PROPERTIES OF INDUSTRIAL WOOD WASTE ASH CONCRETE

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DECLARATION

I hereby declare that this work is the product of my research efforts undertaken under the supervision of Engr. Dr. O.A.U Uche and has not been presented anywhere for the award of a degree or certificate. All sources have been duly acknowledged.

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CERTIFICATION

This is to certify that the research work for this dissertation and the subsequent write up by Akinola Sunday Tifase (SPS/11/MCE/00027) were carried out under my supervision

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APPROVAL

This Dissertation has been examined and approved for the award of Degree of master in Civil Engineering.

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This research work is dedicated to my mother a rare and irreplaceable gem, you”ll forever be in my heart - Late Mrs. Florence Ajoke Tifase.

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ABSTRACT

This study investigated the use of industrial wood waste ash (IWWA) as partial replacement of Portland cement in the production of concrete. The IWW was incinerated in an uncontrolled (open incineration) and controlled environment (incineration in a furnace at a temperature 0f 550 ^{o}c-600^{o}c). Samples from both incineration conditions were divided into three different particle sizes of 0.66mm, 0.83mm and 1.20mm using a Disk mill (FFC 15). By using absolute volume method of 1:2:4 concrete mix with a water/cement ratio of 0.55, twenty five different concrete mixes were prepared by using IWWA to replace 0%, 5%, 10%, 15% and 20% of Portland cement by mass for both incineration condition. The workability of the fresh concrete mixes was evaluated using the slump test and the compressive strengths of concrete cubes were evaluated at 1, 7, 28, 56 and 90 days. Test results indicate that IWWA is pozzolanic, workability of the concrete mix decreases with an increase in replacement percentage of cement with IWWA. The workability also increases with an increase in particle size of IWWA. Compressive strength of IWWA/OPC concrete increases with age of curing and it decreases with increasing IWWA replacement. As the particle size of the IWWA decreases the compressive strength of the concrete increases. The compressive strength of concrete continued to improve significantly up to 90 days. The optimum compressive strength is 20.15N/mm^2 for uncontrolled replacement of cement with 20% of 1.20mm IWWA at 28 days. The maximum compressive strength at all ages of testing for replaced cement was obtained at 90 days for 5% (31.40N/mm^2) replacement of cement with IWWA of controlled incineration and particle size of 0.66mm.

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Concrete is a heterogeneous product produced when water is added to a suitable proportion of cement, fine and coarse aggregate. It is among the most widely used construction materials in the world. Concrete provides wide range in surface textures and colours and can be used to construct wide variety of structures, such as large buildings, highways, streets, bridges, dams, airport runways etc, (Oyenuga, 1999).

Cement in concrete and mortar can be described as a material with adhesive and cohesive properties, which make it capable of binding mineral fragments into compact whole. It is generally used as a binding material in civil and building engineering works. It is used to bind sand, gravel and water to form a bulky mass called concrete. Cement is the most costly of the constituents of mortar and concrete and hence influences the concrete cost.

Cement manufacturing process releases carbon dioxide (CO_2) into the atmosphere both directly when calcium carbonate is heated, producing lime and carbon dioxide, and also indirectly through the use of energy; its production involves the emission of CO_2 which is very harmful to the green environment. The cement industry produces about 5% of global man-made CO_2 emissions, of which 50% is from the chemical process, and 40% from burning fuel, (Habeeb, Fayyadh, 2009). The amount of CO_2 emitted by the cement industry is nearly 900 kg of CO_2 for every 1000 kg of cement produced, (Habeeb, Fayyadh, 2009). The hydration process of cement also evolves heat which in turn affects the environment. The cost of cement is also one of the contributing factors to the high cost of building and other structures.

Therefore, there is need for affordable and environmental friendly building materials in providing adequate housing among other structures for the teaming populace of the world. The cost of conventional building materials continue to increase as the majority of the population continues to fall below the poverty line. Thus, there is the need to search for local and environmental friendly materials as alternatives for the construction of functional but low-cost buildings in both the rural and urban areas. Some of the local and waste materials that have been used are Rice husk ash (Waswa-Sabuni et al. 2002), Corn cob ash (CCA) (Adesanya and Raheem, 2009a; 2009b; 2010; Raheem et al. 2010;Raheem and Adesanya, 2011) and Influence Of Millet Husk Ash (MHA) On the Properties Of Plain Concrete (Uche, et al,2012).

Continuous generation of waste arising from industrial by-products and agricultural residue, create acute environmental problems both in terms of their treatment and disposal. The construction industry has been identified as the one that absorbs the majority of waste materials as filler in concrete, (Antiohos et al., 2005). If these fillers have pozzolanic properties, they impart technical advantages to the resulting concrete and also enable larger quantities of cement replacement (green cement) to be achieved, (Hossain, 2003). Green cement is a cementitious material that meets or exceeds the functional performance capabilities of ordinary Portland cement by incorporating and optimizing recycled materials, thereby reducing consumption of natural raw materials, water, and energy, resulting in a more sustainable and environmental friendly construction material. Appropriate utilization of these materials brings about ecological and economical benefits.

One of the local materials that may be recycled to partially replace cement is Industrial wood waste (IWW). IWW is a waste material from the timber industry. It is a by-product of cutting, grinding, drilling, sanding, or otherwise pulverizing wood with a saw or other tools; it is composed of fine and smaller particles of wood. IWW is produced as timber is sawn into planks at saw mills located in virtually all major towns in the country. As the demand for wood products rises in a quest to meet the developmental drive of the society, the generated wood waste also increases and this increase overwhelms its present utility causing heaps of unutilized wood waste to be generated daily. A total of 104 metric tonnes of wood waste is generated daily in Nigeria, (Lasode et al, 2012). The need to convert this waste product into a useful cementing material for construction is the focus of this research.

Some industrial waste has been studied for use as supplementary cementing materials such as Pulverized fuel ash (Balendran and Martin- Buades, 2000), Fly ash (Siddique, 2004; Wang and Baxter, 2007; Wang et al., 2008), Silica fume (Turker et al., 1997; Lee et al., 2005), Volcanic ash (Hossain, 2005), Sawdust Ash (SDA) as Partial Replacement of Cement (Marthong, 2012).

1.2 BACKGROUND OF STUDY

IWW is an organic waste resulting from the mechanical milling or processing of timber (wood) into various shapes and sizes. Until recently, industrial by-products such as blast furnace slag, fly ash, and silica fume were essentially waste products that cause industries to incur additional disposal cost, the industries pays for the unutilized waste to be disposed either by burning or taking it to a dump site, (Madina and Nafisa, 2010). IWW is also not left out as it is a product that caused wood mills to incur additional disposal cost. A major use of IWW is for particleboard; coarse IWW may be used for wood pulp. IWW has a variety of other practical uses, including use as filling material, poultry/animal bedding material, mulch and cooking fuel (charcoal briquettes), (Lasode et al, 2012).

In an attempt to convert waste product into useful material for the construction industries, this research looks into the use of IWWA as pozzolana in concrete production. Although, some works on IWW components on concrete production has been studied such as Sawdust Ash (SDA) as Partial Replacement of Cement (Marthong, 2012) and Saw Dust Ash as Partial Replacement for Cement in Concrete (Raheem et al,2012) but attention on incineration conditions and particle sizes have not been studied and this is what work is set to accomplish.

Wood wastes generation is inevitable either during felling of trees for log production in the forest or diverse sawing processes of logs/planks at the mills.When considered as waste, it will have negative consequences on the environment as pollutant. But when incinerated, either in controlled or uncontrolled environment gives ash having amorphous silica which has potential pozzolanic properties.

When pozzolanic materials are added to cement, the silica (SiO_2) present in these materials reacts with free lime released during the hydration of cement and forms additional calcium silicate hydrate (CSH) as new hydration product, (Boating and Skeete, 1990). This might improve the properties of concrete formulation and also the cost of construction. Not only is IWW a waste product in industries, it can also be found in all furniture shops and wood mills across the country.

1.3 JUSTIFICATION

The cost of construction works is very high especially when one considers the cost of cement, this makes it increasingly difficult to undertake new infrastructural development. Cement is a major construction material whose cost accounts for two-thirds of the building production cost, (Okereke, 2007). A reduction in its cost will have a positive effect on the populace of the nation by reducing the cost of structures.

Therefore, to arrest this unhealthy situation, it becomes necessary to research into the possibility of using local materials for construction as against the conventional materials which are either imported or too expensive, thereby making the cost of these materials to be very high.

It is with this in mind that this project was carried out in other to determine the effect of the pozzolanic properties of IWWA in concrete. IWWA is inexpensive and readily available locally through incineration of IWW. Therefore, a positive result will provide a medium for partial replacement of cement with IWWA in construction works. This will go a long way in reducing the overall construction cost. It will also help as an environmental control process since the IWW that would have constituted and fill the environment will be effectively utilized in concrete works and the rate if cement consumption in construction work will be greatly reduced; the production of cement which causes environmental pollution will be greatly reduced.

1.4 AIM AND OBJECTIVES

1.4.1 Aim

This project is aimed at assessing the potential of IWWA in concrete work. This is with the view of reducing the cost of cement used in concrete production.

1.4.2 Objectives

1. To determine the chemical properties of IWWA.
2. To determine the workability of concrete for various percentage replacement of cement with IWWA of different particle sizes.
3. To determine the compressive strength of concrete for various percentage replacement of cement with IWWA for a period of 1, 7, 28, 56 and 90 days.
4. To determine the optimum amount of IWWA to replace cement in concrete.

5. To determine the effect of incineration conditions on the compressive strength of IWWA concrete.

6. To determine the effect of particle sizes on the compressive strength of IWWA-concrete.

1.5 SCOPE AND LIMITATIONS

1.5.1 Scope

This experimental research was carried out with IWWA on 1:2:4 concrete mixes, to determine the effect of IWWA on the compressive strength of concrete and the effects of particle sizes of IWWA on the of concrete.

1.5.2 Limitations

- This research work was done on a 1:2:4 mix ratio for concrete.
- The water-cement ratio was limited to 0.55 for batching/mixing of concrete.

1.6 SIGNIFICANCE

If the investigation of IWWA as pozzolana meets with the standard requirements, it will maximize the use of IWWA to provide affordable, durable and environmental friendly building materials,(Raheem et al., 2012) It will also bring down the cost of construction and reduce environmental pollution caused by the production of cement and the disposal of IWW. It will also help to know the effect of particle size of IWWA on the properties of concrete. This research will also help to determine the chemical properties of IWWA.

1.7 CONTRIBUTION TO KNOWLEDGE

It is hoped that this study will add the knowledge of IWWA concrete to the existing knowledge of recycled waste materials in the construction industries.

CHAPTER TWO

LITERATURE REVIEW

2.1 GENERAL

As large quantities of waste materials and by-products are generated from manufacturing processes, service industries and municipal solid wastes, solid waste management has become one of the major environmental concerns in the world. With the increasing awareness about the environment, scarcity of land-fill space and due to its ever increasing cost, waste materials and by-products utilization has become an attractive alternative to disposal. High consumption of natural resources, high amount production of industrial wastes and environmental pollution require obtaining new solutions for a sustainable development (Siddique, 2008). The construction industry has been identified as one that utilizes the majority of such materials as filler in concrete (Antiohos et al., 2005).

Utilization of waste materials and by-products in concrete is a partial solution to environmental and ecological problems. Use of these materials not only helps in getting them utilized in cement, concrete, and other construction materials, but helps in reducing the cost of cement and concrete manufacturing. It also has numerous indirect benefits such as reduction in land-fill cost, saving in energy, and protecting the environment form possible pollution effects. Furthermore, their utilization may improve the microstructure, mechanical and durability properties of mortar and concrete, which are difficult to achieve by the use of only ordinary Portland cement in mortar and concrete production, (Siddique, 2008).

Concrete is currently the most widely used man-made material in the world. It is a fundamental building material to fulfil the housing and infrastructure needs of our society (Moya et al., 2010). However, the current concrete construction practice is considered unsustainable because it consumes huge quantities of stone, sand, drinking water and cement. The essential part of concrete is, of course, cement which is being produced at enormous quantities to satisfy the ever-increasing demand for concrete (Cembureau, 1999).

Cement manufacturing has become a major mineral commodity industry to supply the high levels of cement consumption. Output from the cement industry is directly related to the state of the construction industry in general, with world cement production growing steadily since 1950 (Moya et al., 2010). Increased production in developing countries (particularly in Asia) has played an important role in the overall production rise. World cement production rate, although hindered by the economic recession, still continued to rise reaching 3.3 billion tonnes in 2010, double the amount of a decade ago (Cembureau, 2011).

Cement industry has a huge environmental impact. Cement production is not only energy consuming, it is also responsible for a considerable part of man-made CO_2 emissions which, along with other greenhouse gases, lead to global warming (Patricija et al., 2012). The total amounts of CO_2 emitted during cement production are roughly within the range of 720-1140 kg/tonne clinker (Moya et al., 2010). The weighted average of CO_2 at worldwide level in 2009 was approximately 853 kg/tonne cement, while at European level – 846 kg/tonne cement (Cement Sustainability Initiative, 2009). Demand for cement is forecast to continue increasing worldwide, in particular in emerging economies where much needed housing and infrastructure boosts development. From this point of view, cement is not an environment-friendly material; it is therefore an important and urgent task to reduce energy consumption and emissions to the air during concrete manufacture.

One way to achieve the necessary reductions is by partial replacement of cement with industrial by products or waste materials; this will lower the amount of cement production and also help utilize waste materials or by products. Currently this could be viewed as the most prospective scenario in the near future, because it has relatively low investment needs and therefore is easier to implement worldwide (Patricija et al., 2012). Replacing cement partially would reduce energy use and CO_2 emissions considerably. However, those would not be the only gains; other benefits include potential improvements of concrete properties, reduced cost for raw materials and higher utilisation of waste products (Kumar et al., 2010)

2.2 CEMENT

Cement is a binder, a substance that sets and hardens independently, and can bind other materials together. Cement according to Shetty (2005) is composed primarily of silica and lime, which form the essential cementing compounds tricalcium (C_3S) and dicalcium silicate (C_2S). Cements used in construction can be characterized as being either hydraulic or non-hydraulic. Hydraulic cements (e.g., Portland cement) harden because of hydration, a chemical reaction between the anhydrous cement powder and water. Thus, they can harden underwater or when constantly exposed to wet weather. The chemical reaction results in hydrates that are not very water-soluble and so are quite durable in water. Non-hydraulic (e.g. lime and gypsum plaster) cements do not harden underwater, it must be kept dry in other to retain its strength.; for example, slaked limes harden by reaction with atmospheric carbon dioxide, (Gartner et al, 2011).

The most commonly used cement is the Portland cement which is obtained from the combination of raw materials rich in calcium such as chalk or limestone and others rich in silicon such as clay and shale. Cement is the basic ingredient of mortar, concrete and plaster. English masonry worker, Joseph Aspdin, patented Portland cement in 1824; it was so named because of its similarity in colour to Portland limestone, quarried from the English isle of Portland and used extensively in London architecture.

Table 2.1 Chemical Compounds of Portland Cement

NAME OF COMPOUND	CHEMICAL COMPOSITION	ABBREVIATION
Tri calcium silicate	$3CaO\ SO_2$	C_3S
Di calcium silicate	$2CaO\ SO_2$	C_2S
Tri calcium aluminate	$3CaO\ Al_2O_3$	C_3A
Tetra calcium alumino ferrite	$4CaO\ Al_2O_3\ Fe_2O_3$	C_4AF

Source: Neville, 2003.

These compounds contribute to the properties of cement in different ways;

- Tricalcium aluminate, C_3A: - It liberates a lot of heat during the early stages of hydration, but has little strength contribution. Gypsum slows down the hydration rate of C_3A. Cement low in C_3A is sulphate resistant.

- Tricalcium silicate, C_3S:- This compound hydrates and hardens rapidly. It is largely responsible for Portland cement's initial set and early strength gain.

- Dicalcium silicate, C_2S: C_2S hydrates and hardens slowly. It is largely responsible for strength gain after one week.

- Tetra calcium alumino Ferrite, C_4AF:- This is a fluxing agent which reduces the melting temperature of the raw materials in the kiln. It hydrates rapidly, but does not contribute much to strength of the cement paste.

By mixing these compounds appropriately, manufacturers can produce different types of cement to suit several construction environments, (Mamlouk & Zaniewski, 1999).

2.2.1 Types of Cement

1. Portland Cement

Portland cements are commonly characterized by their physical properties for quality control purposes. Their physical properties can be used to classify and compare Portland cements.

Types of Portland cement

A. Ordinary Portland cement; this type of cement is used in constructions when there is no exposure to sulphates in the soil or groundwater. The chemical composition requirements are listed as shown below:

Lime Saturation Factor =

$$\{CaO-0.7(SO_3)\}/ \{2.8(SiO_2) +1.2(Al_2O_3) +0.65(Fe_2O_3)\}$$

L.S.F. is limited between 0.66-1.02

Where, each term in brackets denotes the percentage by mass of cement composition. This factor is limited to assure that the lime in the raw materials, used in the cement manufacturing is not so high, so as it cause the presence of free lime after the occurrence of chemical equilibrium. While too low a L.S.F. would make the burning in the kiln difficult and the proportion of C_3S in the clinker would be too low.

B. Rapid Hardening Portland cement

This type develops strength more rapidly than ordinary Portland cement. The initial strength is higher, but they equalize at 2-3 months. Setting time for this type is similar for that of ordinary Portland cement. The rate of strength gain occurs due to increase of C_3S compound, and due to finer grinding of the cement. Rate of heat evolution is higher than in ordinary Portland cement due to the increase in C3S and C_3A, and due to its higher fineness. Chemical composition and soundness requirements are similar to that of ordinary Portland cement

Uses

a) The uses of this cement is indicated where a rapid strength development is desired (to develop high early strength, i.e. its 3 days strength equal that of 7 days ordinary Portland cement), for example:

i) When formwork is to be removed for re-use.

ii) Where sufficient strength for further construction is wanted as quickly as practicable, such as concrete blocks manufacturing, sidewalks and the places that cannot be closed for a long time, and repair works needed to construct quickly.

b) For construction at low temperatures, to prevent the frost damage of the capillary water.

c) This type of cement does not use at mass concrete constructions.

Special Types of Rapid Hardening Portland cement

a. Ultra High Early Strength Cement

The rapid strength development of this type of cement is achieved by grinding the cement to a very high fineness. High fineness leads to rapid hydration, and therefore to a high rate of heat generation at early ages and to a rapid strength development (7 days strength of rapid hardening).There is little gain in strength beyond 28 days. It is used in structures where early prestressing or putting in service is of importance. This type of cement contains no integral admixtures.

b. Extra Rapid Hardening Portland cement

This type of cement is prepared by grinding $CaCl_2$ with rapid hardening Portland cement. The percentage of $CaCl_2$ should not be more than 2% by weight of the rapid hardening Portland cement.

By using $CaCl_2$:

- **i.** The rate of setting and hardening increase (the mixture is preferred to be cast within 20 minutes).
- **ii.** The rate of heat evolution increase in comparison with rapid hardening Portland cement, so it is more convenient to be use at cold weather.
- **iii.** The early strength is higher than for rapid hardening Portland cement, but their strength is equal at 90 days.
- **iv.** Because $CaCl_2$ is a material that takes the moisture from the atmosphere, care should be taken to store this cement at dry place and for a storage period not more than one month so as it does not deteriorate.

C. Low Heat Portland cement

Composition

It contains less C_3S and C_3A percentage, and higher percentage of C_2S in comparison with ordinary Portland cement.

Properties

1) Reduce and delay the heat of hydration. British standard (B.S1974) limit the heat of hydration of this cement by: 70 cal/g at 28 days age

2) It has lower early strength (half the strength at 7 days age and two third the strength at 28 days age) compared with ordinary Portland cement.

3) Its fineness is not less than 3200 cm2/g (according to B. S. 1370: 1974).

Uses

It is used in mass concrete constructions: the rise of temperature in mass concrete due to progression in heat of hydration cause serious cracks. So it is important to limit the rate of heat evolution in this type of construction, by using the low heat cement.

D. Sulphate- resisting Cement

Composition

It contains Lower percentage of C_3A and C_4AF which considers as the most affected compounds by sulphates, higher percentage of silicates in comparison with ordinary Portland cement and for this type of cement C_2S represents a high proportion of the silicates.

Properties

i. Low early strength.

ii. Its resulted heat of hydration is little higher than that resulted from low heat cement.

iii. Its cost is higher than ordinary Portland cement – because of the special requirements of material composition, including addition of iron powder to the raw materials.

For the hardened cement, the effects of sulphates are on two types:

1. Hydrated calcium aluminates in their semi-stable hexagonal form (before its transformation to the stable state – C3AH6 as cubical crystal form – which have high sulphate resistance) react with sulphates (present in fine aggregate, or soil and ground water), producing hydrated

calcium sulfoaluminate, leading to increase in the volume of the reacted materials by about 227% causing gradual cracking.

2. Exchange between $CA(OH)_2$ and sulphates resulting gypsum, and leading to increase in the volume of the reacted materials by about 124%.

The cure of sulphates effect is by using sulphate-resisting cement. The resultant of reaction C4AF with sulphates is calcium sulfoaluminate and calcium sulfoferrite, leading to expansion; but an initial layer will form which surround the free C3A leading to reduce its affect by sulphates, so C4AF is more resistant to sulphates effect than C3A.

It is possible to add some additive to Portland cement to produce the following types:

2. Portland Blast furnace Cement

This type of cement consists of an intimate mixture of Portland cement and ground granulated blast furnace slag. Slag is a waste product in the manufacture of pig iron. Chemically, slag is a mixture of 42% lime, 30% silica, 19% alumina, 5% magnesia, and 1% alkalis, that is, the same oxides that make up Portland cement but not in the same proportions. The maximum percentage of slag use in this type of cement is limited by British standard B.S. 146: 1974 to be 65%, and by American standard ASTM C595-76 to be between 25-65%.

Properties

- **i.** Its early strength is lower than that of ordinary cement, but their strength is equal at late ages (about 2 months).
- **ii.** The requirements for fineness and setting time and soundness are similar for those of ordinary cement (although actually its fineness is higher than that of ordinary cement).
- **iii.** The workability is higher than that of ordinary cement.

iv. Heat of hydration is lower that of ordinary cement.

v. Its sulphate resistance is high.

Uses

i. Mass concrete

ii. It is possible to be use in constructions subjected to sea water (marine constructions).

iii. May not be used in cold weather concreting.

3. Pozzolanic Cement

Production

This type of cement consists of an intimate mixture of Portland cement and pozzolana. American standard limit the pozzolana content by 15-40% of Pozzolanic cement. It is essential that pozzolana be in finely divided state as it is only then that silica can combine with calcium hydroxide (produced by thehydrating Portland cement) in the presence of water to form stable calcium silicates which have cementitious properties.

Properties & Uses

i. They are similar to those of Portland blast furnace cement.

4. White Cement

White Portland cement is made from raw materials containing very little iron oxide (less than 0.3% by mass of clinker) and magnesium oxide (which give the grey colour in ordinary Portland cement). China clay (white kaoline) is generally used, together with chalk or limestone, free from specified impurities. Its manufacture needs higher firing temperature because of the absence of iron element that works as a catalyst in the formation process of the clinker. In some cases kreolite (sodium-aluminumfluoride) might be added as a catalyst. The compounds in this cement are similar for those in ordinary Portland cement, but C4AF percentage is very low. Contamination of the cement with iron during grinding of clinker has also to be avoided. For this reason, instead of the usual ball mill, the expensive nickel and molybdenum alloy balls are used in a stone or ceramic-lined mill. The cost of grinding is thus higher, and this, coupled with the more expensive raw materials, makes white cement rather expensive. It has a slightly lower specific gravity (3.05-3.1), than ordinary Portland cement. The strength is usually somewhat lower than that of ordinary Portland cement.

Other Cements

1. Colored Portland cement

It is prepared by adding special types of pigments to the Portland cement. The pigments added to the white cement (2-10% by weight of the cement) when needed to obtain light colors, while it added to ordinary Portland cement when needed to obtain dark colors. The 28-day compressive strength is required to be not less than 90% of the strength of a pigment-free control mix, and the water demand is required to be not more than 110% of the control mix. It is required that pigments are insoluble and not affected by light. They should be chemically inert and don't contain gypsum that is harmful to the concrete.

2. Anti-bacterial Portland Cement

It is a Portland cement interground with an anti-bacterial agent which prevents microbiological fermentation. This bacterial action is encountered in concrete floors of food processing plants where the leaching out of cement by acids is followed by fermentation caused by bacteria in the presence of moisture.

3. Hydrophobic Cement

It is prepared by mixing certain materials (stearic acid, oleic acid, … etcby 0.1-0.4%) with ordinary Portland cement clinker before grinding, to form water repellent layer around the cement particles, so as the cement can be store safely for a long period. This layer removes during mixing process with water.

4. Expansive Cement

It has the property of expanding in its early life so as to counteract contraction induced by drying shrinkage.

2.2.2 Cement Chemistry

Non-hydraulic cement such as slaked limes (calcium hydroxide mixed with water), harden due to the reaction of carbonation in presence of the carbon dioxide naturally present in the air. Calcium oxide is produced by lime calcination at temperatures above 825 °C (1,517 °F) for about 10 hours at atmospheric pressure:

$$CaCO_3 \rightarrow CaO + CO_2 \qquad (2.1)$$

The calcium oxide is then spent mixing it to water to make slaked lime:

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad (2.2)$$

Once the water in excess from the slaked lime is completely evaporated (this process is technically called setting), the carbonation starts:

$$Ca\,(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad (2.3)$$

This reaction takes a significant amount of time because the partial pressure of carbon dioxide in the air is small. The reaction of carbonation requires the air be in contact with the dry cement, hence, for this reason the slaked lime is non-hydraulic cement and cannot be used under water.

Conversely, the chemistry ruling the action of the hydraulic cement is the hydration. Hydraulic cements (such as the Portland cement) are made of a mixture of silicates and oxides, the four main components being:

Belite ($2CaO \cdot SiO_2$);

Alite ($3CaO \cdot SiO_2$);

Celite ($3CaO \cdot Al_2O_3$);

Brownmillerite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$).

The reactions during the setting of the cement are:

$$(3CaO \cdot Al_2O_3)_2 + (x+8)\ H_2O \rightarrow 4\ CaO \cdot Al_2O_3 \cdot xH_2O + 2\ CaO \cdot Al_2O_3 \cdot 8H_2O$$

$$(3CaO \cdot Al_2O_3) + 12\ H_2O + Ca(OH)_2 \rightarrow 4\ CaO \cdot Al_2O_3 \cdot 13\ H_2O$$

$$(4CaO \cdot Al_2O_3 \cdot Fe_2O_3) + 7\ H_2O \rightarrow 3\ CaO \cdot Al_2O_3 \cdot 6H_2O + CaO \cdot Fe_2O_3 \cdot H_2O \qquad (2.4)$$

And during the hardening (the chemistry of the reaction of hydration is still not completely clear):

$$(3CaO \cdot SiO_2)_2 + (x+3)\ H_2O \rightarrow 3\ CaO_2 \cdot SiO_2 \cdot xH_2O + 3\ Ca(OH)_2$$

$$(2CaO \cdot SiO_2)_2 + (x+1)\ H_2O \rightarrow 3\ CaO_2 \cdot SiO_2 \cdot xH_2O + Ca(OH)_2 \qquad (2.5)$$

The silicates are responsible of the mechanical properties of the cement, the celite and the browmillerite are essential to allow the formation of the liquid phase during the cooking. The chemistry of the above listed reactions is not completely clear and is still object of research.

Extensive research has shown the use of substitute's material, which possessing pozzolanic properties can produce concrete of better resistance to sulphate attack, reduce permeability and help reduce the environmental pollution caused by the production of cement, (Marthong, 2012).

2.3 POZZOLANAS

Pozzolana is a siliceous or a siliceous aluminous material which contains little or no cementitious value, but in finely divided form and in the presence of moisture or water, chemically reacts with calcium of moisture at ordinary temperature to form compound possessing cementitious properties, (Marthong, 2012). They are an important ingredient in the production of alternative cementing material to Portland cement (OPC).

Cement or some form of binding agent is a vital element in almost all types of construction and in recent years the cement market has been dominated by one product, OPC. In many countries, OPC is an expensive and sometimes scarce commodity and this has severely limited the construction of affordable housing in much of the Third World (Building Advisory Service and Information Network (BASIN), 2010). Also, the production of cement causes environmental pollution by releasing CO2 in to the atmosphere. Alternative cements provide an excellent technical option to OPC at a much lower cost and have the potential to make a significant contribution towards the provision of low cost building materials, affordable shelter and, consequently, a friendly environment.

Pozzolana material independently has fewer cementitious properties but in the presence of lime-rich medium, like Calcium hydroxide, it shows better cementitious properties towards the later day strength (28days and above), (Madina and Nafisa, 2010). A wide variety of siliceous or aluminous materials may be pozzolanic. Pozzolanas can be divided into two groups: natural pozzolanas such as volcanic ash and diatomite, and artificial pozzolanas such as calcined clays, pulverized fuel ash and ash from burnt agricultural wastes. When mixed with lime, pozzolanas will greatly improve the properties of lime-based mortars, concretes and renders and, in this form, can be used in a wide range of building applications. Alternatively, they can be blended with OPC to reduce costs considerably and to improve certain characteristics of OPC-based concretes, such as long-term strength, resistance to sulphate attack and workability.

Some waste materials and by-products have established their credentials as pozzolana in their usage in cement-based materials and for others research is in progress for exploring the potential applications. Some industrial wastes that have been studied for use as supplementary cementing materials are Fly ash (Sid- dique, 2004; Wang and Baxter, 2007; Wang et al., 2008), Silica fume (Lee et al., 2005; Turker et al., 1997), Pulverized fuel ash (Balendran and Martin-Buades, 2000), Volcanic ash (Hossain, 2005), Rice husk ash (WaswaSabuni et al. 2002) and Corn cob ash (CCA) (Adesanya and Raheem, 2010), Saw Dust Ash as Partial Replacement for Cement in Concrete (Raheem et al, 2012). It is in this vain, that IWWA, which is a wood-based waste is being studied as a possible pozzolan in cement based concrete. A total of 104,000m^3 of IWW is generated daily in Nigeria, (Lasode et al., 2012). These IWW can be easily converted into ash by burning. Based on the measured physical, chemical, morphological properties, Naik(1999) reported that wood ash has a substantial potential for use as a pozzolanic mineral admixture and an activator in cement-based materials. He further indicated that wood ash has signi cant potential for use in numerous other materials including Controlled Low Strength Materials (CLSM), low- and medium-strength concrete, masonry products,roller-compacted concrete pavements (RCCP), materials for road base, and blended cements. Cheah and Ramli (2011) also investigated the implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar. Elinwa et al. (2008) assessed the fresh concrete properties of self- compacting concrete containing saw dust ash. Elinwa and Mahmoodb (2002) considered ash from timber waste as cement replacement material. It is in this vain, that IWWA which is a wood-based waste is being studied as a possible pozzolana in cement based products. However, this present study considers the effect of IWWA Average Particle Size (APS) and the incineration conditions on the properties of mortar and concrete.

2.4 INDUSTRIAL WOOD WASTE ASH (IWWA)

Industrial Wood Waste Ash (IWWA) is the residue generated due to combustion of wood and its residue (chips, saw dust, bark, etc.). It is the inorganic and organic residue remaining after the combustion of wood or unbleached wood fiber. Typical wood burnt for fuel at pulp and paper mills and wood products industries may consist of saw dust, wood chips, bark, and saw mill scraps, hard chips rejected from pulping, excess screenings such as sheaves and primary residuals without mixed secondary residuals. The physical and chemical properties of wood ash, which determine its beneficial uses, are dependent upon the species of the wood and the combustion methods that include combustion temperature, efficiency of the boiler, and supplementary fuels used. Ash content yield decreases with increasing combustion temperature (Etiegni and Campbell, 1991).

Hardwoods usually produce more ash than softwoods and the bark and leaves generally produce more ash than the inner woody parts of the tree, (Siddique, 2008). On the average, the burning of wood results in about 6–10% ashes, (Siddique, 2008). When ash is produced in industrial combustion systems, the temperature of combustion, cleanliness of the fuel wood, the collection location, and the process can also have profound effects on the nature of the ash material.

Therefore, wood ash composition can be highly variable depending on geographical location and industrial processes. This makes testing the ash extremely important. Typically, wood ash contains carbon in the range of 5–30% (Campbell, 1990). The major elements of wood ash include calcium (7–33%), potassium (3–4%), magnesium (1–2%), manganese (0.3–1.3%), phosphorus (0.3–1.4%), and sodium (0.2–0.5%). Density of wood ash decreases with increasing carbon content. The chemical and physical properties depend upon the type of wood, combustion temperature, etc. (Campbell, 1990; Mishra et al., 1993).

2.4.1 Properties of Iwwa

The properties of IWWA are influenced by species of tree, tree growing regions and conditions, method and manner of combustion including temperature, other fuel used with wood fuel, and method of wood ash collection (Etiegni, 1990; Etiegni and Campbell, 1991; National Council for Air and Stream Improvement, Inc., 1993) Further quality variation in the wood ash properties occur when wood is co- red with other supplementary fuels such as coal, coke, gas, and the relative quantity of wood versus such other fuels NCASI (1993). Physical and chemical properties of wood ash are important in determining their bene cial uses.

2.4.1.1 Physical Properties of Iwwa

Raheem et al. (2012) reported the physical properties of wood ash, used to partially replace cement in concrete. They use waste wood collected from saw mill points at Apake in Ogbomoso, Oyo State, Nigeria. The collected sample was burnt into ashes by open burning in a metal container.The physical properties of the wood ash are shown in Table 2.2;

Table 2.2 Physical Properties of Wood Waste Ash of Some Researchers

Name of Researcher(s) and year of research	Specific Gravity	Loose Bulk density(kg/m^3)	Loss of Ignition (%)	Moisture Content (%)
Raheem et. al (2012)	2.19	1010	4.3	0.3
Udoeyo et. al (2006)	2.43	....	10.46	1.81
Abdullahi (2006)	2.13	760	......	1.6
Naik et. Al (2003)	2.48	827	....	2.2

Udoeyo et al. (2006) also reported the physical properties of waste wood ash (WWA), used as additive in concrete. They used wood waste collected from a dump site at the timber market in Uyo, AkwaIbom State of Nigeria. The waste was subjected to a temperature of 1000 C in an oven to incinerate it into ash before it was used as an additive in concrete. The WWA had a speci c gravity of 2.43, a moisture content of 1.81%, and a pH value of 10.48. The average loss on ignition of the ash was found to be 10.46.

Abdullahi (2006) determined the properties of wood waste ash to be used as partial replacement of cement. The wood ash used was powdery, amorphous solid, sourced locally, from a bakery. The wood ash was passed through BS sieve 0.075mm size. The specific gravity of wood ash was found to be 2.13 and a moisture content of 1.81%. The bulk density of wood ash was found to be 760kg/m3.

Naik et al. (2003) evaluated the wood ashes from five different sources in Wisconsin (USA) for possible use in making controlled low-strength materials (CLSM). The average moisture content values for the wood ash studied were about 22%, bulk density exhibited average density values of 827kg/m3 and an average speci c gravity value of 2.48.

From properties reported by the researchers above it can be seen that the properties of IWWA varies depending on the species of wood, location and method of combustion.

2.4.1.2 Chemical Composition of Iwwa

The table below shows the chemical composition of IWWA of some researchers.

Table 2.3 Chemical Composition of WWA of Some Researchers

Chemical Composition	Name of Researcher(s) and year of research		
	Raheem et al (2012)	Naik et al (2003)	Abdullahi (2006)
SiO_2	65.75	26.84	31.8
Al_2O_3	5.23	10.58	2.8
Fe_2O_3	2.09	6.34	2.34
CaO	9.62	12.86	10.53
MgO	4.09	3	9.32
SO_3	1.09	3.56	-------
Na_2O	0.06	1.48	6.5
K_2O	2.43	1.8	10.38
$CaCO_3$	7.92	-------	---------

Naik et al. (2003) studied the chemical composition of wood ashes from five different sources for their possible use in making controlled low-strength materials (CLSM). Wood ashes from five different sources in Wisconsin (USA) designated as W1, W2, W3, W4, and W5 were used. ASTM standards do not exist for wood ash. The nearest ASTM standard (ASTM C 618, 1994) available is for coal ash and volcanic ash, was used for analysis of its properties. Chemical composition of all the five sources of wood ash is presented in Table 2.3. All wood ashes did not meet all the chemical requirements of ASTM C 618, particularly for the amount of carbon as shown by LOI (loss of ignition) test results. The LOI obtained for the wood ashes ranged from 6.7 to 58.1%. These high LOI ashes probably will present some difficulties when developing air-entrained concrete mixtures. The high carbon content tends to reduce the amount of air en- trained in the concrete mixture and thus requires higher dosages of air-entraining admixtures. However, the higher carbon contents of the wood ashes should not affect the performance of these ashes in CLSM.

Abdullahi (2006) determined the chemical composition of wood ash to be used as partial replacement of cement. The results of chemical analysis of wood ash are shown in Table 2.3.The total percentage composition of Iron oxide (Fe_2O_3 =2.34%), aluminium oxide (Al_2O_3 =28.0%) and silicon dioxide (SiO_2 = 31.80%) was found to be 62.14%. This is less than 70% minimum required for pozzolana (ASTM C 618, 1994). This reduces the pozzolanic activity of the wood ash. The loss on ignition obtained was 27%. The value is more than 12%; the maximum as required for pozzolana (ASTM C 618-94). This means that the wood ash contain appreciable amount of un-burnt carbon which reduces its pozzolanic activity. The un-burnt carbon is not pozzolanic and its presence serves as filler to the mixture. The alkali content (Na_2O) was found to be 6.5%. This value is higher than the maximum alkali content of 1.5% required for pozzolana. The alkali content is important where the wood ash is to be used with reactive aggregate (Neville, 1995). This result shows that the Wood ash will not be suitable for construction work where reactive aggregate is to be used.

2.4.1.3 Elemental Analysis

Mishra et al. (1993) investigated the elemental and molecular composition of mineral matters in ash from five types of wood and two types of barks as a function of temperature. The mass loss occurred in the range of 23 to 48% when the combustion temperature was increased from 500 to 1300 C. This was attributed to decreased elemental mass concentrations resulting from increased temperature.

Steenari and Lindqvist (1998) characterized fly ashes derived from co-combustion of wood chips and fossil fuels, and compared their properties with those obtained from combustion of wood ash alone. In their work, wood fly ash samples were obtained by the co-firing of wood chips with coal, oil, and peat in utility boilers in Sweden. The fly ashes derived from the co-combustion of wood with coal or peat exhibited lower concentrations of calcium, potassium, and chlorine, and higher concentrations of aluminum ion and sulphur relative to pure wood ash. The pH of leachates obtained from the co-combustion ashes were lower compared to pure wood ash. The concentrations of trace metals in these ashes were similar to those observed in pure wood ashes.

Naik et al. (2002) studied the elemental analysis of wood obtained from Rothschild, Wisconsin in United States, and compared it with that of the Type-I cement. Analysis was done using Instrumental Neutron Activation Analysis. The neutron activation analysis method exposes the sample to neurons, which results in an activation of many elements. This activation consists of radiation of various elements. For the ash and cement utilized in this project, gamma-ray emissions were detected. Many different elements may be detected simultaneously based on the gamma-ray energies and half-lives. The elemental composition of the cement and wood ash differed considerably.

Predominate elements contained in the wood ash were Aluminum, Cadmium, Calcium, Iron, Magnesium, Manganese, Potassium, Sodium, and Titanium. Primary elements in the cement were Aluminum, Calcium, Iron, and Potassium. The wood ash had much higher amounts of Magnesium, Manganese, Potassium, Aluminum, and Sodium than the cement. The total elemental composition of these materials gives some indication of the potential for leaching.

2.4.1.4 Mineralogical Analysis

Campbell (1990) presented data onmajor and trace elements in wood ash. The major elements were calcium (7–33%), potassium (3–4%), magnesium (1–2%), phosphorus (0.3–1.4%), manganese (0.3–1.3%), and sodium (0.2–0.5%). The trace elements were zinc, boron, copper, molybdenum, and others at parts per million levels. Carbon content in wood ash was found to vary between 4 and 34% by mass.

Naik et al. (2002) studied the mineralogical analysis of wood ash obtained from Rothschild in Wisconsin in United States. Major mineral species (crystalline phases) that were found in the wood ash are shown in Table 2.4. The predominant crystalline phase present in the wood ash sample was quartz (SiO_2). Additional trace amounts of crystalline phases detected in wood ash included gypsum ($CaSO_4H_2O$), magnetite (Fe_3O_4), microcline ($KASi_3O_8$), mullite ($Al_2O_3.SiO_2$), periclase (MgO), and plagioclase (NaCa). The mineralogical analysis also indicated large amounts of amorphous material present in the wood ash (46.9%). The calcite, hematite, magnetite, microcline,mullite, plagioclase, and quartz present in the wood ash are generally not reactive when used in concrete. Generally, cement had predominant phases of tricalcium aluminate, amorphous, dicalcium silicate, tetracalcium aluminoferrite, and tricalcium silicate.

Table 2.4 Mineralogical Analysis of WWA

Analysis parameter	%
Amorphous	46.9
Calcite ($CaCO_3$)	3.6
Quartz (SiO_2)	34.5
Microcline ($KAlSi_3O_8$)	7.9
Mullite ($Al_2O_3SiO_2$)	–
Albite ($NaAlSi_3O_8$)	5.7
Portlandite ($Ca(OH)_2$	1.4
Syngenite ($K_2Ca(SO_4)2H_2O$)	–

Source: Naik et al., 2002.

2.4.2 Uses of Wood Ash

Wood ash is commonly disposed of in landfills, but with rising disposal costs ecologically friendly alternatives are becoming more popular, (Demeyer, 2001). For a long time wood ash has been used in agricultural soil applications as it recycles nutrients back to the land. Wood ash has some value as a fertilizer, but does not contain nitrogen. Due to the presence of calcium carbonate it acts as a liming agent and will de-acidify the soil increasing its pH. The liming ability of wood ash is generally estimated by using a laboratory measured parameter called the calcium carbonate equivalent (CCE). The CCE indicates how well the wood ash will raise the soil pH compared to lime (calcium carbonate). As with the nutrient composition of wood ash, the CCE of different wood ash may vary considerably, however, most are within the range of 25-60 %,(Siddique, 2008).

Potassium hydroxide can be indirectly made from wood ash by the addition of calcium hydroxide, and in this form is known as caustic potash or lye. Due to this property, wood ash has also traditionally been used to make wood-ash soap.

Wood ash with high char content has also proven to be effective as an odor control agent, especially in composting operations, (Rosenfeld and Henry, 2001). Wood ash has been used as a replacement of lime or cement kiln dust in the solidification of hazardous wastes (NCASI, 1993). It has also been used for odour as well as pH control of hazardous and non-hazardous wastes. Wood ash has been added to compost as a colour and odour control. Wood ash has been found to capture several water borne contaminants (NCASI, 1993).

Some work has been reported relating to the applications of wood ash as a construction material, particularly in cement-based materials. Mukherji et al. (1995) conducted experiments to explore the use of wood ash in the ceramic industry. They reported that wood ash derived from the "Neem" (Margosa) tree could be used as a substitute for $CaCO_3$ in the manufacture of glaze. A series of colour stains was also manufactured using the "Neem" wood ash and other ingredients. These stains were calcined at 1250 C. The glazes and colors developed using this wood ash were tested and evaluated for the desired properties for these materials. The authors concluded that the glazes and colors developed in their investigation are suitable for use in both green and baked ware.

Due to high carbon content in wood ash, its use is limited to low- and medium-strength concrete materials. In Europe, wood ash has also been used as a feedstock in the manufacture of Portland cement (Etiegni, 1990). Based on the measured physical, chemical, morphological properties, Naik (1999) reported that wood ash has a substantial potential for use as a pozzolanic mineral admixture and an activator in cement-based materials such as concrete and mortar. Any alteration in silica content of cement will invariably affect the strength characteristics of cement, which is expected when IWWA which is a pozzolana is used to partially replace with any grades of cement for making concrete.

2.5 CONCRETE

Like mortar, concrete is a mixture of sand, cement, and water, but it also contains rock chippings or gravel which makes it much stronger and more durable than mortar. Because it needs a low water to cement ratio, it is much thinner when mixed, making it difficult to use as a bonding element. Concrete is a composite construction material that is composed of cement (commonly Portland cement) and other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate made of gravels or crushed rocks such as limestone or granite), plus fine aggregate such as sand, water and chemical admixtures (lynne,2005).

The word concrete comes from the Latin word 'concretus', meaning compact or condensed. Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. Reinforced concrete and prestressed concrete are the most widely used modern kinds of concrete functional extensions. Many ancient civilizations used forms of concrete using dried mud, straw, and other materials. Concrete has relatively high compressive strength, but much lower tensile strength. For this reason it is usually reinforced with materials that are strong in tension (often steel).

The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress level as matrix cracking develop. Concrete has a very low coefficient of thermal expansion and shrinks as it matures. All concrete structures crack to some extent, due to shrinkage and tension. Concrete that is subjected to long-duration forces is prone to creep, (Henry and Russel, 2013). Concrete with different properties are produced by varying the proportion of the main ingredients.

2.5.1 Concrete Production

Concrete production is the process of mixing together the various ingredients-water, aggregate, cement, and any additives-to produce concrete. Concrete production is time-sensitive. Once the ingredients are mixed, workers must put the concrete in place before it hardens. There is a wide variety of equipment for processing concrete-from hand tools to heavy industrial machinery. Whichever equipment builders use, the objective is to produce the desired building material. Ingredients must be properly mixed, placed, shaped, and retained within time constraints. Once the mix is where it should be, the curing process must be controlled to ensure the concrete attains desired attributes. During concrete preparation, various technical details may affect the quality and nature of the product.

When initially mixed, Portland cement and water rapidly form a gel of tangled chains of interlocking crystals, and components of the gel continue to react over time. Initially the gel is fluid, which improves workability and aids in placement of the material, but as the concrete sets, the chains of crystals join into a rigid structure, counteracting the fluidity of the gel and fixing the particles of aggregate in place. During curing, the cement continues to react with the residual water in a process of hydration. In properly formulated concrete, once this curing process has terminated the product has the desired physical and chemical properties, (Ferrari, 2011).

2.5.2 Properties of Concrete

2.5.2.1 Properties of Fresh Concrete

1. **Workability:** it is the term used to describe the fluidity of concrete and it is defined as the ease with which a given set of materials can be mixed into concrete and subsequently handled, transported and placed with minimum loss of homogeneity, (Ella, 2012).

2. **Segregation:** it is defined as the separation of the constituents of a heterogeneous concrete mixture so that their distribution is no longer uniform. Segregation is quite detrimental to concrete as it prevents proper compaction which results in rock pockets, porous layers, crazing and surface sealing, (Ella, 2012).

3. **Bleeding:** this is the kind of segregation in which the water in the mix tends to rise to the surface of fresh concrete as solid constituents settle downwards. Bleeding may produce porous and weak concrete, (Ella, 2012).

2.5.2.2 Properties of Hardened Concrete

1. **Compressive strength:** is the most important property of concrete and can be defined as the maximum compressive load a concrete can carry per unit area. All other properties depend on the compressive strength of concrete. When the compressive strength of concrete increases all the other properties of concrete usually improve. The result of the strength test can be used for the control purpose in determining the particular grade of concrete. Strength of concrete usually gives an overall picture of the quality of concrete. This is so because strength is directly proportional to the hardened concrete between 1-28 days, (Neville, 2003).

2. **Ultimate Tensile strength:** Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength, is the maximum stress that concrete can withstand while being stretched or pulled before failing or breaking. Tensile strength is not the same as compressive strength and the values can be quite different. Tensile strength is about one tenth of the compressive strength, (Ella, 2012).

3. **Modulus of elasticity:** the dynamic modulus is determined by subjecting a beam specimen to longitudinal vibration. The value obtained is unaffected by creep and is approximately equal to the tangent modulus, (Ella, 2012).

4. **Bond strength:** is a measure of the effectiveness of the grip between concrete and steel. It is the shearing stress or force between a bar and surrounding concrete. The force in the bar is transmitted to the concrete by bond or vice-versa. Bond is made up of chemical adhesion, friction and mechanical interaction between concrete and steel. Bond of plain bars depends

primarily on chemical adhesion and friction, although there is some mechanical inter-locking due to roughness of the bar surface. Deformed bars, however, depend primarily on mechanical inter-locking for superior bond properties, (Ella, 2012).

5. **Creep:** is the gradual increase in strain with time in a member subjected to prolonged stress. It can be regarded as a progressive decrease in stress with time for a stressed concrete specimen subjected to a constant strain. Creep is calculated as the difference between the total time-deformation of the loaded specimen and the shrinkage of a similar unloaded specimen stored under the same conditions through the same period, (Ella, 2012).

6. **Shrinkage:** when the environment and forces acting cause reduction in volume of concrete, shrinkage is said to occur whether the concrete is subjected to load or not. Shrinkage of concrete could be plastic, autogeneous or drying depending on the period during the lifetime of the concrete they manifest themselves, (Ella, 2012).

7. **Density:** it is defined as the mass of concrete per unit volume. The density of concrete is dependent on many factors such as the heterogeneous and porous nature, degree of compaction, water/cement ratio and moisture content of the concrete at the time of testing. The dependency of concrete on its moisture condition makes it necessary to be classified in terms of its degree of dryness into saturated surface dry (SSD), Air dry or Oven dry, (Ella, 2012).

8. **Permeability:** it is the rate at which concrete permits the passage of fluid through its internal structure. Concrete is inherently porous to water because not all the spaces between the aggregate particles become filled with solid cementitious materials, (Ella, 2012).

9. **Durability:** a durable concrete is one which will withstand the effects of the service conditions to which is subjected, such as weathering, chemical action and water. Many laboratory tests have been developed for measuring durability of concrete, but it is

extremely difficult to obtain a direct correlation between laboratory tests and field service, (Ella, 2012).

2.5.3 Uses of Concrete

The usage of concrete, worldwide is twice as much as steel, wood, plastics, and aluminium combined. The concrete supply chain reaches well beyond construction to include mining, equipment, transportation and industrial sectors of every economy. Concrete's use in the modern world is only exceeded by the usage of naturally occurring water, (cement trust, 2013)

The benefits of concrete to society are immense, being used to build our schools, hospitals, apartment blocks, bridges, tunnels, dams, sewage systems, pavements and architectural structures, foundations, parking structures, runways, roads and more. It is the foundation of homes of every design and size. It is cast into solid shapes to form blocks, bricks, panels and beams. We use it for both simple decoration and critical protection from the elements. Reinforced concrete, prestressed concrete, and precast concrete are the most widely used types of concrete for functional extensions in modern days.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 MATERIALS COLLECTION

A. Industrial Wood Waste Ash (IWWA)

The IWW was collected from timber industrial markets located at Naibawa and RijiyaLemu timber markets, Kano which was generated as a result of cutting, grinding, drilling, smoothing, or otherwise pulverizing wood.

The IWW was collected in bags and some of it was transported to the civil engineering laboratory, BUK, where it was spread out on a clean surface to dry up before it was burnt to ash in a locally constructed container (uncontrolled burning). The remaining bags of the sample were transported to School of Technology; Department of Art and Industrial Design, Kano Polytechnic where it was burnt in a furnace (controlled burning) at a temperature of 550^{o}C- 600^{o}C. The resulting ash was allowed to cool and it was divided into three different particle sizes of 0.66mm, 0.83mm and 1.20mm using a Disk mill (ffc 15). The Disk mill has three interchangeable sieves sizes; the sieve sizes were measured using a digital calliper. The sieve sizes are shown in appendix A-1.

B. Fine Aggregate

Clean river sand which is free from leaves, sticks and dirt was obtained from a local dealer along Bayero University, Kano Gwarzo road, Rijiya Zaki, was used for this research. The fine aggregate was air dried for 24hours after which sieve analysis and specific gravity test of the aggregate were carried out. The result of the sieve analysis and specific gravity test are presented in Table 3.1 and Table 3.3 respectively. The details of sieve analysis are tabulated in Appendix A-2.

Table 3.1: Sieve Analysis Result of Fine Aggregate

Particle Description		Diameter (mm)	Cummulative Passing %
Cobbles		75	100.00
		63	100.00
		50	100.00
Gravel	Coarse	37.6	100.00
		28	100.00
		20	100.00
		14	100.00
		10	100.00
	Fine	6.3	99.09
		5.0	95.69
		3.4	91.56
Sand	Coarse	2.0	78.18
		1.2	58.72
	Medium	0.600	31.11
		0.425	10.94
		0.212	5.70
	Fine	0.15	2.93
		0.063	0.00
	clay or Silt	Pass 63 microns	0.00

C. Coarse Aggregate

Granite having 20mm nominal diameter was obtained from a local dealer along Bayero University, Kano Gwarzo road, Rijiya Zaki, was used for this research. Sieve analysis and specific gravity test of the coarse aggregate were carried out. The result of the sieve analysis and specific gravity test are presented in Table 3.2 and Table 3.3 respectively. The details of sieve analysis are tabulated in Appendix A-3.

Table 3.2: Sieve Analysis Result of Coarse Aggregate

Particle Description		Diameter (mm)	Cummulative Passing %
Cobbles		75	100.00
		63	100.00
		50	100.00
Gravel	Coarse	37.6	100.00
		28	100.00
		20	67.00
		14	1.70
		10	0.25
	Fine	6.3	0.00
		5.0	0.00
		3.4	0.00
Sand	Coarse	2.0	0.00
		1.2	0.00
	Medium	0.600	0.00
		0.425	0.00
		0.212	0.00
	Fine	0.15	0.00
		0.063	0.00
	clay or Silt	Pass 63 microns	0.00

D. Cement

Ordinary Portland cement (Dangote 3x cement, grade 42.5) was used for this research work. The cement was obtained from a local dealer along Bayero University, Kano Gwarzo road, Rijiya Zaki, was used for this research. Specific gravity test was carried out on the cement and the result is presented in Table 3.3.

E. Water

Portable tap water used was obtained from the Water Resources Laboratory, Civil Engineering Department; Bayero University Kano, for mixing and curing purposes.

3.2 SPECIFIC GRAVITY TEST

The test was done in accordance with BS 812-2 (1995) "Methods of determination of density"

The gas jar method was employed.

Table 3.3. Average Specific Gravity of IWWA, Cement, Fine and Coarse Aggregate. Details is tabulated in Appendix A-5

Materials	Sample 1	Sample 2	Average Specific Gravity
IWWA	2.14	2.23	2.19
Cement	3.14	3.18	3.16
Fine aggregate	2.54	2.58	2.56
Coarse aggregate	2.75	2.64	2.70

3.3 CHEMICAL ANALYSIS OF IWWA

Chemical analysis was carried out on the burnt ash before dividing it into different particle sizes. The analysis was carried out at the 'National Geosciences Research Laboratory (NGRL), Kaduna'. X-Ray Fluorescence (XRF) was used to analyse the IWWA.

The result of the chemical analysis of the IWWA is presented in Table 4.1.

3.4 CONCRETE MIX DESIGN

Concrete Mix Design is the process of selecting suitable ingredients of concrete and determining their relative quantities with the objective of producing as economically as possible concrete of certain minimum properties, notably consistency, strength and durability. For the purpose of this project the absolute volume method is used.

The quantity of material to produce a meter cube of concrete using absolute volume method is given by:-

$$\frac{w}{1000} + \frac{C}{1000Gs(cement)} + \frac{F}{1000Gs(fine)} + \frac{G}{1000Gs(coarse)} = 1m^3$$ ....eq. (3.1)

Where;

W= water

C=cement

F= fine aggregate

G=coarse aggregate

For 1:2:4 concrete mix ratio and water/cement ratio of 0.55. Details are presented in Appendix A-6.

3.5 BATCHING AND MIXING OF CONCRETE

The test was done in accordance with BS 1881-125 (1986) “methods for mixing and sampling fresh concrete in the laboratory”

Hand mixing tool was adopted for the mixing.

Cement was then replaced by mass for 5%, 10%, 15% and 20% with 3 different particle sizes of IWWA for controlled and uncontrolled incineration condition and the mixing procedures were carried out for each percentage replacement and particle sizes.

3.6 WORKABILITY TEST

This test was done according with BS 1881 part 102 (1983) "Method for the Determination of Slump". The result is presented in Table 3.4. The slump test used to determine workability is shown in Plate I.

Table 3.4 Workability of Concrete (slump test results)

Paticle Sizes(mm) % IWWA	Incineration Condition	0.66	0.83	1.20
		Average Slump (mm)		
0	Control Mixture	20.00 -	-	-
5	Controlled	8.67	11.33	16.33
	Uncontrolled	8.33	12.00	14.33
10	Controlled	8.00	8.33	12.00
	Uncontrolled	5.00	8.00	10.33
15	Controlled	1.33	3.67	10.33
	Uncontrolled	0	2.00	8.00
20	Controlled	0	3.00	8.00
	Uncontrolled	0	0	4.33

Plate I. Slump Test

3.7 CASTING OF CONCRETE CUBES

A total number of 375 cubes of 1:2:4 mix concrete were cast, 3 samples of cubes were cast with various addition of 0%, 5%, 10%, 15% and 20% of IWWA for 3 different particle sizes of 0.66mm, 0.83mm and 1.20mm for controlled and uncontrolled incineration conditions to determine the strength at 1,7,28,56 and 90 days respectively.

3.8 CURING OF CONCRETE

The cubes were removed from the mould 24 hours after casting; the cubes were then immersed into a clean tank filled with drinkable tap water, after the density of each cubes have been determined. Thus, the curing was carried out for the periods of 1, 7, 28, 56 and 90 days. Sample specimen in steel curing tank is shown in plate II.

Plate II. Curing Of Concrete Cube in Water

3.9 COMPRESSIVE STRENGTH TEST

This test was done according with BS 1881 part 116 (1983) “method for determination of compressive strength of concrete cubes”.

Avery Denison compression machine model LS102DE with a capacity of 200 tonnes was used to test the compressive strength of the concrete cubes. The loading rate of the machine was set at 120KN/min and the cubes at different ages were crushed at room temperature at different ages.

The summary of the result is presented in table 3.5 and details are presented in Appendix A-7-A-31.

Table 3.5 Mean Compressive Strength (N/mm^2) for Uncontrolled and uncontrolled Incinerated IWWA

sieve size (mm)	IWWA content	Incineration condition	Compressive Strength				
			1 day	7 days	28 days	56 days	90 days
	0%		19.70	25.04	28.74	33.48	36.59
0.66	5%	Controlled	14.07	24.44	27.40	29.33	31.40
		Uncontrolled	13.63	20.30	24.59	26.22	27.41
	10%	Controlled	13.93	23.56	26.67	27.40	29.63
		Uncontrolled	12.89	16.67	23.11	25.19	26.52
	15%	Controlled	11.70	18.37	25.48	26.07	28.15
		Uncontrolled	10.81	17.93	22.07	24.00	25.93
	20%	Controlled	10.96	16.15	21.19	23.11	25.33
		Uncontrolled	10.07	16.00	20.15	22.67	24.74
0.83	5%	Controlled	13.93	23.37	25.93	26.37	27.70
		Uncontrolled	13.04	19.85	22.67	25.48	26.37
	10%	Controlled	13.19	21.19	24.30	25.33	26.52
		Uncontrolled	12.59	18.07	22.07	23.70	25.77
	15%	Controlled	11.41	17.19	23.85	24.30	24.89
		Uncontrolled	10.22	17.19	20.74	22.37	24.00
	20%	Controlled	9.63	13.93	18.96	22.22	23.70
		Uncontrolled	9.63	13.48	18.67	21.19	23.11
1.20	5%	Controlled	13.48	18.52	24.15	25.48	26.07
		Uncontrolled	12.30	19.41	21.93	24.00	25.93
	10%	Controlled	11.40	17.19	22.22	24.00	25.04
		Uncontrolled	11.70	17.63	21.04	22.22	24.89
	15%	Controlled	10.52	13.33	18.37	22.81	23.70
		Uncontrolled	10.37	16.44	18.81	21.63	22.96
	20%	Controlled	9.63	12.59	18.07	21.04	22.96
		Uncontrolled	9.78	12.30	17.63	20.59	22.22

CHAPTER FOUR

RESULT AND DISSCUSSION

The summary of result of the experimentation detailed in chapter three are presented, analyzed and discussed in this chapter.

4.1 CHEMICAL COMPOSITION OF IWWA

X-ray fluorescence was used to determine chemical composition of wood ash in terms of silicon oxide (SiO_2), aluminium oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), potassium oxide (K_2O), and sodium oxide (Na_2O). Loss on ignition (LOI) was also determined. The results are shown in Table 4.1.

Table 4.1 Oxide Composition of IWWA under Controlled and Uncontrolled Condition

Oxide	% Composition Of Controlled IWWA	% Composition Of Uncontrolled IWWA
SiO_2	46.90	44.50
Al_2O_3	1.34	1.31
Fe_2O_3	1.21	1.20
CaO	21.60	21.51
MgO	1.20	1.22
SO_3	0.22	0.31
Na_2O	2.03	2.00
K_2O	1.00	1.02
LOI	24.50	25.53
$SiO_2 + Al_2O_3 + Fe_2O_3$	49.90	47.01

The total percentage composition of Iron oxide (Fe_2O_3), aluminium oxide (Al_2O) and silicon dioxide (SiO_2) for both controlled and uncontrolled incineration was found to be 49.90% and 47.01% respectively. This is less than 70% minimum required for pozzolana specified in ASTM C 618-94, 1994. Furthermore, the magnesium oxide values (average as well as range of values) for IWWA were lower than the value of MgO found in typical coal fly ash. Therefore, these wood ashes tested should not have soundness/durability-related problems created due to a high-MgO value. The average value of SO_3 is less than the maximum 5% permitted by ASTM C 618 for coal fly ash. The alkaline content is slightly higher than 1.5% specified by ASTM C 618 for coal fly ash. The loss on ignition obtained was 24.50% and 25.53% for controlled and uncontrolled IWWA respectively. The value is more than 12% maximum as required for pozzolana. This means that the wood ash contain appreciable amount of un-burnt carbon which reduces its pozzolanic activity. The un-burnt carbon is not pozzolanic and its presence serves as filler to the mixture. This high LOI might present some difficulties when making air-entrained concrete (Naik et al, 2003). The calcium oxide contents of the wood ashes were generally above the values for a typical ASTM Class F fly ash with an average of 16% for wood fly ash and 11.4 % for wood bottom ash. IWWA results show that it has some properties that can contribute to pozzolanic reactions, and therefore can be used as successful partial replacement for cement.

4.2 PARTICLE SIZE DISTRIBUTION OF FINE AGGREGATES

The grading curve of fine aggregate is shown in the figure below:

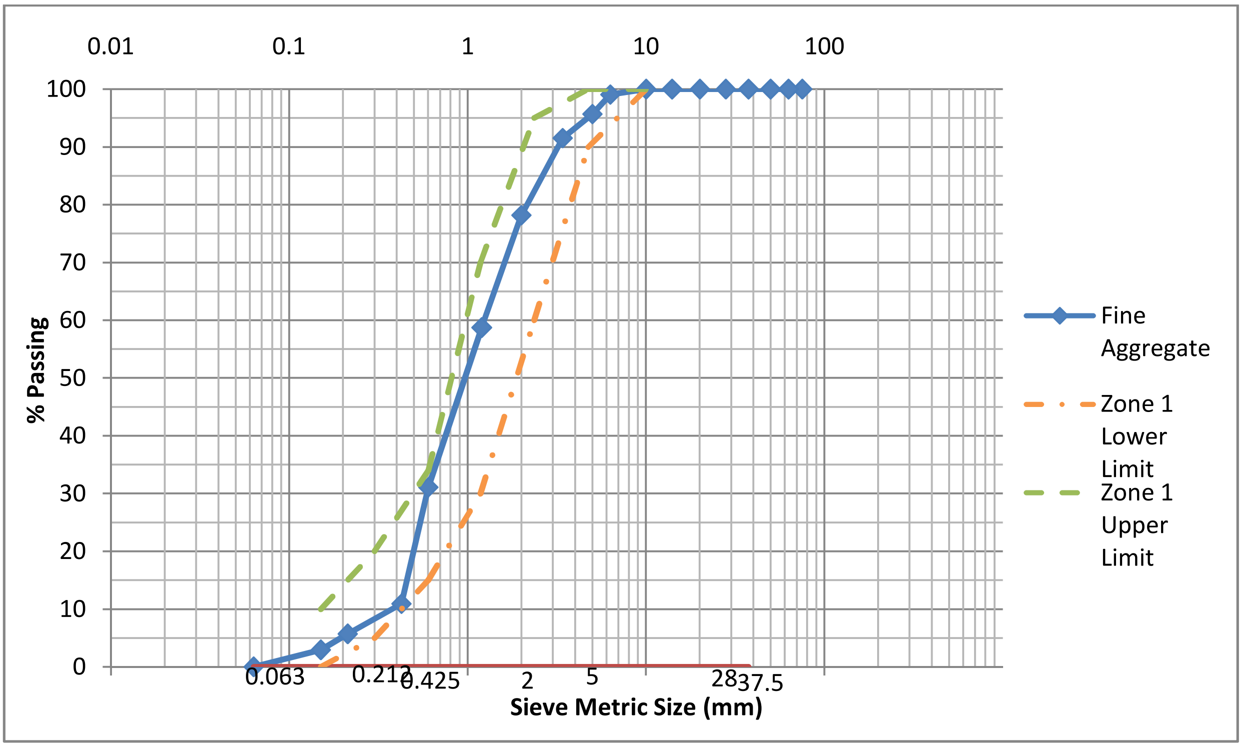

Fig. 4.1: Grading curve of fine aggregate

From the grading curve of fine aggregate shown in Figure. 4.1, it can be noted that the fine aggregate falls within zone 1 based on BS 882(1992) grading limit. This shows that there are more medium and coarse sand than fine sand. It is a well graded aggregate, which makes it desirable for making concrete.

4.3 PARTICLE SIZE DISTRIBUTION OF COARSE AGGREGATES

The figure below shows the grading curve of coarse aggregate.

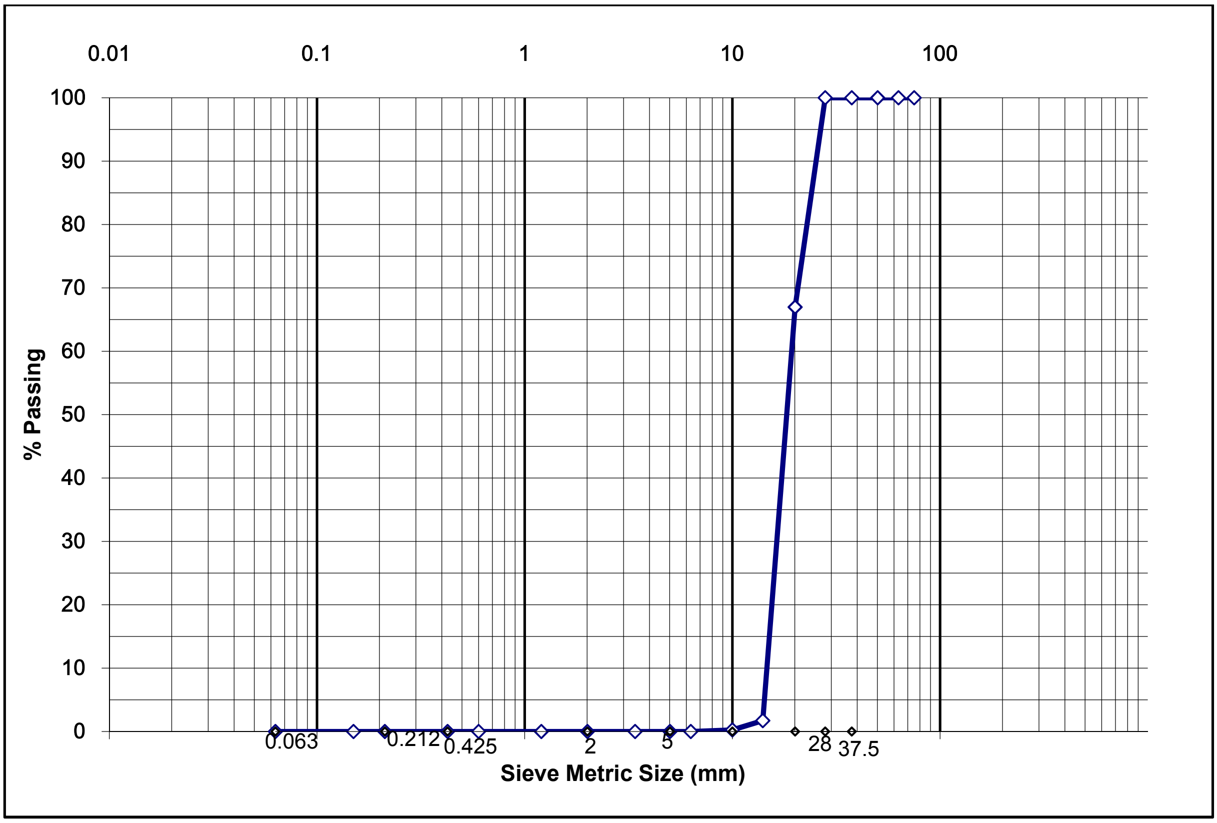

Fig. 4.2: Grading curve of coarse aggregate

From Figure. 4.2 the grading curve shows that majority of the aggregates are coarse making it suitable for concrete.

4.4 WORKABILITY

The figure below shows the effect of IWWA content and particle size on the workability of concrete.

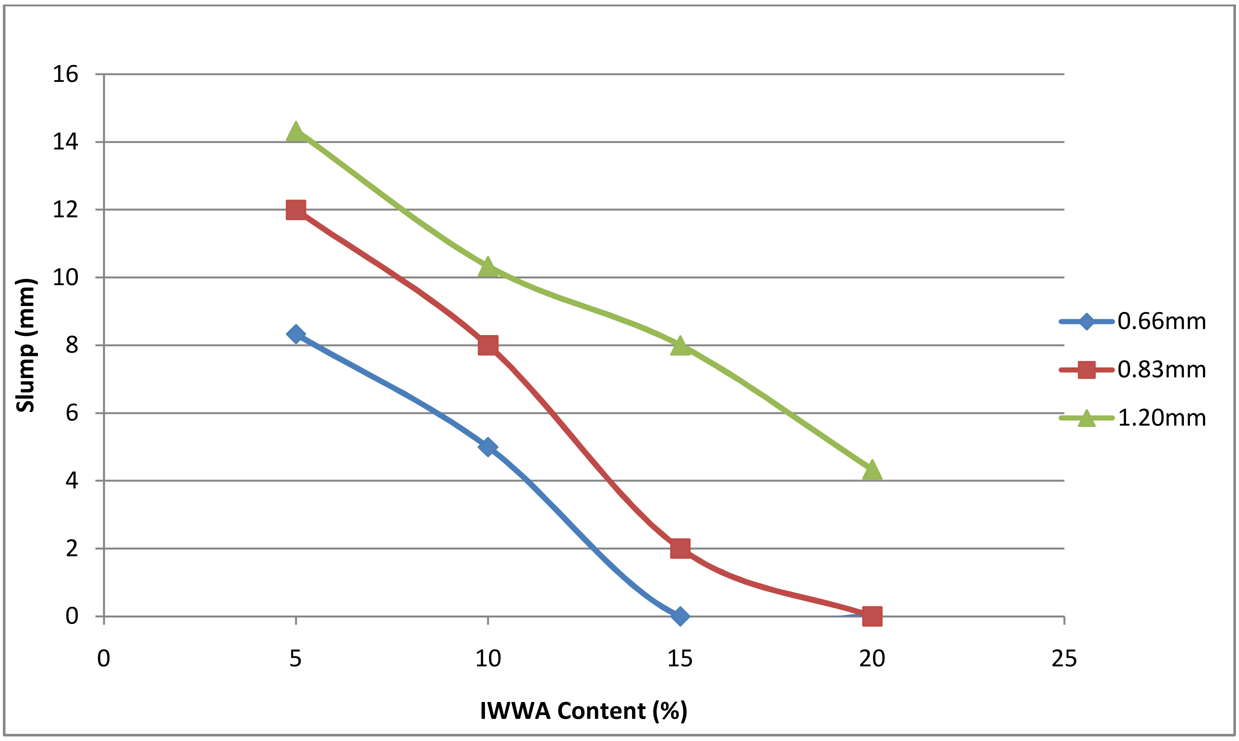

Fig 4.3 Effect of Uncontrolled IWWA on Workability

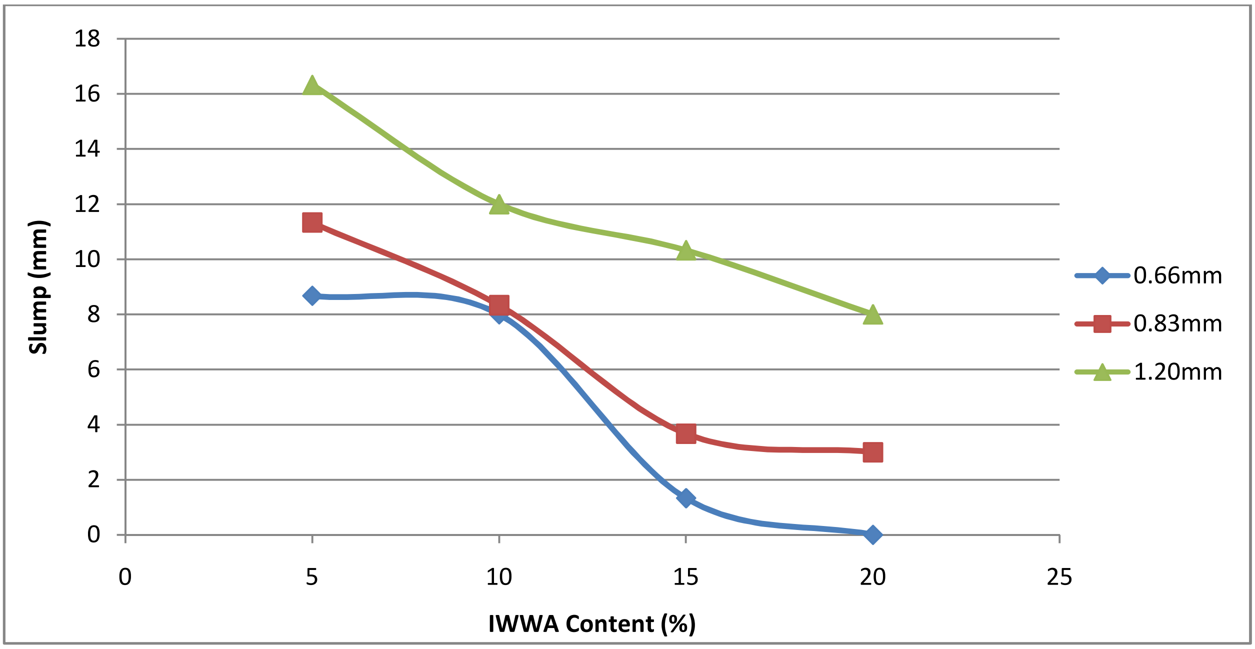

Fig 4.4 Effect of Controlled IWWA on Workability

From Figure. 4.3 and 4.4 it can be seen that as the percentage replacement of OPC with IWWA increases, the workability of concrete decreases for both controlled and uncontrolled incineration; replacing cement by an equal mass of IWWA causes an increase in volume since the density of cement is higher than that of IWWA. This therefore increases the water demand thereby causing a reduction in the workability of the concrete since the quantity of water remains the same for all concrete mix.

Also, as the particle size of IWWA increases the workability increases, this is due to the high specific surface area of finer IWWA which would increase the water demand. Coarser IWWA exhibited higher workability.

4.5 COMPRESSIVE TEST RESULTS

The strength development at various age, particle size and incineration condition are shown in the figures 4.5-4.10.

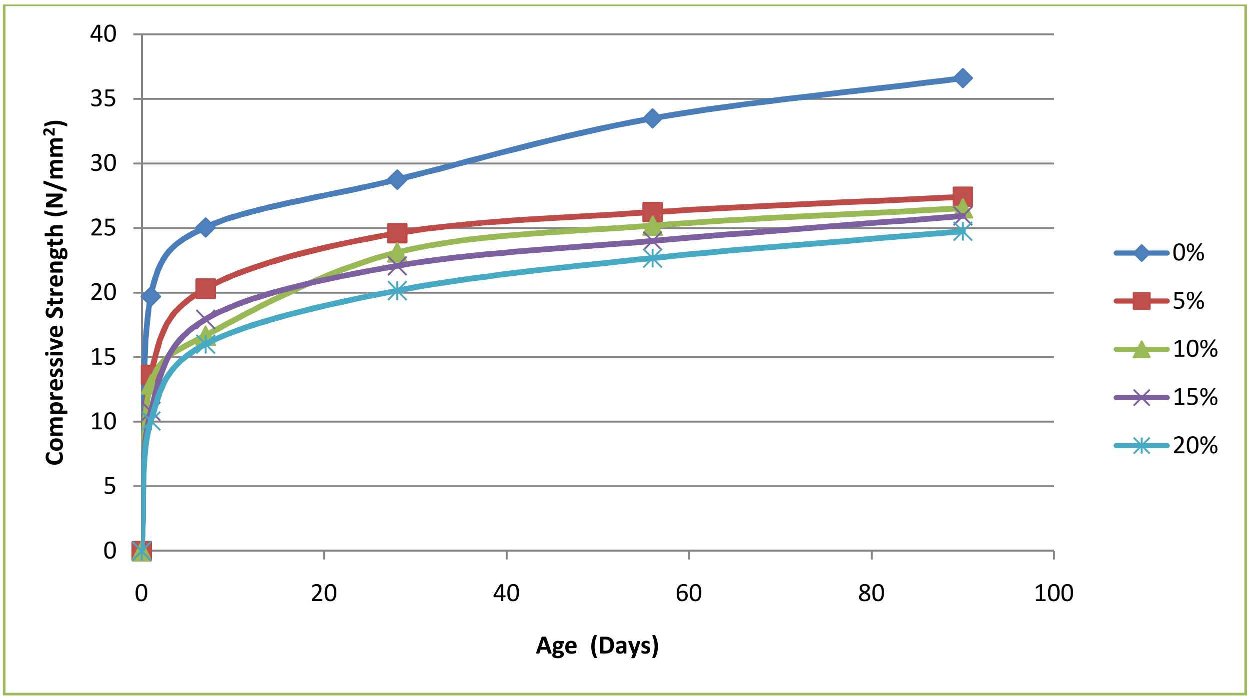

Fig 4.5 Variation of Compressive Strength with Curing Age for 0% and 0.66mm Uncontrolled IWWA

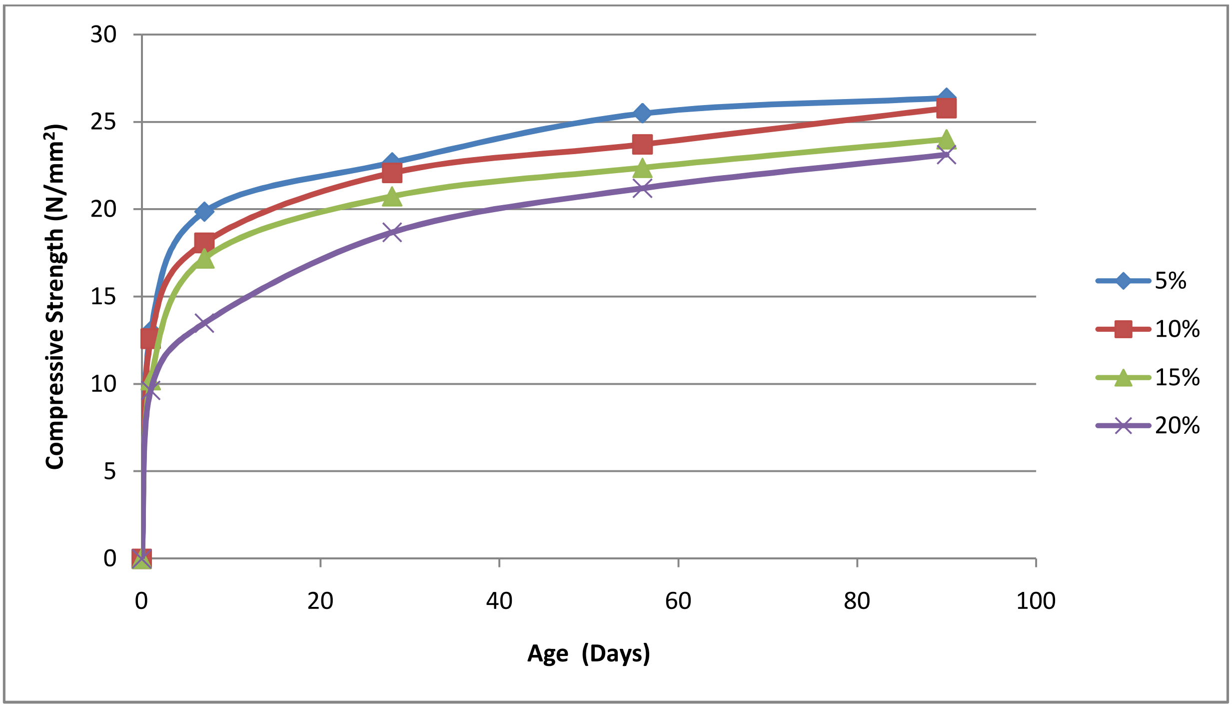

Fig 4.6 Variation of Compressive Strength with Curing Age for 0.83mm Uncontrolled IWWA

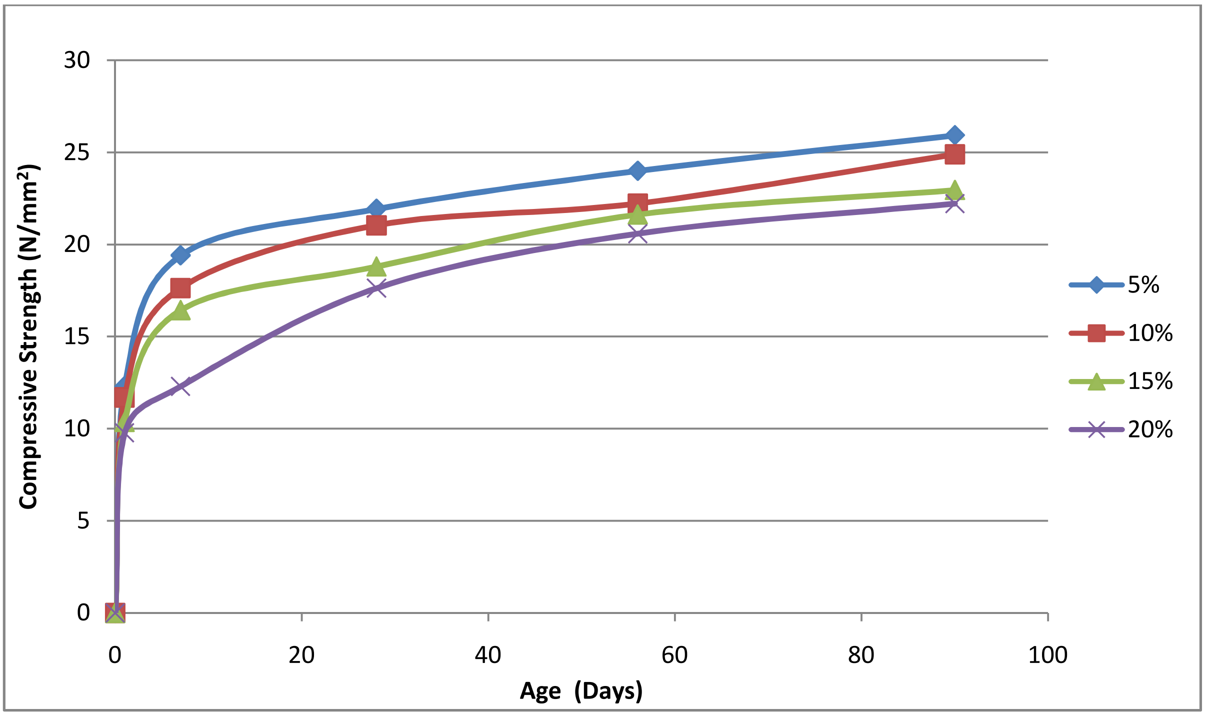

Fig 4.7 Variation of Compressive Strength with Curing Age for 1.2mm Uncontrolled IWWA

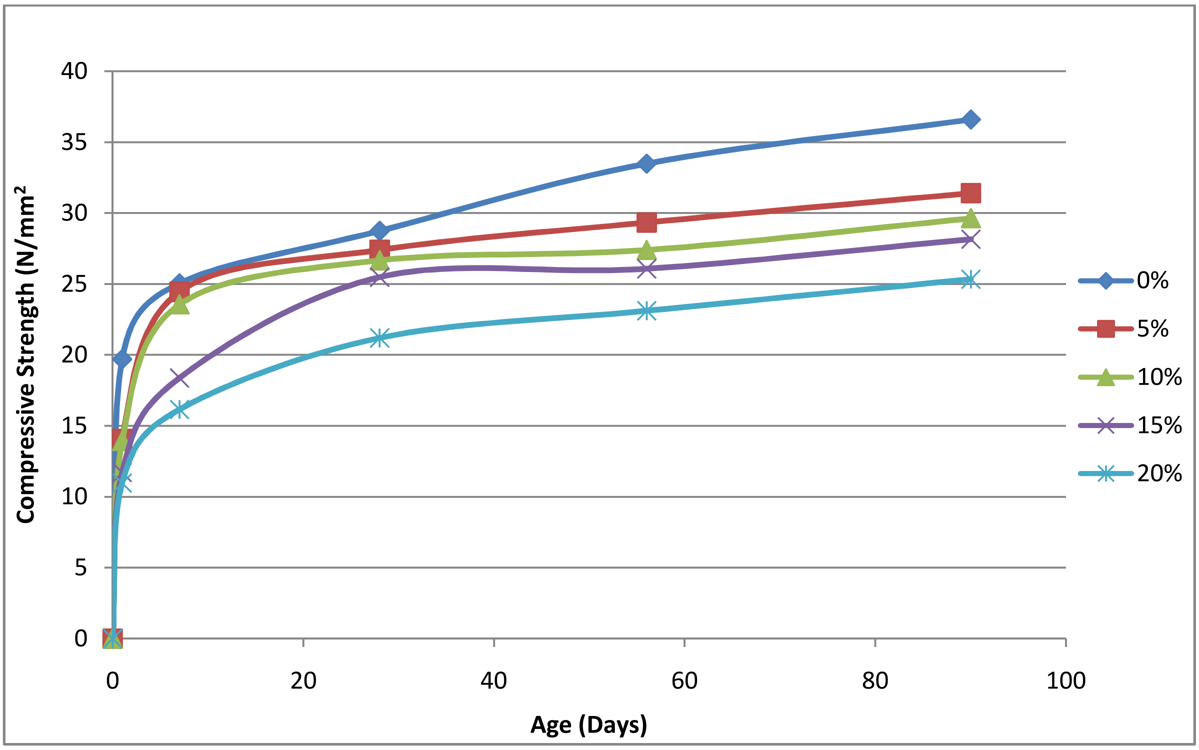

Fig 4.8 Variation of Compressive Strength with Curing Age for 0% and 0.66mm Controlled IWWA

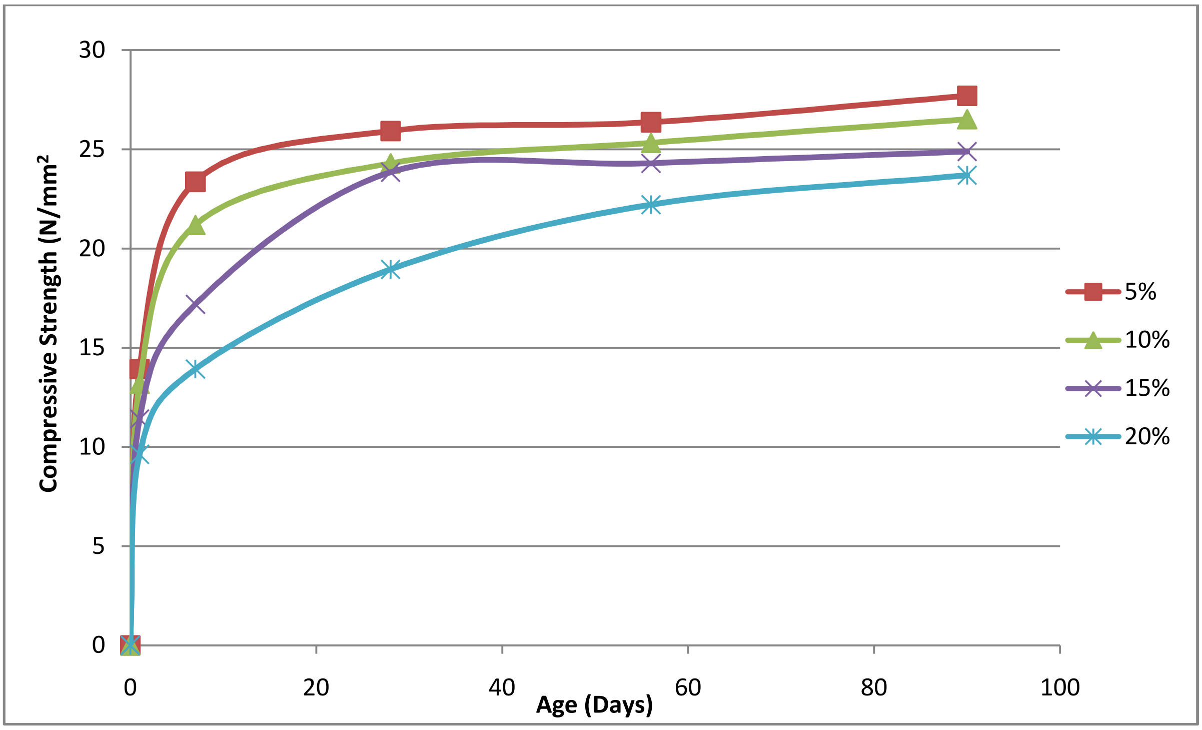

Fig 4.9 Variation of Compressive Strength with Curing Age for 0.83mm Controlled IWWA

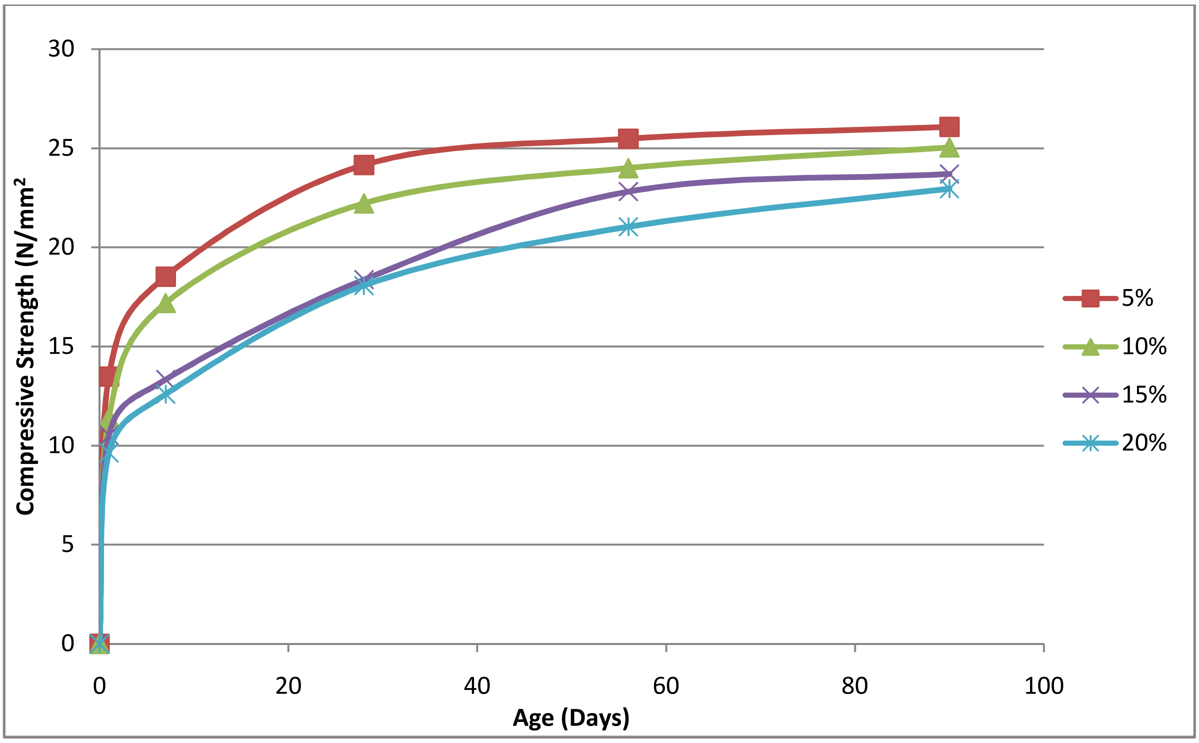

Fig 4.10 Variation of Compressive Strength with Curing Age for 1.20mm Controlled IWWA

The variation of compressive strength of concrete with curing age is presented in Figure 4.5-4.7 for uncontrolled and Figure 4.8-4.10 for controlled incinerated IWWA replacement respectively. The compressive strength continued to increase with curing age but there is a slow strength gain at age 1 and 7 for both incineration condition. The result at 1 day showed a decrease in strength from 19.70N/mm^2 for control to 10.96N/mm^2 and 10.07N/mm^2 for 20% IWWA (0.66mm) controlled and uncontrolled replacement respectively. Similar trend was also observed for particle size of 0.83mm and 1.20mm for day 1 and 7. These results indicate that concrete containing IWWA gain strength slowly at early curing age. This is in line with previous findings that concrete containing pozzolanic materials gained strength slowly at early curing ages (Hossain, 2005; Adesanya and Raheem 2012).

The result at 28 days indicated that hydration action had commenced in IWWA concrete as evident from the higher percentage increase in compressive strength by IWWA concrete over that of the control. The percentage increase with respect to the 7 days strength for control was 14.78%, while it was 12.11%, 13.20%, 38.70%, and 31.21% for 5%, 10%, 15% and 20% for controlled IWWA replacements and 21.31%, 38.63%, 23.09%, and 25.94% for 5%, 10%, 15% and 20% for controlled IWWA replacements both for 0.66mm particle size. Similar trend was observed for 0.83mm and 1.20mm particles sizes. This increase in compressive strength can be attributed to the reaction of IWWA with calcium hydroxide liberated during the hydration of cement and the pozzolanic reaction of IWWA.

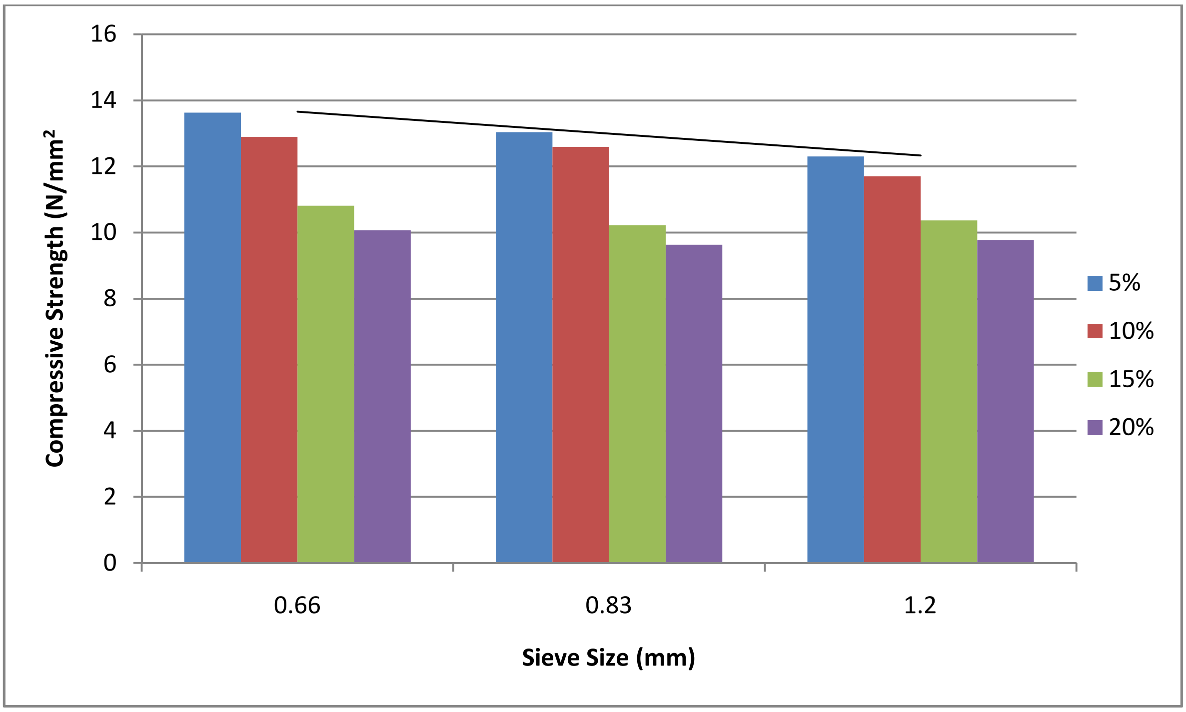

Fig 4.11 Variation of Compressive Strength with Particle Size of Uncontrolled IWWA (1 Day)

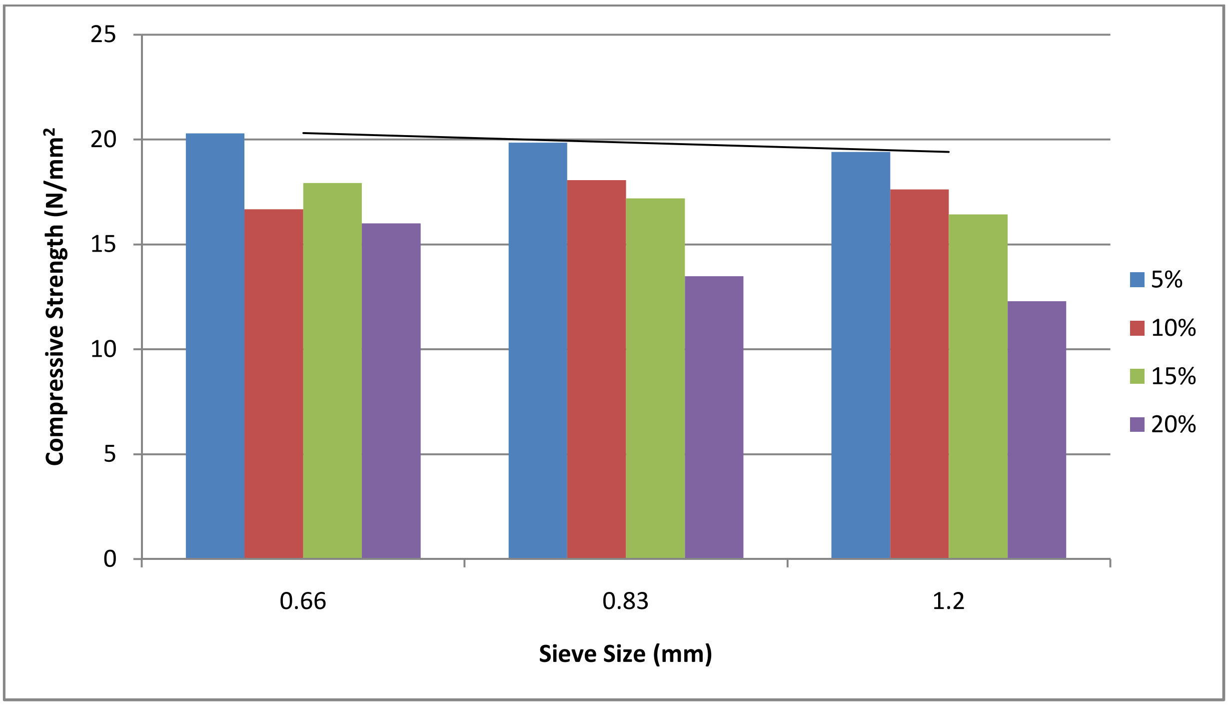

Fig 4.12 Variation of Compressive Strength with Particle Size of Uncontrolled IWWA (7 Days)

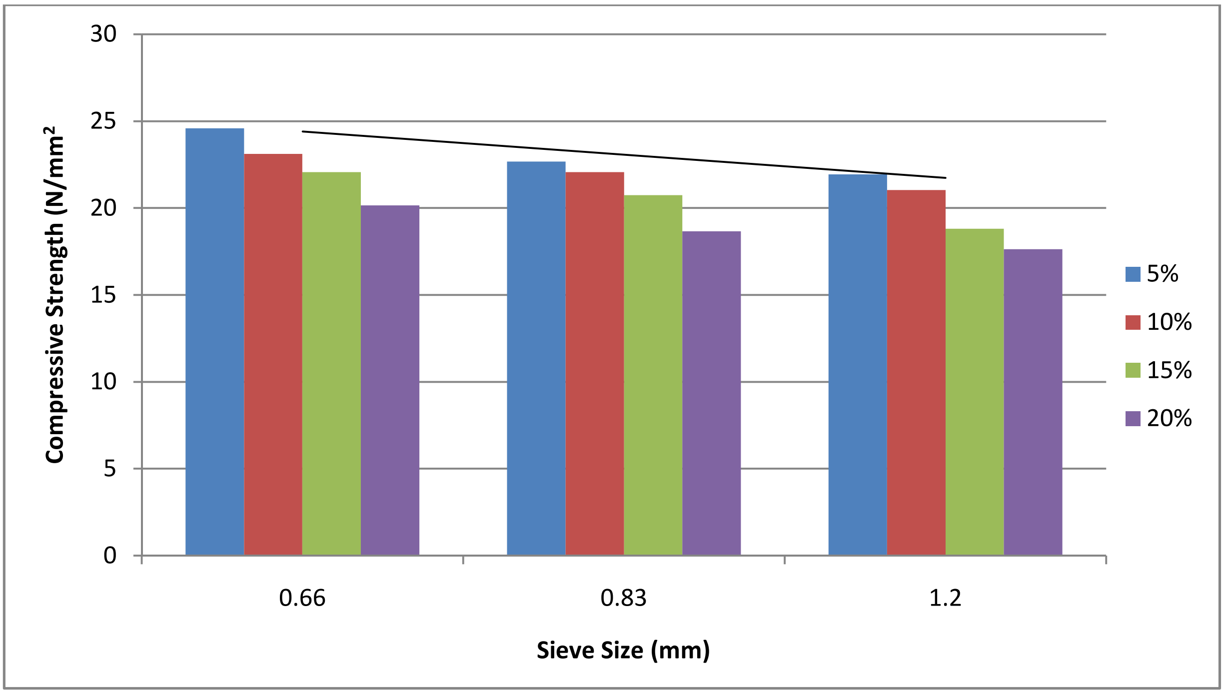

Fig 4.13 Variation of Compressive Strength with Particle Size of Uncontrolled IWWA (28 Days)

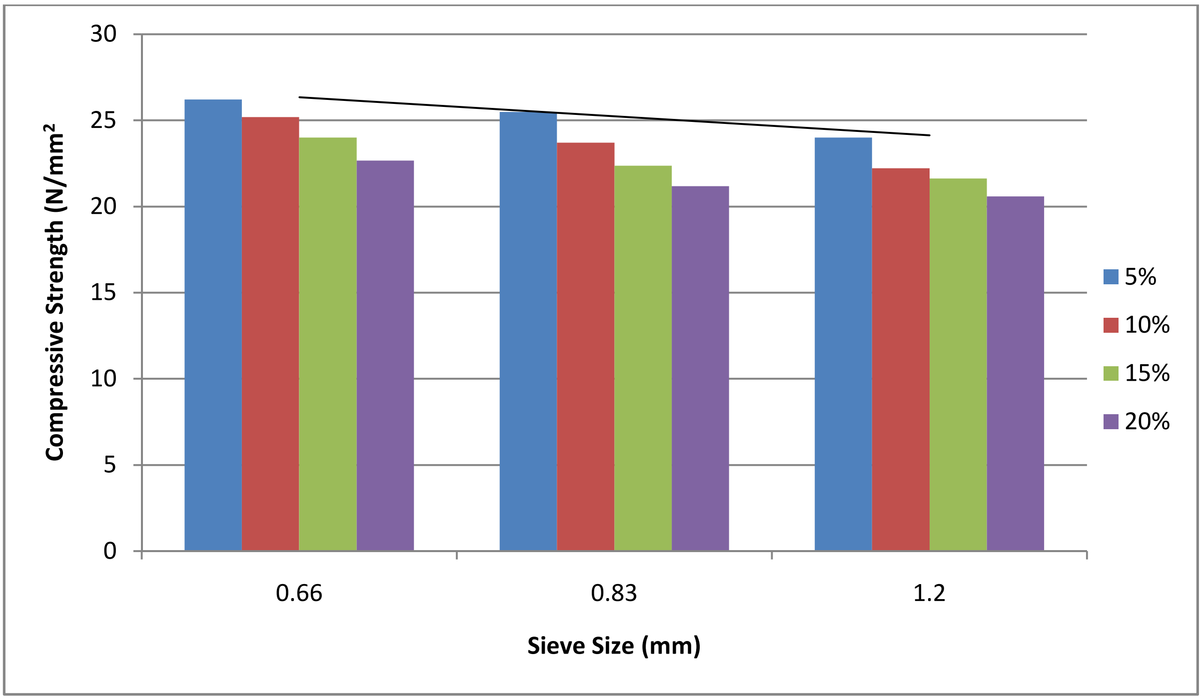

Fig 4.14 Variation of Compressive Strength with Particle Size of Uncontrolled IWWA (56 Days)

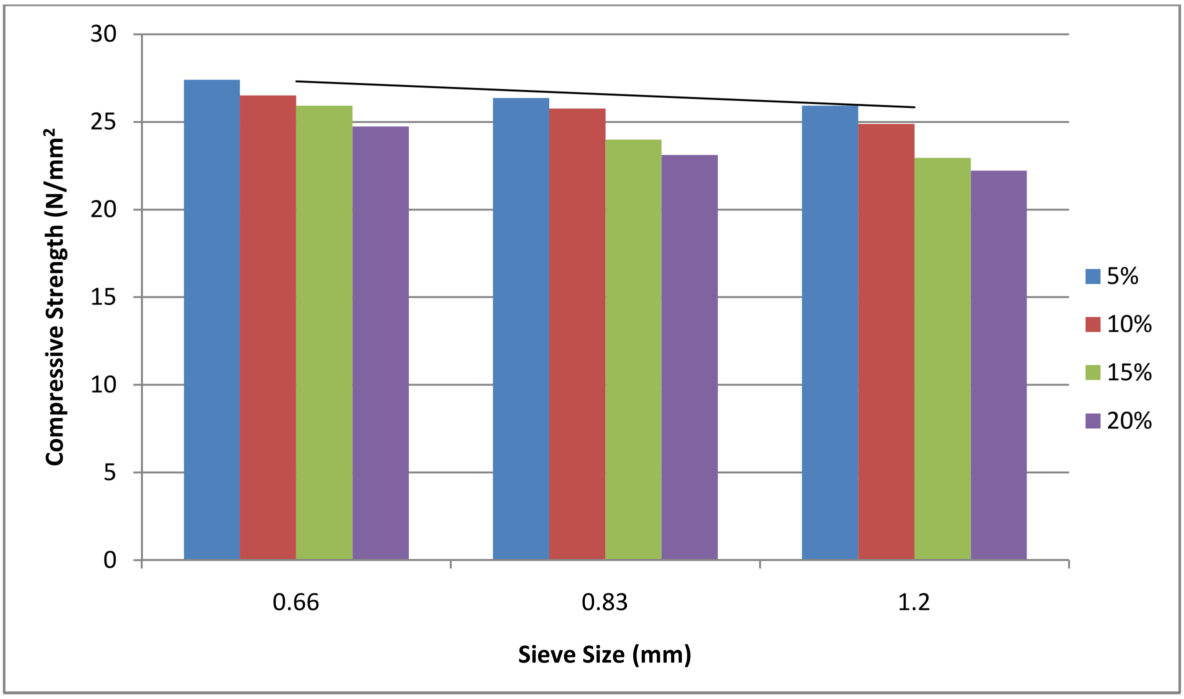

Fig 4.15 Variation of Compressive Strength with Particle Size of Uncontrolled IWWA (90 Days)

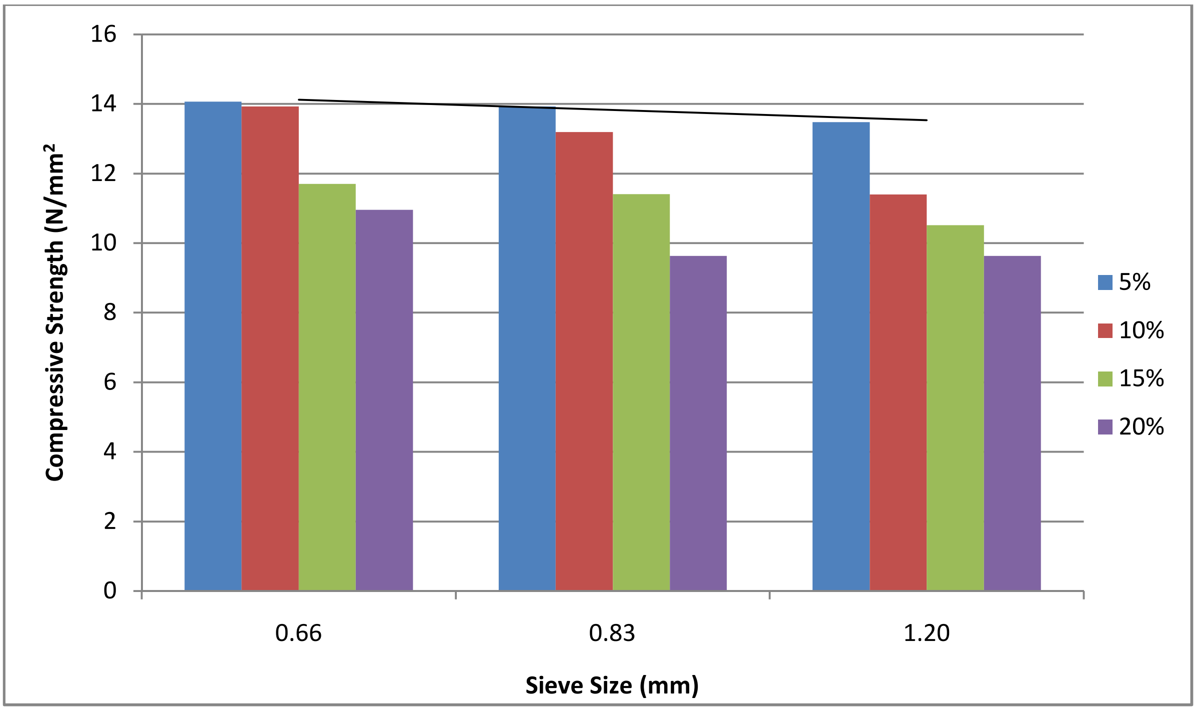

Fig 4.16 Variation of Compressive Strength with Particle Size of Controlled IWWA (1 Day)

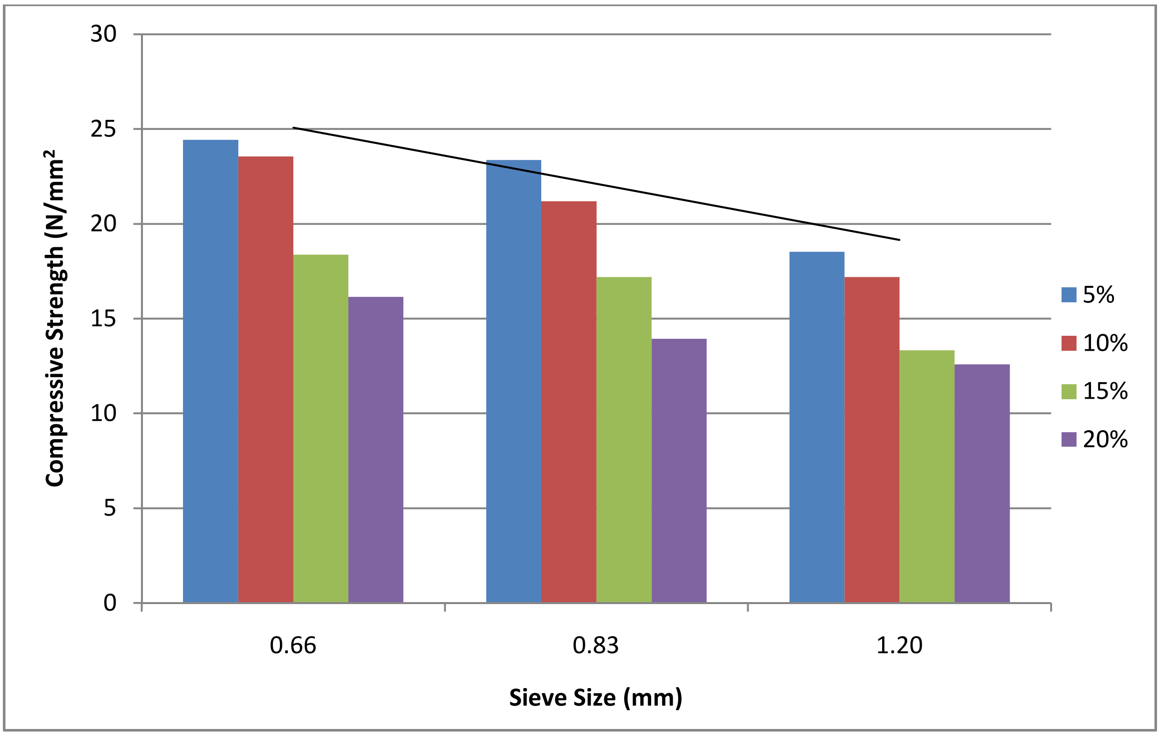

Fig 4.17 Variation of Compressive Strength with Particle Size of Controlled IWWA (7 Days)

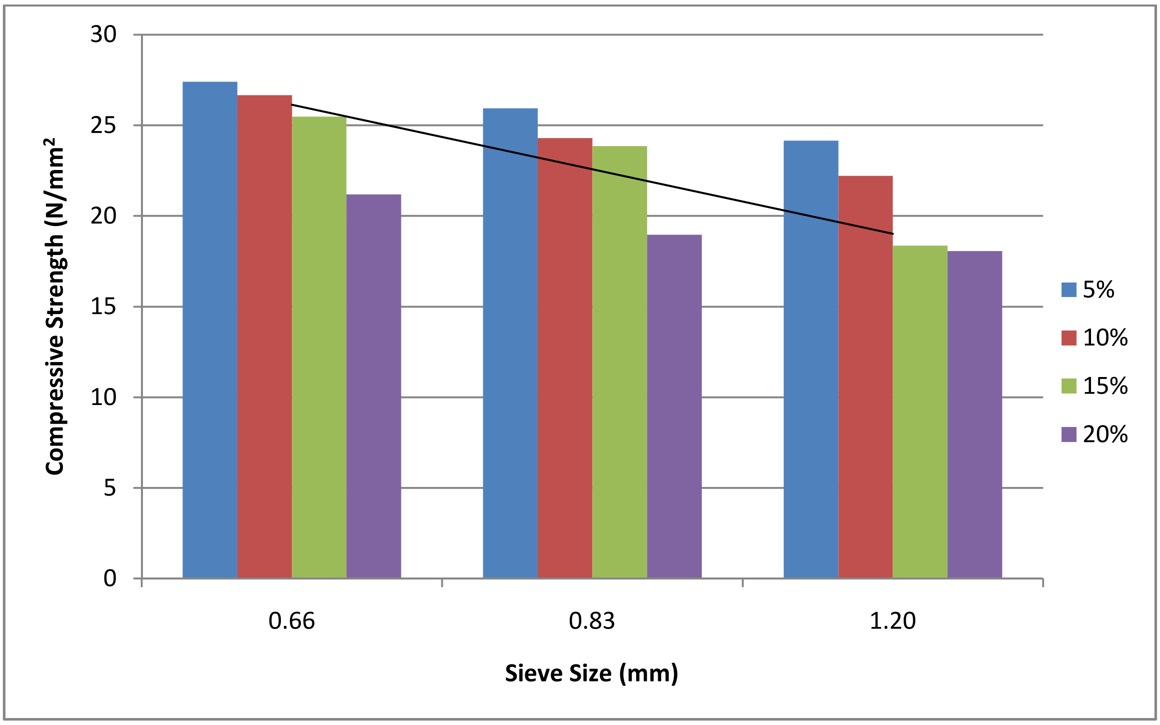

Fig 4.18 Variation of Compressive Strength with Particle Size of Controlled IWWA (28 Days)

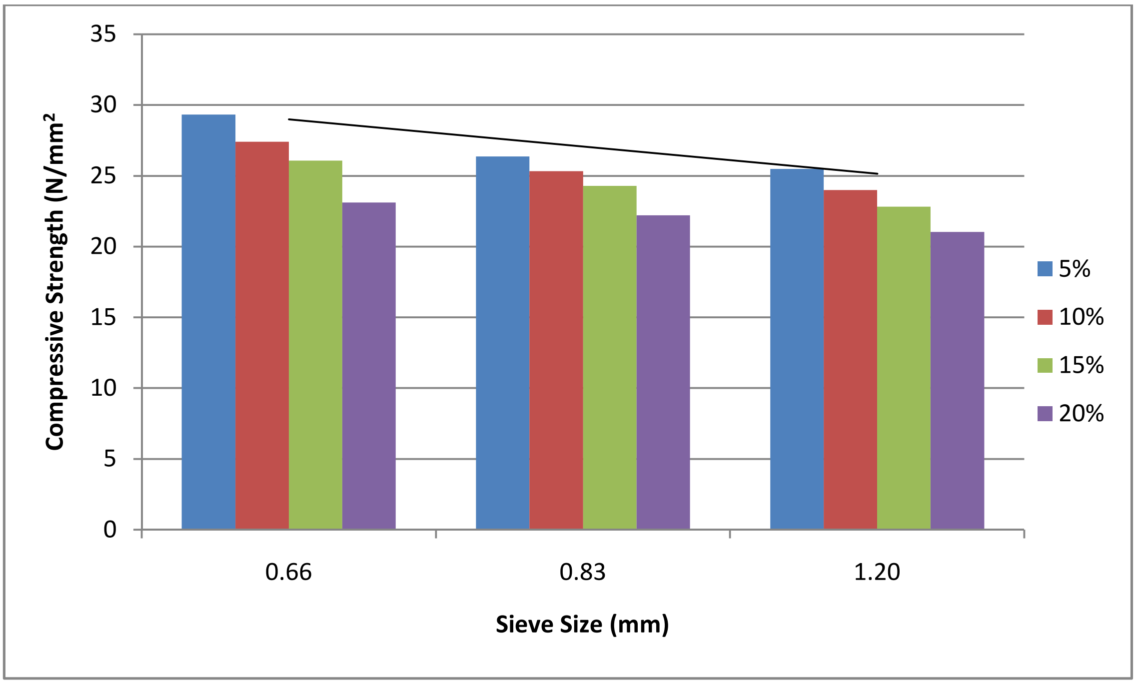

Fig 4.19 Variation of Compressive Strength with Particle Size of Controlled IWWA (56 Days)

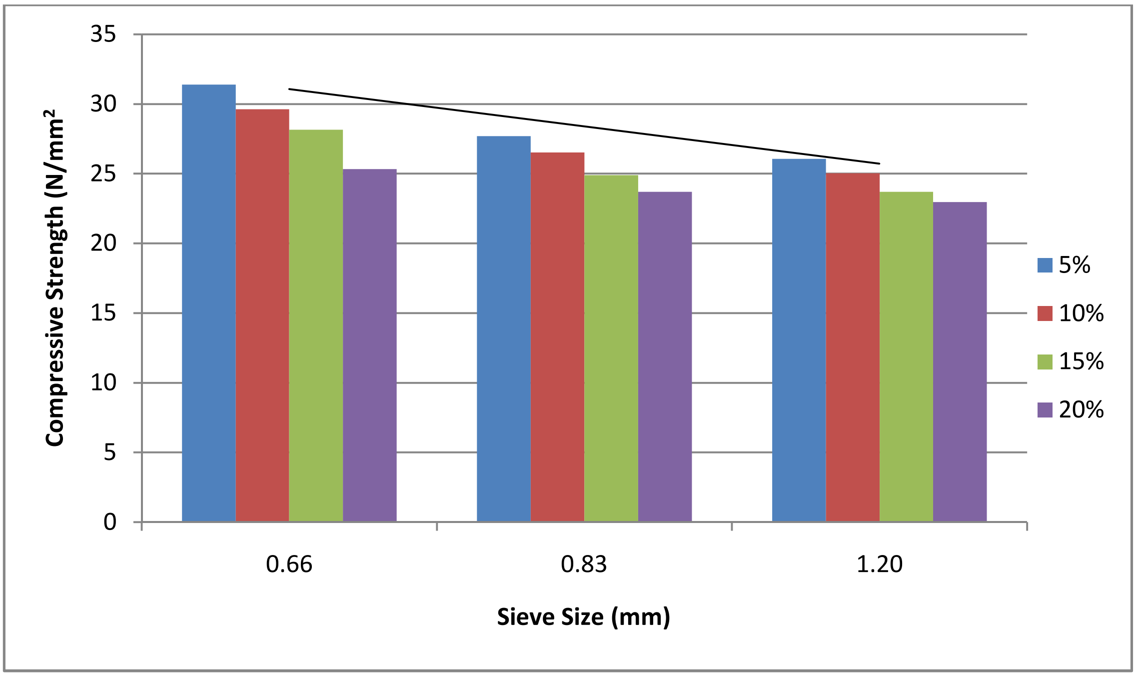

Fig 4.20 Variation of Compressive Strength with Particle Size of Controlled IWWA (90 Days)

From figure 4.11-4.20, it can be noted that as the particle size of the IWWA increases the compressive strength of the concrete decreases. Finer IWWA exhibited higher strength than the samples with coarser IWWA. This is due to the higher fineness of IWWA which may allow the IWWA particles to increase the reaction with $Ca(OH)_2$ to give more calcium silicate hydrate (C-S-H) which resulted in higher compressive strength (Ismail and Waliuddin, 1996). It was also observed that controlled IWWA exhibited higher strength than Uncontrolled IWWA for all particle sizes; this might be due to difference in percentage composition of the oxide and lower LOI of the controlled IWWA.

From the figures it is observed that as the percentage composition of IWWA increases, the compressive strength of the concrete decreases for both incineration conditions for all particle sizes. An optimum value of 20.15N/mm^2 at 28 days was obtained for concrete with 20% IWWA replacement for particle size 0.66mm for uncontrolled IWWA. The maximum compressive strength at all ages of testing for replaced cement was obtained at 90 days for 5% (31.40N/mm^2) replacement of cement with IWWA of controlled incineration and particle size of 0.66mm.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the experiment, analysis and observations of the research, it can be concluded that:

1. From the chemical composition analysis result, controlled IWWA was noted to be predominantly of Silicon Oxide SiO_2 (46.90%) and Calcium Oxide CaO (21.60%). The un-burnt carbon in IWWA is relatively high (LOI is 24.50%), this high LOI might present some difficulties when making air-entrained concrete.
2. From the chemical composition analysis result, uncontrolled IWWA was noted to be predominantly of Silicon Oxide SiO_2 (44.50%) and Calcium Oxide CaO (21.51%). The

un-burnt carbon in IWWA is relatively high (LOI 25.53%), this high LOI might present some difficulties when making air-entrained concrete.

3. Concrete becomes less workable as the IWWA percentage increases meaning that more water is required to make the mixes more workable. This means that IWWA concrete has higher water demand.
4. As the particle size increases the demand for water also decreases, controlled IWWA has a higher workability than uncontrolled incinerated IWWA.
5. The strength development of IWWA at early age is slow compared to the control mix and the strength of IWWA concrete is lower than that of control at all ages of curing. Controlled incinerated IWWA developed higher strength than Uncontrolled IWWA
6. The finer particle sizes of IWWA exhibited higher compressive strength than coarser IWWA for all incineration condition.
7. The compressive strength generally increases with curing period and decreases with increased amount of IWWA. The samples have compressive strength that are within the British Standard (BS1881), which stipulate a minimum of 20 N/mm^2 compressive strength for concrete after curing for 28 days excluding samples from 15% uncontrolled 1.20mm IWWA replacement and 20% uncontrolled and controlled 0.83mm and 1.20mm IWWA replacement.
8. Test result indicates that it is possible to achieve environmentally friendly concrete compositions with low cement content utilising IWWA. However, the positive impact on environment is only in terms of reduced CO2 emissions, increased waste product utilisation and reduced energy use.

5.2 RECOMMENDATIONS

Based on the results and conclusions, it is therefore recommended that:

1. The use of IWWA in concrete work should be increased to reduce pollution caused during the production of cement.
2. IWWA concrete can be used for mass concrete work and it can also be used as controlled low-strength materials (CLSM).
3. Increasing controlled IWWA fineness would enhance the compressive strength and also improve the workability of the concrete.

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APPENDIX

APPENDIX A-1

Plates of the Disk Mill

Plate AI: Sieve 0.66mm

Plate AII: Sieve 0.83mm

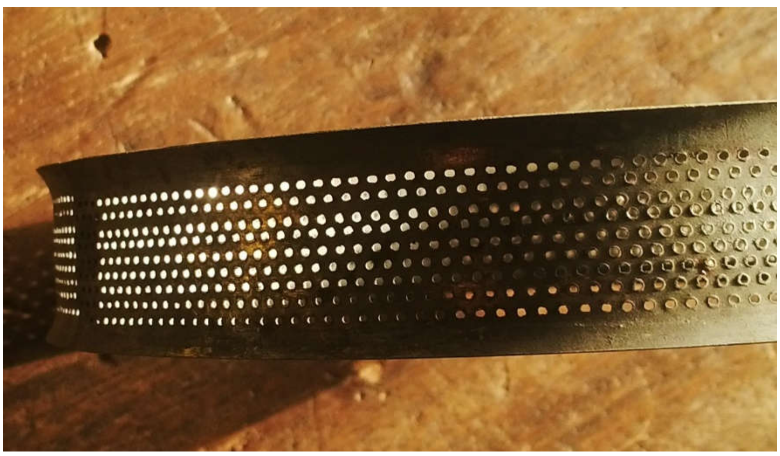

Plate AIII: Sieve 1.20mm

APPENDIX A-2

Table A1: Details of fine aggregate sieve analysis

Particle Description		Diameter (mm)	Initial Weight 1000(g)		
			Weight (gm)	Retained %	Passing %
Cobbles		75	0	0.00	100.00
		63	0	0.00	100.00
		50	0	0.00	100.00
Gravel	Coarse	37.6	0	0.00	100.00
		28	0	0.00	100.00
		20	0	0.00	100.00
		14	0	0.00	100.00
		10	0	0.00	100.00
	Fine	6.3	9.1	0.91	99.09
		5.0	34.0	3.4	95.69
		3.4	41.3	4.13	91.56
Sand	Coarse	2.0	133.8	13.38	78.18
		1.2	194.6	19.46	58.72
	Medium	0.600	276.1	27.61	31.11
		0.425	201.7	20.17	10.94
		0.212	52.4	5.24	5.70
	Fine	0.15	27.7	2.77	2.93
		0.063	29.3	2.93	0.00
	clay or Silt	Pass 63 microns	0	0.00	0.00
			1000	0	

APPENDIX A-3

Table A2: Details of coarse aggregate sieve analysis

Particle Description		Diameter (mm)	Initial Weight 2000(g)		
			Weight (gm)	Retained %	Passing %
Cobbles		75	0.00	0.00	100.00
		63	0.00	0.00	100.00
		50	0.00	0.00	100.00
Gravel	Coarse	37.6	0.00	0.00	100.00
		28	0.00	0.00	100.00
		20	660.00	33.00	67.00
		14	1306.00	65.3	1.70
		10	29.00	1.45	0.25
	Fine	6.3	5.00	0.25	0.00
		5.0	0.00	0.00	0.00
		3.4	0.00	0.00	0.00
Sand	Coarse	2.0	0.00	0.00	0.00
		1.2	0.00	0.00	0.00
	Medium	0.600	0.00	0.00	0.00
		0.425	0.00	0.00	0.00
		0.212	0.00	0.00	0.00
	Fine	0.15	0.00	0.00	0.00
		0.063	0.00	0.00	0.00
	clay or Silt	Pass 63 microns	0.00	0.00	0.00
			2000	0	

APPENDIX A-4

Table A3: BS 882 Part 2: Grading Limit for Fine Aggregate.

IS Sieve Designation	Percentage passing for			
	Zone 1	Zone 2	Zone 3	Zone 4
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

APPENDIX A-5

Table A4: Specific Gravity of Constituent Materials

Materials	Sample	W1	W2	W3	W4	Specific Gravity	Average Specific Gravity
IWWA	1	1064	1265	2440	2333	2.14	2.19
	2	1064	1265	2451	2340	2.23	
Cement	1	1064	1265	2484	2347	3.14	3.16
	2	1064	1265	2485	2347	3.18	
Fine Aggregate	1	1064	1265	2470	2348	2.54	2.56
	2	1064	1265	2475	2352	2.58	
Coarse Aggregate	1	1064	1265	2473	2345	2.75	2.70
	2	1064	1265	2474	2349	2.64	

The relation below was used to calculate the specific gravity of the materials.

$$G_s = \frac{w_2 - w_1}{(w_4 - w_1) - (w_3 - w_2)} \qquad \text{.......... (3.1)}$$

Where;

W1= weight of empty glass jar and seal

W2= weight of empty glass jar, seal and sample

W3= weight of empty glass jar, seal, sample and water

W4= weight of empty glass jar, seal and water

Sample 1 of IWWA

$$Gs = \frac{1265 \quad 1064}{(2333 \quad 1064) \quad (2440 \quad 1265)} = 2.14$$

Sample 2 of IWWA

$$Gs = \frac{1265 \quad 1064}{(2340 \quad 1064) \quad (2451 \quad 1265)} = 2.23$$

$$Gs.av = \frac{2.14 + 2.23}{2} = 2.19$$

Sample 1 of cement

$$Gs = \frac{1265 \quad 1064}{(2347 \quad 1064) \quad (2484 \quad 1265)} = 3.14$$

Sample 2 of cement

$$Gs = \frac{1265 \quad 1064}{(2347 \quad 1064) \quad (2485 \quad 1265)} = 3.18$$

$$Gs.av = \frac{3.14 + 3.18}{2} = 3.16$$

Sample 1 of Fine aggregates

$$Gs = \frac{1265 \quad 1064}{(2348 \quad 1064) \quad (2470 \quad 1265)} = 2.54$$

Sample 2 of Fine Aggregates

$$Gs = \frac{1265 \quad 1064}{(2352 \quad 1064) \quad (2475 \quad 1265)} = 2.58$$

$$Gs.av = \frac{2.54 + 2.58}{2} = 2.56$$

Sample 1 of Coarse Aggregate

$$Gs = \frac{1265 \quad 1064}{(2345 \quad 1064) \quad (2470 \quad 1265)} = 2.75$$

Sample 2 of Coarse Aggregate

$$Gs = \frac{1265 \quad 1064}{(2349 \quad 1064) \quad (2474 \quad 1265)} = 2.64$$

$$Gs.av = \frac{2.75 + 2.64}{2} = 2.70$$

APPENDIX A-6

Table A5: Design quantities of IWWA 1:2:4 mix concrete

% replacement of cement	cement kg/m^3	IWWA kg/m^3	fine aggregate kg/m^3	coarse aggregate kg/m^3	water kg/m^3
0	318.87	0	637.74	1275.48	175.40
5	302.93	15.94	637.74	1275.48	175.40
10	286.98	31.89	637.74	1275.48	175.40
15	271.04	47.83	637.74	1275.48	175.40
20	255.10	63.77	637.74	1275.48	175.40

The quantity of material to produce a meter cube of concrete is given by:-

$$\frac{w}{1000} + \frac{C}{1000gc} + \frac{F}{1000gs} + \frac{G}{1000gg} = 1m^3 \qquad (3.6)$$

Where,

W= water

C= cement Gsc=3.16

F=fine aggregate Gsf=2.56

G=coarse aggregate Gsg=2.70

For 1:2:4 concrete mix

w/c=0.55

W= 0.55C

F=2C

G=4C

$$\frac{0.55C}{1000}+\frac{C}{1000gc}+\frac{2C}{1000gs}+\frac{4G}{1000gg}=1m^3$$

1.74C + C + 2.49C + 4.68C = 3160

9.91C=3160

C= 318.87kg/m^3

For 0% replacement of cement with IWWA

W= 0.55 x 318.87= 175.40 kg/m^3

F= 2 x 318.87 = 637.74 kg/m^3

G= 4 x 318.87 = 1275 kg/m^3

C= 318.87 kg/m^3

For 5% replacement of cement with IWWA

IWWA= $\frac{5}{100}\ x\ 318.87 = 15.94$kg/m3

Cement= 318.87 – 15.94= 302.93 kg/m^3

For 10% replacement of cement with IWWA

IWWA= $\frac{10}{100}\ x\ 318.87 = 31.89$kg/m3

Cement= 318.87 – 31.89= 286.98 kg/m^3

For 15% replacement of cement with IWWA

IWWA= $\frac{15}{100}\ x\ 318.87 = 47.83 \text{kg/m3}$

Cement= 318.87 – 47.83= 271.04 kg/m^3

For 20% replacement of cement with IWWA

IWWA= $\frac{20}{100}\ x\ 318.87 = 63.77 \text{kg/m3}$

Cement= 318.87 – 63.77= 255.10 kg/m^3

Volume of cube = L x B x H

Volume= (150x150x150) mm^3

= 3375000 mm^3

=$3.375 x 10^{-3}$ m^3

According to BS 1881-125(1986), the quantity of concrete in each batch shall be atleast 10% more than required for the proposed test, adding 10% waste.

The water, fine aggregate and coarse aggregate constituent remains constant in all concrete mix, only the IWWA and cement was varied due to the percentage replacement.

APPENDIX A-7

Compressive strength of 1:2:4 concrete with 0% replacement of cement with IWWA.

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Co st cub
	1.1				450	
0%	1.2	01/09/2014	03s/09/2014	1 day	430	
	1.3				450	
	7.1				580	
0%	7.2	01/09/2014	09/09/2014	7 days	550	
	7.3				560	
	28.1				660	
0%	28.2	01/09/2014	30/09/2014	28 days	680	
	28.3				600	
	56.1				760	
0%	56.2	01/09/2014	28/10/2014	56 days	720	
	56.3				780	
	90.1				800	
0%	90.2	01/09/2014	01/12/2014	90 days	830	
	90.3				840	

APPENDIX A-8

Compressive strength of 1:2:4 concrete with 5% replacement of cement with uncontrolled IWWA (0.66mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compress strength of c (N/mm2
5%	1.1	02/09/2014	04/09/2014	1 day	300	13.33
	1.2				300	13.33

	1.3				320	14.22
	7.1				480	21.33
5%	7.2	02/09/2014	10/09/2014	7 days	440	19.56
	7.3				450	20.00
	28.1				560	24.89
5%	28.2	02/09/2014	01/10/2014	28 days	540	24.00
	28.3				560	24.89
	56.1				600	26.67
5%	56.2	02/09/2014	29/10/2014	56 days	580	25.78
	56.3				590	26.22
	90.1				640	28.44
5%	90.2	02/09/2014	02/12/2014	90 days	610	27.11
	90.3				600	26.67

APPENDIX A-9

Compressive strength of 1:2:4 concrete with 10% replacement of cement with uncontrolled IWWA (0.66mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compress strength of c (N/mm2
	1.1				300	13.33
10%	1.2	03/09/2014	05/09/2014	1 day	290	12.89
	1.3				280	12.44
	7.1				400	17.78
10%	7.2	03/09/2014	11/09/2014	7 days	440	19.56
	7.3				410	18.22
	28.1				500	22.22
10%	28.2	03/09/2014	02/10/2014	28 days	540	24.00
	28.3				520	23.11
	56.1				560	24.89
10%	56.2	03/09/2014	30/10/2014	56 days	560	24.89
	56.3				580	25.77
10%	90.1	03/09/2014	03/12/2014	90 days	600	26.67

90.2				590	26.22
90.3				600	26.67

APPENDIX A-10

Compressive strength of 1:2:4 concrete with 15% replacement of cement with uncontrolled IWWA (0.66mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compres strength of (N/mm
	1.1				260	11.56
15%	1.2	08/09/2014	10/09/2014	1 day	240	10.67
	1.3				230	10.22
	7.1				390	17.33
15%	7.2	08/09/2014	16/09/2014	7 days	420	18.67
	7.3				400	17.78
	28.1				480	21.33
15%	28.2	08/09/2014	07/10/2014	28 days	500	22.22
	28.3				510	22.67
	56.1				530	23.56
15%	56.2	08/09/2014	04/11/2014	56 days	550	24.44
	56.3				540	24.00
	90.1				590	26.22
15%	90.2	08/09/2014	08/12/2014	90 days	580	25.78
	90.3				580	25.78

APPENDIX A-11

Compressive strength of 1:2:4 concrete with 20% replacement of cement with uncontrolled IWWA (0.66mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compres strength of (N/mm
	1.1				230	10.22
20%	1.2	09/09/2014	11/09/2014	1 day	220	9.78

1.3				230	10.2
20% 7.1	09/09/2014	17/09/2014	7 days	370	16.4
7.2				360	16.0
7.3				350	15.5
20% 28.1	09/09/2014	08/10/2014	28 days	420	18.6
28.2				480	21.3
28.3				460	20.4
20% 56.1	09/09/2014	05/11/2014	56 days	510	22.6
56.2				500	22.2
56.3				520	23.1
20% 90.1	09/09/2014	09/12/2014	90 days	570	25.3
90.2				540	24.0
90.3				560	24.8

APPENDIX A-12

Compressive strength of 1:2:4 concrete with 5% replacement of cement with uncontrolled IWWA (0.83mm).

ID No.	Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compress strength of (N/mm2
5% 1.1	10/09/2014	12/09/2014	1 day	270	12.00
1.2				310	13.78
1.3				300	13.33
5% 7.1	10/09/2014	18/09/2014	7 days	460	20.44
7.2				460	20.44
7.3				420	18.67
5% 28.1	10/09/2014	09/10/2014	28 days	520	23.11
28.2				490	21.78
28.3				520	23.11
5% 56.1	10/09/2014	06/11/2014	56 days	580	25.78
56.2				580	25.78
56.3				560	24.89

90.1				600	26.67
5% 90.2	10/09/2014	10/12/2014	90 days	590	26.22
90.3				590	26.22

APPENDIX A-13

Compressive strength of 1:2:4 concrete with 10% replacement of cement with uncontrolled IWWA (0.83mm).

ID No.	Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compres strength of (N/mm
1.1				280	12.44
10% 1.2	15/09/2014	17/09/2014	1 day	280	12.44
1.3				290	12.89
7.1				420	18.67
10% 7.2	15/09/2014	23/09/2014	7 days	410	18.22
7.3				390	17.33
28.1				510	22.67
10% 28.2	15/09/2014	14/10/2014	28 days	500	22.22
28.3				480	21.33
56.1				520	23.11
10% 56.2	15/09/2014	11/11/2014	56 days	560	24.89
56.3				520	23.11
90.1				580	25.77
10% 90.2	15/09/2014	15/12/2014	90 days	590	26.22
90.3				570	25.33

APPENDIX A-14

Compressive strength of 1:2:4 concrete with 15% replacement of cement with uncontrolled IWWA (0.83mm).

ID No.	Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compres strength of (N/mm
15% 1.1	16/09/2014	18/09/2014	1 day	220	9.78

	1.2				230	10.22
	1.3				240	10.67
15%	7.1	16/09/2014	24/09/2014	7 days	400	17.78
	7.2				380	16.89
	7.3				380	16.89
15%	28.1	16/09/2014	15/10/2014	28 days	440	19.56
	28.2				480	21.33
	28.3				480	21.33
15%	56.1	16/09/2014	12/11/2014	56 days	500	22.22
	56.2				500	22.22
	56.3				510	22.67
15%	90.1	16/09/2014	16/12/2014	90 days	540	24.00
	90.2				540	24.00
	90.3				540	24.00

APPENDIX A-15

Compressive strength of 1:2:4 concrete with 20% replacement of cement with uncontrolled IWWA (0.83mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compressi strength of cu (N/mm2)
20%	1.1	17/09/2014	19/09/2014	1 day	210	9.33
	1.2				220	9.78
	1.3				220	9.78
20%	7.1	17/09/2014	25/09/2014	7 days	300	13.33
	7.2				300	13.33
	7.3				310	13.78
20%	28.1	17/09/2014	16/10/2014	28 days	410	18.22
	28.2				420	20.89
	28.3				430	19.11
20%	56.1	17/09/2014	13/11/2014	56 days	480	21.33
	56.2				480	21.33

	56.3				470	20.89
	90.1				530	23.56
20%	90.2	17/09/2014	17/12/2014	90 days	530	23.56
	90.3				500	22.22

APPENDIX A-16

Compressive strength of 1:2:4 concrete with 5% replacement of cement with uncontrolled IWWA (1.20mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compres strength of (N/mm
	1.1				280	12.44
5%	1.2	22/09/2014	24/09/2014	1 day	260	11.56
	1.3				290	12.89
	7.1				440	19.56
5%	7.2	22/09/2014	30/09/2014	7 days	440	19.56
	7.3				430	19.11
	28.1				480	21.33
5%	28.2	22/09/2014	21/10/2014	28 days	490	21.78
	28.3				510	22.67
	56.1				540	24.00
5%	56.2	22/09/2014	18/11/2014	56 days	550	24.44
	56.3				530	23.56
	90.1				580	25.78
5%	90.2	22/09/2014	22/12/2014	90 days	590	26.22
	90.3				580	25.78

APPENDIX A-17

Compressive strength of 1:2:4 concrete with 10% replacement of cement with uncontrolled IWWA (1.20mm).

ID No.	Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compre strength o (N/m

10%	1.1 1.2 1.3	23/09/2014	25/09/2014	1 day	270 260 260	12. 11. 11.
10%	7.1 7.2 7.3	23/09/2014	01/10/2014	7 days	400 410 380	17. 18. 16.
10%	28.1 28.2 28.3	23/09/2014	22/10/2014	28 days	480 460 480	21. 20. 21.
10%	56.1 56.2 56.3	23/09/2014	19/11/2014	56 days	510 490 500	22. 21. 22.
10%	90.1 90.2 90.3	23/09/2014	23/12/2014	90 days	560 560 560	24. 24. 24.

APPENDIX A-18

Compressive strength of 1:2:4 concrete with 15% replacement of cement with uncontrolled IWWA (1.20mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compressi strength of c (N/mm2
15%	1.1 1.2 1.3	24/09/2014	26/09/2014	1 day	240 240 220	10.67 10.67 9.78
15%	7.1 7.2 7.3	24/09/2014	02/10/2014	7 days	360 390 360	16.00 17.33 16.00
15%	28.1 28.2 28.3	24/09/2014	23/10/2014	28 days	420 410 440	18.67 18.22 19.56
15%	56.1 56.2	24/09/2014	20/11/2014	56 days	480 490	21.33 21.78

	56.3				490	21.78
	90.1				510	22.67
15%	90.2	24/09/2014	24/12/2014	90 days	540	24.00
	90.3				500	22.22

APPENDIX A-19

Compressive strength of 1:2:4 concrete with 20% replacement of cement with uncontrolled IWWA (1.20mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compres strength of (N/mm
	1.1				230	10.22
20%	1.2	29/09/2014	01/10/2014	1 day	220	9.78
	1.3				210	9.33
	7.1				270	12.00
20%	7.2	29/09/2014	07/10/2014	7 days	280	12.44
	7.3				280	12.44
	28.1				390	17.33
20%	28.2	29/09/2014	28/10/2014	28 days	400	17.78
	28.3				400	17.78
	56.1				470	20.89
20%	56.2	29/09/2014	25/11/2014	56 days	460	20.44
	56.3				460	20.44
	90.1				500	22.22
20%	90.2	29/09/2014	29/12/2014	90 days	500	22.22
	90.3				500	22.22

APPENDIX A-20

Compressive strength of 1:2:4 concrete with 5% replacement of cement with controlled IWWA (0.66mm).

ID No.	Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	C str

5%	1.1 1.2 1.3	06/10/2014	08/10/2014	1 day	320 320 310	
5%	7.1 7.2 7.3	06/10/2014	14/10/2014	7 days	540 560 550	
5%	28.1 28.2 28.3	06/10/2014	04/11/2014	28 days	610 640 600	
5%	56.1 56.2 56.3	06/10/2014	02/12/2014	56 days	670 630 680	
5%	90.1 90.2 90.3	06/10/2014	05/01/2015	90 days	700 720 700	

APPENDIX A-21

Compressive strength of 1:2:4 concrete with 10% replacement of cement with controlled IWWA (0.66mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Com stre cubes
10%	1.1 1.2 1.3	07/10/2014	09/10/2014	1 day	330 310 300	1 1 1
10%	7.1 7.2 7.3	07/10/2014	15/10/2014	7 days	530 520 540	2 2 2
10%	28.1 28.2 28.3	07/10/2014	05/11/2014	28 days	580 620 600	2 2 2
10%	56.1	07/10/2014	03/12/2014	56 days	600	2

56.2				610	2
56.3				640	2
10% 90.1	07/10/2014	06/01/2015	90 days	680	3
90.2				650	2
90.3				670	2

APPENDIX A-22

Compressive strength of 1:2:4 concrete with 15% replacement of cement with controlled IWWA (0.66mm).

ID No.	Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	C str
15% 1.1	08/10/2014	10/10/2014	1 day	260	
1.2				250	
1.3				280	
15% 7.1	08/10/2014	16/10/2014	7 days	420	
7.2				400	
7.3				420	
15% 28.1	08/10/2014	06/11/2014	28 days	590	
28.2				570	
28.3				560	
15% 56.1	08/10/2014	04/12/2014	56 days	580	
56.2				600	
56.3				580	
15% 90.1	08/10/2014	07/01/2015	90 days	640	
90.2				620	
90.3				640	

APPENDIX A-23

Compressive strength of 1:2:4 concrete with 20% replacement of cement with controlled IWWA (0.66mm).

ID No.	Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	C s cub

	1.1				260	
20%	1.2	17/11/2014	19/11/2014	1 day	240	
	1.3				240	
	7.1				350	
20%	7.2	17/11/2014	25/11/2014	7 days	380	
	7.3				360	
	28.1				470	
20%	28.2	17/11/2014	16/12/2014	28 days	480	
	28.3				480	
	56.1				500	
20%	56.2	17/11/2014	13/01/2015	56 days	540	
	56.3				520	
	90.1				580	
20%	90.2	17/11/2014	16/02/2015	90 days	560	
	90.3				570	

APPENDIX A-24

Compressive strength of 1:2:4 concrete with 5% replacement of cement with controlled IWWA (0.83mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Com stre cubes
	1.1				310	1
5%	1.2	18/11/2014	20/11/2014	1 day	300	1
	1.3				300	1
	7.1				500	2
5%	7.2	18/11/2014	26/12/2014	7 days	510	2
	7.3				500	2
	28.1				580	2
5%	28.2	18/11/2014	17/12/2014	28 days	600	2
	28.3				570	2

	56.1				580	2
5%	56.2	18/11/2014	14/01/2015	56 days	610	2
	56.3				590	2
	90.1				600	2
5%	90.2	18/11/2014	17/02/2015	90 days	660	2
	90.3				610	2

APPENDIX A-25

Compressive strength of 1:2:4 concrete with 10% replacement of cement with controlled IWWA (0.83mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Co st cub
	1.1				290	
10%	1.2	19/11/2014	21/11/2014	1 day	300	
	1.3				300	
	7.1				470	
10%	7.2	19/11/2014	27/11/2014	7 days	490	
	7.3				470	
	28.1				580	
10%	28.2	19/11/2014	18/12/2014	28 days	510	
	28.3				550	
	56.1				510	
10%	56.2	19/11/2014	15/01/2015	56 days	570	
	56.3				630	
	90.1				640	
10%	90.2	19/11/2014	18/02/2015	90 days	590	
	90.3				560	

APPENDIX A-26

Compressive strength of 1:2:4 concrete with 15% replacement of cement with controlled IWWA (0.83mm).

ID No.	Date of Casting	Date of Testing	Age of Curing	Load at Failure	Co

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	st cube
15%	1.1	24/11/2014	26/11/2014	1 day	270	
	1.2				260	
	1.3				240	
15%	7.1	24/11/2014	02/12/2014	7 days	370	
	7.2				390	
	7.3				400	
15%	28.1	24/11/2014	23/12/2014	28 days	560	
	28.2				520	
	28.3				530	
15%	56.1	24/11/2014	20/01/2015	56 days	540	
	56.2				590	
	56.3				510	
15%	90.1	24/11/2014	23/02/2015	90 days	560	
	90.2				580	
	90.3				540	

APPENDIX A-27

Compressive strength of 1:2:4 concrete with 20% replacement of cement with controlled IWWA (0.83mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Con stre cubes
20%	1.1	17/11/2014	19/11/2014	1 day	260	
	1.2				240	
	1.3				240	
20%	7.1	17/11/2014	25/11/2014	7 days	350	
	7.2				380	
	7.3				360	
20%	28.1	17/11/2014	16/12/2014	28 days	470	
	28.2				480	

28.3				480	
20% 56.1	17/11/2014	13/01/2015	56 days	500	
56.2				540	
56.3				520	
20% 90.1	17/11/2014	16/02/2015	90 days	580	
90.2				560	
90.3				570	

APPENDIX A-28

Compressive strength of 1:2:4 concrete with 5% replacement of cement with controlled IWWA (1.20mm).

ID No.	Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Con str cubes
5% 1.1	26/11/2014	28/11/2014	1 day	320	
1.2				320	
1.3				300	
5% 7.1	26/11/2014	04/12/2014	7 days	420	
7.2				360	
7.3				380	
5% 28.1	26/11/2014	26/12/2014	28 days	570	
28.2				520	
28.3				540	
5% 56.1	26/11/2014	22/01/2015	56 days	580	
56.2				600	
56.3				540	
5% 90.1	26/11/2014	25/02/2015	90 days	600	
90.2				580	
90.3				580	

APPENDIX A-29

Compressive strength of 1:2:4 concrete with 10% replacement of cement with controlled IWWA (1.20mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Compre strengt cubes (N/
10%	1.1	01/12/2014	03/12/2014	1 day	280	12.4
	1.2				240	10.6
	1.3				250	11.1
10%	7.1	01/12/2014	09/12/2014	7 days	410	18.2
	7.2				410	18.2
	7.3				430	19.1
10%	28.1	01/12/2014	30/12/2014	28 days	490	21.7
	28.2				500	22.2
	28.3				510	22.6
10%	56.1	01/12/2014	26/12/2014	56 days	550	24.4
	56.2				550	24.4
	56.3				520	23.1
10%	90.1	01/12/2014	25/02/2015	90 days	570	25.3
	90.2				580	25.7
	90.3				540	24.0

APPENDIX A-30

Compressive strength of 1:2:4 concrete with 15% replacement of cement with controlled IWWA (1.20mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Co st cube
15%	1.1	02/12/2014	04/12/2014	1 day	260	
	1.2				230	
	1.3				220	
15%	7.1	02/12/2014	10/12/2014	7 days	300	
	7.2				280	
	7.3				300	
15%	28.1	02/12/2014	31/12/2014	28 days	430	

	28.2				400	
	28.3				410	
	56.1				520	
15%	56.2	02/12/2014	28/01/2015	56 days	520	
	56.3				500	
	90.1				560	
15%	90.2	02/12/2014	03/03/2015	90 days	540	
	90.3				530	

APPENDIX A-31

Compressive strength of 1:2:4 concrete with 20% replacement of cement with controlled IWWA (1.20mm).

ID No.		Date of Casting	Date of Testing	Age of Curing	Load at Failure (KN)	Con str cubes
	1.1				210	
20%	1.2	03/12/2014	05/12/2014	1 day	220	
	1.3				220	
	7.1				280	
20%	7.2	03/12/2014	11/12/2014	7 days	310	
	7.3				310	
	28.1				400	
20%	28.2	03/12/2014	02/01/2015	28 days	400	
	28.3				420	
	56.1				460	
20%	56.2	03/12/2014	29/01/2015	56 days	480	
	56.3				480	
	90.1				500	
20%	90.2	03/12/2014	04/03/2015	90 days	520	
	90.3				530	