

**INVESTIGATING THE PROPERTIES OF CONCRETE  
INCORPORATING CALCINED EARTHWORM CAST AS  
PARTIAL REPLACEMENT FOR CEMENT.**

BEING

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## CHAPTER ONE

### INTRODUCTION

#### 1.0 BACKGROUND OF STUDY

Concrete is a major material in the construction industry in Nigeria and the world at large, either mass concrete alone or sometimes complimented with other materials like steel. Concrete is able to take on different shapes and often, the stability of the structure depends on it.

In spite of this fact, the cost of concrete usually accounts for a major percentage of the total cost of the project, and in concrete, cement amounts for a bulk of the materials.

Concrete is basically a mixture of two components: aggregates and paste. The paste is usually composed of Portland cement and water, and it binds together the fine and coarse aggregates. Supplementary cementing materials may also be included in the paste. A typical mix is about 10 to 15 % cement, 60 to 75 % sand/aggregate, 10 to 20 % water, and 5 to 8 % air. When freshly mixed, it is plastic and malleable, allowing it to be poured into place and finished. Then, through a chemical reaction called hydration, the mixture hardens and gains strength to form the concrete we see in buildings, sidewalks, bridges, and other structures. Concrete is the most commonly used construction material in the world (Ecosmart, 2004). Concrete is associated with high strength, hardness, durability, imperviousness and mouldability. It is a poor thermal insulator but has high thermal capacity. Concrete is not flammable and has good fire resistance, but there is serious loss of strength at high

temperatures. Concrete made with ordinary Portland cement has low resistance to acids and sulphates but good resistance to alkalis. ("Concrete", 2006)

The hardening of these composite materials into artificial stone like element is obtained by the action of cement and water (Neville, 1981).

Cement has been proven to be essential in construction. Portland cement is the key component of concrete and is produced by intergrinding clinker and gypsum into a fine grey powder. Clinker is a granular product produced by intergrinding raw materials such as limestone, shale, clay and sand in predetermined proportions, and heating the ground materials at very high temperatures ( $>1500$  °C) in rotating kilns. Gypsum (a mineral) is added to regulate the setting time of the cement after the clinker is cooled, prior to conversion into cement. Producing 1 tonne of cement causes an emission 1.25 tonnes of CO<sub>2</sub> gas (which is a green house gas) due to the calcination of the raw materials and the combustion of fuel (Osha, Aroke, & Aliyu, 2005). Concrete is a relatively expensive building material for structures. The cost can be lowered if some of the Portland cement is replaced with an admixture. However, when admixtures are used the chemical reaction is slower and strength development is delayed ("Concrete", 2006). Mardock (1978) in Nshol (2000) stated that admixtures are used to modify for a particular reason, the properties of either fresh or hardened concrete which cannot be obtained by changes in the composition or proportion of the normal mix.

### **1.01 Pozzolanas**

The rising cost of cement has brought about the introduction of materials referred to as pozzolanas. A simple everyday definition of 'pozzolan' could be 'a finely powdered material which can be added to lime mortar (or to Portland

cement mortar) to increase durability and, in the case of lime mortars, to provide a positive set'. A more formal definition is given by ASTM C618 as 'a siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties' (Gibbons, 1997). The Canadian Standards Association (CSA) defines a pozzolan, a supplementary cementing material as follows: a siliceous or alumino-siliceous material that, in finely divided form and in the presence of moisture, chemically reacts at ordinary room temperature with calcium hydroxide released by the hydration of Portland cement to form compounds possessing cementitious properties. Gray, Atwater, & Dunbar (2003) defined natural pozzolan as a natural material which may be calcined and/or processed (e.g. diatomaceous earth, meta kaolin, rice husk ash, volcanic ash, or calcined shale, pulverized fuel ash, saw dust ash)

These artificial cements are also called admixtures. They are ingredients that can be used as partial replacements for Portland cements in concrete.

## **1.02 Calcination**

Calcination (also referred to as Calcining) is a thermal treatment process applied to ores and other solid materials in order to bring about a thermal decomposition, phase transition, or removal of a volatile fraction ("Calcination"2005). The calcination process normally takes place at temperatures below the melting point of the product materials. Calcination is to be distinguished from roasting, in which more complex gas-solid reactions take place between the furnace atmosphere and the solids.

The process of calcination derives its name from its most common application, the decomposition of calcium carbonate (limestone) to calcium oxide (lime). The product of Calcination is usually referred to in general as "Calcine," regardless of the actual minerals undergoing thermal treatment. Calcination is carried out in furnaces or reactors (sometimes referred to as kilns) of various designs including shaft furnaces, rotary kilns, multiple hearth furnaces, and fluidized bed reactors. Sometimes, calcination can be in natural processes as in the heating of volcanic ash. At the inception of the use of admixtures in 150 BC, the Romans discovered that finely divided pozzolan had to be amorphous (glassy) to chemically react. This was possible because the pozzolan was heated (calcined) by the volcano (Herring, 2002).

### **1.03 Earthworm Cast**

Earthworm cast is the faeces of earthworm. These can be found at all seasons whether dry or wet. It is easily found and therefore readily available.

Recently, it has been seen that earthworm cast contains some of the basic chemical compounds which when used as an admixture, would be of great advantage in concrete work (Nshol, 2000)

The motivation for this research stems from the question of what properties (chemical and physical) improvement is found by the incorporation of calcined earthworm cast.

## 1.1 PROBLEM STATEMENT

According to Neville (1983), concrete and steel are the two most commonly used structural materials for construction purposes and they sometimes complement one another. Concrete being relatively cheaper is the most widely used construction material these days and as such efforts have been made to reduce the cost of production. This is achieved by reducing the cost of the most expensive constituents of concrete with cement being the most essential and expensive constituent of concrete which has attracted much attention for its high cost due to its industrial process during its manufacture and transportation from its point of production to points of usage.

One of the ways of reducing cement cost in concrete is by partially replacing it with some cheaper materials, referred to as pozzolanas

Troxell (1968) in Okpara (1999) stated that the essential problem for the engineer is in obtaining a satisfactory product at reasonable cost. A satisfactory product is one, which has the necessary and desired properties. For concrete, the properties would include workability, uniformity, strength, water tightness, durability, and volume consistency in the hardened product.

Because of the rising cost of cement, it has become imperative to find supplements for cement that can lead to the overall reduction in the cost of construction. Over the years, different materials have been researched as admixtures in concrete. This is with the intention of providing an ideal supplement for cement in concrete and mortar mixes. Materials tested have included; Fly ash, Rice husk ash, and Municipal waste ash, earthworm cast, etc.

Perhaps if the properties observed are suitable for partial replacement of cement, the ready availability of earthworm cast will be an answer to the question of reduced housing cost in Jos metropolis and its surroundings.

## **1.2 AIM AND OBJECTIVES OF THE STUDY**

The primary aim of this research is to determine the characteristics of concrete incorporating calcined earthworm cast as partial replacement, with the following objectives in focus:

- i. To obtain the optimum amount or percentage of calcined earthworm cast that can be used in cement in the concrete concerned
- ii. To examine the mechanical, physical, and chemical properties of the admixtures (calcined earthworm cast).
- iii. To assess the potential use of calcined earthworm cast from deposits around Jos metropolis and environment as supplementary cementing material in Portland cement concrete

## **1.3 SCOPE AND DELIMITATIONS**

This research is limited to the series of test on earthworm cast material as well as determining its physical and chemical properties which would include; compressive strength, chemical analysis, and water absorption test will be carried out on the concrete incorporated with calcined earthworm cast at four percentage replacement levels (0, 10, 20, 30, 40)

The properties that will be tested for include the specific gravity and bulk density test, water content and water absorption test, initial and final setting time of cement and calcined earthworm cast.

The mix ratio will be 1:2:4 by volume of cement. 100 × 100mm cubes will be cast and a hydration period of 7, 14, 28 days will be used to ascertain the compressive strength.

The research however will not be able to cover the long-term observation of the concrete in question because of the limitation of time available to observe the build up of the strength by over a long period of time and determine the final strength of the concrete.

#### **1.4 METHODOLOGY**

This will include literature review (identification, collection and review of information applicable to the study) of journals and other relevant materials, laboratory experiments, and field works that will involve the collection of materials. Earthworm cast will be collected and series of laboratory tests will be performed to determine their properties suitability for research work. The cement to be used will be in conformity to BS 1881; 1970. The fine aggregate will be sharp river sand washed and thoroughly cleaned to remove deleterious element so that it conforms to the specification of BS 882 part 2 (1973) The fine aggregates will be made to pass through a 5mm sieve while the coarse aggregates will be passed through a 20 mm sieve.

The laboratory tests will include; Slump test to determine the desired workability of the concrete and the required amount of water content; Sieve analysis to determine the particle size distribution and the fineness of the pozzolan and the aggregates; Chemical analysis to determine the chemical composition of earthworm cast; Compacting factor test which will be used determine the work required to compact or consolidate the concrete completely;



initial and final setting time; Compression test which will be used to determine the quality of concrete, this is usually ascertained by the crushing strength of the concrete.

Mixing will be done manually, after which specimens will be moulded using 150 × 150mm moulds. Casting and curing will be done manually as well. The periods for test of compressive strength, and other parameters will be 7, 14, and 28 days respectively. The results obtained will be presented in the chapter for analysis of results.

### **1.5 SIGNIFICANCE OF STUDY**

The relevance of this study comes in to play by the way it affects both the practitioners and the scholars. The knowledge of how earthworm cast can be further utilized in concrete will be an asset to the scholars. The results obtained will provide knowledge of; the optimum percentage replacement of cement with earthworm cast, an alternative method of utilizing Earthworm cast in concrete, the modifications that take place in the concrete that has been incorporated with earthworm cast.

Bearing in mind the heavy production of Green House Gases (GHG) by cement production process, the incorporation of alternatives for partial replacement of cement in concrete might reduce cement production, which will in turn reduce GHG emission. The partial replacement of Ordinary Portland Cement with Calcined Earthworm Cast in concrete production will be a welcome development in the country. Considering its benefit of cost reduction in rural construction, the cost of production of calcined earthworm cast should be relatively low compared to OPC production

## CHAPTER TWO.

### LITERATURE REVIEW

#### 2.1 EARTHWORM

Earthworm is the common name for the largest members of the Oligochaeta (which is either a class or sub-class depending on the author) in the phylum Annelida. In classical systems they were placed in the order Opisthopora, on the basis of the male pores opening to the outside of the body posterior to the female pores, even though the male segments are anterior to the female. Folk names for earthworm include "dew-worm", "rainworm", "night crawler" and "angleworm".

Earthworms are also called megadriles (or big worms), as opposed to the microdiles, which include the families' tubificidae, Lumbriculidae, and Enchytraeidae, among others.

There are over 5,500 named species known worldwide, everywhere but polar and arid climates. They range in size from two centimeters (less than one inch) to over three meters (almost ten feet) in the Giant Gippsland Earthworm. Amongst the main earthworm species commonly found in temperate regions are the reddish coloured, deep-burrowing Lumbricus Terrestris.

In temperate zone areas, the most commonly seen earthworms are lumbricids (Lumbircidae), mostly due to the recent rapid spread of a relatively small number of European species, but there are many other families, e.g. Megascolecidae, Octochaetidae, Sparganophilidae, Glossoscolecidae, etc. These

other families often differ from the lumbricids in behaviour, physiology and habitat.

## **2.2 EARTHWORM CAST**

This is simply defined as the undigested ingest food (like soil, water and salt) which has been eliminated during excretion by the earthworm Cockrum, (1966) in Ajime (1999). The earthworm secretes a long thick column of faeces, which produces a hollow mould about 5cm height and 2.5 cm in diameter (Edwards & Lofty, 1972).

Earthworm cast contains certain microorganisms, inorganic minerals in a form available to plant. Casts also contain enzymes such as protease, amylase, lipase, cellulose, and chitinase, which continues to disintegrate organic matter even after they have been, excreted Ghabbour (1966) in Ajime (1999).

Earthworms are terrestrial animals, which burrow in soil. They swallow soil, which is rich in organic material and it is on this they feed together with vegetable matter, which they collect from outside their burrow at night Robinson, (1973) in Okpara (1999).

### **2.2.1 Effect Of Earthworm On Soil**

The major benefits of earthworm activities to soil can be summarized as:

Biological. The earthworm is essential to composting; the process of converting dead organic matter into rich humus, a medium vital to the growth of healthy plants, and thus ensuring the continuance of the cycle of fertility. This is achieved by the worm's actions of pulling down below any organic matter deposited on the soil surface (for example, leaf fall, manure, etc) either for food or when it needs to plug its burrow. Once in the burrow, the worm will shred

the leaf and partially digest it, then mingle it with the earth by saturating it with intestinal secretions. Worm casts can contain 40% more humus than the top 150mm of soil in which the worm is living.

### **Chemical effects of earthworm on soil.**

As well as dead organic matter, the earthworm also ingests any other soil particles that are small enough—including stones up to 1/20 of an inch (1.25mm) across—into its 'crop' wherein minute fragments of grit grind everything into a fine paste which is then digested in the stomach. When the worm excretes this in the form of casts which are deposited on the surface or deeper in the soil, a perfectly balanced selection of minerals and plant nutrients is made available in an accessible form. Investigations in the US show that fresh earthworm casts are 5 times richer in available nitrogen, 7 times richer in available phosphates and 11 times richer in available potash than the surrounding upper 6 inches (150 mm) of soil. In conditions where there is plenty of available humus, the weight of casts produced may be greater than 4.5 kg (10 lb) per worm per year, in itself an indicator of why it pays the gardener or farmer to keep worm populations high.

### **Physical effects of earthworm on soil.**

By its burrowing actions, the earthworm is of great value in keeping the soil structure open, creating a multitude of channels which allow the processes of both aeration and drainage to occur. Mollison (1988) points out that by sliding in their tunnels, earthworms "act as an innumerable army of pistons pumping air in and out of the soils on a 24 hour cycle (more rapidly at night)".

Thus the earthworm not only creates passages for air and water to traverse, but is itself a vital component in the living biosystem that is healthy soil.

### **2.2.2 Burrowing and Casting Of Earthworm**

Earthworms form burrows by literally eating their way through the soil and pushing through crevices. Not all species of earthworms have burrows; it is usually only those species (*Lumbricus Terrestris*) that have permanent burrows with smooth walls cemented together with mucous secretions and ejected soil, pressed into the soil interspaces. Often the mucous secretions serve as substratum for growth of fungi (Edwards and Lofty, 1972).

Earthworms of the genus *lumbricus* do not burrow extensively, so long as adequate food supply is present on the surface, but when food is scarce, burrowing activity is greatly stimulated (Parmak, 1997). It is usually the burrowing species that produce casts on the soil surface near the exit of their burrows. Lumbricoid species, *Eisena Rosea* produce cast, on the surface of the soil Thompson and Davies, (1974) I Ajime, (1999). Casting by tropical species of earthworm is limited to the wet season (Madge and gate, 1961)

### **2.2.3 Chemical Composition of Earthworm Cast**

The chemical composition of earthworm cast is dependent on the chemical composition of the parent soil in which it burrows through to form cast. Ireland (1965) in Edwards and Lofty (1972) analyzed that iron, zinc, and calcium intake is regulated in the animal tissue to produce lead, which is taken up and retained by the earthworm. The available material nutrients in the earthworm cast generally have a higher Base Exchange capacity, and more exchangeable calcium, magnesium and potassium, and available phosphorus.

## **2.3 CALCINATION**

Calcination, in metallurgy, is the process of heating solid material to drive off volatile chemically combined components, e.g., carbon dioxide. It is sometimes a step in the extraction of metals from ores. Calcination is distinguished from drying, in which mechanically held water is driven off by heating, and from roasting, in which a material is heated in the presence of air to oxidize impurities. Originally calcination meant the method of obtaining lime (calcium oxide) from limestone by heating it to drive off carbon dioxide (CALCINATION, 2007)

Calcination (also referred to as Calcining) is thermal treatment process applied to ores and other solid materials in order to bring about a thermal decomposition, phase transition, or removal of a volatile fraction. The calcination process normally takes place at temperatures below the melting point of the product materials. Calcination is to be distinguished from roasting, in which more complex gas-solid reactions take place between the furnace atmosphere and the solids. Industrial processes

### **2.3.1 Industrial Processes**

The process of calcination derives its name from its most common application, the decomposition of calcium carbonate (limestone) to calcium oxide (lime). The product of Calcination is usually referred to in general as "Calcine," regardless of the actual minerals undergoing thermal treatment. Calcination is carried out in furnaces or reactors (sometimes referred to as kilns) of various designs including shaft furnaces, rotary kilns, multiple hearth furnaces, and fluidized bed reactors.

Examples of calcination processes include the following:

- decomposition of hydrated minerals, as in calcination of bauxite, to remove crystalline water as water vapor;
- decomposition of carbonate minerals, as in the calcination of limestone to drive off carbon dioxide;
- volatilization of organic compounds (usually under inert or reducing atmospheres), as in petroleum coke calcination;
- heat treatment to effect phase transformations, as in conversion of anatase to rutile or devitrification of glass materials

### **2.3.2 Calcination Reactions**

Calcination reactions usually take place at or above the thermal decomposition temperature (for decomposition and volatilization reactions) or the transition temperature (for phase transitions). This temperature is usually defined as the temperature at which the standard Gibb's free energy of reaction for a particular calcination reaction is equal to zero. For example, in limestone calcination, a decomposition process, the chemical reaction is  $\text{CaCO}_3 = \text{CaO} + \text{CO}_2 (\text{g})$ . The standard Gibb's free energy of reaction is approximated as  $\Delta G^\circ_r = 177,100 - 158 T$  (J/mol) (Gilchrist, 1989). The standard free energy of reaction is zero in this case when the temperature,  $T$ , is equal to  $848^\circ\text{C}$ .

Examples of chemical decomposition reactions common in calcination processes, and their respective thermal decomposition temperatures include:

- $\text{CaCO}_3 = \text{CaO} + \text{CO}_2; 848^\circ\text{C}$

## 2.4 CEMENT

Portland cement is a material, which is obtained by intimately mixing together calcareous or other lime-bearing materials with, if required, argillaceous and /or other silica, alumina, or iron oxide bearing materials burning them at clinkering temperature and grinding the resulting clinker (BS: 12, 1978)

The main raw materials used in the cement manufacturing process are limestone, sand, shale, clay, and iron ore. The main material, limestone, is usually mined on site while the other minor materials may be mined either on site or in nearby quarries. Another source of raw materials is industrial by-products. The use of by-product materials to replace natural raw materials is a key element in achieving sustainable development.

Mining of limestone requires the use of drilling and blasting techniques. The blasting techniques use the latest technology to insure vibration, dust, and noise emissions are kept at a minimum. Blasting produces materials in a wide range of sizes from approximately 1.5 meters in diameter to small particles less than a few millimetres in diameter.

Material is loaded at the blasting face into trucks for transportation to the crushing plant. Through a series of crushers and screens, the limestone is reduced to a size less than 100 mm and stored until required. Depending on size, the minor materials (sand, shale, clay, and iron ore) may or may not be crushed before being stored in separate areas until required.



### **2.4.1 Raw Grinding**

In the wet process of cement production, each raw material is proportioned to meet a desired chemical composition and fed to a rotating ball mill with water. The raw materials are ground to a size where the majority of the materials are less than 75 microns. Materials exiting the mill are called "slurry" and have flowability characteristics. This slurry is pumped to blending tanks and homogenized to insure the chemical composition of the slurry is correct. Following the homogenization process, the slurry is stored in tanks until required. In the dry process, each raw material is proportioned to meet a desired chemical composition and fed to either a rotating ball mill or vertical roller mill. The raw materials are dried with waste process gases and ground to a size where the majority of the materials are less than 75 microns. The dry materials exiting either type of mill are called "kiln feed". The kiln feed is pneumatically blended to insure the chemical composition of the kiln feed is well homogenized and then stored in silos until required.

### **2.4.2 Pyroprocessing**

Whether the process is wet or dry, the same chemical reactions take place. Basic chemical reactions are: evaporating all moisture, calcining the limestone to produce free calcium oxide, and reacting the calcium oxide with the minor materials (sand, shale, clay, and iron). This results in a final black, nodular product known as "clinker" which has the desired hydraulic properties. In the wet process, the slurry is fed to a rotary kiln, which can be from 3.0 m to 5.0 m in diameter and from 120.0 m to 165.0 m in length. The rotary kiln is made of steel and lined with special refractory materials to protect it from the

high process temperatures. Process temperatures can reach as high as 1450°C during the clinker making process. In the dry process, kiln feed is fed to a preheater tower, which can be as high as 150.0 meters. Material from the preheater tower is discharged to a rotary kiln which can have the same diameter as a wet process kiln but the length is much shorter at approximately 45.0 m. The preheater tower and rotary kiln are made of steel and lined with special refractory materials to protect it from the high process temperatures. Regardless of the process, the rotary kiln is fired with an intense flame, produced by burning coal, coke, oil, gas or waste fuels. Preheater towers can be equipped with firing as well. The rotary kiln discharges the red-hot clinker under the intense flame into a clinker cooler. The clinker cooler recovers heat from the clinker and returns the heat to the pyroprocessing system thus reducing fuel consumption and improving energy efficiency. Clinker leaving the clinker cooler is at a temperature conducive to being handled on standard conveying equipment.

#### **2.4.3 Finish Grinding and Distribution**

The black, nodular clinker is stored on site in silos or clinker domes until needed for cement production. Clinker, gypsum, and other process additions are ground together in ball mills to form the final cement products. Fineness of the final products, amount of gypsum added, and the amount of process additions added are all varied to develop a desired performance in each of the final cement products. Each cement product is stored in an individual bulk silo until needed by the customer. Bulk cement can be distributed in bulk by truck, rail, or water

depending on the customer's needs. Cement can also be packaged with or without color addition and distributed by truck or rail.

## 2.5 CHEMICAL COMPOSITION OF ORDINARY PORTLAND CEMENT

Table 2.1 Chemical composition of ordinary Portland cement

TYPICAL COMPOSITION	OXIDE	PERCENTAGE COMPOSITION	(WT)
CaO		63.0	
SiO <sub>2</sub>		20.0	
Al <sub>2</sub> O <sub>3</sub>		6.0	
Fe <sub>2</sub> O <sub>3</sub>		3.0	
MgO		1.5	
SO <sub>3</sub>		2.0	
K <sub>2</sub> O		-	
Na <sub>2</sub> SO <sub>4</sub>		1.0	
Other		1.0	
Loss of Ignition		2.0	
Insoluble Residue		0.5	

(Ajime, 1999)

## 2.6 AGGREGATES

Aggregate was originally viewed as an inert material dispersed throughout the cement paste largely for economic reasons. In fact, aggregate is not truly inert and its physical, thermal, and sometimes also chemical properties influence the performance of concrete Jackson (1988) in Ajime (1999).

Aggregates form approximately three quarters of volume of concrete, which is why its quality is of considerable importance. The aggregates used in concrete does not only limit the strength of the concrete, but the aggregate properties greatly affect the durability and structural performance of concrete (Neville and Brooks, 1972)

Aggregates could be naturally formed or artificially and this is based on the grain size whether fine or coarse (Murdock, 1979). The natural aggregate consist of broken particles of stone deposited by erosion of rivers and streams or glaciers. Aggregates formed by this process are mainly sand and gravel (Jackson and Dhir, 1979).

The types deposited by streams and rivers are more satisfactory for use than those deposited by glacier erosion, this is because the former consist of the moulded particles in wide ranges of sizes (non-uniform) and where materials have been eroded away with it by erosive action of water. Another reason is that glacier deposition tends to have angular particles of variable sizes and poorly graded that adversely affects the workability of concrete in which they are used (Jackson and Dhir, 1979).

Aggregates are generally classified as fine or coarse by size, natural or artificial, heavyweight, normal or lightweight (Murdock, 1979).

## **2.7 CONCRETE ADMIXTURES**

Admixtures are materials that are added to concrete at some stage in its making to give to the concrete new properties either when fluid or plastic and/or in the set or cured conditions (Hewlett and Rivon, 1977).

Chemical admixtures are materials in the form of powder or fluids that are added to the concrete to give it certain characteristics not obtainable with plain concrete mixes. In normal use, admixture dosages are less than 5% by mass of cement, and are added to the concrete at the time of batching/mixing (U.S. Federal Highway Authority (USFHA), 2007) Admixtures in concrete have been widely accepted in the United States of America and on the continent – particularly in Germany – than in the United Kingdom. However, with the present trend in cement price, it is probably timely that the users and manufacturers of concrete should take a keen and informed interest in the part that admixtures could play in making the best of the cement paid for (Hewlett, 1961).

According to Murdock (1979), Admixtures, ranging from addition of chemicals to the use of waste materials for which an outlet is being sought, have been advocated for use in concrete almost from the time when cement was first invented. In Great Britain alone, there are well over 100 proprietary admixtures available on the market, and the selection of a suitable one for a particular purpose can be confusing (Shacklopck, 1969) in Murdock (1979).

The use of an admixture should therefore be considered where it is desired to modify for a particular reason the properties of either fresh or hardened concrete, or both, which can not be modified or obtained by changes in the composition or proportions of the normal concrete mix (Murdock, 1979).

In order to be able to assess the suitability of an admixture the active ingredients must be known, because, while some properties of the concrete may be enhanced by one ingredient, other ingredients may cause detrimental effects to other properties.

The control of the quality of admixtures has been tightened in recent years, particularly since the introduction of CP110-1972, which states that the Engineer should be provided with the following data:

- (i) The typical dosage and detrimental effects of under dosage and over dosage.
- (ii) The chemical name(s) of the main active ingredient(s) in the admixture.
- (iii) Whether or not the admixture contains chloride and, if so, the chloride content of the admixture expressed as a percentage of equivalent anhydrous calcium chloride by weight of the admixture.
- (iv) Whether or not the admixture leads to the entrainment of air when used at the manufacturer's recommended dosage.

The importance of testing admixtures, particularly with the cement and aggregates to be used on a site, cannot be overemphasized. Such test should be designed to show that no adverse side effects are likely, such as increased

drying shrinkage, reduced bond strength, reduced ultimate compressive strength, and reduced modulus of elasticity.

A concrete of fundamentally poor quality will not be converted into a good concrete by any type of admixture Callet (1949) in Murdock (1979).

## **2.8 POZZOLANNAS**

### **2.8.1 Introduction.**

Pozzolanas are materials containing reactive silica and / or alumina, which on their own have little or no binding property but, when mixed with lime in the presence of water, will set and harden like cement. They are an important ingredient in the production of an alternative cementing material to ordinary Portland cement (OPC). The addition of a pozzolana in either a lime or OPC-based product has two major advantages. Firstly, the properties of the cement will be improved, and secondly, as the costs of a pozzolana are usually low and certainly well below that of lime or OPC, overall cost will be significantly reduced assuming the pozzolana does not have to be transported too far.

Cement or some form of binding agent is a vital element in all types of construction and in recent years the cement market has been dominated by one product, OPC. In many countries of the developing world, OPC is an expensive and sometimes scarce commodity and as a factor, this has severely limited the construction of affordable housing. Many of these countries have large supplies of pozzolanic materials readily available. In volcanic areas such as Central Africa, Central America and Indonesia there are enormous deposits of volcanic ash. In India and other Asian countries rice husk ash (RHA), provides a good



source of pozzolana for use in masonry cements. Although still limited in comparison with the growth of the use of pozzolanas in Europe and the USA, there are a growing number of developing countries now using more and more pozzolanas in combination with lime or OPC.

Pozzolanas, by their diverse and varied nature, tend to have widely varying characteristics. The chemical composition of pozzolanas varies considerably, depending on the source and the preparation technique. Generally, a pozzolana will contain silica, alumina, iron oxide, and a variety of oxides and alkalis, each in varying degrees. This presents problems for small-scale manufacturers wishing to use pozzolanas in a lime or OPC - pozzolana mix. The Romans were fortunate builders in that certain volcanic soils in Italy were found to be suitable for producing a hydraulic mortar. One of such soil was found near the town of pozzuli, near Naples, and although the Romans called the material 'pulvis puteolanus', it subsequently became known as pozzolana. The Romans used lime-pozzolana mortars extensively in building and in the colonization and settlement of their empire; evidence has been found of the use of mortars containing trass (an old form of pozzolana) in old roman building along the Rhine. In OPC-based concretes pozzolanas are used to replace up to 30 per cent of OPC for use in structural applications and up to 50 per cent for non-structural purposes. As OPC is an expensive and sometimes scarce commodity, this can represent a significant cost saving ("Pozzolanas - An Introduction", 2006). In addition Portland-pozzolana blended cement has a number of significant technical advantages over plain OPC. These are:

- Improved workability

- Improved water retention/reduced bleeding
- Improved sulphate resistance
- Improved resistance to alkali aggregate reaction
- Lower heat of hydration
- Enhanced long-term strength

The only disadvantage of these blended cements is that their early strength gain is slightly slower. This might mean that the dismantling of formwork on structural concrete may need to be delayed by a day or so, but this disadvantage is far outweighed by the advantages ("Pozzolanas - An Introduction", 2006). These technical and economic advantages are well recognized by many 'enlightened' engineers and Portland-pozzolana blends are now commonly specified, particularly on major civil engineering works, in both the developed and developing world.

**Table 2.2 Physical and Chemical Requirements for Pozzolanas ASTM C618 – 78**

Property of Pozzolana	ASTM Requirements
Water soluble fraction percentage	10.00
Fineness ; amount retained when dry sieved	
No. 30 sieve (max %)	2.00
No. 200 sieve (max %)	30.00
Dry Shrinkage (max %)	0.15
Pozzolanic activity index at 28 days (min % of control)	75.00
Water requirement (max. % of control)	115
SiO <sub>2</sub> + Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub> ( minimum percentage)	70.00
Specific Gravity	2.10 – 2.40
Magnesium Oxide (max %)	5.00
Loss of ignition (max %)	12.00

(Ezem, 1997)

### **2.8.2 Classification of Pozzolana**

The name pozzolana was originally reserved for vitreous pyroclastic material produced by violent eruptive volcanic action. It is now used as a generic term to describe all materials which exhibit reactivity with lime and which set harden and develop strength in the presence of water. The range of pozzolanic materials continues to increase, but their origin, structure, chemical, and mineralogical composition vary widely ( Sersale, 1980). Massaza (1980) has also expressed reservation in the use of the word pozzolana to cover the

whole range of these materials and it is probably correct to refer to them as mineral additives. Accordingly, classes of mineral additives would include natural pozzolana, calcined clay, and shale, fly ash, silica fume and ash from agricultural residues (Cook, 1986).

Mielenz, Witte, and Glantz (1950), proposed one of the first classifications of natural pozzolanas, which is given in table 2. —

**Table 2.3 Classification of pozzolanas by Mielenz et al**

Activity type	Essential active constituent
1	Volcanic Glass
2	Opal
3a	Kaolinite-type Clay
3b	Montmorillonite-type clay
3c	Illite-type clay
3d	Mixed clay with vermiculite
4	Zeolites
5	Hydrated oxides of aluminium
6	Non-pozzolanas

In a later classification, Mielenz et al, (1951), added activity type 3e which attapulkgite-type clay was the active constituent. In this classification system, only activity types 1, 2, and 4 are natural pozzolanas. Types 3 and 5 react with lime but are only considered pozzolanic after they have been calcined.

A more recent classification was proposed by Massaza, (1974). In it; he broadly divided the natural pozzolana into three classes, namely, pyroclastic rocks, altered materials of mixed origin, and clastic rocks. The pyroclastic rocks, he further subdivided into; incoherent rocks and altered coherent rocks. On the other hand, the clastic rocks were divided into; materials of organic origin and materials of simple decomposition.

True pozzolanas consist predominantly of silica with alumina and ferric oxide being the next major constituent. True pozzolanas are formed by violent ejection of molten magma when the subsequent rapid quenching produces glassy material containing entrapped gas bubbles. The reactivity of the pozzolana with lime increases as the vitreous compound increases (Cook, 1986).

Matawal (2005) stated that the reasons for the employment of ashes to cement have a three-dimensional purpose that can be summed up in three major headings, namely;

- i. Technological; pozzolanas can modify the properties of cement, increasing or decreasing its durability and reaction to aggressive agents as well as to time. The improved behaviour is a function of the activity of the addition and this varies from one pozzolana to another.
- ii. Economically; active additions reduce the quantity of cement required.
- iii. Environmentally; employing such additions utilizes waste material,

### **2.8.3 Pozzolanic Activity**

The reactivity of a pozzolana with lime is influenced by inherent characteristics of the pozzolana, such as chemical and mineralogical composition, morphology, the amount of glassy phase and fineness. It is also influenced by external factors such as the addition of admixtures and thermal treatments.

All pozzolanas have a high  $\text{SiO}_2 + \text{Al}_2\text{O}_3$  content and have a glassy or amorphous structure, with the exception of zeolitic tuffs (Cook, 1986).

Costa and Massaza (1974) showed that for Italian pozzolanas, long-term strength can be related to the  $\text{SiO}_2 + \text{Al}_2\text{O}_3$  content but initially (within seven days) the reactivity with lime is more related to the specific surface area of the lime.

### **2.8.4 Products of Pozzolanic Reaction**

For natural pozzolanas, there has been general consensus in the literature (Sersale, 1980), (Massazza, 1980), (Takemoto and Uchikawa, 1980) that the products of the lime- pozzolana reaction are as follows:

- (a) Calcium silicate hydrate of the form C-S-H,
- (b) Calcium aluminate hydrate of the form  $\text{C}_4\text{AH}_x$  with x varying from 9 to 13,
- (c) Hydrated gehlenite-  $\text{C}_2\text{ASH}_8$ ,
- (d) Calcium carboaluminate-  $\text{C}_4\text{A}.\text{CaCO}_3\text{H}_{12}$ ,
- (e) Ettringite-  $\text{C}_3\text{A}.\text{CaSO}_4.32\text{H}_2\text{O}$ ,
- (f) Calcium aluminate monosulphate-  $\text{C}_3\text{A}.\text{CaSO}_4.12\text{H}_2\text{O}$ .

However, the presence of these products in the hydrate products depends on the chemical constituents of the pozzolana, the availability of lime, the extent or age of the hydration reaction and conditions of ambience during hydration. In general, all products will not be present at the same time. For example, the monosulphate is usually only observed at the beginning of hydration and is only converted to ettringite later. Hydrated gehlenite is normally only observed with high alumina pozzolanas and reduces the amount of C-S-H present (Cook, 1986). The chemical composition of a pozzolana will only provide a rough guide to its reactivity. Chemical tests tend to indicate the presence of a pozzolanic reaction but not its magnitude. The best way to determine the reactivity of a pozzolana is to measure the compressive strength of a mortar cube made with a mixture of lime, sand, and the pozzolana to be tested. A simple test of this type is described in another leaflet in this series on testing and performance standards of pozzolanas.

#### **2.8.5 Artificial Pozzolanas**

Calcined soils in the form of crushed pottery fragments were the first artificial pozzolanas and have remained to this day as traditional materials in India and Egypt. It is recognized that the pozzolanicity of clay soils is by driving off the water molecules, which result in the formation of quasi- amorphous material. Calcination also develops pozzolanicity in shales and bauxitic and lateritic soils (Cook, 1986).

Pozzolanas produced by calcination modify the properties of lime and Portland cement mortars and concrete in a similar manner to natural pozzolanas. While they were used extensively in the United States up until the

mid sixties, nowadays other artificial pozzolanas, notably fly ash, are widely available. Commercial production appears to be limited to large mass concrete projects, through traditional manufacture in developing countries produces a pozzolana for a wide spectrum of users.

### **Effects of Calcination on Soils**

Calcined soils were the first artificial pozzolanas and have remained to this day as traditional materials in India and Egypt. Calcination also develops pozzolanicity in shales, bauxitic and lateritic soils (Cook, 1986).

Cook (1986) points out that the reactive components of calcined soils and shales are formed by driving off the water molecules. This process results in the formation of a collapsed quasi- amorphous material which is reactive with lime. The reactivity of the calcined soil or shale with lime depends on the quasi- amorphous nature of the collapsed structure. Hence an optimum calcination temperature for each soil or shale type; at temperatures beyond the optimum, recrystallization begins, while at temperatures below the optimum, the clay lattice structure is still intact.

Apart from the temperature of calcination, it is well established that the time at the calcination temperature also influences the reactivity of the pozzolana. It is apparent that prolonged exposure to temperatures above the dehydroxylation temperature promotes recrystallization and hence pozzolanic reactivity (Cook, 1986).

Results obtained by Forrester (1975) for an illitic clay put forward that the dehydroxylation temperature was 550°C; however the optimum temperature for



strength is 800°C. Forrester (1975) also found out that the optimum time of calcination at 800°C is 40 minutes.

Below are a few examples of some well known pozzolanas.

### **Fly ash**

A by product of coal fired electric generating plants, it is used to partially replace Portland cement (by up to 60% by mass). The properties of fly ash depend on the type of coal burnt. In general, silicious fly ash is pozzolanic, while calcareous fly ash has latent hydraulic properties (USFHA, 2007).

### **Granulated blast furnace slag(GGBFS or GGBS)**

A by product of steel production, is used to partially replace Portland cement (by up to 80% by mass). It has latent hydraulic properties (USFHA, 2007).

### **Silica fume**

A byproduct of the production of silicon and ferrosilicon alloys. Silica fume is similar to fly ash, but has a particle size 100 times smaller. This results in a higher surface to volume ratio and a much faster pozzolanic reaction. Silica fume is used to increase strength and durability of concrete, but generally requires the use of superplasticizers for workability (USFHA, 2007).

### **High reactivity metakaolin (HRM)**

Metakaolin produces concrete with strength and durability similar to concrete made with silica fume. While silica fume is usually dark gray or black in color, high reactivity metakaolin is usually bright white in color, making it the preferred choice for architectural concrete where appearance is important.

## 2.9 CONCRETE

Concrete is basically a mixture of cement, sand, and gravel, with water serving as a lubricant, which goes to form a solid mass on hardening.

Adams (1969) defined concrete as an artificial material similar in appearance and properties to some natural limestone rock formed by binding together particles of natural or artificial stone, brick, or other aggregate with cement.

While Nelson and Winter (1991) defined concrete as "... a stone like material obtained by permitting a carefully proportioned mixture of cement, gravel and sand or other aggregate, and water to harden in forms of the shape and dimension of the desired structure".

Meskvin (1980) defined concrete also as, "... a multi-component, man-made stone with properties acquired in the process of its making and hardening".

On the other hand, Tretyakov and Rozhnenko (1987) said, "concrete mix is a properly selected, homogeneous plastic mixture comprising a binder, aggregate water and optionally special, additions". The rigid moulded concrete mix is called concrete.

The desirability and suitability of concrete as a structural material as well as properties, usage and functions has given various reasons to bring it into focus. The bulk of the constituent materials of concrete is made up of fine and coarse aggregate which generally constitute about 70% of the total material used in the preparation of concrete when certain amount of cement and water interact chemically with the addition of aggregate to form a solid mass on

hardening, extra water, over and above that needed for hydration, acts as an extender of the cement paste, allowing it to coat the surface of all particles of aggregate and thereby to function as a lubricant, providing the workability necessary for handling and placing the mix.

To avoid excess water for workability, which is to form voids or pores thereby causing a reduction in density, strength and durability of concrete, water content of mixes should normally be kept as low as possible, consistent with providing adequate workability to allow placing and full compaction (Adams, 1969).

Concrete has a wide range of properties such as compressive and tensile strength, which can be achieved by appropriate adjustment of the proportion of the constituent materials (Fine and Coarse aggregate).

Generally, a good concrete needs to be hard, dense, strong, durable, non-porous, fire resisting and economical (Neville, 1961). The characteristics of concrete are influenced by the quality of its constituents materials, proportion, the grading of aggregate, amount of water used and workmanship (Orchard, 1979). For concrete to be of a good quality, the technical know-how is required since the material for making good or bad quantity concrete are the same and it is only the workmanship that distinguishes one from the other at no extra cost (Agor, 1997).

To enhance satisfactory state of concrete, the fresh concrete should be cohesive enough for the method of placing used not to produce segregation, with a consequent lack of homogeneity of the finished product and satisfactory compressive strength can be achieved at the hardened state.

### **2.9.1 Curing**

Because the cement requires time to fully hydrate before it acquires strength and hardness, concrete must be cured once it has been placed and achieved initial setting. Curing is the process of keeping concrete under a specific environmental condition until hydration is relatively complete. Good curing is typically considered to provide a moist environment and control temperature. A moist environment promotes hydration, since increased hydration lowers permeability and increases strength resulting in a higher quality material. Allowing the concrete surface to dry out excessively can result in tensile stresses, which the still-hydrating interior cannot withstand, causing the concrete to crack.

Also, the amount of heat generated by the exothermic chemical process of hydration can be problematic for very large placements. Allowing the concrete to freeze in cold climates before the curing is complete will interrupt the hydration process, reducing the concrete strength and leading to scaling and other damage or failure.

The effects of curing are primarily a function of geometry (the relation between exposed surface area and volume), the permeability of the concrete, curing time, and curing history.

Improper curing can lead to several serviceability problems including cracking, increased scaling, and reduced abrasion resistance (CONCRETE, 2007).

### **2.9.2 Shrinkage Cracking**

Shrinkage cracks occur when concrete members undergo restrained volumetric changes or shrinkage as a result of drying, autogenous shrinkage, or

thermal effects. Restraint is provided either externally (i.e. supports, walls, and other boundary conditions) or internally (differential drying shrinkage, reinforcement). Once the tensile strength of the concrete is exceeded, a crack will develop. The number and width of shrinkage cracks that develop are influenced by the amount of shrinkage that occurs, the amount of restraint present, and the amount and spacing of reinforcement provided.

Concrete is placed while in a wet (or plastic) state, and therefore can be manipulated and moulded as needed. Hydration and hardening of concrete during the first three days is critical. Abnormally fast drying and shrinkage due to factors such as evaporation from wind during placement may lead to increased tensile stresses at a time when it has not yet gained significant strength, resulting in greater shrinkage cracking (CONCRETE, 2007). The early strength of the concrete can be increased by keeping it damp for a longer period during the curing process. Minimizing stress prior to curing minimizes cracking. High early-strength concrete is designed to hydrate faster, often by increased use of cement, which increases shrinkage and cracking.

Plastic-shrinkage cracks are immediately apparent, visible within 0 to 2 days of placement, while drying-shrinkage cracks develop over time. Precautions such as mixture selection and joint spacing can be taken to encourage cracks to occur within an aesthetic joint instead of randomly.

### **2.9.3 Workability**

Workability is the ability of a fresh (plastic) concrete mix to fill the form/mold properly with the desired work or vibration and without reducing the

concrete's quality. Workability depends on water content, aggregate (shape and size distribution), cementitious content and age which implies level of hydration, and can be modified by adding chemical admixtures. Raising the water content or adding chemical admixtures will increase concrete workability. Excessive water will lead to increased bleeding-production of surface water and/or segregation of aggregates, with the resulting concrete having reduced quality. The use of an aggregate with an undesirable gradation can result in a very harsh mix design with a very low slump, which cannot be readily made more workable by addition of reasonable amounts of water (Wikipedia, 2007).

A concrete is said to be workable when the strength of concrete of a given mix proportion is very seriously affected by the degree of its compaction such that the consistence of the concrete mix can be transported, placed and finished sufficiently easily and without segregation.

Neville (1981) said that the process consists essentially of the elimination of entrapped air from the concrete until it has achieved, as close a configuration as is possible for a given mix.

Adams (1969) put forward an alternative definition of workability as the "ease with which concrete can be placed and compacted".

Troxell et al (1968) defined workability in a traditional way as a composite quality, as involving ease of placement and resistance to segregation.

Glanville, Collins, and Mathew (1947) in Agor (1997) put forward an alternative definition of workability as the amount of useful internal work necessary to produce full compaction. Neville and Brooks (1987) agree with this definition as they continue that, workability in any particular case would

depend on the means of compaction available and the amount of useful internal work necessary to produce full compaction, like-wise a workability suitable for mass concrete is not necessarily sufficient for inaccessible, or heavily reinforced sections. Thus the work done is used to overcome the friction between the individual particles in the concrete and also between the concrete and the surface of the mould or the reinforcement referred to as the internal friction and surface friction respectively (Agor, 1997).

Glanville, et al (1947) referred to the part of the energy used in vibrating the mould or in shock and indeed in shaking parts of the concrete which have already been fully consolidated as the wasted work done since only the internal friction is an intrinsic property of the mix.

Numerous attempts have been made to correlate workability with some easily determinable physical measurement, but according to Neville (1981) there is no acceptable test that will measure workability directly as defined above, because none of the test is fully satisfactory although they may provide useful information within a range of variation in workability. Some of the test conducted on workability include, the compacting factor test, slump test, vebe test, flow test, remembering test, ball penetration test and Nasser's K-probe test etc.

Nevertheless Neville (1981) claims that the probe test appears to be related to slump test.

Neville (1981) gave value of 25-50mm and 0.85, 50-100mm and 0.92, and 100-175mm and 0.95 for slump and compacting factors respectively for low, medium and high degree of workability for normal weight aggregate. Ikpong (1989), obtained values of slump test ranging between 54mm and

85mm, and compacting factor, ranging between 0.87 and 0.93 in his research on the use of rice Husk Ash for medium workability.

The workability of a concrete mix depends on many factors such as: the amount of cement; the fineness of cement and its chemical composition, the amount of water; the grading and shape of the fine aggregate, the grading, shape and surface texture of the coarse aggregate; the ratio of fine to coarse aggregate; and the presence or absence of entrained air or other admixtures (Orchard, 1979).

Apart from the above factors, it is also necessary to mention the effect of time and temperature on workability. Fresh mix concrete stiffens with time since some of the free water content is absorbed by the aggregate, and if the concrete is exposed to air, wind or sun, some water may evaporate (Neville, 1981). Also with time, the hydration of cement hardens concrete thereby reducing workability (Kong and Evans, 1986).

#### **2.9.4 Specific Gravity**

The specific gravity, sometimes called the relative density test is normally based on the density of the specimen. Neville (1981) defined specific gravity as the ratio of the weight of the solid (vacuum), to the weight of an equal volume of gas-free distilled water at a stated temperature. He stated further that if the volume of the solid is deemed to include the impermeable pore excluding the capillary ones, the resulting specific gravity is prefixed by the word apparent. He (Neville) therefore defined the apparent specific gravity as the ratio of the mass of the aggregate dried in an oven at 100-110<sup>0</sup>c (212-230<sup>0</sup>F) for 24 hours, to the mass of water occupying a volume equal to that of the solid including the



impermeable pores. The specific gravity is used to determine the type of weight of the aggregates.

The classification is necessary in order to get high quality of concrete or other wet process mix for construction work. The higher the density, the higher the average specific gravity. Broadly speaking, for any given type of aggregate, high density in concrete is associated with high strength, hardness, durability, imperviousness, and thermal conductivity (Orchard, 1979). The absolute specific gravity is not normally required and rather difficult to determine. It is the apparent specific gravity that is most easily and frequently determined and is necessary for calculations of yield of concrete or of the quantity of aggregate required for a given volume of concrete. The apparent specific gravity of the minerals of which the aggregate is composed, and on the amount of voids. The values of the specific gravity vary and the limit of the majority of the naturally occurring aggregate have a specific gravity of between 2.6 and 2.7 (Neville 1981). The lesser the specific gravity, the greater the voids of the aggregate Murdock (1979). The sample within this limit is classified as normal weight aggregate, below the limit; the sample is termed as lightweight aggregate, while above this 2.7 normally referred to as heavy weight aggregate.

The specific gravity is normally determined at saturated surface dry condition and calculated as;

$$GS = \frac{W_2 - W_1}{W_5 - W_1 - W_4}$$

Where:

G <sub>s</sub>	=	Specific gravity
W <sub>1</sub>	=	Weight of cylinder
W <sub>2</sub>	=	Weight of cylinder + aggregate
W <sub>3</sub>	=	Weight of cylinder + aggregate + water to 1.0 litre mark
W <sub>4</sub>	=	(W <sub>3</sub> – W <sub>2</sub> ) weight of water to 1.0 litre mark
W <sub>5</sub>	=	Weight of cylinder + water to 1.0 litre mark

### **2.9.5 Bulk Density**

When aggregate is to be batched by volume it is necessary to know the weight of aggregate that would fill a container of unit volume. This is termed as the bulk density of aggregate and this density is used to convert quantities by weight to quantities by volume (Neville 1981). Bulk density depends on how densely the aggregate is packed. It therefore follows that for a material of a given specific gravity, the bulk density depends on the size distribution and shape of the particles and also on the actual compact achieved that determine the potential degree of packing. BS 812: Part 2: 1975 recognizes two degrees of bulk density as loose (uncompacted) and compacted, and the degree of compaction has to be specified for test purpose. The values of the bulk density depend on how loose or compacted is the aggregate. The ratio of the loose bulk density to the compacted bulk density usually lies between 0.87 and 0.96 (Neville, 1981).

### **2.9.6 Compressive Strength**

Concrete has relatively high compressive strength, but significantly lower tensile strength- about 10% of the compressive strength (Concrete, 2005). As a result, concrete always fails from tensile stresses even when loaded in

compression. The practical implication of this is that concrete elements subjected to tensile stresses must be reinforced. Concrete is most often constructed with the addition of steel or fiber reinforcement. The reinforcement can be by bars (rebar), mesh, or fibers, producing reinforced concrete. Concrete can also be prestressed (reducing tensile stress) using internal steel cables (tendons), allowing for beams or slabs with a longer span than is practical with reinforced concrete alone. Inspection of concrete structures must non-destructive, so equipment such as a Schmidt hammer is used to estimate concrete strength.

Strength can be defined as the maximum stress sustained by the test specimen, that is the maximum load registered on the testing machine ( $P_{max}$ ), divided by the cross-sectional area ( $A$ ) of the specimen (Soroka, 1979). The compressive strength of concrete is one of the most important properties in such a way that concrete structures are designed under an assumption that the concrete resists compressive stresses but not tensile stresses; hence for the purposes of structural design, the compressive stress is the criterion of quality (Kong and Evans 1986).

The compressive strength of concrete is usually determined by using cubes and cylinders. The test results however, depend on the specific test conditions such as specimen shape and dimensions, rate of loading etc. Different results may be obtained with the same concrete because of the differences employed.

Neville (1981) shows that the type of aggregate used in casting concrete are shown to have some effects on its compressive strength. Kaplan and Jones

(1960) in Agor (1997) indicated that the mechanical interlocking of the coarse aggregate contributes to the strength of concrete in compression.

Stock (1979) in the studies on the influence of aggregate content on the strength of concrete with a given quality of cement paste indicated that when a volume of aggregate (as a percentage of the total volume) is increased from 0-20%, there is a gradual decrease in compressive strength, but between 40 – 80% there is an increase.

According to Kong and Evans (1986), the compressive strength of concrete is the most common measure for judging the quality of concrete. Concrete mixes are therefore designed to provide a mean compressive strength at 28 days after mixing, which will provide an adequate margin over the characteristic or the minimum strength to satisfy the designer Murdock (1979).

The ultimate strength of concrete is influenced by the water-cement ratio ( $w/c$ ) [water-cementitious materials ratio ( $w/cm$ )], the design constituents, and the mixing, placement and curing methods employed. All things being equal, concrete with a lower water-cement (cementitious) ratio makes a stronger concrete than a higher ratio. The total quantity of cementitious materials (Portland cement, slag cement, pozzolans) can affect strength, water demand, shrinkage, abrasion resistance and density. As concrete is a liquid which hydrates to a solid, plastic shrinkage cracks can occur soon after placement; but if the evaporation rate is high, they often can occur during finishing operations (for example in hot weather or a breezy day).

## CHATER THREE

### MATERIALS AND METHODS

#### 3.1 MATERIALS

Concrete is composed mainly of three materials, cement aggregates, and water. A material like earthworm cast was added to modify some of its properties such as strength. It was also introduced to replace some quantities of cement so that high cost of cement which gives rise to high cost of building projects can be reduced.

##### **3.1.1 Cement**

Cement has important property that when mixed with water, a chemical reaction (hydration) takes place, which with time produces a very hard and strong binding medium for the aggregate particles (Neville 1981).

The cement type used in the research was Ashaka brand of ordinary Portland cement (OPC) manufactured by the Ashaka cement Plc Gombe in Nigeria.

##### **3.1.2 Fine Aggregates**

The fine aggregate used is natural burrow pit sharp sand which was stored outdoors of the building laboratory of the department. The sand was air dried in the laboratory. The sand was sieved in order to remove both those particles passing a 600 microns sieve and those retained on a 4.75mm sieve. A sieve analysis of the sand sample was undertaken using standard sieves manufactured in conformance with BS 812 part 1: 1975.

### **3.1.3 Coarse Aggregates**

The coarse aggregates used in the concrete mixes is crushed rock (granite) which was stock piled in the open air. It was assumed to be moisture free since it was in the dry season and the aggregates were exposed to the open air.

### **3.1.4 Calcined Earthworm Cast**

It is composed of mainly clay materials and very fine sand as well as little humus. The earthworm cast used for this research work was collected from Giring village, Abattoir, Jos. They were collected in lumps and in dry form. The earthworm-cast was first of all grinded. Earthworm casts was sieved through B.S sieve size 75 microns to get the size corresponding to that of cement. The grinded earthworm cast was then subjected to a temperature of 850 degrees Celsius in a furnace at the Nigerian Metallurgical Development Centre in Jos.

### **3.1.5 Water**

The water used for all the mixing and curing purposes in this research work was portable drinking water obtained from the public supply system. It is meant to be deemed fit for human consumption.

Water used in concrete, in addition to reacting with cement and thus causing it to set and harden, also facilitate mixing, placing, and compacting of the fresh concrete (Adams 1969). In general, water fit for drinking, such as tap water is acceptable for mixing concrete. The impurities that are likely to have adverse effect when presenting appreciable quantities include silts, clay, acids, alkalis and other salts, organic matter and sewage.

## **3.2 METHODS**

### **3.2.1 Chemical Analysis of Calcined Earthworm Cast**

Samples of raw earthworm cast and calcined earthworm cast were taken and analyzed chemically. The various chemical compounds were determined according to their percentage presence.

### **3.2.2 Sieve Analysis**

Sieve analysis is the grading of aggregate into fractions each containing particles of the same sieve size (Neville, 1981). The aggregate grading is known to have a major effect upon the physical characteristics of concrete (Neville, 1981). It defines the proportions of particles of different size in the aggregate. The grading of an aggregate can have a considerable effect on the workability of a concrete mix and is one of the most important factors in concrete mix design.

The grading of the aggregates and earthworm cast were determined using standard BS sieve sizes by the procedure specified in BS 812 (1971), BS 812:part 1: 1975, BS 82: 1973, BS 3681: Part 2: 1973 and ASTM C 136-92. The apparatus normally used for this procedure include, series of sieves arranged in descending order, mechanical shaker, scoop, weighing balance, and a stopwatch. The sieve analysis results for fine and coarse aggregates are presented in the next chapter.

### **3.2.3 Specific Gravity Test**

The specific gravity of a substance is regarded as the ratio of the weight of a given volume of that substance to the weight of an equal volume of water. This equal volume of water can easily be determined from the volume of water displaced by that substance when it is immersed in water. The apparatus used include; density bottle, pycnometre, weighing scale, scoop, measuring cylinder, cloth for drying. This test procedure was carried out in accordance to BS 812: 1975.

The specific gravity test was carried out on the calcined earthworm cast; fine and coarse aggregates and the values of the respective specific gravities are given in the next chapter.

### **3.2.4 Bulk Density Test**

The bulk density of a material is the weight a material held by a container of unit volume when filled under predefined conditions. The bulk density of a substance is affected by factors such as the amount of compaction effort used in filling the container and the amount of, moisture present (Neville, 1980). The apparatus usually adopted for this procedure include; Weighing balance, rod of 16mm round diameter, a cylinder of known volume, weights, scoop, and straight edge. The test was carried out in accordance with the specification set out by BS 812: 1975. the values of the calculated bulk densities of calcined earthworm cast, fine aggregates and coarse aggregates are presented in the next chapter.



### **3.2.5 Setting Time and Consistency Test**

The standard consistency required by ASTM C 191-92 and BS 12 for determining the initial and final setting time of ordinary Portland cement is obtained by mixing the cement with water of about 30% weight of the cement provided. If the consistency is not satisfactory, the water percentage is then increased or decreased in order for the mixture to arrive at the required consistency.

Setting time is the name given to the initial stiffening of the cement paste when hydration by water begins. The setting time test assists in determining the length of time it takes concrete to set in practice and the setting tests was conducted for the various percentages of modifications of 0, 10, 20, 30 and 40 percent. Two setting times are measured, the initial and final setting time.

Paste of standard consistency is required to meet two conditions of hydration in that the initial setting time should not be too long or too short and the final setting time should allow for placing and compaction. BS 12 limits the initial setting time to be not less than 45 minutes, while the final setting time should not exceed 10 hours. The basic apparatus for this test is the vicat's apparatus

### **3.3 MIX DESIGN**

Mix design is the process of selecting suitable materials of concrete and determining their relative quantities. This is done for the purpose of producing an economic concrete which has minimum properties, notably workability, strength, and durability (Neville, 1981). For ease of reference, the process of

mix design is divided in to five stages with each stage dealing with a particular parameter.

**Table 3.1 Summary of the Quantity of Materials Used By Weight**

S.No.	Percentage Replacement	Cement (Kg)	Calcined Earthworm cast (Kg)	Fine Aggregate s(Kg)	Coarse Aggregates (Kg)	Water (Kg)
1	0	11.34	0.00	22.48	57.92	6.89
2	10	10.21	1.13	22.48	57.92	6.89
3	20	9.07	2.27	22.48	57.92	6.89
4	30	7.94	3.40	22.48	57.92	6.89
5	40	6.80	4.54	22.48	57.92	6.89

### **3.3.1 Workability Test**

Workability is strictly defined as the amount of useful internal work necessary to produce full compaction. Workability tests were carried out to ensure that the concrete used in casting cubes was of adequate quality. The workability tests carried out were the slump and the compacting factor test.

### **3.3.2 Slump Test**

Slump test was carried out for the various percentage replacement levels of cement with calcined earthworm cast. That is at 0%, 10%, 20%, 30%, and 40% respectively. The test was carried out in accordance to the stipulations of the BS 1881: part 102:1983 and ASTM C 143-90a.

### **3.3.4 Compacting Factor Test**

The compacting factor test was carried out to measure the degree of compaction for a standard amount of work and therefore offer a direct and reliable assessment of the workability of the concrete (Neville, 1981)

The compacting factor test was carried out for the respective percentage replacement of cement with calcined earthworm cast that is for 0, 10, 20, 30, and 40 % partial replacement. The test was carried out in accordance with BS 1881: part 103: 1983 and ASTM C 143-90a.

### **3.3.5 Casting and Curing of Cubes**

After the workability test, cubes were cast in moulds of 150 x 150 x 150mm moulds. The cubes were vibrated mechanically to reduce the presence of voids. After a period of 24 hours, the moulds were dismantled and the cubes were placed in a curing tank. The curing duration was 7, 14 and 28 days respectively. The casting and curing was done in accordance with the BS 1881: part 108: 1983, part 111: 1983, and ASTM C 192-90a.

### **3.3.6 Compressive Strength Test**

Compressive strength is the maximum stress sustained by the specimen, that is the maximum load registered on the testing machine divided by the cross sectional area of the specimen (Soroka, 1979).

The cubes were tested at 7, 14 and 28 days of hydration period for compressive strength.

The compressive strength test was carried out in the laboratory of the Building department, University of Jos, in the Universal compressive testing machine.

For each of the partial replacements, four cubes were crushed for each hydration period. This provided a reliable average value. The point of failure for each cube was recorded in (KN). The average of failure load from the four cubes for each mix was used in estimating the compressive strength of the concrete for the category of mix proportion.

The compressive strength of concrete is a very important factor, which determines the overall quality of concrete. The procedure for testing and crushing were carried out in accordance with the BS 1881: part 114: 1983 and BS 1881: part 116.

## CHAPTER FOUR

### PRESENTATION OF RESULTS AND DISCUSSION

#### 4.1 PHYSICAL PROPERTIES OF CALCINED EARTHWORM CAST

The earthworm cast used for this research work was collected, grinded and then calcined at the temperature of 850<sup>0</sup> Celsius. In order to ascertain the suitability of the calcined cast, tests namely; specific gravity, and bulk density tests were carried out and the results are presented and discussed in tables 4.1 and 4.2 respectively.

**Table 4.1 Specific gravity of Calcined Earthworm cast**

WEIGHT	TEST 1	TEST 2
Pycnometer w1	36.00	36.00
Pycnometer + sand w2	65.04	73.54
Pycnometer + sand + water w3	151.51	156.67
Pycnometer + water (full) w4	134.77	134.77
Weight of water (w4 – w1)	98.77	98.77
Weight of water added to aggregate (w3 – w2)	86.47	83.13
Weight of sand (w2 – w1)	29.04	37.54
Weight of water displaced by sand (w4 – w1) – (w3 – w2) = w	12.31	15.64
Specific gravities of sand (w2 - w1) / w	2.36	2.40

Average specific gravity of Calcined Earthworm cast = 2.38

From table 4.1, it can be observed that the specific gravity of the calcined earthworm cast that was calculated to be 2.38 falls within the range that has been provided in ASTM C618 – 78 for pozzolanas (between 2.1 and 2.4).

**Table 4.2 Bulk Density of Calcined Earthworm Cast (CEWC)**

Weight of cylinder w1	4.60
Weight of cylinder + water w2	11.40
Weight of uncompacted CEWC + cylinder w3	12.40
Weight of compacted CEWC + cylinder w4	13.40
Weight of uncompacted CEWC (w3 – w1)	7.80
Weight of compacted CEWC (w4 – w1)	8.80
Volume of water (v) = (w2 – w1) /1000	0.0068
Density of uncompacted CEWC = (w3 – w1)/ v	1147
Density of compacted CEWC = (w4 – w1)/ v	1294

Calcined earthworm cast has a bulk density of 1294 when compacted and 1147 when loose or uncompacted. This produces a ratio of 0.89 this places it in the region of a non lightweight material as specified by Neville (1981). Vivian (1950) in Neville (1981) stipulated that the range for non lightweight material is from 0.87 to 0.96

## 4.2 CHEMICAL PROPERTIES OF CALCINED EARTHWORM CAST

Samples of both raw and calcined earthworm cast were taken and analyzed at the chemical laboratories of the Nigerian Metallurgical Development Centre, Jos. the results are presented in table 4 .3

**Table 4.3 Result of the chemical analysis of Earthworm cast**

TYPICAL OXIDE COMPOSITION	PERCENTAGE (WEIGHT) COMPOSITION	
	RAW EARTHWORM CAST	CALCINED EARTHWORM CAST
CaO	1.51	1.60
SiO <sub>2</sub>	60.08	58.86
Al <sub>2</sub> O <sub>3</sub>	17.88	18.98
Fe <sub>2</sub> O <sub>3</sub>	7.8	8.82
MgO	0.11	0.17
SO <sub>3</sub>	0.26	-
K <sub>2</sub> O	6.00	5.10
Na <sub>2</sub> O	0.06	0.10
MnO	0.10	0.16
ZnO	0.08	0.05
BaO	0.05	0.10
CuO	0.04	-
Loss of Ignition	-	6.06

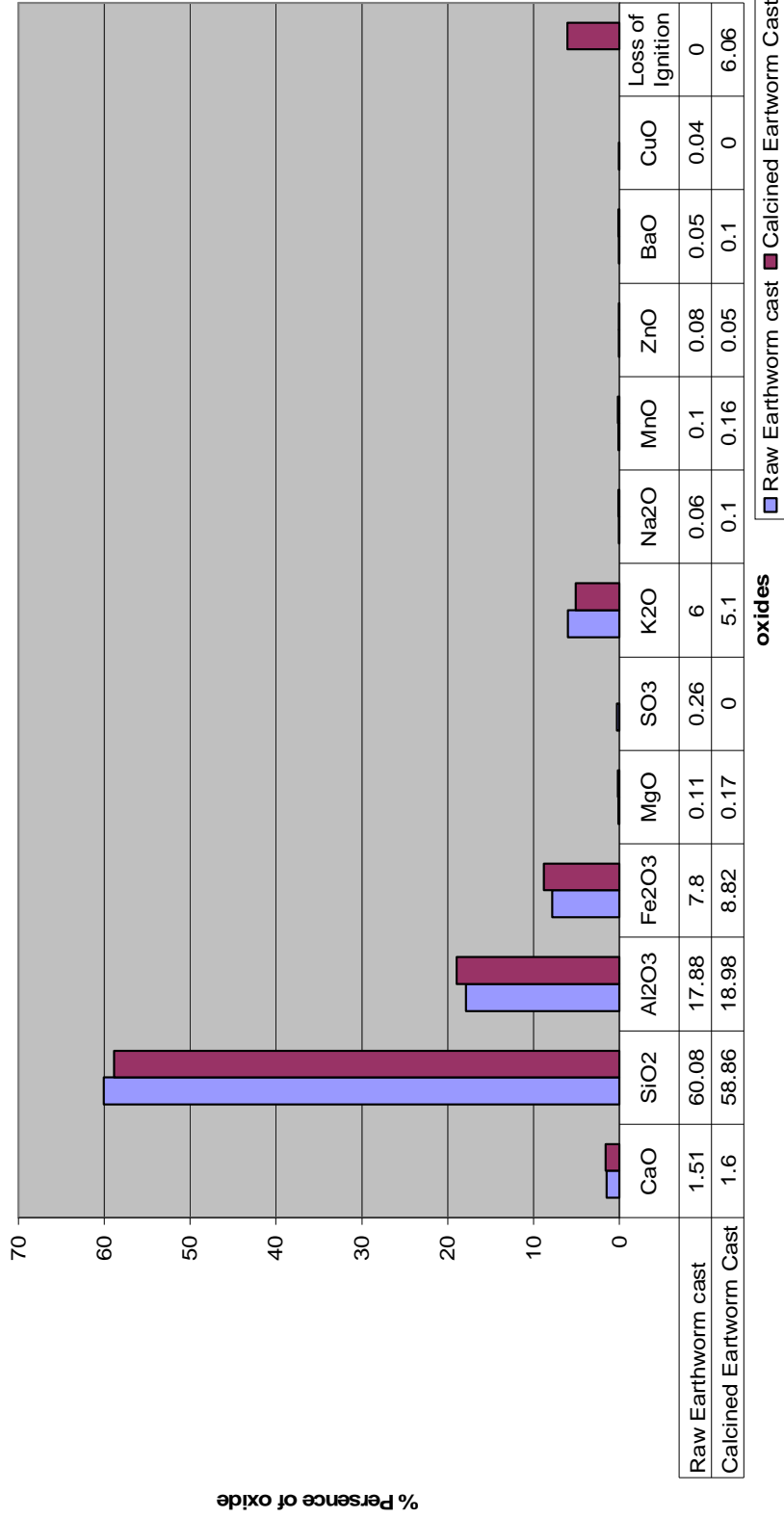


fig 4.1 Chemical Properties of Earthworm Cast ( Raw and Calcined)



**Table 4.4 Approximate composition limits of Portland cement**

Oxide	Percentage present
CaO	60 – 67
SiO <sub>2</sub>	17 – 25
Al <sub>2</sub> O <sub>3</sub>	3 – 8
Fe <sub>2</sub> O <sub>3</sub>	0.5 – 6.0
SO <sub>3</sub>	1 – 3
Na <sub>2</sub> O	0.5 – 1.3
K <sub>2</sub> O	0
Other Alkalis	0.2 – 1.3

\*(Neville and Brooks, 1987)

Table 4.3 and figure 4.1 shows that the highest constituent of the Earthworm cast both raw and calcined are 60.08% and 58.86% respectively for SiO<sub>2</sub>. It may be reasoned that the heat the raw sample was subjected to might have resulted in the loss of 1.22%.

A comparative examination of the chemical constituents of raw earthworm cast and calcined earthworm cast indicate a slight change that takes place as a result of the calcination. From figure 4.1 and table 4.4, it is seen that the compound with highest percentage is SiO<sub>2</sub> which is 58.86%. This is greater than the range in Ordinary Portland cement (between 17% – 25%), while the percentage for CaO is far lower than in both calcined and raw Earthworm cast.

The calcium content of the calcined earthworm cast which is 1.60% is less than that present in Ordinary Portland Cement (between 60% – 67%). Calcium oxide, which is a major constituent of Ordinary Portland cement, is responsible for the high rate of hydration. This explains the reason for the increase in the setting time of cement paste mixed with calcined earthworm cast.

The combined  $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$  (silicon dioxide, aluminum oxide, and iron oxide content) is 86.66 % ( see table 4.3). This meets the specifications for pozzolanas as provided in ASTM C618 – 84 (70% minimum requirement). The absence of  $\text{SO}_3$  indicates that there is no likelihood of sulphate attack on reinforcements. The Sodium oxide ( $\text{Na}_2\text{O}$ ) content in Calcined earthworm cast at 0.10% is lower than the range present in cement which is between 0.5 – 1.3. This low value is indicative that there will be very low salt content in the concrete. The oxide, Potassium oxide ( $\text{K}_2\text{O}$ ), is present in a very high percentage, 5.10% as opposed to its absence in ordinary Portland cement. This could increase the risk of failure in concrete elements due to alkali- aggregate activity. Magnesium oxide at 0.17 % is within the range of 0.1 – 5.5 in OPC. Although high MgO content can lead to unsoundness in concrete, that risk is reduced in this case. The loss of ignition was 6.06%. According to BS 3982: part 1: 1982, it is specified the loss of ignition should not be 7%. This means that the Loss of ignition in the calcined earthworm cast is within range.

### 4.3 AGGREGATES

#### 4.3.1 Grading of Aggregates

From the sieve analysis results, it will be easy to ascertain if the aggregates are well graded or not. Grading of soil is the distribution of particles of different sizes in a soil mass. This is determined from the particle size distribution curve (Arora, 2003).

**Table 4.5 Sieve analysis for fine aggregates**

SIEVE SIZE	WEIGHT RETAINED (g)	PERCENTAGE RETAINED (%)	CUMULATIVE PERCENTAGE RETAINED (%)	PERCENTAGE PASSING (%)
4.75mm	0	0	0	100
2.36mm	141.11	14.11	14.11	85.89
1.18mm	408.66	40.87	54.98	45.02
600µm	290.24	29.02	84.00	16.00
300µm	131.24	13.12	97.12	2.88
150µm	26.65	2.67	99.79	0.21
75µm	2.10	0.21	100	0
Pan	-	0	-	0

**Table 4.6 Sieve analysis for coarse aggregates**

SIEVE SIZE	WEIGHT RETAINED (g)	PERCENTAGE RETAINED (%)	CUMULATIVE PERCENTAGE RETAINED (%)	PERCENTAGE PASSING (%)
25.00	0	0	0	100
mm	99.85	9.99	9.99	90.01
20.00	603.80	60.38	70.37	29.63
mm	191.85	19.19	89.56	10.44
13.20	72.75	7.28	96.84	3.16
mm	31.75	3.18	100	-
10.00				
mm				
4.75m				
m				
Pan				

The result of the sieve analysis was used to produce a grading curve that gives a clear indication of the size distribution and relative percentages of the particles of the aggregate. From the grading curve drawn from the values of the sieve analysis, it can be observed that the grading for the fine aggregates used fall within the boundaries set out by ASTM C33-78.

The coarse aggregate grading similar to the fine aggregate was within range of the parameters set out by BS 882: 1992 the stone samples corresponded to requirements of the nominal size of graded aggregate to size

20mm. It is important to note that any aggregate meeting the criteria set by the British standard may be suitable for use in concrete production. The grading curves for the fine and coarse aggregates are presented in figs 4.2 and 4.3 respectively.

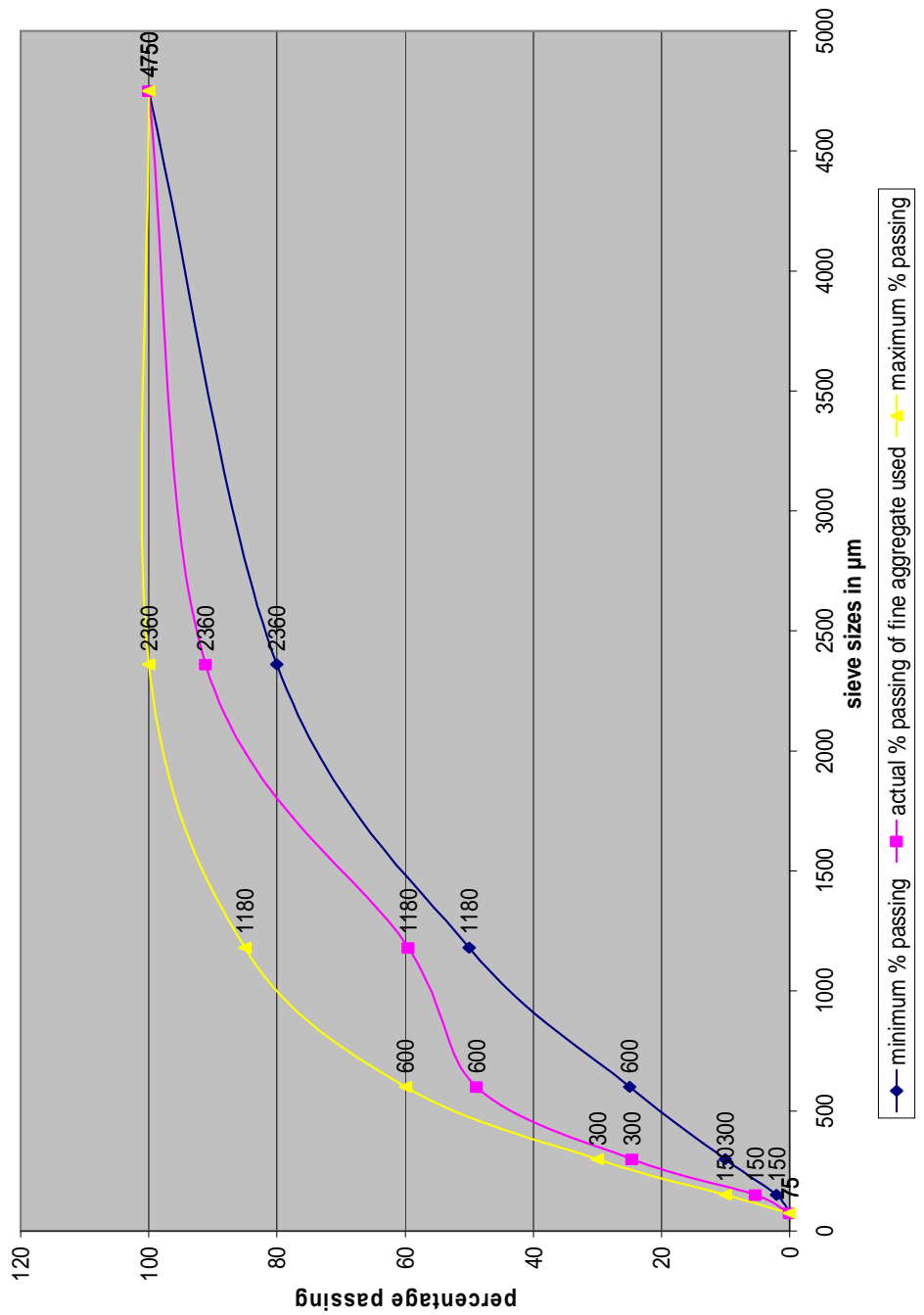


Fig. 4.2 Grading Curve According to ASTM C33-78

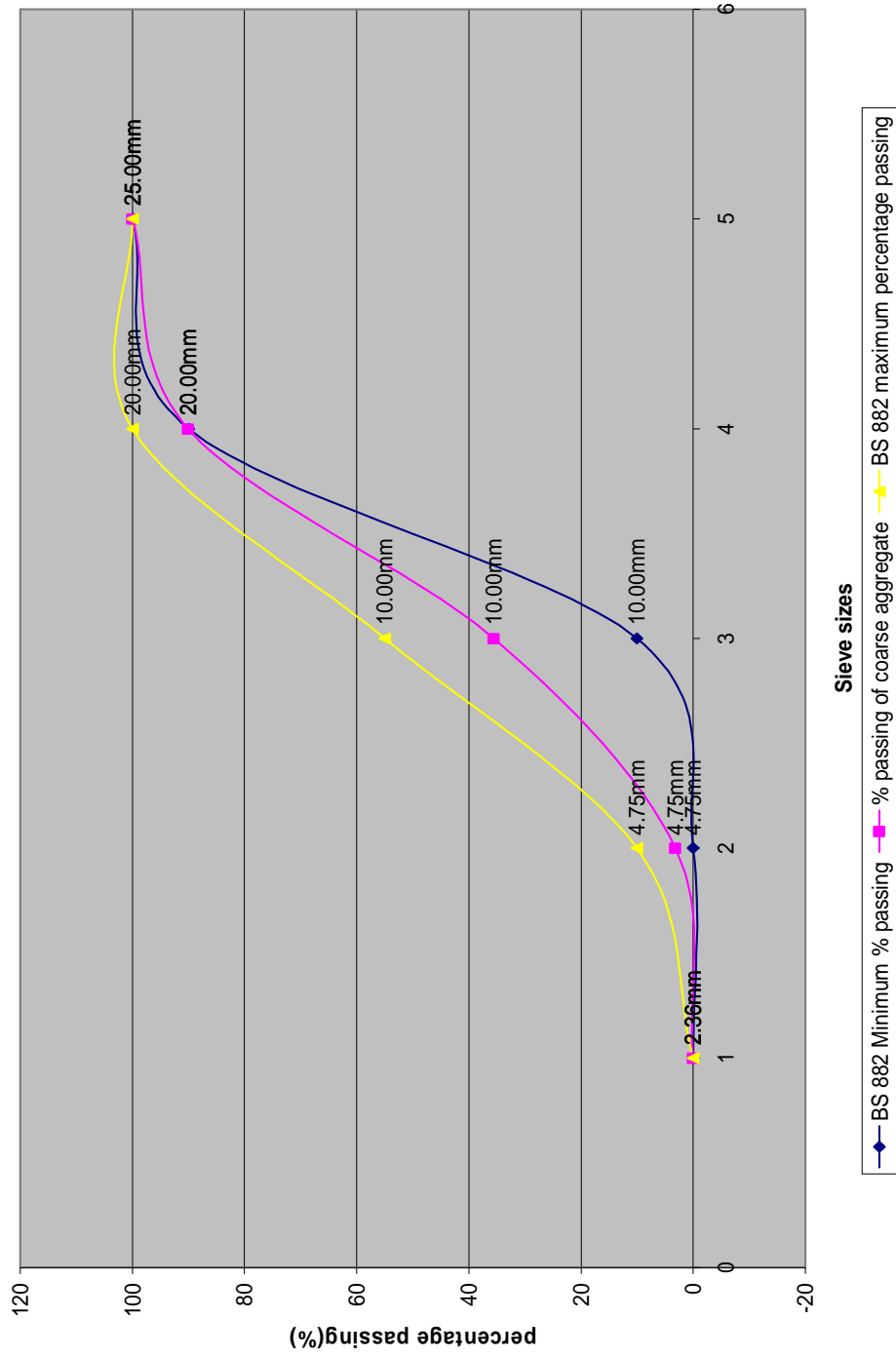


Fig. 4.3 Grading curve according to BS882: 1992

### **4.3.2 Specific Gravity**

The results for the specific gravity test on the aggregates are shown in tables 4.7 and 4.8 the specific gravities of the fine and coarse aggregates were found to be 2.68 and 2.66 respectively which fall within the range provided by Neville (1981). Neville (1981) points to the fact that majority of natural aggregates have a specific gravity that fall between 2.67 and 2.70.

**Table 4.7 Specific Gravity of fine Aggregates**

WEIGHT	TEST	TEST 2
	1	

Pycnometer w1		36.00	36.00	A
Pycnometer + sand w2		84.58	95.50	ver
Pycnometer + sand + water w3		165.2	171.98	age
Pycnometer + water (full) w4	2		134.77	spe
Weight of water (w4 – w1)		134.7	98.77	cifi
Weight of water added to aggregate (w3 – w2)	7		76.48	c
		98.77	59.50	gra
Weight of sand (w2 – w1)		80.64		vity
Weight of water displaced by sand		48.58	22.29	of
$(w4 - w1) - (w3 - w2) = w$			2.67	fine
Specific gravities of sand $(w2 - w1) / w$		18.13		agg
		2.68		reg
				ate

= 2.68

**Table 4.8 Specific gravity of coarse aggregates**

WEIGHT	TEST	
	1	2



Pycnometer w1	600	600
Pycnometer + aggregate w2	1100	1100
Pycnometer + aggregate + water w3	1832	2060
Pycnometer + water (full) w4	1500	1500
Weight of water (w4 – w1)	900	900
Weight of water added to aggregate (w3 – w2)	700	560
Weight of aggregate (w2 – w1)	532	900
Weight of water displaced by aggregate	200	340
$(w4 - w1) - (w3 - w2) = w$	2.66	2.65
Specific gravities of aggregate $(w2 - w1) / w$		

Average specific gravity of coarse aggregate = 2.66

#### **4.3.3 Bulk Density**

Tables 4.9 And 4.10 display the result of the bulk density of the aggregates used in this research.

#### **Table 4.9 Bulk density of fine aggregate**

Weight of cylinder w1	4.6 0
Weight of cylinder + water w2	11. 40
Weight of uncompacted fine aggregate + cylinder w3	14. 60
Weight of compacted fine aggregate + cylinder w4	15. 75
Weight of uncompacted fine aggregate (w3 – w1)	10. 00
Weight of compacted fine aggregate (w4 – w1)	11. 15
Volume of water (v) = (w2 – w1) /1000	0.0 068
Density of uncompacted fine aggregate = (w3 – w1)/ v	147 0
Density of compacted fine aggregate = (w4 – w1)/ v	163 9

**Table 4.10 Bulk density of coarse aggregate**

Weight of cylinder w1	4.6
	0
Weight of cylinder + water w2	11.
	40
Weight of uncompacted coarse aggregate + cylinder w3	13.
	75
Weight of compacted coarse aggregate + cylinder w4	14.
	45
Weight of uncompacted coarse aggregate (w3 – w1)	9.1
	5
Weight of compacted coarse aggregate (w4 – w1)	9.8
	5
Volume of water (v) = (w2 – w1) /1000	0.0
	068
Density of uncompacted coarse aggregate = (w3 – w1)/ v	134
	6
Density of compacted coarse aggregate = (w4 – w1)/ v	144
	9

The ratios of the loosed densities to the compacted density are as follows.

Fine aggregates:

$$\frac{1470}{1639} = 0.90$$

Coarse aggregates:

$$\frac{1346}{1449} = 0.93$$

The ratios of loose density to the compacted density for fine and coarse aggregates are 0.90 and 0.93 respectively which agree with the stipulated range of 0.87 and 0.96 by Vivian (1950) in Neville (1981).

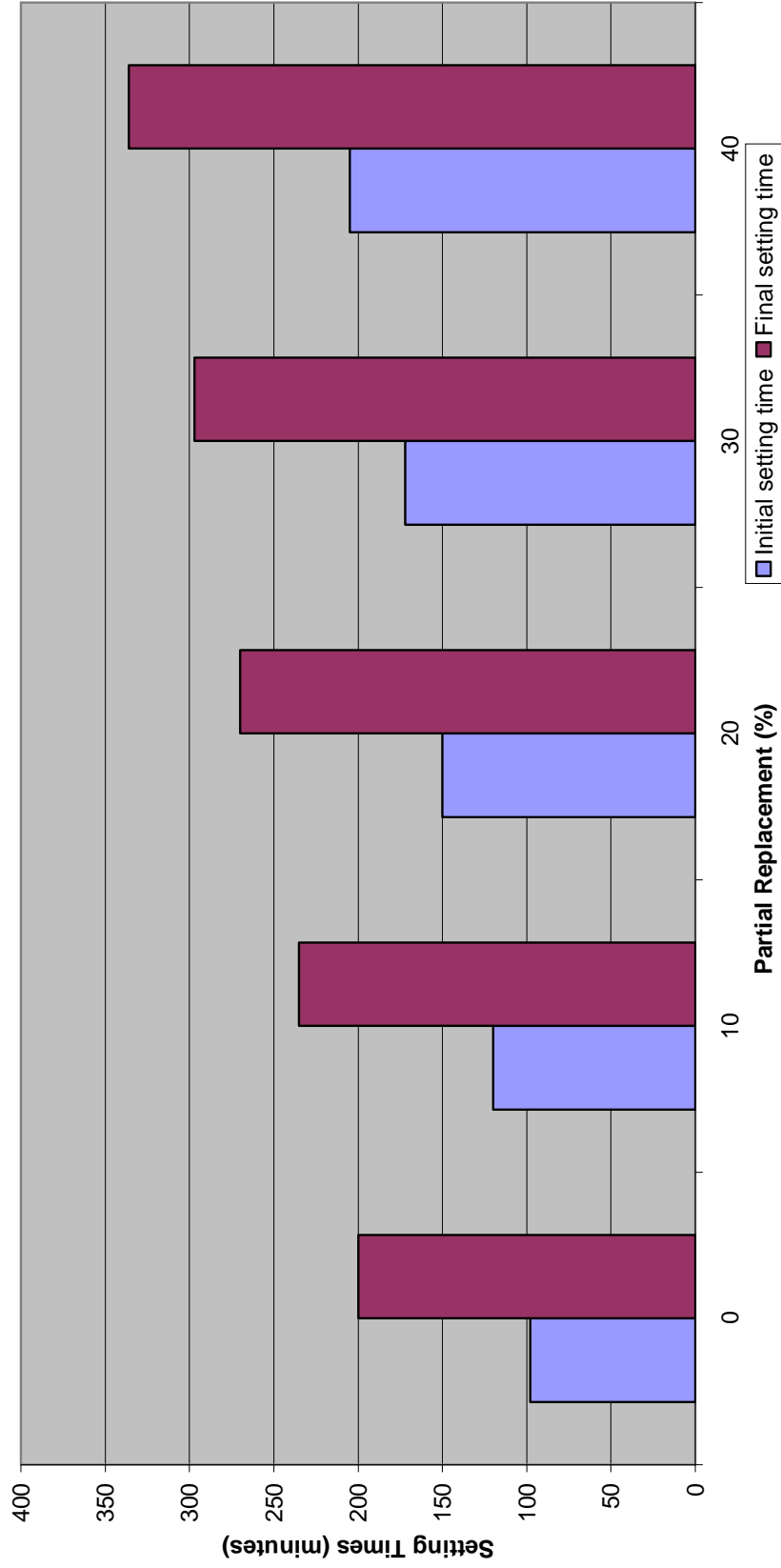
#### 4.4 SETTING TIME

The initial and final setting time was determined for each percentage replacement. The results are shown in table 4.3

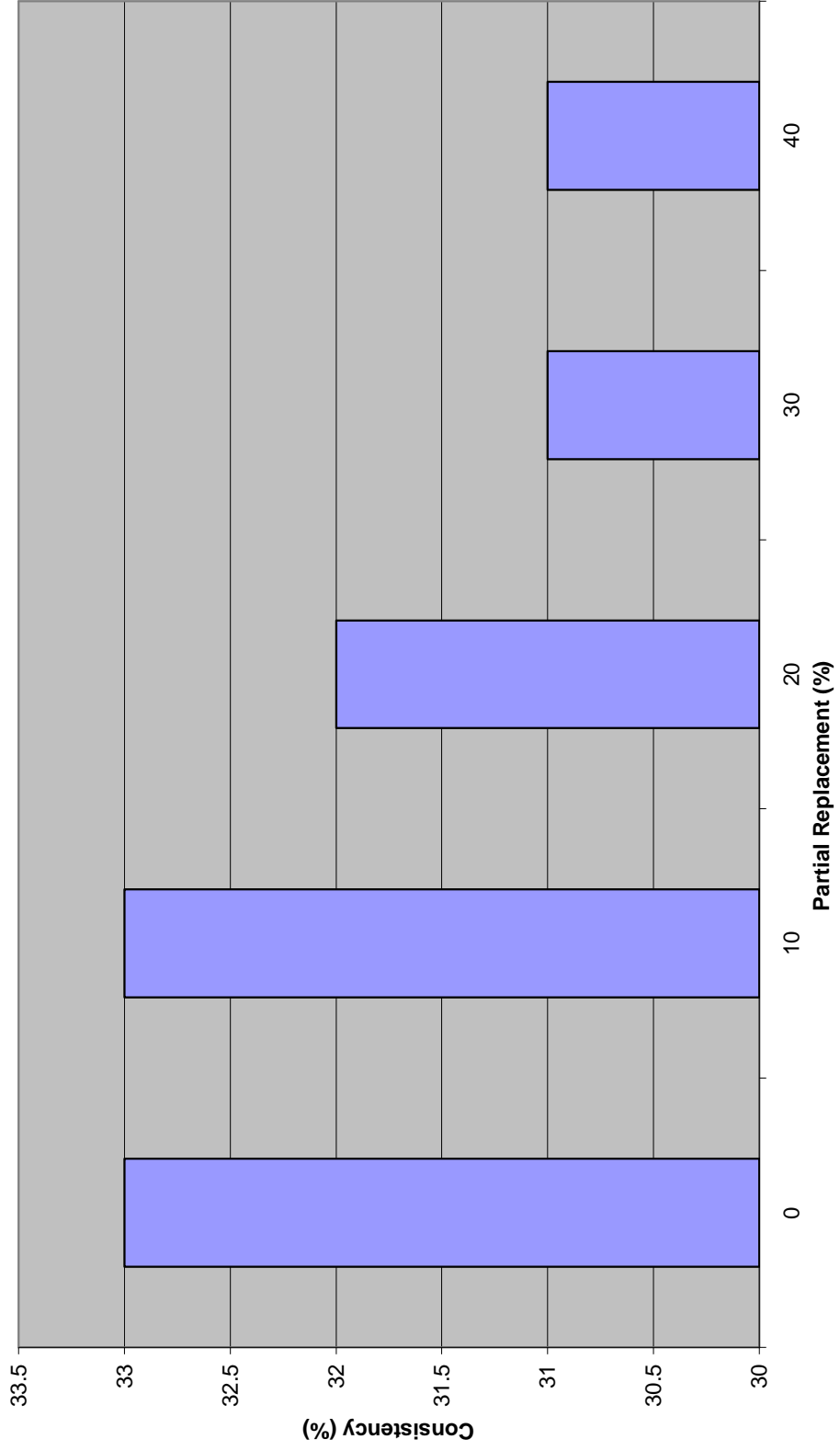
**Table 4.11 Setting time and Consistency test results**

%	0	10	20	30	40
Partial Replacement					
Consistency (%)	33	33	32	31	31

Initial Setting Time (min)	98	120	150	172	20
Final Setting Time (min)	200	235	270	297	33



**Fig.4.4 Setting Time Results of Cements Paste at Various Percentage Partial Replacement With Calcined Earthworm Cast**



**Fig. 4.5 Result of Consistency Tests at Various Percentages of Partial Replacement of Cement with Calcined Earthworm Cast**

From the table 4.11, it can be deduced that the increase in the percentage of calcined earthworm cast increases both the initial and final setting time. This is likely due to the very high silicate and low calcium oxide present in the earthworm cast. This would reduce the heat of hydration that usually would cause the cement to set fast (Taylor, 1979). The setting time (initial and final) of all the percentage replacements fall within the provisions of BS 12: 1978 and ASTM 191-92, which state that the initial setting time must not be less than 45mins and the final setting time must not be more than 10 hours. The consistency on the other hand reduces with increase of calcined earthworm cast percentage replacement.

The figures 4.4 and 4.5 give a bar chart representation of the setting time test results and the consistency test results respectively.



## 4.5 FRESH CONCRETE

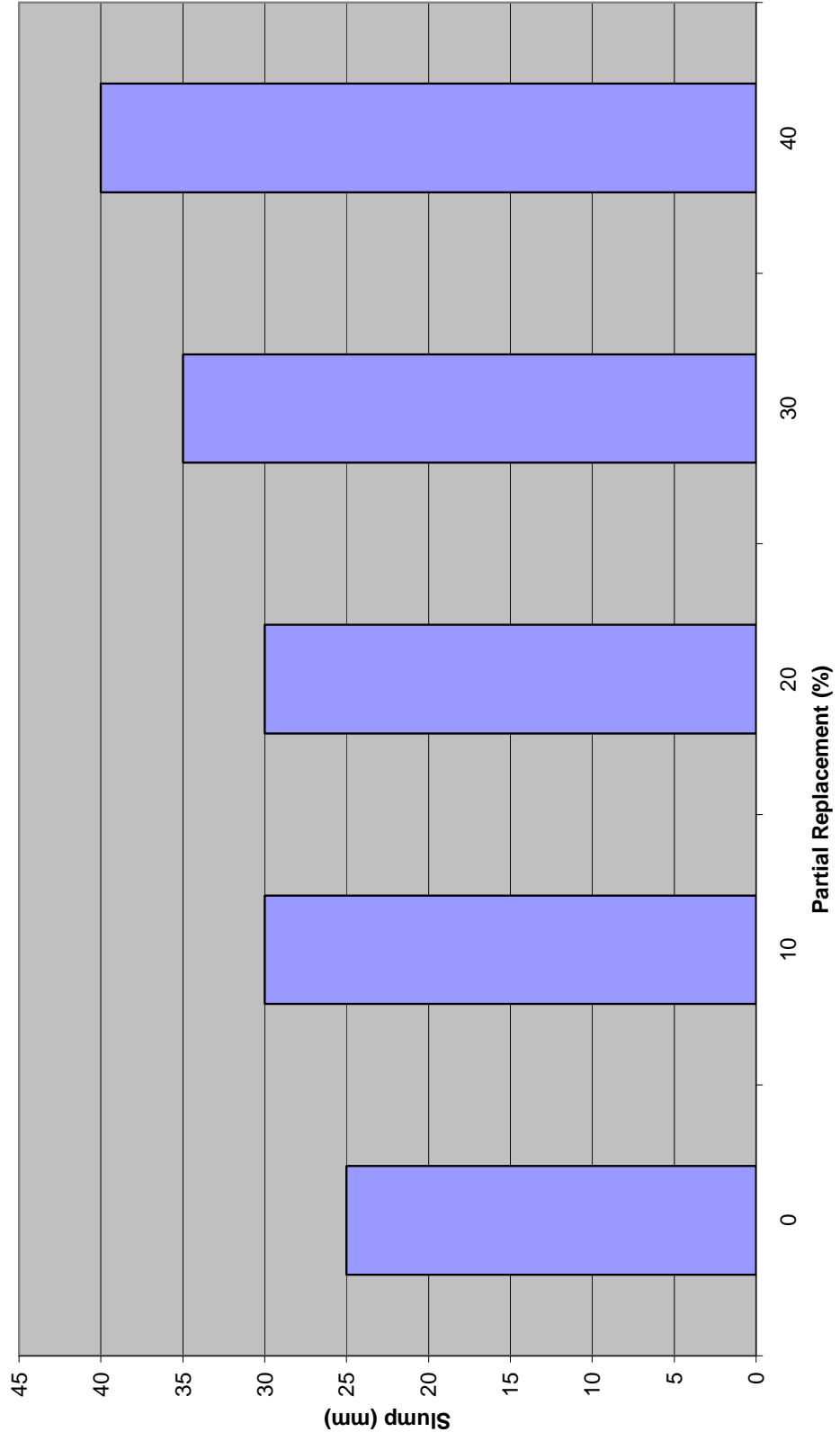
### 4.5.1 Workability Tests

The workability test provided the following results as presented in table 4.12

**Table 4.12 Results of the workability test**

Serial no.	Percentage replacement	Cement	Calcined Earthworm Cast	Water/cement ratio	Slump (mm)	Compacting Factor
1	0	11.34	0.00	0.6	25	0.83
2	10	10.21	1.13	0.6	30	0.87
3	20	9.07	2.27	0.6	30	0.88
4	30	7.94	3.40	0.6	35	0.88
5	40	6.80	4.54	0.6	40	0.89

From the table 4.12, it can be seen that at a constant water cement ratio, the slump increases from 25mm to 40 mm as the partial replacement increases from 0% to 40%. The compacting factor also increases form 0.83 to 0.89 as the percentage replacement increases from 0% to 40%. This is for low workability. A bar chart representation of results for the slump test and compacting factor test are presented in figures 4.6 and 4.7 respectively



**Fig. 4.6 Slump of Concrete at Various Percentages of Partial Replacement of Cement with Calcined Earthworm Cast**

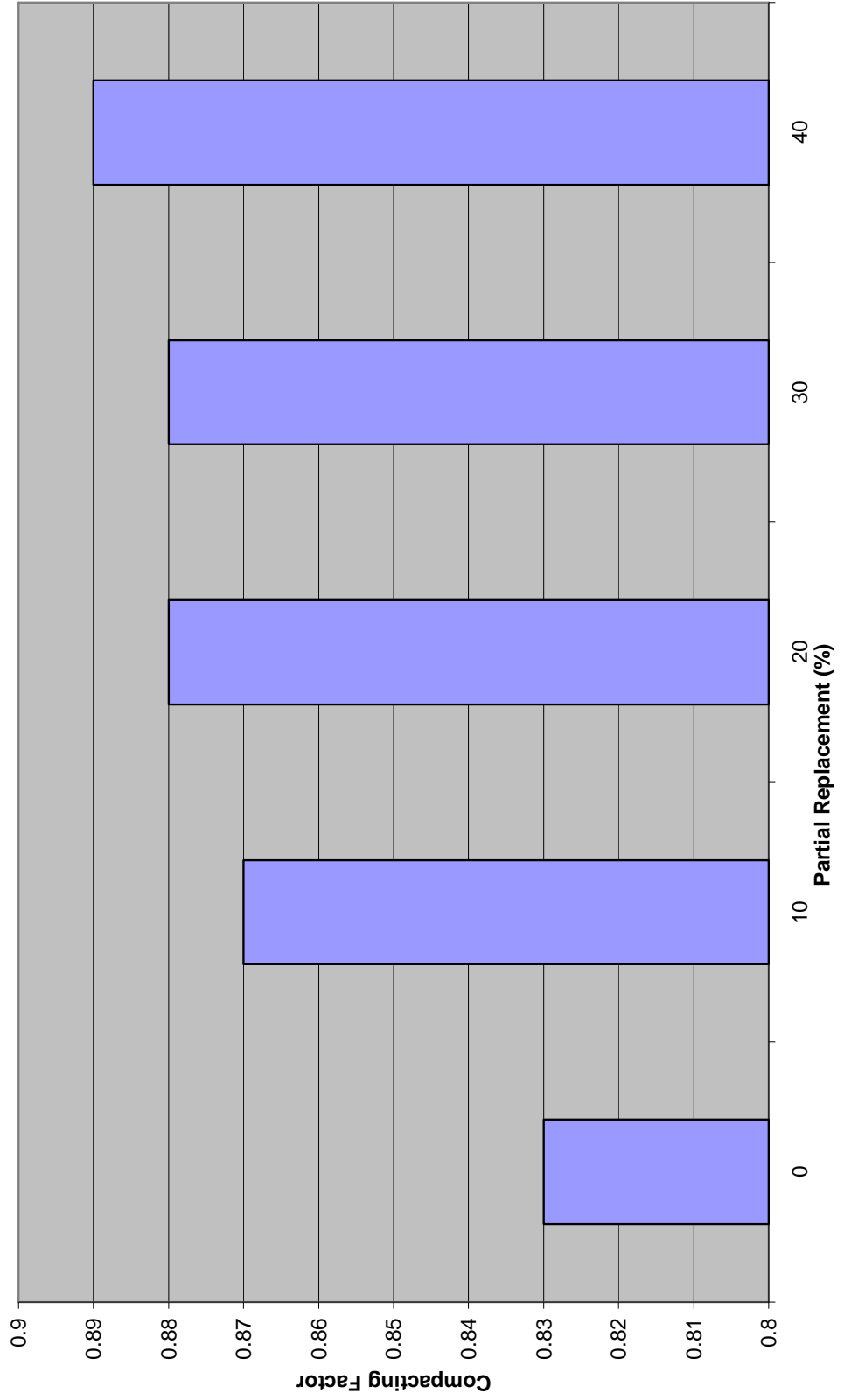


Fig. 4.7 Compacting Factor Results of Concrete at Various Percentages Replacements Levels

## 4.6 HARDENED CONCRETE

### 4.6.1 Compressive Strength Test Results

The results of the compressive strength developed with hydration period of 7, 14 26 days for all the percentage replacements are presented in table 4.13 while the rate of strength gain is presented in table 4.14

**Table 4.13 Compressive Strengths Corresponding to Percentage Replacement**

Percentage Replacement	0	10	20	30	40
AGE OF CURING	COMPRESSIVE STRENGTH TEST RESULTS (N/mm <sup>2</sup> )				
7	12.4	12.00	11.30	10.11	8.25
14	17.5	15.11	13.11	11.02	10.43
28	25.1	21.69	19.64	18.13	15.66
Cube density at 28 days (N/mm <sup>3</sup> )	2439	2421	2384	2375	2352

**Table 4.14 Rate of Strength Gain as a Fraction of the 28 Days Strength**

Percentage Replacement	0	10	20	30	40
Age of curing	STRENGTH AS A PERCENTAGE OF 28 DAYS COMPRESSIVE STRENGTH (%)				
7	50	48	45	40	38
14	70	60	52	44	42
28	100	86	78	72	62

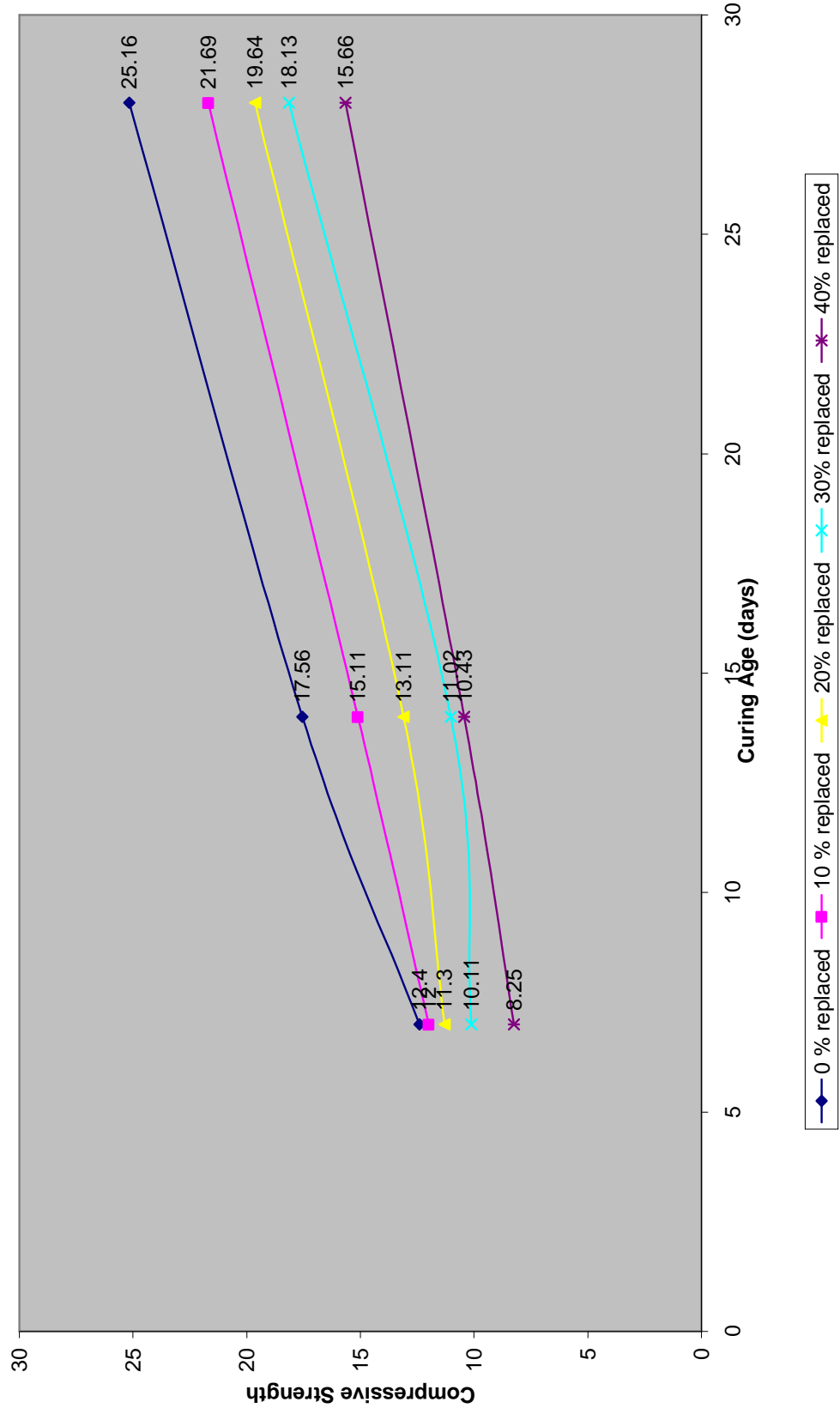
**Table 4.15 Rate of strength gain in ratio of curing/ hydration period**

Percentage replacement	14: 7 day strength	28:14 day strength
0	1.42	1.43
10	1.26	1.43
20	1.16	1.50
30	1.10	1.65
40	1.26	1.50

The tables 4.13, 4.14, and 4.15 indicate the following:

1. At 7, 14 and 28 days hydration period, the compressive strength attained by the replacement of 0, 10, 20, 30, and 40 percent calcined earthworm cast decreases with increase in calcined earthworm cast. This decrease in strength is attributed to the very low percentage of calcium oxide (CaO). It can be further observed that the compressive strength generally increases as the curing period increases, independent of the percentage replacement
2. The ratios of the 14 day to 7 day and 28 day to 14 day strength (from table 4.15) were 1.42 and 1.43, 1.26 and 1.44, 1.16 and 1.50, 1.10 and 1.65 and 1.26 and 1.50 for 0, 10, 20, 30, and 40 percent replacements respectively. This indicates that the rate of strength gain decreases with increase in calcined earthworm cast.

3. Strength increases with density (Neville, 1981). The density is a function of the aggregate pore space and in the case, the density reduced with increase in percentage replacement of calcined earthworm cast. This can be attributed to comparatively low specific gravity of calcined earthworm cast to cement.
4. At the end of 28 days, the concrete cubes with 40% replacement of cement failed to reach 70% of the 28 day strength of conventional concrete mixes. This could be attributed to the fact that the maximum percentage replacement had been exceeded



**Fig. 4.8 Compressive Strength Corresponding to Hydration Period and Percentage Partial Replacement of Cement with Calcined Earthworm Cast**



## CHAPTER FIVE

### FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

#### 5.1 SUMMARY OF RESULTS

From the test carried out on the characteristics of concrete using Calcined earthworm cast as a partial replacement for cement, the following findings were made:

1. The specific gravity of calcined earthworm cast is 2.38. This is within the range specified in ASTM C618 – 78 for pozzolana.
2. The bulk density of calcined earthworm cast is 1294 kg/m<sup>3</sup> compared to that of cement which is 1440 kg/m<sup>3</sup> as provided by Neville (1981).
3. In all mixes, compressive strength decreased with increase in calcined earthworm cast replacement.
4. The values of the compressive strength continued to increase with age of concrete regardless of the calcined earthworm cast replacement
5. The 28 day compressive strength ranged between 25.16 – 15.66 for 1:2:4 mixes.
6. From the chemical analysis of raw and calcined earthworm cast, it is seen that there is very little improvement on the chemical properties of earthworm cast after it has been calcined for 4 hours in a furnace at 850° C. therefore it is not economical and cost effective to calcine earthworm cast.

## 5.2 CONCLUSIONS

The optimum percentage replacement in the case of this study can only be determined when the concrete has attained its full strength. However, this was not attained due to time constraint. Popovics (1986) highlighted that pozzolanic materials may result in concrete of lower strength in the early ages and by 90 days, the concrete would have attained close to if not more than the strength of conventional concrete. This explains why the concrete incorporating calcined earthworm cast, failed to reach its full strength at the end of 28 days.

While earthworm cast is readily available, calcined earthworm cast is not. This is due to the fact that the calcination has to take place in a controlled environment and these kinds of environments are not common.

## 5.3 RECOMMENDATION FOR FURTHER STUDY

1. This research focused on the earthworm cast gotten from a single region. Further work could be done in collecting earthworm cast from different locations and comparing in order to obtain the best location for collecting earthworm cast as pozzolanas. This difference in chemical composition could be attributed to the fact that there are mineralogical differences in diverse soils.
2. Properties such as thermal conductivity, sound insulation, and acoustic properties of concrete with calcined earthworm cast as partial replacement of cement.
3. Research should be carried out on the behaviour of concrete containing calcined earthworm cast at elevated temperatures.
4. Studies can be made into the possible ways of increasing the lime content (CaO) of calcined earthworm cast. Neville pointed out that

the addition of calcium chloride (CaCl) in concrete mix increases the strength development of concrete.

#### **5.4 CONTRIBUTION TO KNOWLEDGE**

This research work has contributed to knowledge by providing detailed information on the chemical and physical properties of calcined earthworm cast.

It has also shown that there is very little improvement on the chemical properties of earthworm cast after it has been calcined for 4 hours in a furnace at 850° C. therefore it is not economical and cost effective to calcine earthworm cast.

As an empirical study on the effective utilization of calcined earthworm cast, the findings have contributed greatly in the area of construction material development in that the use of calcined earthworm cast is discouraged because of the unnecessary expenses that are incurred in its production.

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