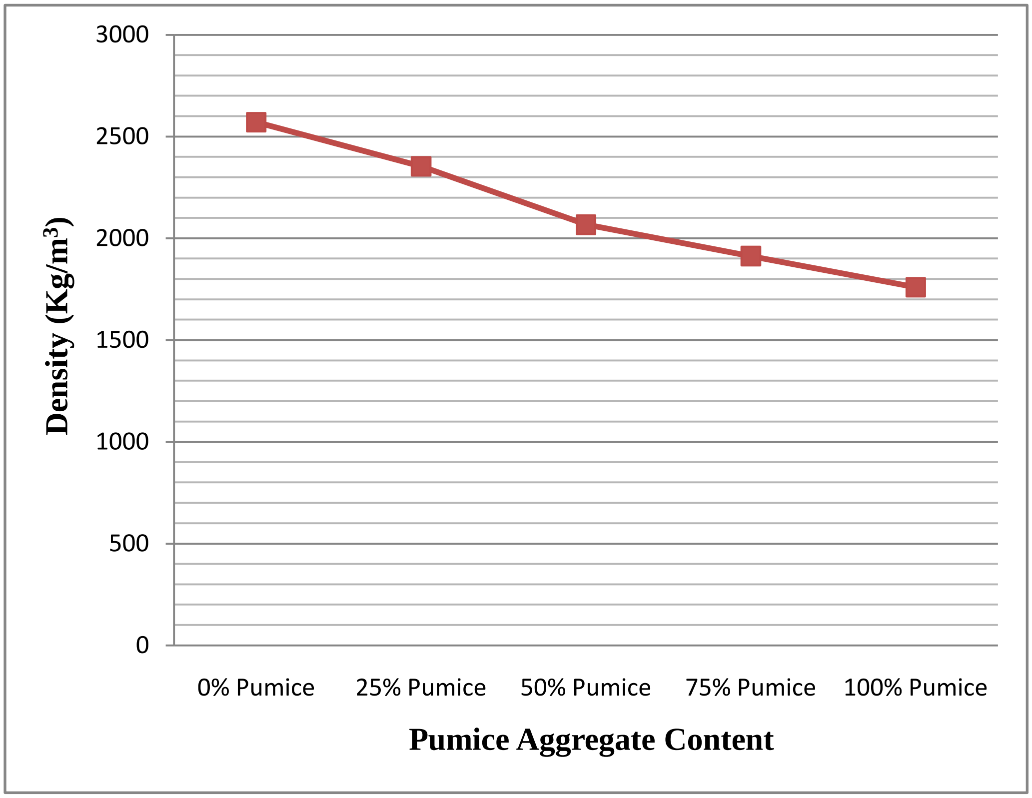

Figure 4.1: Density of concrete specimens
Laboratory Experiment (2018)

The density values for 0% pumice and 25% pumice concretes are within the specified limit of 2200 to 2600 kg/m^3 for normal weight concrete as presented by Gupta and Gupta (2012). The density value for 100% pumice concrete is in line with what Mehta and Menteiro (2006) stated as lightweight concrete with range of 1440 to 1840 kg/m^3. The density values for 50% pumice and 75% pumice concrete showed that they are neither lightweight nor normal weight concrete. Therefore, they can be classified as medium weight concrete. The density determined is presented in Appendix C1.

4.4.2 Compressive Strength of Concrete

The Compressive strength was determined on different concrete samples containing various percentage replacements of granite with pumice aggregate.

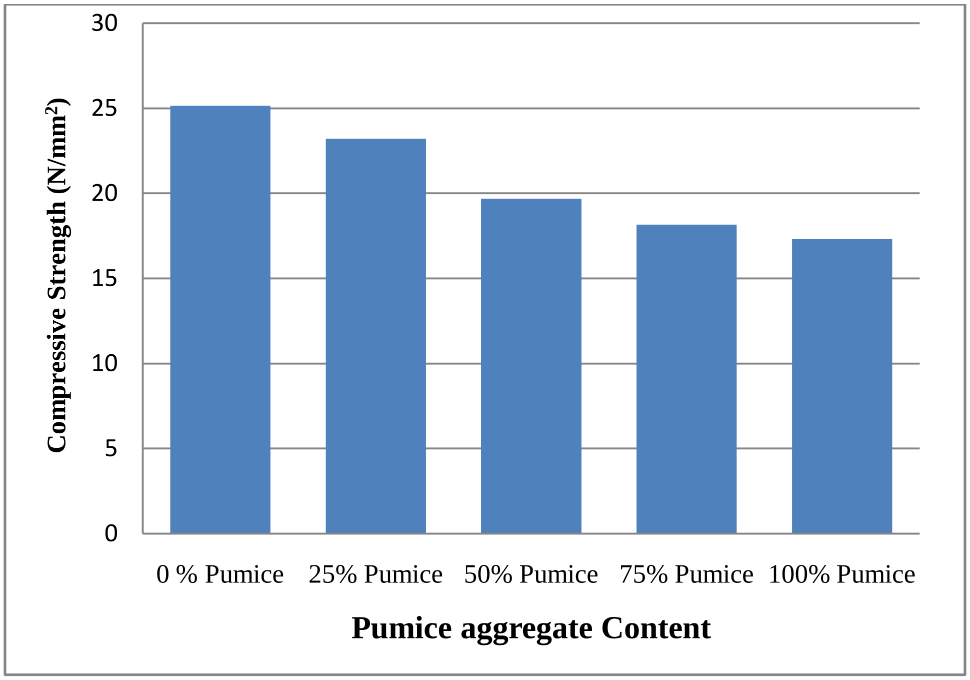

Figure 4.2: Compressive strength of concrete samples at 28 days curing Laboratory Experiment (2018)

Figure 4.2 gives the results of the compressive strength test at 28 days curing age. The strength for l 0% pumice sample attained 100% of the designed strength conforming to BS 5075 (1982) which states that at least 90% should be attained. The strength determined is presented in Appendix C2. For the 25% pumice concrete, the strength recorded was 92.32% of the control which is also in line with the Standard (BS 5075, 1982). The strength obtained for 50% pumice, 75% pumice and 100% pumice concretes are 21.72%, 27.72% and 31.15% respectively, they are less than the strength of 0% pumice concrete sample. The reduction in strength could be due to the lower strength and higher void content of the pumice aggregate (Shetty, 2005). The compressive strength obtained for 50% pumice, 75% pumice and 100% pumice concretes are in line with what was presented by Gupta and Gupta (2012) which state that for structural application, lightweight concrete should not be less than 17 N/mm^2 at 28 days curing age.

4.4.3 Tensile Strengths of Concrete

Figure 4.3 presents the tensile strength of concrete produced with different percentage of pumice aggregate. The values determined for tensile strength are presented in Appendix C3

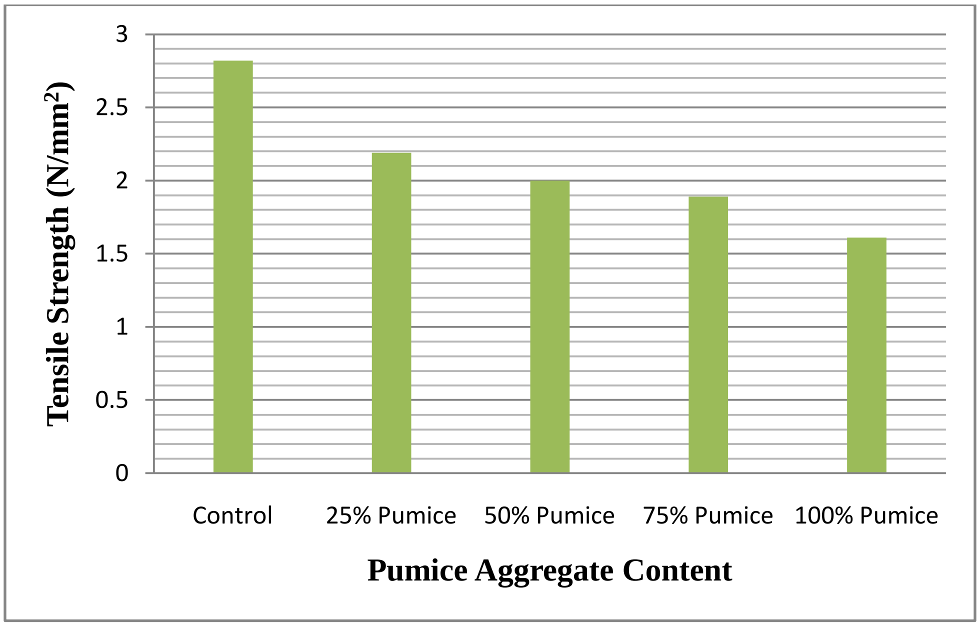

Figure 4.3: Tensile Strength of Samples at 28 days Curing Age
Source: Laboratory Experiment (2018)

The tensile strength of the specimens kept reducing as the percentage of pumice was increased. This could be as a result of the type of aggregate used (Shetty, 2010). The tensile strength for the 0% is 11% of it compressive strength. The results for 25% pumice, 50% pumice, 75% pumice and 100% pumice concretes are 9.43%, 10.16%, 10.40% and 9.30% of their compressive strengths respectively. It indicated that all the results of the concretes are within the range of 7 – 11% as presented by Gupta and Gupta (2012).

4.4.4 Ultrasonic pulse velocity (UPV) for Concrete Specimens

The results of UPV obtained on the 0% pumice (control), 25% pumice, 50% pumice, 75% pumice and 100% pumice concrete samples at 28 days is presented in figure 4.4. The UPV values increase linearly with increase in percentage of pumice for up to 50% replacement. The result determined for UPV is presented in Appendix C4.

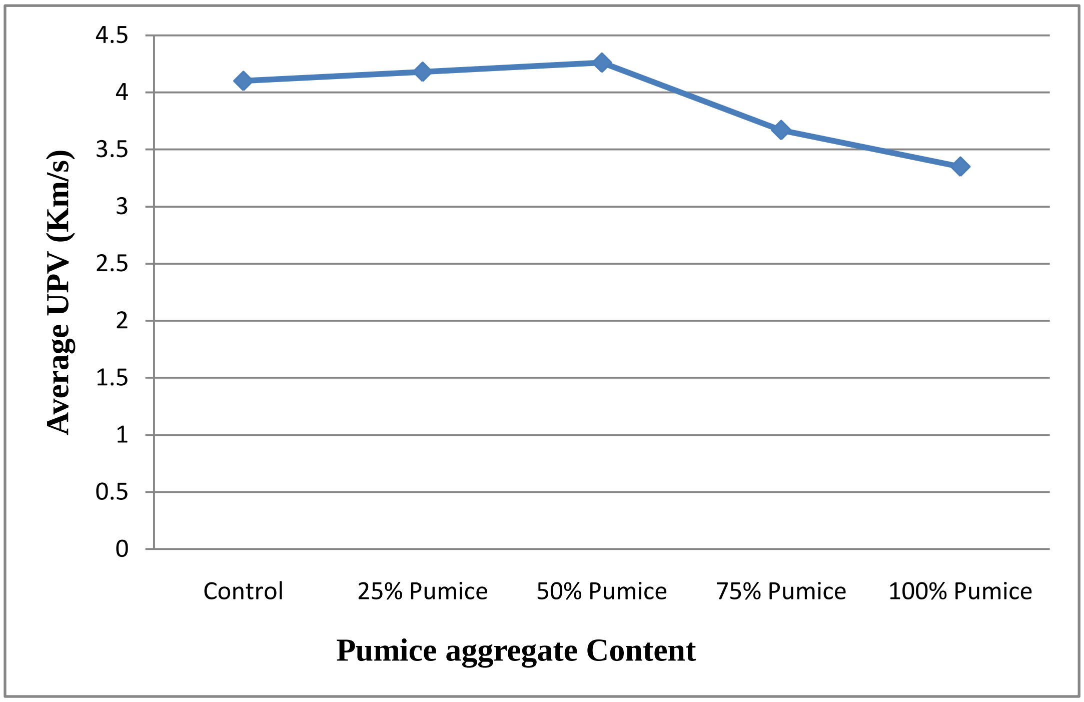

Figure 4.4: Ultrasonic Pulse Velocity
Source: Laboratory Experiment (2018)

A decrease in quality of concrete for 75% and 100% pumice replacement was noticed. This is because higher velocities were obtained when the quality of concrete in terms of density, homogeneity and uniformity is good (Lawson, Danso, Odoi and Adjei, 2011)

All of the concrete 0%, 25%, 50% and 75% pumice have good concrete quality except for 100% pumice concrete which has doubtful quality concrete. The results obtained are in accordance with the provision of BS 1881 (1983) and IAEA (2002).

4.4.5. Water absorption capacity of Concrete.

The test results of water absorption capacity of the 0% pumice (control), 25% pumice, 50% pumice, 75% pumice and 100% pumice concrete at 28 days curing age are shown in Figure 4.5. The values recorded for absorption capacity are presented in appendix C6.

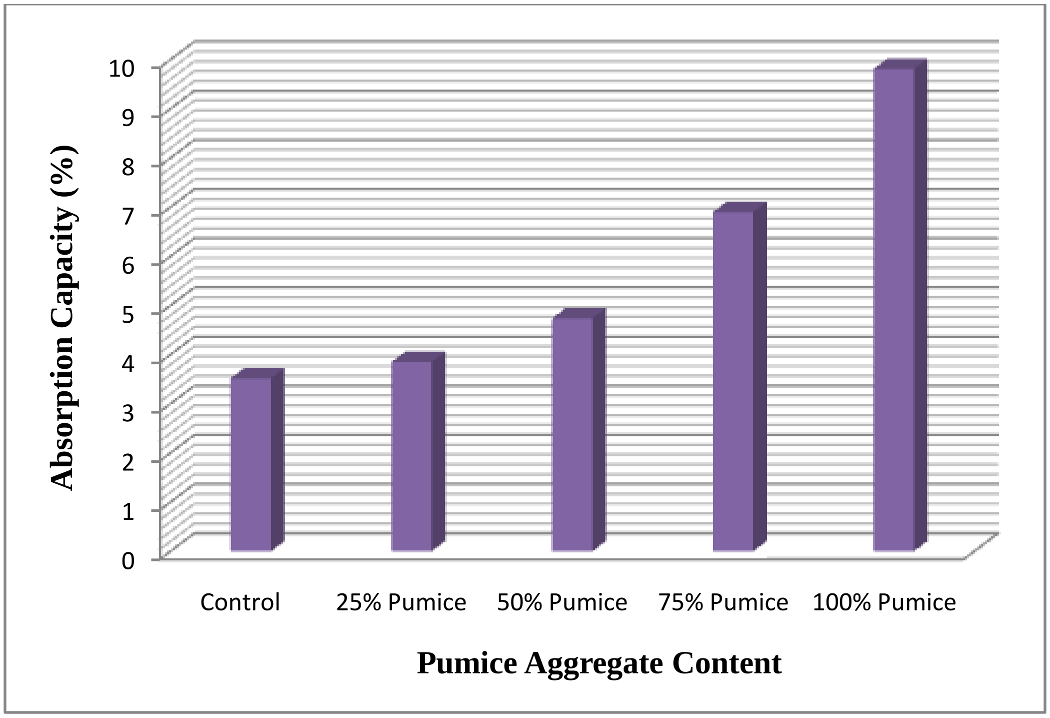

Figure 4.5: Water Absorption Capacity of Concrete at 28 days Curing Age Laboratory Experiment (2018)

The results indicate that the 0% pumice concrete has least absorption capacity of 3.52% whereas the 100% pumice concrete has the absorption capacity of 9.10%. The absorption capacity of all the concretes increases with increase in the percentage of pumice. This could be as a result of pore spaces of the pumice aggregate and high absorption capacity. The result for the 0% pumice, 25% pumice and 50% pumice concretes agree with the conclusion made by Shah, Aslam, Shah and Ord (2014) which state that average absorption capacity of concrete should not be greater than 5%.

4.4.6. Abrasion Resistance of Concrete Samples

Figure 4.6 shows that concrete made with 100% pumice has least resistance to abrasion than the 0% and 25% pumice concrete with weight loss of 0.09%. From the 25% pumice concrete, the abrasion resistance increases with increase in percentage replacement of granite with pumice aggregate. This could be as a result of the low crushing strength of the pumice aggregate material.

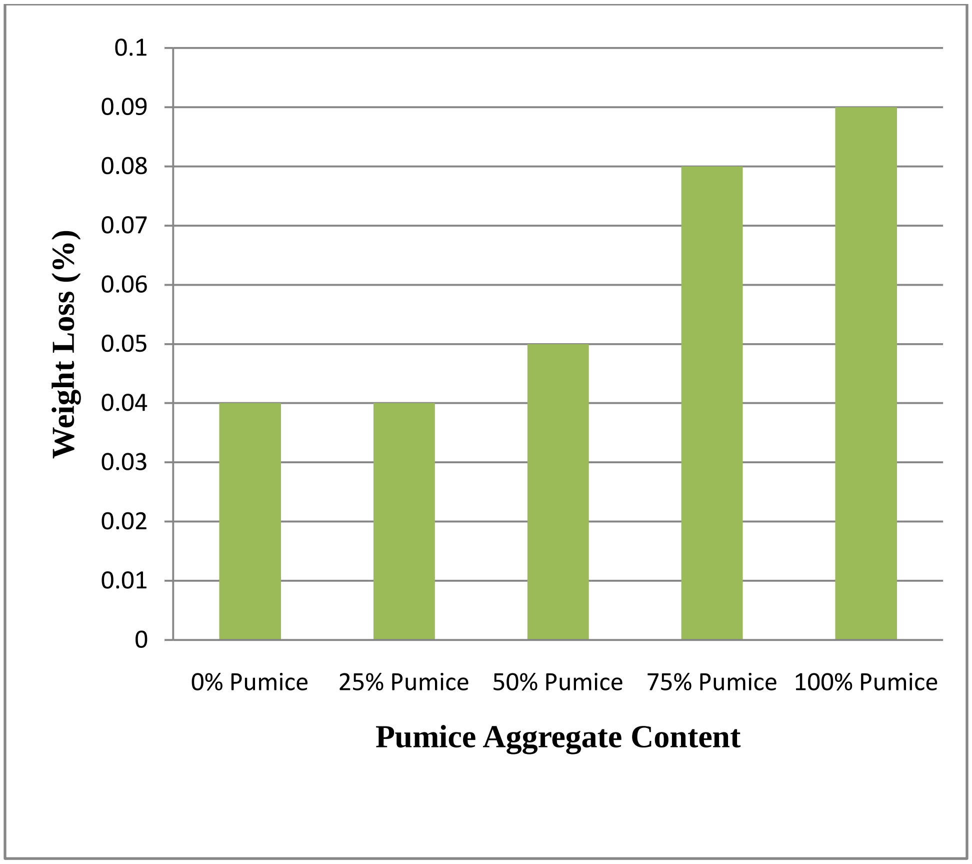

Figure 4.6: Abrasion Resistance of Concretes at 28 days of Curing Laboratory Experiment (2018)

4.5 Effect of Elevated Temperature on the Concrete Pumice Aggregate

The concretes were subjected to temperatures of 200°C, 400°C, 600°C and 800°C.

4.5.1 Residual compressive strength of specimens exposed to elevated temperatures

Figure 4.7 shows the retained compressive strength of concrete subjected to 200°C, 400°C, 600°C and 800°C elevated temperatures. The retained compressive strength is in relation to the initial compressive strength for all the concrete samples.

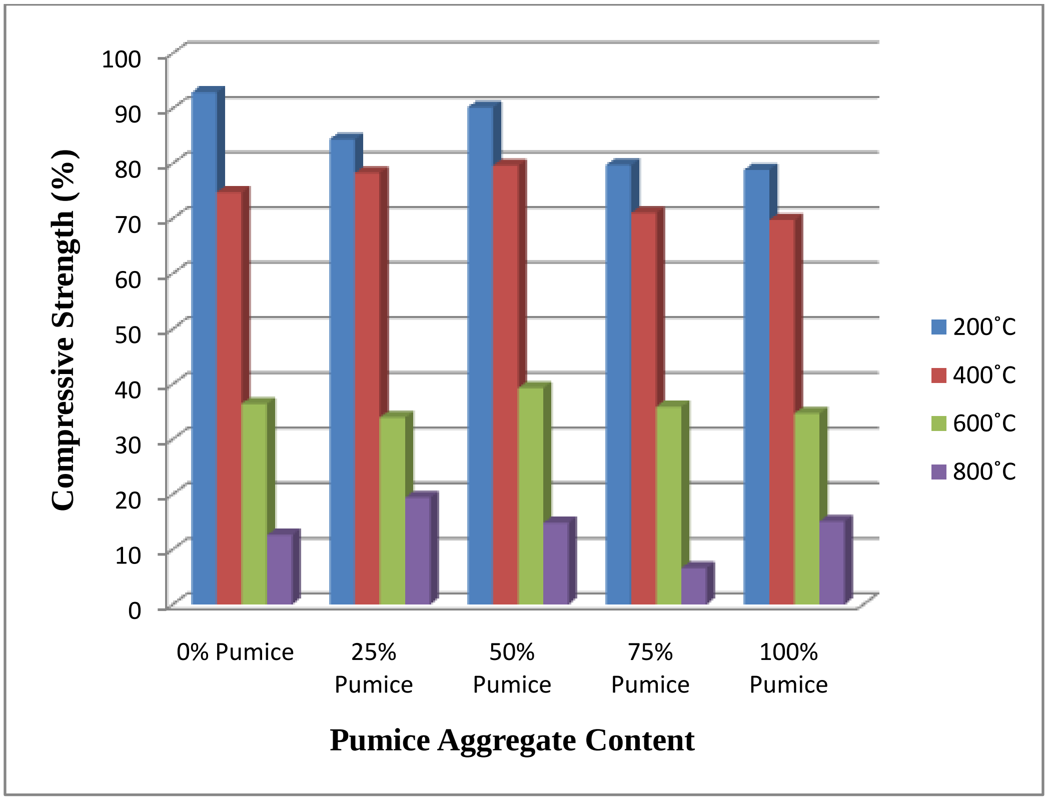

Figure 4.7: Retained compressive strength of concrete at 28 days exposed to elevated temperatures.
Laboratory Experiment (2018)

The retained compressive strength of the concrete decrease with increase in temperature. At 200^{o}C, 0% pumice aggregate concrete has the highest retained compressive strength of 92.98% follow by a slight decrease in 50% pumice aggregate concrete with retained compressive strength of 90.20% while 100% pumice aggregate concrete has the least retained compressive strength of 78%.

At 400^{o}C, the 50% pumice aggregate concrete has the highest retained compressive strength of 80% with slight decrease in 25% pumice aggregate concrete followed by the 0% pumice aggregate concrete with 75% retained compressive strength. The decrease in strength could be as a result of dehydration of calcium silicate hydrate making the cement losses its binding strength (Vasusmitta and Rao, 2012).

At the temperature of 600^{o}C, 50% pumice concrete has the highest retained compressive strength followed by a slight decrease of about 3% in the control sample and 4% in the remaining samples. The strength reduction at this temperature is about 60% of the initial strength. This is an indication of large dehydration of calcium silicate hydrate in the specimens.

At the temperature of 800^{o}C, 25% pumice concrete has the highest strength followed by a decrease in strength for 50% pumice concrete with retained compressive strength of 15%. The 0% pumice sample has about 12% retained compressive strength. This shows that there is a large loss of water bond in the hydrates. The results of the retained compressive strength agree with the statement made by Koksal *et al.* (2012) that at about 600^{o}C, concrete loss half of its strength while at about 800^{o}C, the loss of strength may reach up to about 80% of its strength due to loss of water bond in the hydrates. The values recorded are presented in Appendices C5.1 to C5.4.

4.5.2 Retained Ultrasonic Pulse Velocity Result.

Figure 4.8 depicts the retained values of UPV for all concrete specimens exposed to elevated temperatures. The values for UPV determined are presented in Appendix C10. The retained UPV values for a given concrete sample decrease with increase in elevated temperatures. At 200^{o}C, the 0% and 25% pumice concrete have good concrete quality of 3.51 km/s and 3.76 km/s respectively; followed by slight decrease in UPV values for the remaining concrete sample with medium concrete quality of less than 3.5 km/s. At 400^{o}C, all the concrete samples; 0%, 25%, 50%, 75% and 100% pumice concrete have 2.77, 2.83, 2.89 2.48 and 2.36 km/s respectively which are poor concrete quality but 50% pumice concrete has the highest quality of concrete.

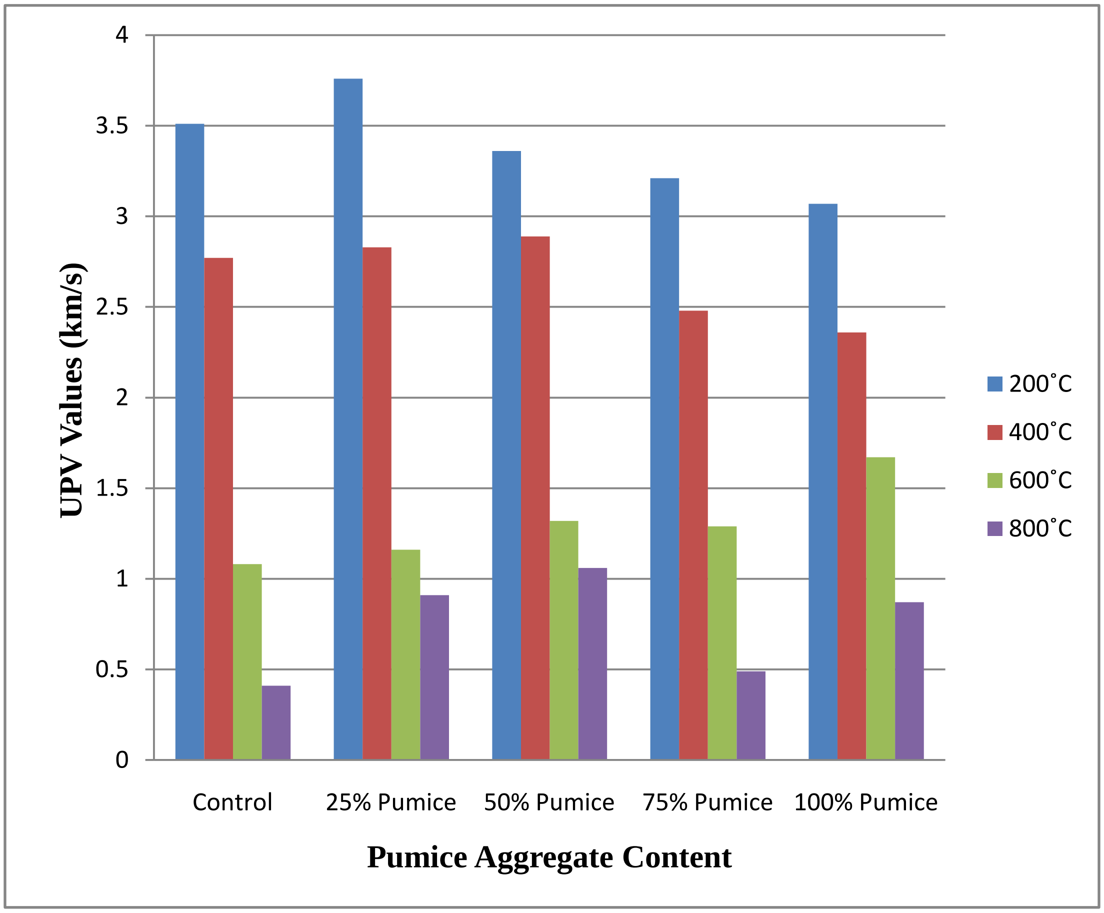

Figure 4.8: Retained Ultrasonic Pulse Velocity Test of Concrete at 28 days.
Laboratory Experiment (2018)

At 600^oC and 800^oC, all the samples are found to have a very poor concrete quality but 50% pumice concrete has the highest concrete quality of 1.06 km/s at 800^oC while 100% pumice concrete has highest concrete quality of 1.06 km/s at 600^oC and the 0% pumice concrete with lowest concrete quality respectively. This shows that the 50% pumice concrete has better UPV values at elevated temperature compare to the control and other percentage replacement of pumice concrete except at 200^oC. The result is in agreement with the work of Lawson *et al*. (2011) and Kirchhof, Lorenzi and Filho (2015).

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the Research Findings

The research determined the effect of elevated temperature on varied proportions of pumice aggregate concrete. Five different specimens were produced including the control sample. The pumice aggregate replacements were 0%, 25%, 50%, 75% and 100%. Fresh and hardened properties of the concrete were assessed and the summary of the major findings are presented as follows;

i. The granite and pumice aggregates were found to have bulk densities of 1557 kg/m^3 and 589 kg/m^3, specific gravities of 2.55 and 1.28 and absorption capacity of 0.80% and 20%.

ii. Increase in the percentage replacement of granite with pumice aggregate in concrete mix increases the workability of the concrete mixes by range of 17.65 to 98% of the control mix. The workability of the control (0% pumice), 25% pumice and 50% pumice concretes were within medium range, this agrees with Gambir (2006).

iii. The densities of the 0%, 25% pumice, 50% pumice, 75% pumice and 100% pumice concretes were found to be 2570 kg/m^3, 2353 kg/m^3, 2067 kg/m^3, 1913 kg/m^3 and 1760 kg/m^3 respectively.

iv. The control sample attained 100% of the designed strength at 28 days curing and the strength of other specimens decrease as the percentage of pumice aggregate increase in the concrete by 7.68%, 21.71%, 27.72% and 31.14% of control respectively.

v. It was found that the tensile strength of concrete samples with pumice replacement is better than the control sample at 28 days curing period.

vi. The retained compressive strength of the samples decreases with increase in exposure temperatures. And also, as the percentage of pumice replacement increase for 25% and 50% pumice concrete, the strength retained increased by a range of 2 to 7% than the control sample except at 200^{o}C temperature.

vii. The retained ultrasonic pulse velocity results decrease with increase in exposed temperature for all the samples.

5.2 Conclusion

After carrying out the experiments, observations, analysis and discussions on the effect of elevated temperatures on concrete containing various proportions of pumice aggregate, the following conclusions were drawn;

i. The bulk density and specific gravity of the pumice aggregate were found to be in the range of lightweight aggregate.

ii. For the fresh concrete, the increase in granite replacement with pumice increases the workability of the concrete by 17.65%, 69% and 98% which reduces the strength of the concrete therefore, the replacement should not be greater than 50%.

iii. The density of 0% pumice and 25% pumice concrete classified the samples as normal weight concrete whereas 75% and 100% pumice concretes as lightweight concrete and the 50% pumice concrete as medium weight concrete.

iv. The concrete made with 50% pumice showed a better resistance to elevated temperatures than 0% pumice concrete sample.

5.3 Recommendations

i. As a result of the high absorption capacity of the pumice aggregate compared to granite aggregate, water should be added to the mix when used its dry condition.

ii. The pumice aggregate can be used for structural element but not for hard wearing surfaces such as road and pavement.

iii. The research recommended that when concrete is to be expose to elevated temperature, pumice aggregate should be used at 50% replacement so as to improve the resistance.

5.4 Recommendations for Further Studies

It is recommended that further researches should be undertaken in the following areas;

i. To determine other properties of concrete and pumice concrete such as shrinkage, creep, permeability, modulus of elasticity, flexural strength etc.

ii. Research should be conducted to determine the effect of sulfate on the concrete when replaced with pumice aggregate.

5.5 Contributions to Knowledge

1. This research established that the used of pumice aggregate in replacement of granite aggregate at 50% improves the resistance of concrete to elevated temperatures.
2. The research established that at 50% replacement of pumice with granite aggregate, concrete of medium weight can be produced.

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APPENDICES

Appendix A1; Results for Sieve Analysis of Crushed Pumice 20mm Maximum Size

Sieve Size (mm)	Weight Retained(g)	Weight Passing(g)	Percentage Passing (%)	Percentage Retained (%)	Grading Zone II
20.00	100	1900	95.00	5.00	95 – 100
10.00	1430	470	23.50	71.50	55 – 65
5.00	398	72	3.6	19.90	35 – 45
2.36	54	18	0.9	2.7	28 – 35
1.18	5	13	0.65	0.25	-
600	3	10	0.50	0.15	-
300	4	6	0.30	0.20	-
150	3	3	0.15	0.15	-
Pan	3	0	0.15	0	-

Laboratory Research Work (2018)

Appendix A2 Results for Sieve Analysis of Crushed Granite 20 mm Maximum Sizes

Sieve Size (mm)	Weight Retained(g)	Weight Passing(g)	Percentage Passing (%)	Percentage Retained (%)	Grading Zone II
20.00	150	1850	92.50	7.50	90 – 100
10.00	1390	460	23.00	69.50	55 – 65
5.00	290	170	8.50	14.50	35 – 45
2.36	155	15	0.75	7.75	28 – 35
1.18	10	5	0.25	0.50	-
600	3	2	0.10	0.15	-
300	2	0	0	0.10	-
150	0	0	0	0	-
Pan	0	0	0	0	-

Laboratory Research Work (2018)

Appendix A3: Results for Sieve Analysis of Fine aggregate 10mm Maximum Size

Sieve Size (mm)	Weight Retained(g)	Weight Passing(g)	Percentage Passing (%)	Percentage Retained (%)	Grading Zone II
10.00	0	1000	100.0	00.00	100
5.00	0.00	1000	100.0	0.00	90 – 100
2.36	13.0	987	98.70	1.30	75 – 100
1.18	234	753	75.30	23.40	55 - 90
600	298	464	46.40	29.80	35 - 59
300	361	103	10.30	36.10	8 – 30
150	46	57	5.7	4.60	0 – 10
Pan	57	0	0	5.7	-

Laboratory Research Work (2018)

Appendix B: Concrete Mix Design for Grade C25 Concrete Using Building Research Establishment Method (BRE)

Design Stipulations and Test data for Materials

Compressive strength at 28 days = 25 N/mm^2

Type of concrete = Plain Concrete

Grade of cement = 42.5

Coarse aggregate type = crushed granite

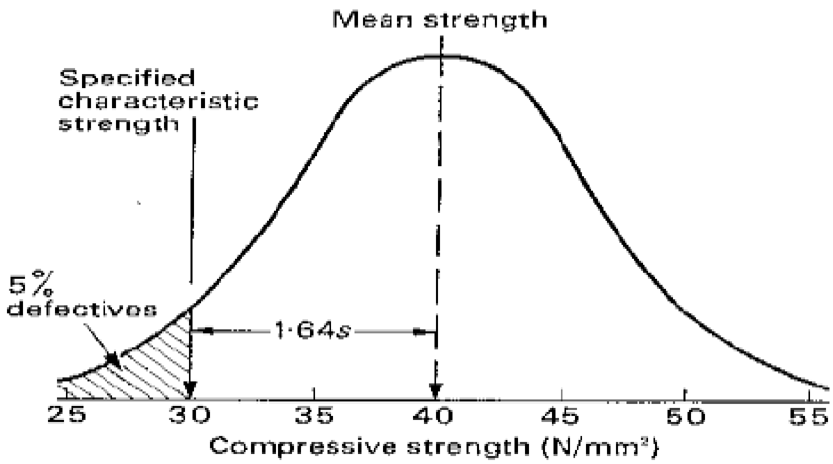

Figure a1: Normal Distribution of Concrete Strength

Source: Building Research Establishment (1997)

Table a3.1: K factor used in Statistical Control

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

Source: Building Research Establishment (1997)

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

$$f_m = f_c + ks$$

Where

f_m= the target mean strength

f_c=the specified characteristic strength

ks = the margin, which is the product of:

s = the standard deviation, and

k = a constant

From figure a3.1 select margin factor = 5% defectives

From table a3.1, k = 1.64 and s =4

f_m= 25N/mm^2 +(1.64 x 4)

f_m =25+6.56

f_m= 31.56/mm^2 = 32 N/mm^2

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

Coarse aggregate = 20mm Maximum sieve size

Percentage of fine aggregate passing through 600μm sieve = 27%

Specific gravity of coarse aggregate based on SSD = 2.50

Condition of Exposure = Alternating wetting and drying

***Step 3**: Determine the Required Water Cement Ratio*

Using cement grade 42.5 and crushed course aggregate at 28 day as it is seen from Table A3.2

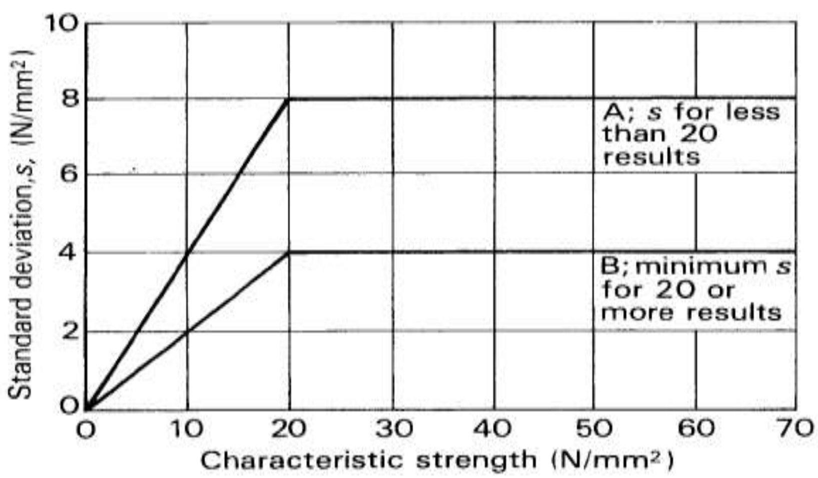

Figure a3.2: Characteristic Strength versus Standard Deviation Relationship
Source: Building Research Establishment (1997)

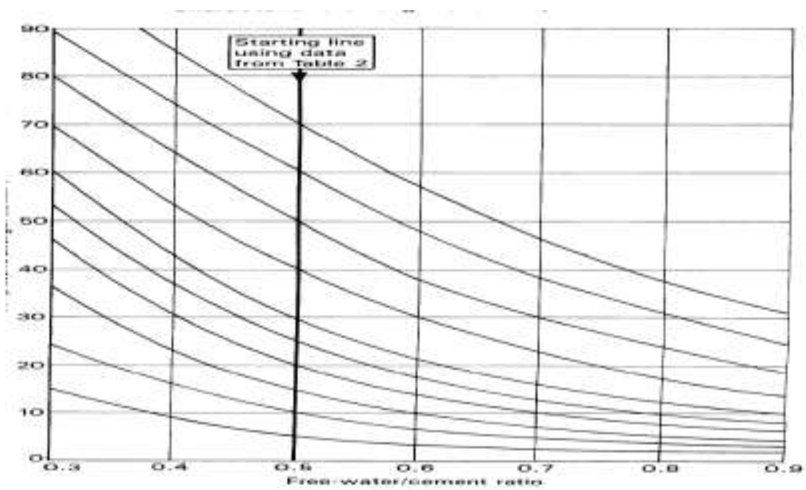

Figure a3.3: Relationship between Compressive Strength and Water/Cement Ratios
Source: Building Research Establishment (1997)

Table a3.2: Approximate Compressive Strength of Concrete Mix with a Free-W/C Ratio

Cement strength class	Type of coarse aggregate	Compressive strengths (N/mm^2) Age (days) 3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Source: Building Research Establishment (1997)

Table a3.3: Maximum water cement ratio for reasonable durability

Condition of Exposure	**Maximum Water Cement Ratio** Plain Concrete	Reinforced Concrete
Internal, Subject to heavy condensation	-	0.60
Alternate wetting and drying	0.60	0.60
Freezing and Thawing	0.55	0.50
Seawater or salt spray	0.50	0.45
Water retaining structure	-	0.50

Source: Building Research Establishment (1997)

Anticipate strength = 49 N/mm^2

Target strength = 32 N/mm^2

Free water/cement ratio =0.5

To determine the new free water/cement ratio to be used: From Figure a3.3

Use the curve drawn from 0.5 free water/cement ratio and 49N/mm^{2}anticipated strength to obtain the required water/cement ratio with target strength of 32N/mm^2

New free water/cement ratio = 0.65 which is not OK according to the standard because from Table a3.3,maximum allowable water/cement ratio for alternate wetting and drying condition of exposure, plain concrete = 0.60

Therefore, maximum allowable water/cement ratio = 0.60

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

Table a3.4:Workability, Slump and Compacting factor of concrete.

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

Source: Building Research Establishment (1997)

From table a3.4, Select medium degree of workability of concrete to be used with a slump ranging from 25 – 100 mm.

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

From Table a3.5, based on the selected workability, maximum size and type of aggregate, the required free water content = 210 kg/m^3

Table a3.5: Approximate Free-Water Content (Kgm^3) Required to Give Various Levels of Workability.

Slump (mm)		**0-10**	**10-30**	**30-60**	**60-180**
Vebe time (s)		**>12**	**6-12**	**3-6**	**0-3**
Max. size of aggregate (mm)	**Type of Aggregate**				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Source: Building Research Establishment (1997)

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

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

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

Cement (kg/m^3) = 350 kg/m^3

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

Table a3.6: Mimimum Cement Content for Concretes with 20 mm Maximum Aggregate Size under Different Condition of Exposure

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

Source: Building Research Establishment (1997)

From Table a3.6, the minimum cement content for reinforced concrete exposed to alternate wetting and drying = $360kg/m^3$ which is more than the $350kg/m^3$. Therefore we use $360kg/m^3$.

Step 8: Determine the Wet Density of the Concrete using Free Water Content

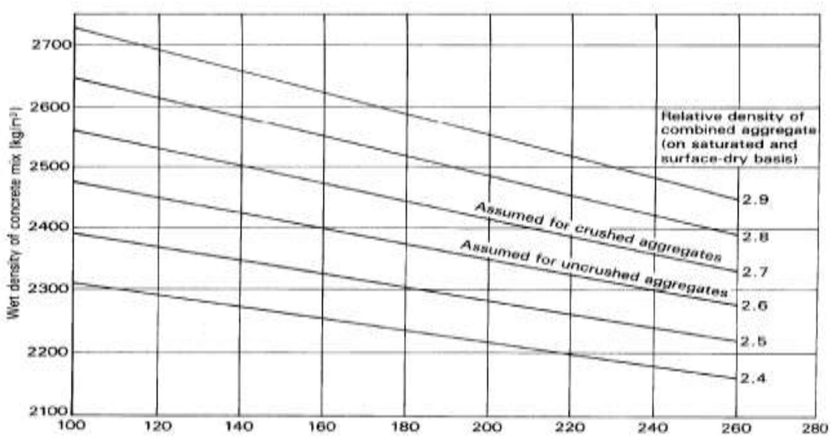

Figure a3.4: Relationship between free-water content and wet density of concrete
Source: Building Research Establishment (1997)

From Figure a3.4, free water content = 210 kg/m^3 (from step 5), combined specific gravity of aggregate at SSD = 2.55, therefore Wet density (plastic density) = 2340 kg/m^3

Step 9: Deducing the Proportion of Fine Aggregate.

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

Percentage of fine aggregate that passed through 600 µm BS sieve = 42%

From Figure a3.5,the proportion of fine aggregate = 42%

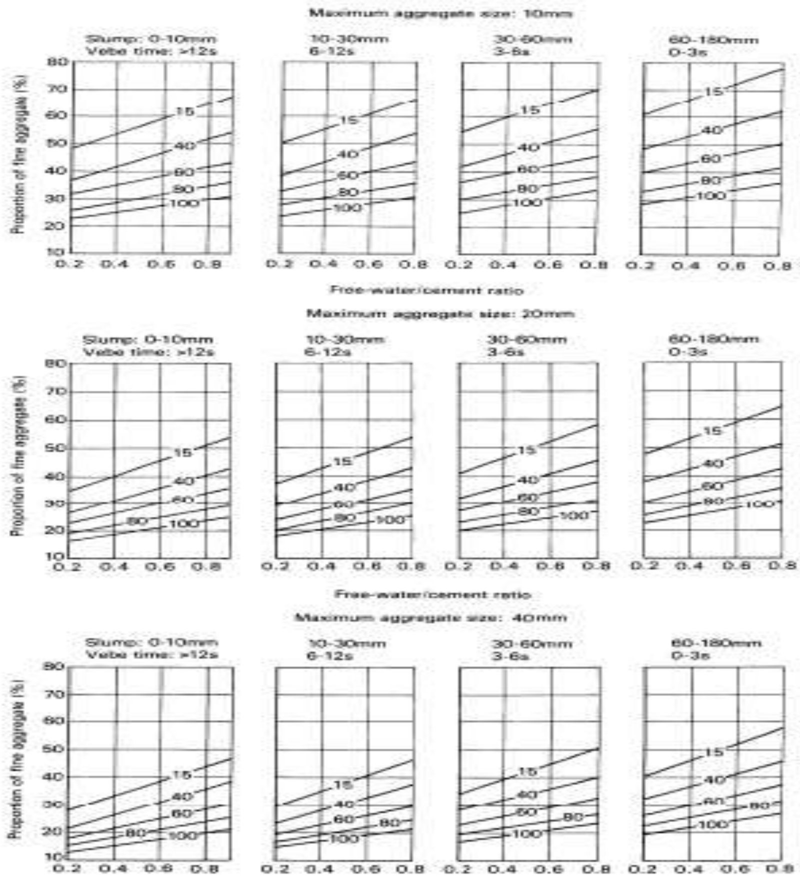

Fig a3.5: Recommended Percentages of fine aggregate in total aggregate as a function of free-water/cement ratio for values of workability and maximum size of aggregate
Source: Building Research Establishment (1997)

***Step 10**: Compute the Quantity of Aggregate*

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

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

TAC = 2340 kg/m^3 – 360 kg/m^3– 210 kg/m^3

TAC = 1770 kg/m^3

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

FAC = 1770 kg/m^{3}x $\frac{42}{100}$

FAC = 742.4 kg/m^3

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

CAC = 1770kg/m^3 – 743.4 kg/m^3

CAC = 1026.60 kg/m^3

***Step 11**: Deducing the Mix Proportion by Weight Taking Cement as 1*

Cement Content = 360 kg/m^3

Fine Aggregate Content = 743.4 kg/m^3

Coarse Aggregate Content = 1026.6 kg/m^3

Water Content = 210 kg/m^3

Mix Proportion =$\frac{360}{360}$: $\frac{743.4}{360}$: $\frac{1026.6}{360}$ and $\frac{210}{360}$ W/C ratio

= 1.00: 2.07: 2.85 and W/C = 0.60

Step 12: Adjust the quantity of mix after to take care of moisture condition of the aggregates on site if necessary (the aggregates used were at saturated surface dry condition)

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

Computing the total volume of concrete required.

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

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

= 0.00115m^3

Unit volume of cylinder =3.142 x 0.05^2 x 0.2 = 0.001571 m^3 .

Add 15% waste of the total volume of concrete = $0.001571 + (\frac{15}{100}\ X\ 0.001571)$

= 0.00181 m^3

Volume of 200 cubes $= 200 \times 0.00115 = 0.230\ m^3$

Volume of 25 cylinders $= 25 \times 0.00181 = 0.0453\ m^3$

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

Quantity of Materials for Cubes;

Quantity of cement = 0.230 m^3 x 360 kg/m^3 = 82.80 Kg

Quantity of F.A = 0.230m^3 x 743.40 kg/m^3 = 170.98 Kg

Quantity of C.A = 0.230m^3 x 1026.60 kg/m^3 = 236.12 Kg

Quantity of water = 0.230m^3 x 210 kg/m^3 = 48.30Kg

Quantity of Materials for Cylinders;

Quantity of cement = 0.0453 m^3 x 360 kg/m^3 = 16.31 Kg

Quantity of F.A = 0.0453 m^3 x 743.40 kg/m^3 = 33.68 Kg

Quantity of C.A = 0.0453 m^3 x 1026.60 kg/m^3 = 46.50 Kg

Quantity of water = 0.0453 m^3 x 210 kg/m^3 = 9.51 Kg

Appendix C1: Weight and Density of Concrete Sample

Pumice Aggregate Content	Volume (m^3)	Weight (kg)	Density (kg/m^3)	Average Density (kg/m^3)
0% Pumice	1.00×10^{-3}	2.56	2560	
	1.00×10^{-3}	2.55	2550	2570
	1.00×10^{-3}	2.60	2610	
25% Pumice	1.00×10^{-3}	2.35	2350	
	1.00×10^{-3}	2.40	2400	2353
	1.00×10^{-3}	2.31	2310	
50% Pumice	1.00×10^{-3}	2.04	2040	
	1.00×10^{-3}	2.06	2060	2067
	1.00×10^{-3}	2.10	2100	
75% Pumice	1.00×10^{-3}	1.95	1950	
	1.00×10^{-3}	1.85	1850	1913
	1.00×10^{-3}	1.94	1940	
100% Pumice	1.00×10^{-3}	1.76	1760	
	1.00×10^{-3}	1.78	1780	1760
	1.00×10^{-3}	1.74	1740	

Laboratory Research Work (2018)

Appendix C2: Compressive Strength Result for specimen cured at 28 days

Pumice Aggregate Content	Weight (Kg)	Failure Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
0% Pumice	2.56	249.95	25.00	
	2.55	251.85	25.19	25.14
	2.50	247.75	24.78	
	2.60	255.65	25.57	
25% Pumice	2.35	230.00	23.00	
	2.30	235.75	23.58	23.21
	2.40	229.90	22.99	
	2.36	232.50	23.25	
50% Pumice	2.04	198.95	19.90	
	2.06	203.05	20.31	19.68
	2.10	193.85	19.39	
	2.15	190.95	19.10	
75% Pumice	1.95	185.00	18.50	
	1.85	183.33	18.33	18.17
	1.90	178.60	17.86	
	1.94	180.00	18.00	
100% Pumice	1.75	172.55	17.26	
	1.70	176.52	17.65	17.31
	1.74	169.95	17.00	
	1.78	173.05	17.31	

Laboratory Research Work (2018)

Appendix C3:Tensile Strength Result for specimen cured at 28 days

Pumice Aggregate Content	Weight (Kg)	Failure Load (KN)	Tensile Strength (N/mm^2)	Average Tensile Strength (N/mm^2)
0% Pumice	4.10	89.30	2.83	
	4.00	87.46	2.79	2.82
	4.00	90.00	2.87	
	4.00	88.00	2.80	
25% Pumice	3.80	68.68	2.19	
	3.70	68.90	2.19	2.19
	3.80	69.00	2.20	
	3.80	67.95	2.16	
50% Pumice	3.40	63.03	2.01	
	3.50	61.75	1.97	2.00
	3.50	63.50	2.02	
	3.80	62.95	2.00	
75% Pumice	3.20	60.76	1.94	
	3.20	60.00	1.91	1.89
	3.25	58.85	1.87	
	3.20	58.00	1.85	
100% Pumice	2.90	49.70	1.58	
	2.90	50.50	1.61	1.61
	2.85	51.00	1.64	
	2.90	50.95	1.62	

; Laboratory Research Work (2018)

Appendix C4: Ultrasonic Pulse Velocity Result for Concrete samples at Room Temperature for 28 days Age.

Pumice Aggregate Content	UPV Result (Km/s)
Control	4.10
25% Pumice	4.18
50% Pumice	4.26
75% Pumice	3.67
100% Pumice	3.35

Laboratory Research Work (2018)

Appendix C5.1: Retained Compressive Strength of Concrete at 200^{0}C Exposure

Pumice Aggregate Content	Failure Load (KN)	Retained Compressive Strength (N/mm^2)	Average Retained Compressive Strength (N/mm^2)
0% Pumice	240.86	24.09	
	232.96	23.30	23.36
	230.88	23.09	
	229.52	22.95	
25% Pumice	197.69	19.77	
	187.54	18.75	19.60
	200.00	20.00	
	198.58	19.86	
50% Pumice	174.08	17.41	
	180.09	18.01	17.75
	185.37	18.54	
	170.50	17,05	
75% Pumice	148.07	14.81	
	138.50	13.85	14.49
	145.90	14.59	
	147.00	14.70	
100% Pumice	139.61	13.66	
	148.47	14.85	13.65
	130.95	13.10	
	129.99	13.00	

Laboratory Research Work (2018)

Appendix C5.2: Retained Compressive Strength of Concrete at 400^0C Exposure

Pumice Aggregate Content	Failure Load (KN)	Retained Compressive Strength (N/mm^2)	Average Retained Compressive Strength (N/mm^2)
0% Pumice	195.35	19.54	
	180.72	18.07	18.79
	185.53	18.55	
	190.00	19.00	
25% Pumice	180.39	18.04	
	182.30	18.23	18.16
	185.50	18.55	
	178.00	17.80	
50% Pumice	158.39	15.84	
	145.57	14.56	15.66
	162.12	16.21	
	160.14	16.01	
75% Pumice	131.59	13.16	
	128.88	12.89	12.90
	125.50	12.55	
	130.00	13.00	
100% Pumice	112.36	11.24	
	123.76	12.38	12.07
	120.95	12.10	
	125.74	12.57	

Laboratory Research Work (2018)

Appendix C5.3: Retained Compressive Strength of Concrete at 600^0C Exposure

Pumice Aggregate Content	Failure Load (KN)	Retained Compressive Strength (N/mm^2)	Average Retained Compressive Strength (N/mm^2)
0% Pumice	90.05	9.00	
	97.70	9.77	9.16
	88.49	8.85	
	90.39	9.04	
25% Pumice	87.37	8.74	
	80.69	8.07	7.88
	69.99	7.00	
	77.11	7.71	
50% Pumice	70.00	7.00	
	70.14	7.01	7.20
	72.48	7.25	
	75.10	7.51	
75% Pumice	62.73	6.27	
	65.99	6.60	6.53
	68.68	6.87	
	63.90	6.39	
100% Pumice	60.00	6.00	
	58.49	5.85	6.00
	60.21	6.02	
	61,12	6.11	

Laboratory Research Work (2018)

Appendix C5.4: Residual Compressive Strength of Concrete at 800^{0}C Exposure

Pumice Aggregate Content	Failure Load (KN)	Retained Compressive Strength (N/mm^2)	Average Retained Compressive Strength (N/mm^2)
0% Pumice	34.01	3.40	
	29.37	2.94	3.17
	30.89	3.09	
	32.50	3.25	
25% Pumice	43.44	4.34	
	42.40	4.24	4.50
	45.18	4.52	
	48.76	4.88	
50% Pumice	32.43	3.24	
	30.60	3.06	2.91
	28.18	2.82	
	25.10	2.51	
75% Pumice	12.46	1.25	
	10.32	1.03	1.20
	13.36	1.39	
	11.10	1.11	
100% Pumice	29.52	2.95	
	25.64	2.56	2.62
	21.76	2.18	
	28.50	2.85	

Source; Laboratory Research Work (2018)

Appendix C6: Water Absorption Capacity of Concrete Sample at 28 Days Curing

Pumice Aggregate Content	Oven Dry Weight (g)	S.S.D Weight (g)	Absorption Capacity (%)	Average Absorption Capacity (%)
0% Pumice	2401	2482	3.37	3.52
	2434	2523	3.66	
25% Pumice	2217	2298	3.65	3.85
	2278	2370	4.04	
50% Pumice	1917	2011	4.90	4.74
	2142	2240	4.58	
75% Pumice	1867	1982	6.17	6.90
	1900	2045	7.63	
100% Pumice	1683	1844	9.57	9.81
	1634	1798	10.04	

Laboratory Research Work (2018)

Appendix C7: Abrasion Resistance of Concrete Sample at 28 Days Curing

Pumice Aggregate Content	Weight Before Brushing (g)	Weight After Brushing (g)	Difference (g)	Lost in Weight (%)	Average Lost in Weight (%)
0% Pumice	2567	2566	01	0.04	0.04
	2548	2547	01	0.04	
25% Pumice	2352	2351	01	0.04	0.04
	2315	2314	01	0.04	
50% Pumice	2041	2040	01	0.05	0.05
	2063	2062	01	0.05	
75% Pumice	1946	1945	01	0.05	0.08
	1950	1948	02	0.10	
100% Pumice	1756	1755	01	0.06	0.09
	1736	1734	01	0.12	

Source; Laboratory Research Work (2018)

Appendix C8: Density of Concrete Subjected to Elevated Temperatures

Pumice Aggregate Content	Density (Kg/m^3)			
	200^0C	400^0C	600^0C	800^0C
Control	2400	2340	2300	2200
25% Pumice	2300	2260	2160	2070
50% Pumice	2030	1950	1900	1890
75% Pumice	1830	1760	1700	1630
100% Pumice	1670	1600	1540	1450

Laboratory Experiment (2018)

Appendix C9: Retained Compressive Strength of Concrete Exposed to Temperatures at 28 days Curing Age

Pumice Aggregate Content	Retained Compressive Strength (N/mm^2)			
	200^0C	400^0C	600^0C	800^0C
Control	23.36	18.76	9.43	3.17
25% Pumice	19.60	18.16	7.88	4.50
50% Pumice	17.75	15.66	7.20	2.91
75% Pumice	14.49	12.90	6.53	1.20
100% Pumice	13.65	12.07	6.00	2.64

Source: Laboratory Experiment (2018)

Appendix C10: Retained Ultrasonic Pulse Velocity Test of Concrete Exposed to Elevated Temperature at 28 days curing

Pumice Aggregate Content	Retained UPV (Km/s)			
	200^0C	400^0C	600^0C	800^0C
Control	3.51	2.77	1.08	0.41
25% Pumice	3.76	2.83	1.16	0.91
50% Pumice	3.36	2.89	1.32	1.06
75% Pumice	3.21	2.48	1.29	0.49
100% Pumice	3.07	2.36	1.67	0.87

Laboratory Experiment (2018)

Appendix C11: Relative Retained Compressive Strength of Concrete Samples

Mix Designations	Compressive Strength (%)			
	200^0C	400^0C	600^0C	800^0C
Control	92.92	74.75	36.44	12.60
25% Pumice	84.40	78.25	33.96	19.40
50% Pumice	90.20	79.60	39.30	14.80
75% Pumice	79.79	71.0	35.90	6.60
100% Pumice	78.86	69.73	34.70	15.10

Source: Laboratory Experiment (2018)

Appendix D; Physical Properties of the Aggregates Calculations

i) Specific Gravity Calculation

a. Specific Gravity of Pumice aggregate

Using the formula;

Specific gravity (**S.$\boldsymbol{G_{SSD}}$**) = $\frac{B-A}{(D-A)-(C-B)}$

Where: A = 183 g = Weight of empty bottle

B = 220 g = Weight of empty bottle + Sample

C = 439 g = Weight of cylinder bottle + Sample + water

D = 431 g = Weight of cylinder bottle + water

S.G_{SSD} pumice = $\frac{220-183}{(431-183)-(439-220)}$ = $\frac{37}{248-219}$ = 1.28

1st Reading = 1.28

2nd Reading= 1.27

Average S/G Pumice = $\frac{1.28+1.27}{2}$ = 1.28

b. Specific Gravity of Granite aggregate

Using the formula;

Specific gravity (**S.$\boldsymbol{G_{SSD}}$**) = $\frac{B-A}{(D-A)-(C-B)}$

Where: A = 183 g = Weight of empty bottle

B = 241 g = Weight of empty bottle + Sample

C = 466 g = Weight of cylinder bottle + Sample + water

D = 431 g = Weight of cylinder bottle + water

S.G_{SSD} pumice = $\frac{241-183}{(431-183)-(466-241)}$ = $\frac{58}{248-225}$ = 2.52

1st Reading = 2.52

2nd Reading= 2. 57

Average S/G Granite = $\frac{2.52+257}{2}$ = 2.55

ii) Bulk Density Calculation

a) Bulk Density of Pumice aggregate

Weight of aggregate = W_1 = 0.589 kg

Volume of container = V = 0.001 m^3

Bulk Density (Pumice $_{SSD}$) = $\frac{0.589\ kg}{0.001 m^3}$ = <u>589 kg/m^3</u>

b) Bulk Density of Pumice aggregate

Weight of aggregate = W_1 = 1.557 kg

Volume of container = V = 0.001 m^3

Bulk Density (Pumice $_{SSD}$) = $\frac{1.557\ kg}{0.001 m^3}$ = <u>1557 kg/m^3</u>

iii) Moisture Content and Absorption Capacity Calculation

Moisture Content (M.C) = $\frac{W_{stock} - W_{OD}}{W_{OD}} \times 100$ and

Absorption capacity (A.C) = $\frac{W_{SSD} - W_{stock}}{W_{stock}} \times 100$

Where; W_{stock} = weight of air dried of aggregate

W_{SSD} = weight of saturated surface dried of aggregate

W_{OD} = weight of oven dried of aggregate

a) Pumice aggregate

Moisture Content (M.C) = $\frac{200g - 198g}{198g} \times 100$ = <u>1.0 %</u>

Absorption capacity (A.C) = $\frac{240g - 200g}{200g} \times 100$ = <u>20.0 %</u>

b) Granite aggregate

Moisture Content (M.C) = $\frac{500g - 497.91g}{497.91g} \times 100$ = <u>0.42%</u>

Absorption capacity (A.C) = $\frac{504g - 500g}{500g} \times 100$ = <u>0.80%</u>

i) Impact and Crushing Values Calculations for the Aggregates

The impact value is calculated with the relationship below:

Impact Value (%) = $\frac{fine\ weight\ of\ aggregate\ passing\ 2.36mm\ sieve}{Net\ weight} x\ \frac{100}{1}$

(a) Impact Value for Pumice Aggregate

Weight of Cylinder = 2.70kg

Weight of Cylinder + Crushed Pumice = 3.10kg

Weight of fine Pumice passing 2.36mm sieve = 0.095kg

Weight of Pumice (Net Weight) = 3.10 - 2.7kg = 0.4kg

Pumice Impact Value (%) = $\frac{fine\ weight}{Net\ weight} x\ \frac{100}{1}$

= $\frac{0.095kg}{0.4kg}\ x\ \frac{100}{1}$ = 23.75%

(b) Impact Value for Granite Aggregate

Weight of Cylinder = 2.70kg

Weight of Cylinder + Crushed Gravel = 3.40kg

Weight of fine Granite passing 2.36mm sieve = 0.072kg

Weight of Granite (Net Weight) = 3.40kg - 2.7kg

= 0.70kg

Granite Impact Value (%) = $\frac{fine\ weight}{Net\ weight} x\ \frac{100}{1}$

= $\frac{0.072kg}{0.70kg}\ x\ \frac{100}{1}$ = 10.33%

Crushing Value Test

The crushing value is also calculated with the relationship below:

Crushing Value (%) = $\frac{fine\ weight\ of\ aggregate\ \ passing\ \ 2.36mm\ sieve}{Net\ weight} x\ \frac{100}{1}$

(a) Crushing Value for Pumice Aggregate

Weight of Cylinder = 2.0kg

Weight of Cylinder + Crushed Pumice = 3.15kg

Weight of fine Pumice passing 2.36mm sieve = 0.495kg

Weight of Pumice (Net Weight) = 3.15kg-2.0kg

= 1.15kg

Pumice Crushing Value (%) = $\frac{fine\ weight}{Net\ weight} x\ \frac{100}{1}$

= $\frac{0.495kg}{1.15kg}\ x\ \frac{100}{1}$ = 43.0%

(a) Crushing Value for Granite Aggregate

Weight of Cylinder = 2.0kg

Weight of Cylinder + Crushed Gravel = 4.60kg

Weight of fine Granite passing 2.36mm sieve = 0.507kg

Weight of Granite (Net Weight) = 4.60kg - 2.0kg

= 2.60kg

Crushing Value (%) = $\frac{fine\ weight}{Net\ weight} x\ \frac{100}{1}$

= $\frac{0.507kg}{2.60kg}\ x\ \frac{100}{1}$ = 19.50%