EFFECT OF FIRE ON THE COMPRESSIVE STRENGTH OF CONCRETE

BY

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IN CIVIL ENGINEERING.

MARCH, 2012

DECLARATION

I hereby declare that this thesis titled: Effect of fire on the compressive strength of concrete is a collection of my original research work and it has not been presented for any qualification anywhere. Information derived from other sources (published and unpublished) has been duly acknowledge.

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CERTIFICATION

This is to certify that this thesis titled: Effect of fire on the compressive strength of concrete by Lukman Suleman Othman Achile Reg. No PGD/CIVIL/2009/062, meets the regulations governing the award of PGD in Civil Engineering of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation .

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DEDICATION

This project work is dedicated to Almighty God for his mercy, loving kindness and favour bestowed upon me throughout my period of studies and my loved ones who have to endure and tolerate one thing or the other for this course to be possible. May the Almighty God pay them for their endurance, tolerance and cause them to eat the fruit of their labour, Amen.

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ABSTRACT

This project examines the effect of fire on the compressive strength of concrete. Fifty Four (54) concrete cubes were casted, cured for twenty eight (28)days and six (6) cubes for each level of temperature were subjected to various range of temperature (ambient temperature, 50^{oC}, 100^{oC}, 150^{oC}, 200^{oC}, 250^{oC}, 300^{oC} 350^{oC}, and 400^{oC}) for one hour and crushed, concrete materials/mix, curing and all test kept constant. Mix ratio used was 1:2:4 and water cement ratio adopted was 0.50. Average strength for each temperature level was taken and it was noticed that concrete retained its integrity as a load bearing element when subjected to temperature up to 300^{oC}, beyond which the compressive strength start falling. Concrete strength after twenty eight (28) days curing under normal room temperature was retained even when subjected to 50^{oC} and 100^{oC} for one hour each. Beyond this temperature the concrete compressive strength increases (when subjected to 150^{oC}, 200^{oC}, 250^{oC} and 300^{oC}). The strength start falling when 300^{oC} was exceeded to 350^{oC} and $400^{oC.}$ This shows that concrete strength will be retained if exposed to a typical fire/temperature.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Fires are caused by accident, energy sources or natural means, but the majority of fires in buildings are caused by human error (e.g discarded cigarettes or careless placement of kerosene lamp etc). Once the fire starts and the contents and/or materials in a building are burning, then the fire spreads via radiation, convection or conduction.

Harm is caused by a combination of the effects of smoke and gases, which are emitted from burning materials, and effects of flames and high air temperature.

But the obvious fact is that concrete does not burn neither can it be set on fire like other materials in a building and it does not emit any toxic fume when affected by fire. It will also not produce smoke or drip molten particles, unlike some plastic and metals, so it does not add to the fire load.

For this reason concrete is said to have certain degree of fire resistance and, in the majority of applications, concrete can be described as virtually 'fireproof'. This excellent performance is due in the main to concrete's constituent materials (i.e cement, water and aggregates) which when chemically combined (concrete) from a material that is essentially inert and, importantly for fire safety design, has a relatively poor thermal conductivity.

It is this slow rate of heat transfer (conductivity) that enables concrete to act as an effective fire shield not only between adjacent spaces, but also to protect itself from fire damage.

Hence, the research study the effect of fire on the compressive strength of concrete. The heat flow generated by fire in concrete produces differential temperature, moisture levels and pore pressure. These changes may likely affect concrete's ability to perform at the three fire limit states. The structure should retain it's load bearing capacity, the structure should protect people from harmful smoke and gases and the structure should shield people from heat as indicated in UK and European fire safety codes.

One major change that must be avoided is loss of shear or compression strength in concrete, and overall dimensions such that the temperature of concrete throughout the section does not reach critical.

In the making of concrete, strength Vis a Vis the proportion of the basic constituents and other inherent characteristics are predetermined in a process of design to produce concrete to certain maximum properties economically possible. The task involved in designing a concrete mix consist of selecting suitable constituents of concrete and determining the correct proportions of the cement, fine and coarse aggregates and water to produce an economical concrete having the specified properties.

When water is added to the mixture of cement and aggregates (fine and coarse), hydration of cement takes place. This will cause the whole mixture to set and when hardened, form solid rock like mass.

The volume of water used in the mix should be such needed to ensure full hydration into a paste which makes the concrete workable.

The excess water left in the paste after hydration remains free and is redistributed in the paste and whole mass. The excess water must be kept to a minimum compatible with adequate workability for the job to be done. In determining the total water cement ratio, the total mass of water absorbed by the aggregates (coarse and fine) in the batch is added to the volume of water introduced during the mixing. The total water/cement ratio is the total mass of water to the total mass of cement in the mix, hence when deciding how much water that is required, allowance must be made for the absorption by the dry and porous aggregates and for the free surface water. The amount of water used should be the amount sufficient for workability to ensure thorough compaction of the concrete.

Two type of aggregates are normally used in concrete production i.e fine and coarse aggregates. The coarse aggregate compose mainly of gravel, crushed rock or granite, broken bricks, air-cooled blast furnace slag while the fine aggregates are composed of sand and stone dust.

The properties of coarse aggregates which constitute a large percentage of concrete constituents is however affected by many factors such as shape and texture, strength, toughness, hardness, specific gravity, bulk density, porosity and absorption, moisture content, chemical reactivity, elastic modulus and thermal characteristic. The properties mainly specified are the durability of the hardened concrete, workability for fresh concrete and the compressive strength at a specified age.

If the volume of water used is less than sufficient, there will not be enough water for the cement hydration process. It will result in weak and porous concrete. If on the other hand too much water is used, it will result in segregation of the aggregates which gives porous concrete of low strength and low density and poor durability.

Sullivan (2004) stated that strength of concrete is adversely and significantly affected by the presence of voids in the compacted mass, it is vital to achieve maximum possible density. This requires sufficient workability for virtually full compaction to be possible using a reasonable amount of water under given conditions. The presence of voids in concrete reduces its strength such that 5% of voids can lower the strength of concrete by as much as 30%. The volume of voids in hardened concrete due to spaces left after excess water has been removed depend solely on the water/cement ratio of the mix.

The porosity of the aggregates affects both fresh and hardened concrete. The volume of void in hardened concrete due to bubbles of entrapped air is dependent on the grading of the fine aggregates. This is an important fact in concrete mix design.

This project deals with the effect of fire on the compressive strength of concrete at various temperatures using normal concrete with coarse aggregates of 20mm (max size).

1.2 Definition of the Project

The purpose of this project is to determine the effect of fire on the compressive strength of normal concrete (proportion of 1:2:4) by subjecting concrete cubes to varying temperature at the end of 28 days curing. However, the exposure to fire for all the cases is one hour.

1.3 Scope of Work

Scope of works include the following:

Sampling, collection and grading of coarse and fine aggregates

Physical properties of aggregate carried out are Specific gravity, Bulk density, Water absorption, Porosity and Void ratio. Preparation of normal concrete using a mix proportion of 1:2:4. Slump and compacting factor test will be carried out for the workability of the concrete. Preparation of cube samples (6 no each) for the various temperature level. Curing the cubes samples (54 no) by submerging under water in a tank where they would be left for 28days.

Determination of density of hardened concrete

Subjecting 48 of the cube (6 each) for temperature of 50^0c, 100^0c, 150^0c, 200^0c, 250^0c 300^0c, 350^0c and 400c for 1 hour. While the remaining 6 cubes serves as control at ambient temperature (room temperature).

Performing density test on them and carrying out compressive crushing strength test on the concrete cubes.

1.4 Aim and Objective of the Project

The aim of the project is to determine the effect of fire on the compressive strength of concrete.

And the set up objective is to determine the compressive strength of concrete at varying temperature and verify the level of temperature at which the concrete will start losing is compressive strength.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concrete and its Constituent Materials

Concrete as a composite construction material, composed of cement (Commonly Portland Cement) and other cementious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate made of gravel or crushed rocks such as limestone, or plus a fine aggregate such as sand), water and chemical admixtures.

The word concrete comes from the Latin word "concretes" (meaning compact or condensed), the perfect passive participle of "concrescence", from "con" (together) and "crescere" (to grow). Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration.

The water reacts with the cement, which bonds the other components together, eventually creating a robust stone – like material.

Concrete is used to make pavements, pipe, architectural structures, foundations, motor ways/roads, bridges/overpasses parking structures, brick/block walls and footings for gates, fences and poles. Jin . J. (2002).

Concrete is used more than any other man-made material in the world. As of 2006, about 7.5 cubic kilometers of concrete are made each year – more than one cubic meter for every person on earth. Joseph S.(2011).

2.2.0 Effects of Materials on the Compressive Strength of Concrete

Thorough mixing is essentially for the production of uniform, high quality concrete. Therefore equipment and methods should be capable of effectively mixing concrete materials containing the largest specified aggregate to produce uniform mixtures of the lowest slump practical for the work. Separate paste mixing has shown that the mixing of cement and water into a paste before cornicing these materials with aggregates can increase the compressive strength of the resulting concrete. A. M. Neville (1981).

Strength as well as durability and volume changes of hardened cement paste appears to depend not so much on the chemical composition as on the physical structure of the product of hydration of cement and their relative volumetric properties.

In particular it is the presence of flaws, discontinuities and pores which is of significance and to understand their influence on strength, it is necessary to relate strength to measurable perimeters of the structure of hydraulic cement paste. One of the primary factor is porosity i.e the relative volume of pores or voids in the cement paste. These can be viewed as sources of weakness from the cement paste. Infact it will be seen that the overriding factor is water/cement ratio, with the other mix being only of secondary importance. Portable water or drinkable water is usually recommended for mixing concrete.

Some impurities that may likely be found in water are organic matter, sewage, silts, clay and acids so therefore if an impure water is use for washing aggregate it can deposit harmful substances on the surface of the particles and it will reduce the strength and durability of the concrete.

The presence of this imparities during curing does not cause any harm to the concrete but it may spoil the appearance of the concrete. It is always advisable to avoid the use of water containing impurities.

2.3.0 Water for mixing.

The Criterion of portability of water for concrete is not absolute: drinkable water may not be unsuitable as mixing water when the water has a high concentration of sodium or potassium and there is danger of alkali-aggregate reaction. In this reaction concrete may be damaged by a chemical reaction between the active silica constituents of aggregate and the alkalis in the cement: this process is known as alkali-silica reaction. The reactive forms of silica are opal (armophours), and chalcedony (cryptocrystalline fibrous), and (crystalline) these materials occur in several types of rock: opaline or chalcedonic cherts, silicious limestone's, ryholites tuffs, andesite tuffsand phylites. The use of portable water is generally safe; water not fit for drinking may also be satisfactorily used in making concrete. As a result any water with PH (degree of acidity) of 6.0 to 8.0, which does not taste saline or brackish is suitable for use but a dark colour or a smell do not necessarily mean that the deleterious substances are present. Natural water that are slightly acidic are harmless, but water containing humic or the organic acids may adversely affect the hardening of concrete; such water, as well as high alkaline water should be tested. Two somewhat peripheral comments may be made. The presence of algae in mixing water results in air entrainment with consequent loss of strength. Hardness of water does not affect the efficiency of air entraining admixtures.

Occasionally, the use of seawater as mixing water has to be considered. Seawater has typically, a salinity of about 3.5 percent (78 percent of dissolved solids being NaCI and 15 percent $MgCl_2$ and $MgSO_4$) such water leads to a slightly higher early strength but a lower long-term strength; the, loss of strength is usually not more than 15 percent and can therefore be tolerated.

Ahmed E. M. (2001).

The effect of setting time have not been clearly established but these are unimportant if water acceptable from strength consideration; BS 3148: 1980 suggest a tolerance of 30 minutes in the initial setting time. Sea water (or any containing large quantities of chlorides) tends to cause persistent dampness and efflorescence. The extent of sulphate attack depends on its concentration and on the permeability of the concrete i.e on the ease with which water can travel through the system. If the concrete is very permeable, so that water can percolate right through its thickness, $Ca(OH)_2$ will be leached out. Evaporation at the 'far' surface of the concrete leaves deposits of calcium carbonate, formed by the reaction of $Ca(OH)_2$ with carbondixide; this deposit, of whitish appearance, is known as efflorescence (efflorescence is generally harmful). Such water should not be used where appearance of the concrete is of importance or where a plaster – finish is to be applied.

In the case of reinforced concrete, sea water increase the risk of corrosion of the reinforcement especially in tropical countries exposed to humid air when the cover to reinforcement is inadequate or the concrete is not sufficiently dense so that the corrosion action of residual salt in the presence of the moisture can take place. On the other hand, when reinforced concrete is permanently in water, either sea or fresh, the use of sea water in mixing seems to have no ill-effect. However in practice, it is generally considered inadvisable to use sea water in mixing, *Blake L.S. (1975).*

2.4.0 Water Demand

The water demand of concrete can be related to the cement particle size distribution and to the water demand of cement paste. This later property is measurable by a test for standard consistency using the vicat apparatus; the test involves determining the water producing certain plunger penetration in a small sample of freshly compacted paste.

In effect to standard consistency test is a bulk density test like that for aggregate except the medium is not air but water, the medium in which cement is required to operate in concrete.

A typical range values for water content in the vicat test is 24 – 28% by mass i.e water/cement of 0.24 – 0.28. This means void contents of about 0.5 (or a void ratio near unity) which, considering the wide grading of cement is rather high and suggests rather angular and or irregular shaped-particles which is confirmed by photomicrographs. The void is also higher due to some agglomeration of cement particles.

Chemical Admixtures.

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 admixtures dosages are less than 5% by mass of cement, and are added to the concrete at the time of batching/mixing. The most common types of admixtures are:-

Accelerators:- Speed up the hydration (hardening) of the concrete. Without accelerants, concrete may take a longer time than one would have expected.

Retarders:- Slow the hydration of concrete, and are used in large and/or difficult pours where partial setting before the pour complete is undesirable.

Air:- Entrainers add and distribute tiny air bubbles in the concrete, which will reduce damage during – thaw.

Plasticizers (Water – reducing admixtures) increase the workability of plastic or "fresh" concrete, allowing it be placed more easily, with less consolidating effort.

Super plasticizers (high-range water reducing admixtures) are a class of plasticizers, which have fewer deleterious effects when used to significantly increase workability.

Pigments can be used to change the colour of concrete for aesthetics.

Corrosion inhibitors are used to minimize the corrosion of steel and steel bars in concrete.

Bonding agents are used to create a bond between old and new concrete.

2.5.0 Cement

Cement can be defined in general term as a material that has both cohesive and adhesive properties which enable it to effect strong bond between mineral fragments to form a compact mass. The basic materials for Portland cement manufacturing are the mixing together of calcareous and argillaceous or other silica, alumina and iron oxide bearing materials, burning them at a clinkering high temperatures and grinding the resulting clinker. From the above it can be seen that cement is made primarily from a combination of calcareous materials, such as limestone or chalk and of silica and alumina found in clay or shale. The process of manufacture consist essentially of grinding the raw materials into a very fine powder, mixing them intimately in predetermined proportion and burning them in a rotary kiln at a temperature of about 1400 degrees Celsius when the material sinters and partially fuses into clinker. The clinker is cooled and ground to a fine powder with gypsum added, and the resulting product is the commercial Portland cement used throughout used throughout the world.

Approximate compositions of raw materials used for the manufacturing of ordinary Portland cement are:

Calcium oxide (C_aO)	60 – 65%
Silica (SiO_2)	20 – 25%
Aluminium oxide (Al_2O_3)	4 – 8%
Ferrous oxide (Fe_2O_3)	2 – 4%
Magnesium oxide (MgO)	1 – 3%

Tri-calcium silicate is the best cementing material and the more of it present in cement, the better. Cement having lesser aluminates shall have less initial strength but a higher ultimate strength. Hydraulic cement is those that have the property of setting and hardening under water. For construction purpose, the meaning of cement is restricted to the bonding material used with stones, sand, brick, building block etc.

2.6.1 Types of Cement

There are different types of cement manufactured to suit the various specific requirements. Below is the list of some of the different types of cement.

1. Ordinary Portland cement.

2. Rapid hardening Portland cement.
3. Portland blast furnace cement.
4. Low heat Portland cement.
5. High Alumina cement.
6. Sulphate resisting Portland cement.
7. Coloured cement.
8. Air entraining Portland cement.
9. Portland pozolana cement.

Ordinary Portland Cement: Ordinary Portland cement is the commonest type of cement having medium rate of strength development and heat evolution. It is suitable for normal concrete work.

Rapid hardening Portland cement: This cement gains strength faster than ordinary Portland cement. Its initial and setting times are the same as those of ordinary Portland cement. It contains more tri-calcium silicate and is more finely grounded. It gives out more heat while setting and is as such unsuitable for mass concreting. It is used for such structures as are to be subjected to loads early like in the repair of roads and bridges.

Portland Blast Furnace Cement: Portland blast furnace cement has very similar properties to ordinary Portland cement but evolves less heat and it is highly more resistant to chemical attack. It is made by grinding a mixture of cement clinker, gypsum and blast furnace slag in proper proportions and grinding it finely. This cement can advantageously be used in marine works; Manufacture of Portland slag cement is aimed primarily at profitably utilizing blast furnace slag – a waste product from the production of iron in blast furnace.

High Alumina Cement: It is manufactured by fusing together, a mixture of bauxite and limestone in correct proportions and at high temperatures. The resulting product is grounded finely. It develops strength rapidly. It is black in colour and resists well, the attack of chemicals especially of sulphates and sea water. The ultimate strength is much higher than that of ordinary PORTLAND CEMENT. Its initial setting time is more than two hours and the final setting time take place immediately. It is the most expensive of all cement. It is used extensively for refractory purposes – to line the furnace where moderately high temperature is encountered.

Low Heat Portland Cement: Heat generation by cement while setting may cause cracks in structures. In the case of concrete, heat generation is controlled by keeping the percentage of tri-calcium silicate low. Its initial and final setting times are nearly the same as those of ordinary Portland cement but the rate of its development of strength is very slow. It is used for large dam construction where there is danger of high temperature building up.

Sulphate Resisting Portland Cement: Sulphate resisting Portland cement is very similar to ordinary Portland cement but as its name implies, has a much higher resistance to sulphate attack. In certain soils, concentration of sulphate chemical exist which will cause concrete made with ordinary Portland cement to crumble. Where such condition exists, the concrete in contact with the soil should be made with high alumina cement or with sulphate resisting Portland cement.

Air Entraining Portland Cement: This is ordinary Portland cement mixed with small quantities of air entraining materials at the time of grinding. Usually, air entraining materials used are resin; *vinsol resin and darek* are most commonly used. These materials have the property of entraining air in the form of air bubbles in concrete. These bubbles render the concrete more plastic, more workable and more resistance to freezing. However, because of air entraining, the strength of concrete reduces and as such the quantity of air so entrained should not exceed five percent.

Coloured Cement: For architectural purposes, white concrete, or particularly in tropical countries, a pastel colour paint finish is sometimes required. For this purpose, white or coloured cement is used. It is also used because of its low content of soluble alkalis so the straining is avoided. Coloured cement is made from china clay which contains little iron oxide and manganese oxide together with chalk or limestone free from specified impurities.

Portland Pozzolana Cement: Portland pozzolana cement is produced either by grinding together Portland cement clinker and pozzolana or by intimately and uniformly blending Portland cement and fine pozzolana. This cement has properties similar to those of ordinary Portland cement and can therefore be used for all general purposes where the latter is employed with no change of proportion of fine or coarse aggregates and cement. Gypsum is added in both cases. Portland pozzolana cement produces less heat of hydration and offer greater resistance to chemical attack. It takes little longer to gain strength. The ultimate strength of this cement is more than that of ordinary Portland cement but the initial and final setting times are the same.

2.6.2 Properties of Cement

Because the quality of cement is vital for the production of good concrete, the following properties of cement are usually tested in the laboratory to ascertain the level of acceptability:

(a) **Setting Time:** There are two setting times – initial and final setting times. Initial indicates the beginning of noticeable stiffening of the fresh concrete. The final setting time on the other hand indicates the point from which the paste starts to harden and gain strength. Broadly speaking, setting refers to a change from fluid to a rigid state. It is mainly caused by selective hydration of C_3A and C_3S and is accompanied by temperature rise in the paste. Initial set corresponds to a rapid rise while final set corresponds to the peak temperature. These setting times should be distinguished from false set which occurs within a few minutes of mixing with water.

(b) **Soundness:** The soundness of cement refers to its ability to maintain a constant or consistent volume. Unsoundness occurs in cement by delayed or slowed hydration or the presence of free lime in hardened cement. The presence of magnesium or calcium sulphate which expands under restrained conditions can lead to destruction of hardened cement paste. The soundness of cement refers to its ability or otherwise to maintain a constant volume.

(c) **Fineness:** Since hydration starts at the cement particles, it is the total surface area of cement that represents the material available for hydration. Thus the rate of hydration depends on the fineness of the cement particles and for a rapid development of strength, a high degree of fineness is necessary. However, the cost of grinding on the other properties like workability of fresh concrete must be borne in mind. Finer cement promotes stronger reaction with alkali reactive aggregates to produce a paste exhibiting a higher shrinkage and is liable to more cracking. The fineness of cement is specified in terms of surface, which is the calculated surface area of the particles in square centimeter per gram of cement (cm^2/g). A control of the fineness will help keep its properties uniform.

(d) **Strength:** Strength tests are not carried out on neat cement paste because of difficulties in obtaining good specimen and in testing with a consequent large variability of test results. Cement sand motar and in some cases, concrete of prescribed properties made with specified materials under strictly controlled conditions are used for the purpose of determining the strength of concrete. The strength of motar or concrete depends on the cohesion of concrete paste, its adhesion to the aggregates.

Joseph S. (2011).

2.7.0 Aggregates

Aggregate may be defined as non-cementious particle such as natural sand, gravel, crushed rock or a combination of these materials which are mixed with cement and water to produce concrete. Aggregate constitute the bulk of the volume of concrete and influence its properties such as strength and shrinkage. The properties of aggregates greatly affect the durability and confer considerable technical advantages of stability and better durability that the cement paste alone.

The characteristics of concrete aggregates include uniformity, frost action. Liability to oxidation and hydration and coefficient of thermal expansion. Depending upon the size of their particles, aggregates are classified fine, coarse and cyclopean aggregates.

(1) **Fine Aggregates:** Particles of fine aggregates pass through the 4.75mm mesh and are entirely retained on the 0.5mm mesh. Most commonly used fine aggregates are sand and crushed stone dust . Sand consist of small grain of silica and is formed by the disintegration of rocks caused by weather. Depending on the source from which sand is obtained, it is classified as;

(i) Pit or quarry sand, (ii) River sand and (iii) Sea sand.

The following are the qualities of good sand for concrete production purposes:

a Good sand should have coarse and angular grains of pure silica.

b The grain of sand should be hard, strong and durable.

c It should be free from silt, clay and salts.

d It should be well graded – it should contain suitable proportion of all the various sizes.

e It should not contain any organic matter.

f it should not contain any hygroscopic matter.

To check the suitability of sand for being used in motar or concrete, it may be put to the following tests:

i. Rub a little sand between the fingers; stain left on fingers will indicate presence of undesirable clay or silt impurities.

ii Taste of sand shall provide a suitable check for the presence of salts.

(i) Vigorously stir a sample of sand in a glass of water and allow it to rest. Amount of clay or silt present in it will settle on the sand.

(2) **Coarse Aggregates:** Aggregates whose particle sizes is bigger than 4.75mm but smaller than 75mm are known as coarse aggregates. The main coarse aggregates in use in Nigeria are gravels and crushed granites and rocks.

2.7.1 Classification of Aggregates

Concrete aggregates can be classified under the following heading:

(1) **Heavy Weight:** These may be defined as those having high specific gravity (usually high density concrete for radiation shielding construction of biological shield and for concrete counter weight.

(2) **Normal Weight:** The normal weight aggregates are the aggregates which have specific gravity of between 2.50 and 3.00 and bulk density in the range of 1450 to 1750kg/m^3.

(3) **Light Weight Aggregate:** These are either natural or man made porous aggregates used for the production of light weight concrete.

The light weight aggregates have lower thermal conductivity, density and strength.

2.7.2 Types of Aggregates (by Grading)

The grading of aggregate indicates the proportion of the different sizes of aggregate or size distribution of the aggregates. It is accomplished by sieve analysis and it is given in terms of percentage weight passing from the largest to the smallest. Gap grading occurs where some intermediate sizes are missing or omitted. This may be necessary to obtain a certain surface finish.

Aggregate grade sizes commonly used in Nigeria are of two types which are:

(a) **Fine Aggregates:** An aggregate that contains a high proportion of small particles is referred to as finely grained. Fine aggregates have a maximum particle size of 4.75mm. The most commonly used fine aggregate is sand, crushed stone and cinders.

(b) Coarse Aggregate: This is an aggregate that contains high proportion of large particles. The various types of coarse aggregates are as follows:

(i) Gravel: They are obtained from riverbeds, quarries and seashore. It is hard and durable. They are extensively used as coarse aggregates in concrete work.

(ii) Stone Ballast: Stone that are free from undesirable mineral constituents are broken to stone ballast used in concrete production. It is an excellent coarse aggregate. It should be free from organic matter before being used.

(iii) Brick Ballast: It is reasonably a good substitute for stone aggregate when available in sufficient quantity. It is used stone aggregate when available in sufficient quantity. It is used as coarse granite in concrete where aggregates from natural resources are not available or expensive. It can also be used in places where lower strength is required or where it is exposed to less severe conditions of service. The brick ballast should be free from dust and also be thoroughly saturated with water before usage in concrete works.

(iv) Lateritic Rock: The lateritic rocks are those in which laterzation is the dominant soil formation process. The process of their formation is through the leaching silica under hot and moist condition. They are residual soil from tropical regions.

(v) **Granite:** These can also be obtained from quarries. They are hard, strong and durable. They are used extensively as coarse aggregate when making concrete. They should be free from impurities such as clay, salts.

Joseph S. (2011).

2.7.3 Properties of Aggregates:

The properties of aggregate known to have significant effect on quality of concrete are its bond, strength, durability, toughness, volume change, specific gravity, bulk density, porosity and moisture content.

a) **Bond:** Both the shape and surface texture of aggregate influence considerably, the strength of concrete. A rough texture results in greater adhesion or bond between particles and the cement matrix. Likewise the larger surface area of a more angular aggregate provides a greater bond. Generally, when the bond is good, a crushed specimen should show some aggregate particles broken right through, in addition to the more numerous ones separated from the paste matrix.

b) **Strength:** Clearly, the compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. A few weak particles can certainly be rated; after all, air voids can be viewed as aggregate particles of zero strength. The required information about the aggregate particles has to be obtained from indirect tests: crushing strength of prepared rock samples, crushing value of bulk aggregate and performance of aggregate in concrete. The later simply means either previous experience with the given aggregate or a trial use of the aggregate in a concrete mix known to have certain strength with previously proven aggregates.

c) **Toughness:** Toughness can be defined as the resistance of aggregate to failure by impact, and it is usual to determine the aggregate impact value of bulk aggregate. Full details of the prescribed tests are given in BS 812: part 112 of 1990. The apparatus for the test is portable, cheap and simple to operate and it is rapid in application. It can be used in the field for quality control purposes. This property is mostly used in road pavement works.

d) **Hardness:** Hardness or resistance to wear is an important property of aggregate used in roads and floor surfaces subjected to heavy traffic. The aggregate abrasion value of the bulk aggregate can be assessed using BS 812 part 113 of 1990. Aggregate particles between 14.0 and 20.0mm are made up in a tray in a single layer, using a setting compound. The sample is subjected to abrasion in a standard machine. The aggregate abrasion value is defined as the percentage loss in mass on abrasion so that a high value denotes a low resistance to abrasion.

e) **Durability:** This is the resistance of concrete to weathering, chemical attack, abrasion, frost and fire. It depends largely on the quality of mineral composition of the aggregate.

f) **Volume Change:** Volume changes due to limestone movement in aggregate derived from sand stones and sand basalts may result in considerable shrinkage of concrete. If the concrete is restrained, it will produce internal tensile stresses thereby causing tensile cracking and subsequent deterioration of the concrete. If the coefficient of thermal expansion of the aggregate differs considerable from that of cement paste, will cause cracking that may adversely affect the concrete performance.

g) **Specific Gravity:** This is the ratio of the unit weight of the aggregate to the unit weight of water. The specific gravity affects the density of the resulting concrete. BS 812: part 107 uses the term particle density for the specific gravity or relative density. If the mass of the oven dried sample is D, the mass of the vessel full of water is C, and the mass of the vessel with the sample topped with water is B, then the mass of water occupying the same volume as the liquid is D-(B-C). The apparent specific gravity or relative density is then: $r.d = D/[D-(B-C)]$.------------------Equation 1

h) **Bulk Density:** The bulk density of an aggregate is the ratio of the total mass or weight of aggregate to the volume disregarding the voids. The absolute density refers to the volume of the individual particles only, and of course it is not physically possible to pack these particles so that there are no voids between them. Thus when aggregate is to be batched by volume, it is necessary to know the bulk density which is the actual mass that would fill a container of unit volume and this density is used to convert quantities by mass to quantities by volume. The bulk density depends on how density of the aggregate is packed and consequently the size distribution and shape of the particles. BS 812 part 2: 1975 recognizes two degrees; loose and compacted bulk density.

i) **Porosity:** Porosity of aggregate affects the quality of both fresh and hardened concrete. The porosity, permeability and absorption of aggregate influence the bond between it and the cement paste, the resistance of concrete to freezing and thawing as well as chemical stability, resistance to abrasion and specific gravity.

j) **Moisture Content:** Since absorption represents the water contained in the aggregate in a saturated, surface dry condition, we can define the moisture content as the water in excess of the saturated surface dry condition. Thus the total water content of a moist aggregate is equal to the sum of the absorption and moisture content. The moisture content must be allowed for in the calculation of batch quantities and of the total water requirement of the mix. In effect, the mass of water added to the mix has to be decreased and the mass of aggregate must be increased by an equal amount of the moisture content. BS 812: part 109: 1990 prescribed the following method for determination of moisture content. If A is the mass of and airtight container, B the mass of the container and sample, and C the mass of container and sample after drying to a constant mass, the total moisture content (percent) of the dry mass of aggregate is given by;

$M.C = (B-C)/(C-A)*100\%$ --------------- Equation 2

2.8.0 Properties of Concrete

Workability: Workability can be defined as the amount of useful internal work necessary to produce full compaction. It is the ease with which concrete can be placed and compacted. Workability of concrete increases with addition of water but it reduces the strength and as such it is not a very desirable way of increasing workability. Use of aggregates which are round and have smooth surface increases the workability. Slump test gives idea of only the flowing property of wet concrete and not of workability. Workability of concrete is better determined by compaction factor test.

Durability: Durability of concrete is the property of concrete to withstand alterative weather conditions of wetness, dryness and frost.

Strength: Strength of concrete is commonly considered to be the most valuable property. Strength of concrete usually gives overall picture of the quality of concrete because it is directly related to the structure of the cement paste. The strength of concrete is usually measured in 7, 14, 21 and 28 days after it has been cast and thoroughly cured. The compressive strength of concrete id its ability to withstand squeezing and crushing forces. Flexural strength is the ability to withstand bending and resulting tension.

Shrinkage: Shrinkage takes place principally in the cement paste as concrete dries. The amount of shrinkage depend on the amount of water added to the mixture, the cement content, the maximum size of the aggregate, its shape, grading and cleanliness. The lower the water content the lower the shrinkage.

Segregation: Segregation can be defined as the separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform. In this case of concrete, it is the differences in the size of particles (and sometimes in the specific gravity of the mix constituents) that are the primary cause and by care of handling. Other causes of segregation are due to excess water in the mix and over compaction.

Bleeding: Bleeding in concrete is sometimes referred to as water gain. It is a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete. Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. When the cement paste has stiffened sufficiently, bleeding of concrete ceases.

Density: it is common to determine the density of a compacted fresh concrete when measuring workability or the air content. Density is easily obtained by weighing the compacted fresh concrete in a standard container of known volume and mass. BS 1881: part 107: 1983 describe the procedure. If the density, D*, is known, the volume of concrete can be found from the mass of the ingredients. When these are expressed as quantities in one batch put into the mixer, we can calculate the yield of concrete per batch. Let the masses of per batch of water, cement fine aggregate and coarse aggregate be, respectively, W, C, Af, and Ac. Then, the volume of the compacted concrete obtained from one batch is:

$V = (C + Af + Ac + W)/D^*$ -------------------------Equation 3

2.9.0 Production of Concrete

Concrete is produced by mixing together cement, mineral aggregates and water. This mixture is placed in a suitable container or mould, compacted and allowed to harden. The processes of production are listed below:

2.9.1 Batching: Concrete consist of a mix of cement, fine aggregates (sand), coarse aggregates (granite) and water. The mix must be properly designed and the right amount of each material correctly batched must be used.

There are two methods of batching the ingredients of concrete; (i) by weight and (ii) by volume. Except for very large projects, batching by volume would be acceptable though it will not be as accurate as batching by weight. The basis of batching by volume is generally one part of cement to n parts of sand and 2n parts of granite. The coarse aggregate is usually twice the fine aggregate whereas the ratio of cement to fine aggregate depends upon the designed strength of concrete. The ratio being less when the strength needed is great and vice versa.

The proportion of cement to aggregate depends on the strength, permeability and durability required. In general concrete works, the equivalent of 1:2:4 concrete mix is suitable for general construction for economical mix of moderate strength.

Today, except in small sites, batching is by weight. The mix ratios with specific Characteristic strength are listed below.

1:2:4	20N/mm^2
1:1:5:3	25N/mm^2
1:1:2	30N/mm^2

2.9.2 Mixing of Concrete: The mixing operation consists essentially of rotation and stirring, the objective being to coat the surface of all the aggregate particles with cement paste and to blend all the ingredients of concrete into a uniform mass, this uniformity must not be disturbed by the process of discharging from the mixer.

The usual type of mixer is a batch mixer, which means that one batch of concrete is mixed and discharged before any more materials are put into the mixer.

There are four types of mixers as follows:

(i) Tilting drum mixer

(ii) Non tilting drum mixer

(iii) Pan type mixer and

(iv) Dual drum mixer.

The other form of mixing of concrete is by hand mixing (for very small projects), which place the measured quantities of fine and coarse aggregate on a platform or a layer of lean concrete worked to a flat surface. The measured cement is placed on the aggregate and mixed together to obtain even colour with the aid of shovel. The measured coarse aggregate is then spread evenly on the already mixed and spread sand and cement. Water is then added and the whole mixed with shovel into a plastic state without being too wet.

2.9.3 Mixing Time: On site, there is often a tendency to mix concrete as rapidly as possible and hence, it is important to know the minimum mixing time necessary to produce a concrete of uniform composition and consequently of reliable strength. The optimum mixing time depends on the type and size of mixer, on the speed of rotation, and on the quality of blending of ingredients during charging of the mixer. Generally a mixing time of less than 1 or 1.25 minutes produce appreciable non uniformity in composition and significantly lower strength.

Table 2.1 below, gives recommended minimum mixing times.

Capacity of Mixing (m3	Mixing Time (minutes)
0.8	1
1.5	1.25
2.3	1.5
3.1	1.75
3.8	2
4.6	2.25
7.6	3.25

Schak lock F.W (1974)

2.9.4 Conveyance of Concrete

There are many methods of conveying concrete from the mixing point to where it is placed. Whatever may be used, it must ensure that the concrete is quickly and cheaply transported and that it does not change in proportion during drying out, by segregation or by bleeding. Some of the means by which concrete are being conveyed are as listed below:

1) By lorry,
2) By steel skips and buckets,
3) By the use of wheel barrows,
4) By pipelines,
5) By cranes,
6) By monorail transporters

2.9.5 Placing Concrete

After mixing the concrete with water it should be used up within 30 minutes ie before the initial setting of cement starts. Concrete should be properly placed to ensure that it can be well compacted into a homogeneous mass. For uniform result, the operation should be directed by an experienced supervisor. Improper placing results in serious defects such as segregation, bleeding and honey combing.

2.9.6 Compaction of Concrete

The process of compacting concrete by vibration consists essentially of elimination of entrapped air and forcing the particles into a closer and denser configuration. Both compaction by hand and compaction by vibration can produce good quality concrete with the right mix and workmanship. Adequate compaction increases the density of concrete and also prevents abrasion in concrete structures.

2.9.7 Curing

The condition under which concrete is allowed to set and harden after being placed and compacted in formwork is referred to as curing. After concrete has been placed and compacted, the construction cannot be regarded as finished until a period of time has elapsed to allow the concrete to reach a suitable strength. This can only be possible if the curing conditions after placing are suitable to allow strength to develop properly.

Control of curing conditions must be properly exercised to achieve the desired result. The conditions to be controlled are those which have effect on the hydration of concrete namely, temperature and moisture content. Concrete should be protected during the first stage of hardening, from low temperature in cold weather and from drying conditions such as wind and hot sunshine. Curing may be done using any of the following methods:

a. By submerging under water,

b. By sprinkling of water at intervals,

c. By spreading wet sand on the surface of the concrete slab until the curing period elapses,

d. By spreading hessians* on top of the slab and making them overlap well on each other,

e .By spreading burlap on top of the slab until the curing period elapses

f. By drying under air at controlled ambient temperature.

2.10 Concrete Performance in Fire

Everyday examples and international statistics provide ample evidence of concrete's fire protecting properties, and so building owners, insurers and regulators are making concrete the material of choice, increasingly requiring its use over other construction materials. By specifying concrete, you can be sure you have made the right choice because it does not add to the fire load, provides fire shielded means of escape, stops fire spreading between compartments and delays and structural collapse, in most cases preventing total collapse.

In comparison with other common construction materials, concrete offers superior performance on all relevant fire safety criteria, easily and economically.

Table 2.2 Unprotected Construction Materials Performance in Fire

Unprotected Construction Material	Fire Resistance	Combustibility	Contribution to Fire Load	Rate Of Temperature Rise Across a Section	Built in Fire Protection	Reparability After fire	Protection for Evacuees and Fire Fighters
Timber	Low	High	High	Very low	Very low	Nil	Low
Steel	Very low	Nil	Nil	Very high	Low	Low	Low
Concrete	High	Nil	Nil	Low	High	High	High

Joseph S. (2011) Researching fire performance of constituents materials in house. Pp72.

2.11. Fire Resistance

In fire, concrete perform well both as an engineered structure, and as a material in its own right.

Because of concrete's inherent material properties, it can be used to minimize fire the lowest initial cost while requiring the least in terms of ongoing maintenance in most cases. Concrete does not require any additional fire protection because of its build – in – resistance to fire. It is a non – combustible material (i.e it does not burn), and has a slow rate of heat transfer. Concrete ensures that structural integrity remains, fire compartmentation is not compromised and shielding from heat can be relied upon.

2.12.0 Benefits

2.12.1 Concrete as a Material

Concrete does not burn – it cannot be set on fire unlike other materials in a building and it does not emit any toxic fumes when affected by fire.

Concrete is proven to have a high degree of fire resistance and in the majority of applications, can be described as virtually fireproof. This excellent performance is due in the main to concrete's constituent materials (cement and aggregates) which chemically combined within concrete, form a material that is essentially inert and, importantly for fire safety design, has relatively poor thermal fire shield not only between adjacent spaces, but also to protect itself from fire damage.

2.12.2 Concrete Strictures

Concrete structures perform well in fire. This is because of the combination of the inherent properties of the concrete itself, along with the appropriate design of the structured elements to give the required fire performance and the design of the overall structure to ensure robustness.

Fire performance is the ability of a particular structural, element (as opposed to any particular building material) to fulfill its designed function for a period of time in the event of a fire. These criteria appear in UK and European fire safety codes.

2.12.3 Concrete fire Proof/advantage

The impact of major fire in structures were limited due to the fire resistance of the concrete structure.

Using concrete in building and structures offers exceptional levels of protection and safety in fire.

1. Concrete does not burn, and does not add to the fire load.
2. Concrete has high resistance to fire, and stops fire spreading.
3. Concrete is an effective fire shield, providing safe means of escape for occupants and protection for firefighters.
4. Concrete does not produce any smoke or toxic gases, so helps reduce the risk to occupants.
5. Concrete does not drip molten particles, which can spread the fire.
6. Concrete restricts a fire, and so reduces the risk of environmental pollution.
7. Concrete provide built – in fire protection – there is normally no need for additional measures.
8. Concrete can resist extreme fire conditions, making it ideal for storage premises with a high fire load.
9. Concrete's robustness in fire facilitates fire fighting and reduces the risk of structural collapse.
10. Concrete is easy to repair after a fire, and so helps businesses recover sooner.
11. Concrete is not affected by the water used to quench a fire.
12. Concrete pavements stand up to the extreme fire conditions encountered in tunnels.

Sullivan P. J and Shanshar R. (1992).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

The aim of this research work is to determine the effects of fire on concrete. In order to achieve useful results the mix ratio used in the production of concrete cube was 1:2:4 so as to check the variation in strength of the concrete cubes, after been subjected to varying temperature. Physical test were also carried out in order to determine the quantity of materials required for the mix. Materials used for this research work include:-

i. Ordinary Portland cement (Dangote)

ii. Portable water (drinkable water)

iii. Aggregates (coarse and fine)

3.1 SOURCE OF WATER

The drinkable water used was collected from civil engineering laboratory pump which is a product of Niger State Water Board.

3.2 TESTING OF MATERIALS

During the research work the following tests were carried out:-

i. Moisture content test

ii. Specific gravity

iii. Bulk density

iv. Sieve analysis

v. Void ratio

vi. Porosity

3.2.1 MOISTURE CONTENT

Since water absorption represents the water contained in the aggregate in a saturated surface – dry condition, we can define moisture content as the water in excess of the saturated and surface-dry condition. Thus the total water content of moist fine aggregate is equal to the sum of absorption and moisture content.

When fine aggregate (sand) is exposed to rain, it tends to absorb water and further wetting causes it to be surrounded by a film of moisture which is important in the design of concrete mixes. In most cases, this free moisture tends to off-set the workability by altering the water-cement ratio. Thus, it is vital to determine the moisture content of sand and adequately allow for the calculating quantities.

i. Apparatus

Electric oven

Moisture content cans

Samples of materials

Weighing balance

ii. Test procedure

The weight of the can only was first determined as W_1 after which the weight of the sample plus the can was also determined and read as W_2. The can and the sample were then placed in the oven for a period of 24hours. After this, the weight of the can plus the oven dried sample was taken as W_3.

The moisture content of the aggregate is given by the expression:

$$\text{Moisture content (mc)} = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \ldots \text{ (from Eqn 2)}$$

Where ; W_1 = mass of container (g)

W_2 = The mass of container and wet sample (g)

W_3 = the mass of container and oven dry sample (g)

3.2.2 SPECIFIC GRAVITY

This is identified as the ratio of the mass of the material to the mass of the same (absolute) volume of water. This largely depends on the amount of voids and the specific gravities of the materials of which it is composed. It is used in the calculation of quantities of materials and is denoted by Gs

i. Apparatus

(a) A wide mouthed glass, which should be water tight.

(b) A balance of capacity not less than 3kg, readable and accurate to 0.5g and such a type as to permit the weighing of the vessel containing aggregate and water.

(c) Two soft and dry absorbent pieces of cloth each not less than 75cm by 45cm.

(d) An airtight container large enough to hold the sample.

(e) A well ventilated oven thermostatically controlled to maintain a temperature of not less than 100^0C.

(f) A swallow tray of not less than $325cm^2$

ii. Test Procedure

The samples were first screened on a 100mm BS sieve and thoroughly washed to remove fine particles of dust and immerse in clean water, in a glass vessel. The aggregates retained immersed at a temperature of about 20^0C for 24hours. Soon after immersion and at the end of soaking period, air entrapped in, or bubbles on the surface of the aggregate were removed by gentle agitation. More water was added and the vessel overflowing. Plane glass disc was allowed to slide over the mouth to ensure that no air is trapped in the vessel. The vessel was dried on the outside and weighed as (M_3) the vessel was then emptied, dried and weighed (M_1).

The aggregate was placed on a dry cloth and gently surface dried with the cloth. They were then transferred to the second cloth when the first cloth could not remove moisture further. The aggregates were then spread out, not more than one stone deep on the second cloth and left exposed to the atmosphere away from direct sunlight or any direct source of heat for 20minutes until it appeared to be completely surface dried. The aggregate were turned over once this period. The aggregates were then placed in shallow trays, in the oven of a temperature of 100^0C for 24hours. It is allowed to cool down in an air tight container and weighed as M_2. The weight of the vessel filled with water only was recorded as M_4.

$$\frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$$ ---------------- from Eqn 1

3.2.3 BULK DENSITY

Bulk Density is the weight of material in a given volume. It is used to convert quantities by volume and it is affected by several factors including the amount of moisture present and the amount of effort introduced in filling the moistures.

There are two types of bulk densities i.e compacted and uncompacted of loose bulk density which are explained in the procedure

i. Apparatus

Weighing balance

A straight metal tamping rod

A water, rigid container with accurate internal measurements.

Procedure

a. **Compacted Weight:** the metal sample divider was filled to about one-third full with thoroughly mixed sample and tamped 25strokes of the rounded end of the rod.

A further similar quantity of Sample is added and a further tamping of 25trokes is given. The samples divider was finally filled to overflowing and tamped 25times and the surplus sample (sand) struck of using the tamping rod as a straight edge. The net weighed was then taken as (W). this procedures were then followed for materials and bulk density analysed.

$$\text{Bulk Density} = \frac{W}{V} \quad \text{.................. Eqn (4)}$$

Where:

W = Weight of compacted sample (kg)

V = Volume of sample divider (M^3)

b. Uncompacted Weight: the sample divider were filled to over flowing by means of shovel, the sample being discharged from a height not exceeding 5cm above the top of the divider. The surface of the sample were then leveled with a straight edge. The net weight of the sample in the divider was then determined as (W). This procedure also were then repeated for two more trials and the loose bulk density calculated using equation (3) as shown in chapter (4)

3.2.4 SIEVE ANALYSIS

Sieve Analysis otherwise called the particle size distribution is the process of separating materials into various fractions. Each fraction consist of particles within specific limits, these being the opening of standard test sieves. These sieves, are placed one above the other with the large sieve at the top and the smallest at the bottom as per IS: 2386 (part 1) - 1963

The sample is placed from the top and the sieve given a vigorous shake mechanically or manually. At the end of the shaking, the sample retained on a given sieve represents the fraction of aggregate coarser than the retaining sieve but finer than the sieve above. Hence plotting the cumulative percentage passing against the sieve sizes gives the grading curve. Thus a good grading curves gives a good workability and minimum segregation.

i. **Apparatus**

- Materials for analysis
- Head pan
- Scoop
- Electrical sieve shaker
- Sieve cover and pan of the bottom of the sieve.
- B.S test sieves, sizes ranging from 5.00mm to 75.0μm
- A balance readable and accurate to 0.1percent of the weight of the test sample
- Iron brush

3.2.4.1 SEIVE ANALYSIS FOR COARSE AGGREGATE

i. **Apparatus**

- Electric sieve shaker
- Weighing Balance
- Set of sieves ranging from 5.00mm to 75.00mm

ii. **Procedure**

The sieves hole were cleaned using the iron brush to ensure that there was no entrapped particle. The weight of the various sieves sizes were taken and recorded and the sample was then weighed using a balance readable and accurate to 0.1percent of the weight of the test sample. The B.S sieves were then arranged in decreasing aperture size with the largest ones on top with a pan at the bottom of the smallest sieve size. The weighed sample is then poured into the top most sieves and covered with a lid to avoid splashing during vibration and removal.

The entire arrangement was then taken to the sieve shaker. It was then set to shake for ten minutes. As the vibration progresses the sieves were firmly held in position using both hands after shaking, the sieves were removed individually and weighed with the samples retained on each sieve. The weight of the samples retained on each sieve was determined by deducting the initial weight of the sieve from the final weight of the sieve plus the sample retained on them.

3.2.4.2 SIEVE ANALYSIS FOR FINE AGGREGATES

The same procedure, apparatus and mechanical process were used as that of coarse aggregates.

Result obtained and graphs are shown in chapter 4.

3.2.5 VOID RATIO

Void ratio indicates the volume of mortar required to fill the space between the coarse aggregate particles. Void ratio can be calculated from the expression.

$$\text{Void ratio} = 1 - \frac{\text{Bulk density}}{\text{Specific gravity x unit weight of water}} \quad \text{.......Eqn (5)}$$

The result of the void ratio is shown in chapter 4.

3.2.6 POROSITY

Porosity, permeability and absorption of aggregates influences the bond between it and cement paste, the resistant of concrete to freezing and thawing as well as chemical stability, resistance to abrasion and specific gravity. From the result obtained in the bulk density test, the percentage porosity can be determined from the expression given below:

$$\text{Percentage porosity} = 1 - \frac{\text{loose weight}}{\text{Compacted weight}} \times 100\,\% \quad \text{...... Eqn (6)}$$

3.3.0 TRIAL MIX DESIGN

The design of a concrete mix can be defined as the selection of the most suitable materials, i.e cement and aggregates and the most economical proportion of cement, water and the various sizes of aggregates, to produce a concrete having the required physical properties. The water cement "law applies to concrete made with light weight aggregate concrete, and it is possible to follow the usual procedure of mix design when light weight aggregate is employed.

However, it is very difficult to determine how much of the total water in the mix is absorbed by the aggregate and how much actually occupies space within the concrete i.e forms part of the cement paste. This difficulty is caused not only by the very high value of water absorption of lightweight aggregates but also by the fact that absorption varies widely in rate and some aggregates may continue at an appreciable rate for several days.

3.3.1 DESIGN OF CONCRETE MIX

The following quantities are known from the physical test that was carried out.

- Density of cement = 1441kg/m^3 (standard value)
- Specific gravity of cement = 3.15 (standard value)
- Density of sand or fine aggregates = 1549kg/m^3
- Specific gravity of sand or fine aggregates = 2.62
- Density of coarse aggregates = 1487kg/m^3
- Specific gravity of coarse aggregates = 2.65

Volume of mould = 0.15 x 0.15 x 0.15 = 0.003375m^3

The volume is multiplied by 54 = 0.00337 x 54 = 0.1823m^3

Mix ratio = 1: 2: 4

= 1 + 2 + 4 = 7

Cement volume = $^1/_7$ x 0.1823 = 0.0260m^3

Volume of fine aggregate = $^2/_7$ x 0.1823 = 0.0521m^3

Volume of coarse = 4/7 x 0.1823 = 0.1042m^3

Mass of cement required = (1441 x 0.0260) + (10% of 1441 x 0.0260)

= 37.466 + 3.7466 = 41.213kg

Mass of fine aggregate required = (1549 x 0.0521) + (10% of 1549 x 0.0521) = 80.7029 + 8.0703 = 88.7732kg

Mass coarse aggregate required = (1487 x 0.1042) + (10% of 1487 x 0.1042) = 154.9454 + 15.4945 = 170.44kg

Where 10% is for waste

Water/Cement ratio = 0.5

Mass of cement = 41.213kg

W/C = 0.5

W = 0.5 x 41.213kg

= 20.6065kg

= 21kg of water.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1.0 ANALYSIS OF RESULTS

4.1.1 MOISTURE CONTENT

TABLE 4.1 MOISTURE CONTENT TABLE FOR FINE AGGREGATES

DESCRIPTION	1	2	3
Weight of can (g) W_1	21.3	31.2	25.2
Weight of can + wet sample (g) W_2	55.6	68.3	82.2
Weight of can + dry sample (g) W_3	55.2	67.9	81.6
Weight o dry sample (g) $(W_3 - W_1)$	33.9	36.7	56.36
Weight of moisture (g) $(W_3 - W_2)$	0.40	0.40	0.62
Moisture content % $\left(\frac{W_3 - W_2}{W_3 - W_1} \times \frac{100}{1}\right.$	1.18	1.09	1.10
Average moisture content %	1.12		

TABLE 4.2 MOISTURE CONTENT OF COARSE AGGREGATE

DESCRIPTION	**1**	**2**	**3**
Weight of can (g) W_1	2.48	24.9	25.0
Weight of can + wet sample (g) W_2	114.0	105.7	101.9
Weight of can + dry sample (g) W_3	114.0	105.7	101.9
Weight of moisture (g) $(W_3 - W_2)$	0.00	0.00	0.00
Weight o dry sample (g) $(W_3 - W_1)$	89.2	80.8	96.9
Moisture content % $(\frac{W_3 - W_2}{W_3 - W_1} \times \frac{100}{1}$	0.00	0.00	0.00
Average moisture content %	0.00		

TABLE 4.3 SPECIFIC GRAVITY TEST FOR COARSE AGGREGATE

DESCRIPTION	TEST 1	TEST 2	TEST 3
Weight of cylinder (g) W_1	552.3	552.3	552.3
Weight of cylinder + sample (g) W_2	827.0	799.1	813.1
Weight of cylinder + water+ sample (g) W_3	1718.3	1700.1	1709.3
Weight of cylinder + water (g) W_4	1547.0	1547.0	1547.0
Weight of water (g) $(W_4 - W_1)$	994.7	994.7	994.7
Weight of water added to the sample (g) $(W_3 - W_2)$	891.1	901.0	896.2
Weight of sample $(W_2 - W_1)$	274.7	246.8	260.8
Weight of water displaced by sample $(W_4 - W_1) - (W_3 - W_2) = W$	103.4	93.7	98.5
Specific gravity $(W_2 - W_1)/W$	2.66	2.63	2.65
Specific Gravity (average)	2.65		

TABLE 4.4 SPECIFIC GRAVITY TEST FOR FINE AGGREGATE

DESCRIPTION	TEST 1	TEST 2	TEST 3
Weight of cylinder (g) W_1	114.4	97.6	106.0
Weight of cylinder + sample (g) W_2	172.0	146.6	158.5
Weight of cylinder + water+ sample (g) W_3	398.2	376.4	387.3
Weight of cylinder + water (g) W_4	362.5	346.5	354.5
Weight of water (g) $(W_4 - W_1)$	248.1	248.9	248.5
Weight of water added to the sample (g) $(W_3 - W_2)$	226.2	229.8	228.8
Weight of sample $(W_2 - W_1)$	57.2	49.0	52.5
Weight of water displaced by sample $(W_4 - W_1) - (W_3 - W_2) = W$	21.9	19.1	19.7
Specific gravity $(W_2 - W_1)/W$	2.63	2.57	2.67
Specific Gravity (average)	2.62		

4.13 BULK DENSITY

TABLE 4.5 BULK DENSITY FOR 20mm AGGREGATE

DESCRIPTION	LOOSE			COMPACTED		
	1	2	3	1	2	3
Weight of empty cylinder (kg) W	1.0739	1.0739	1.0739	1.0739	1.0739	1.0739
Volume of container (Vo) x 10^{-3}	1.7289	1.7289	1.7289	1.7289	1.7289	1.7289
Weight of sample + container (W_2)kg	3.598	3.690	3.644	3.870	3.992	3.931
Weight of sample (W_2-W_1)kg	2.5241	2.6161	2.5701	2.7961	2.9181	2.8571
Bulk Density Kg/m^3 $\frac{W_2 - W_1}{Vo}$	1460	1513	1487	1617	1688	1653
Average Bulk Density	1487kg/m^3			1653kg/m^3		

TABLE 4.6 BULK DENSITY FOR FINE AGGREGATE

DESCRIPTION	LOOSE			COMPACTED		
	1	2	3	1	2	3
Weight of empty cylinder W(kg)	1.0739	1.0739	1.0739	1.0739	1.0739	1.0739
Volume of container (Vo) x 10^{-3}	1.7289	1.7289	1.7289	1.7289	1.7289	1.7289
Weight of sample + container (W_2)kg	3.6680	3.8400	3.7480	4.1100	3.9990	4.0545
Weight of sample (W_2-W_1)kg	2.5941	2.7661	2.6741	3.0361	2.9251	2.9806
Bulk Density Kg/m^3 $\frac{W_2 - W_1}{Vo}$	1500	1600	1547	1756	1692	1724
Average Bulk Density	1549kg/m^3			1724kg/m^3		

VOID RATIO

$$\text{Void Ratio} = 1 - \frac{\text{Bulk Density}}{\text{Specific gravity x unit weight of water}}$$

$$\text{Void Ratio for Coarse aggregate} = 1 - \frac{1487}{2.65 \times 1000} = 0.44$$

$$\text{Void Ratio for fine aggregate} = 1 - \frac{1549}{2.62 \times 1000} = 0.41$$

POROSITY

$$\text{Porosity} = 1 - \frac{\text{Loose Bulk Density}}{\text{Compacted bulk density}}$$

While percentage porosity = porosity x 100%

$$\text{Porosity for coarse aggregate} = 1 - \frac{1487}{1653} = 0.100$$

Percentage porosity = 0.1 x 100% = 10%

$$\text{Porosity for fine aggregate} = 1 - \frac{1549}{1724} = 0.102$$

Percentage porosity = 0.102 x 100% = 10.2%

4.1.6 SIEVE ANALYSIS

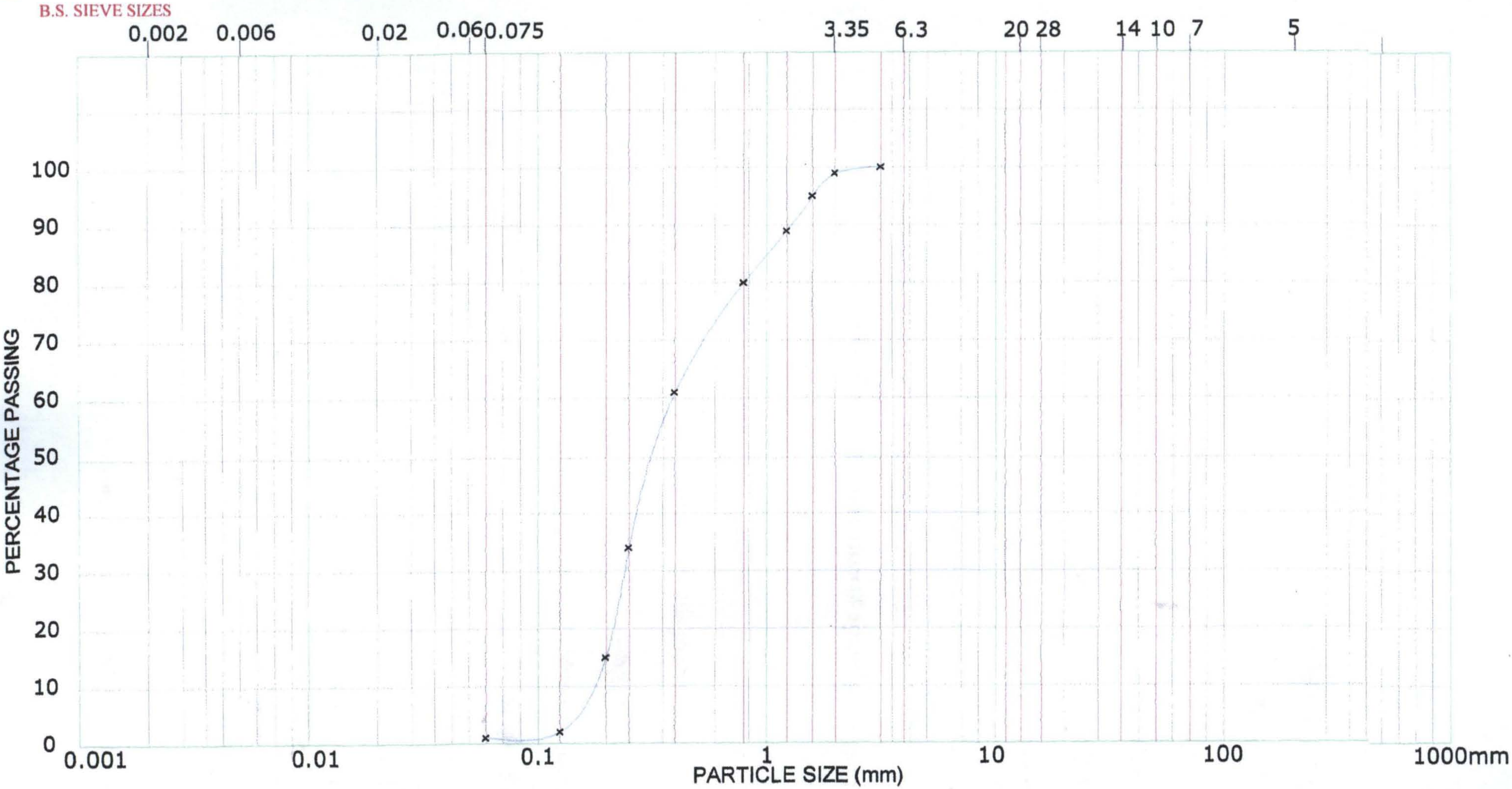
TABLE 4.7 PARTICLE SIZE ANALYSIS FOR FINE AGGREGATE

Weight of Sample: 500g

Sieve No	Weight Retained	Cum. Weight Retained	% Retain	Cum % Retain	% Passing
5.00mm	0	0	0.00	0.00	100.00
3.35mm	4.4	4.4	0.88	0.88	99.12
2.00mm	17.2	21.6	4.32	5.20	95.68
1.18mm	34.2	55.8	11.16	16.36	88.84
850μm	41.2	97	19.40	35.76	80.60
600μm	98.1	195.1	39.02	74.78	60.98
425μm	134	329.1	65.82	140.60	34.18
300μm	98	427.1	85.42	226.02	14.58
150μm	64	491.1	98.22	324.24	1.78
75μm	5.8	496.9	99.38	423.62	0.62
Pan	3.1	500	100.00	523.62	0.00

$$\text{Percentage retained} = \frac{\text{mass retained}}{\text{Total measurement}} \times 100$$

Commutative percentage passing = 100 – cumulative percentage Retained



CLAY	FINE SILT	MEDIUM SILT	COARSE SILT	FINE SAND	MEDIUM SAND	COARSE SAND	FINE GRAVEL	MEDIUM GRAVEL	COARSE GRAVEL	COBBLES	BOULDERS

Specimen Identification	Description of sample	Sample Depth (m)	EMC %	LL %	PL %	PI %	No. 5	No. 7	No. 10	No. 14	No. 18	No. 25	No. 36	No. 52	No. 72	No.100	No.150	No.200	CLAY %	C kN/m	Ø	Permeability mm/sec
SAND	SHARP SAND	0.6						93.7	89.0	86.9		81.3	80.8		73.1	71.2		67.7				

i Coefficient of uniformity (Cu) = $\frac{D_{60}}{D_{10}} = \frac{2.10}{1.00} = 2.10$

ii Coefficient of concavity (Cc) = $\frac{D_{30}^2}{D_{10} \times D_{60}} = \frac{1.65^2}{1.00 \times 2.10} = 1.30$

Where D_{10}, D_{30} and D_{60} are points where cumulative percentage passing at 10, 30 and 60 cuts the curve on particle size.

TABLE 4.8 PARTICLE SIZE ANALYSES FOR COARSE AGGREGATE

Weight of sample: 1000g

Sieve No.	Weight Retained	Cum. Weight Retained	% Retain	Cum. % Retain	% Passing
28.0mm	**0**	**0**	**0**	**0**	**100**
20.0mm	**403.2**	**403.2**	**40.32**	**40.32**	**59.68**
14.0mm	**476.5**	**879.7**	**87.97**	**128.29**	**12.03**
10.0mm	**107.2**	**986.9**	**98.69**	**226.98**	**1.31**
6.30mm	**12.6**	**999.5**	**99.95**	**326.93**	**0.05**
5.00mm	**0.0**	**999.5**	**99.95**	**426.88**	**0.05**
3.35mm	**0.0**	**999.5**	**99.95**	**526.83**	**0.5**
Pan	**0.5**	**1000**	**100**	**626.83**	**0**

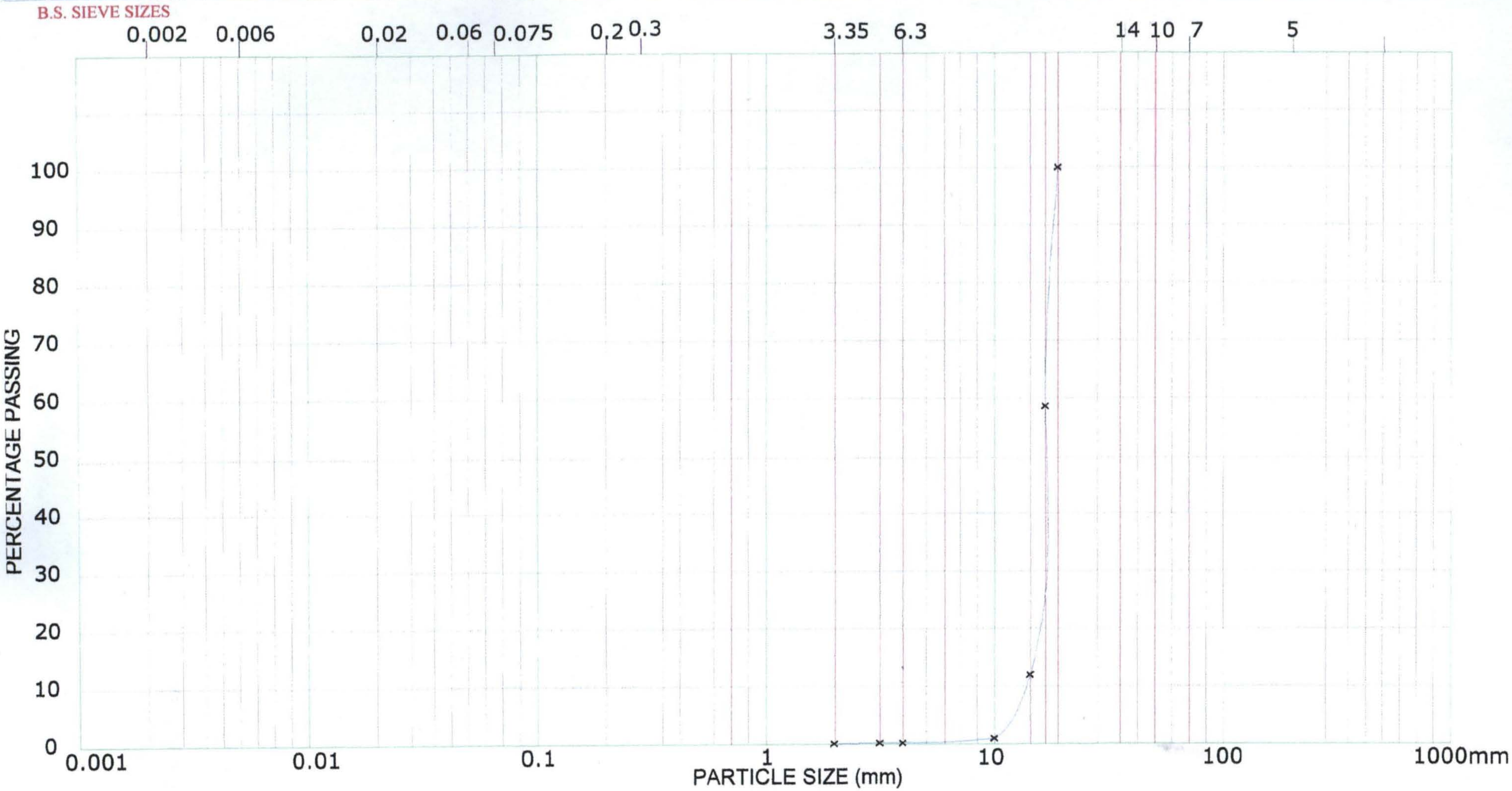
Fig 3.1 Table of particle size analysis for coarse aggregate.

Percentage retained = $\frac{\text{mass retained}}{\text{Total measurement}} \times 100$

Cumulative Percentage Passing = 100 – Cumulative Percentage Retained

i. Coefficient of uniformity (Cu) = $\frac{D60}{D10} = \frac{0.021}{0.017} = 1.24$

ii. Coefficient of concavity (Cc) = $\frac{D30\ 2}{D10 \times D60} = \frac{0.0215\ 2}{0.017 \times 0.012} = 1.29$



CLAY	FINE SILT	MEDIUM SILT	COARSE SILT	FINE SAND	MEDIUM SAND	COARSE SAND	FINE GRAVEL	MEDIUM GRAVEL	COARSE GRAVEL	COBBLES	BOULDERS

Specimen Identification	Description of sample	Sample Depth (m)	EMC %	LL %	PL %	PI %	No. 5	No. 7	No. 10	No. 14	No. 18	No. 25	No. 36	No. 52	No. 72	No.100	No.150	No.200	CLAY %	C KN/m	Ø	Permeability mm/sec
GRAVEL	CRUSHED GRAVEL	0.6						93.7	89.0	86.9		81.3	80.8		73.1	71.2		67.7				

APPENDIX A: PARTICLE SIZE DISTRIBUTION CURVE

Where D10, D30 and D60 are point where cumulative percentage passing at 10, 30 and 60 cuts the curve on particle size.

4.1.7 COMPACTING FACTOR TEST

TABLE 4.9 Compacting factor value

Weight of Cylinder kg	Mix Ratio	Water/Cement Ratio	Mass of partially compacted concrete kg	Mass of fully compacted concrete kg	Compacting factor
1.88	1:2:4	0.5	13.42 – 1.88 = 11.54	15.1 – 1.88 = 13.22	11.54/13.22 = 0.87

4.3 RESULT OF COMPRESSIVE STRENGTH TESTS

TABLE 4.10 STRENGTH OF CUBES CURED AND HEATED AT VARIOUS TEMPERATURE

MARK ON CUBES	TEMPERATURE (°C)	INITIAL WEIGHT (KG)	INITIAL DENSITY (KG/m³)	AVERAGE INITIAL DENSITY (KG/m³)	FINAL WEIGHT (KG)	FINAL DENSITY (KG/m³)	AVERAGE FINAL WEIGHT (KG/m³)	DIFFERNCE IN DENSITY (KG/m³)	CRUSHING VALUE (KN)	STRENGHT FORCE/AREA (N/mm²)	AVERAGE STRENGHT (N/MM²)
01	AMBIENT	8.34	2471	2639	8.25	2444	2593	46	348	15467	15.607
02		9.02	2673		8.84	2619			326	14.489	
03		9.00	2667		8.92	2643			370	16.444	
04		9.10	2696		8.91	2640			358	15.911	
05		8.89	2634		8.70	2578			345	15.333	
06		9.08	2690		8.88	2631			360	16.000	
07	50	8.78	2601	2681	8.52	2524	2626	55	376	16.711	15.741
08		9.01	2670		8.86	2625			354	15.733	
09		9.09	2693		8.82	2613			332	14.756	
10		9.12	2702		9.00	2667			385	15.911	
11		9.31	2759		9.11	2700			350	15.556	
12		8.98	2661		8.86	2625			355	15778	
13	100	8.86	2625	2699	8.34	2471	2627	72	394	17.511	16.067
14		9.40	2785		9.17	2717			330	14.667	
15		9.20	2726		9.00	2667			375	16.667	
16		9.00	2667		8.88	2631			350	15.556	
17		9.30	2756		9.01	2670			368	16.356	
18		8.9	2637		8.79	2604			352	15.644	

MARK ON CUBES	TEMPERATURE (^{O}C)	INITIAL WEIGHT (KG)	INITIAL DENSITY (KG/m^3)	AVERAGE INITIAL DENSITY (KG/m^3)	FINAL WEIGHT (KG)	FINAL DENSITY (KG/m^3)	AVERAGE FINAL WEIGHT (KG/m^3)	DIFFERNCE IN DENSITY (KG/m^3)	CRUSHING VALUE (KN)	STRENGHT $\frac{FORCE}{AREA}$ (N/mm^2)	AVERAGE STRENGHT (N/MM^2)
19		9.02	2673		8.48	2513			398	17.689	
20		9.12	2702		8.65	2563			390	17.333	
21		8.66	2566		8.17	2421			402	17.867	
22	150ºC	8.80	2607	2651	8.33	2468	2507	144	400	17.778	17.56
23		9.00	2667		8.50	2519			392	17.422	
24		9.08	2690		8.63	2557			388	17.244	
25		8.62	2554		8.08	2394			396	17.600	
26		8.92	2643		8.36	2477			408	18.133	
27	200	9.12	2702	2649	8.58	2542	2491	158	420	18.667	18.09
28		9.00	2667		8.46	2507			408	18.133	
29		8.88	2631.1		8.38	2483			410	18.222	
30		9.10	2696		8.58	2542			400	17.778	
31		9.44	2797		8.88	2631			460	20.444	
32		9.30	2756		8.68	2572			498	22.133	
33	250	9.00	2667	2721	8.44	2501			479	21.289	
34		9.36	2773		8.86	2625	2555	166	489	21.733	21.44
35		9.10	2696		8.58	2542			483	21.467	
36		8.89	2634		8.29	2456			486	21.600	

MARK ON CUBES	TEMPERATURE (^{O}C)	INITIAL WEIGHT (KG)	INITIAL DENSITY (KG/m^3)	AVERAGE INITIAL DENSITY (KG/m^3)	FINAL WEIGHT (KG)	FINAL DENSITY (KG/m^3)	AVERAGE FINAL WEIGHT (KG/m^3)	DIFFERNCE IN DENSITY (KG/m^3)	CRUSHING VALUE (KN)	STRENGHT FORCE/AREA (N/mm^2)	AVERAGE STRENGHT (N/MM^2)
37	300°C	8.80	2607	2707	8.30	2459	2553	154	570	25.333	25.319
38		9.58	2839		9.00	2667			580	25.778	
39		9.02	2673		8.49	2516			560	24.889	
40		8.90	2637		8.42	2495			560	24.889	
41		9.41	2788		8.90	2637			590	26.222	
42		9.10	2696		8.59	2545			558	24.800	
43	350°C	8.44	2501	2699	7.88	2335	2503	196	410	18.222	18.489
44		9.50	2815		8.79	2604			414	18.400	
45		9.44	2797		8.74	2590			420	18.667	
46		9.10	2696		8.40	2489			418	18.578	
47		8.88	2631		8.26	2447			424	18.844	
48		9.3	2756		8.62	2554			410	18.222	
49	400°C	9.09	2693	2640	8.42	2495	2441	199	380	16.889	17.067
50		8.90	2637		8.28	2453			390	17.333	
51		8.58	2542		7.96	2359			380	16.889	
52		8.70	2578		8.06	2388			394	17.511	
53		9.10	2696		8.48	2513			374	16.622	
54		8.82	2696		8.22	2436			386	17.156	

DENSITY Of Cube = $\frac{\text{Weight of Cube}}{\text{Volume of Cube}}$

Volume of cube = $(0.15 \times 0.15 \times 0.15)m^3$

Compressive strength = $\frac{\text{Load}}{\text{Area of cube}}$

Area of cube = $(0.15 \times 0.15)\ m^3$

TABLE 4.11

Average Compressive Strength Of 28 Days Cured Concrete and heated at Varying Temperature.

Temperature (^oC)	**Strength (N/mm^2)**	**Difference in Density (initial - final)kg/m^3**
Ambient	15.61	46
50	15.74	55
100	16.07	72
150	17.56	144
200	18.09	158
250	21.44	166
300	25.32	154
350	18.49	196
400	17.07	199

4.5.0 Discussion Of Results

4.5.1. Bulk density of aggregate

As earlier discussed, bulk density is the actual mass that would fill a container of unit volume. This density is used to convert quantities by mass to quantities by volume. The average bulk density is giving in table 4.5 and 4.6 for coarse aggregate; Uncompacted bulk density is 1487kg/m^3 and compacted bulk density is 1653kg/ m^3 For fine aggregate 75ym – 3.35; uncompacted bulk density is 1549kg/m^3 and compacted bulk density is 1724kg/m^3 .The aggregate used falls within the range 1200 – 1800kg/ m^3 specified by BS 812, part 2: 1975 for natural aggregate. However since bulk density depend on how densely the aggregate is parked and size distribution, therefore the lower sizes of aggregate gives higher bulk density because they can be closely packed.

4.5.2 Specific Gravity

Specific gravity specifications for rock groups range between 2.6 to 3.0 for natural aggregates. From the result obtained, the specific gravity of the aggregate used fell within specified range (2.65).

4.5.3 Porosity and void ratio of the aggregate.

Porosity and void ratio have greater effect on durability of concrete. The results rate at which water penetrates into aggregates depends on the pore size. The results. The percentage porosity of the aggregates falls within the specified (0 - 50) % .

(Neville: 1990).

4.5.4 Sieve Analysis

The co-efficient of uniformly of coarse and fine aggregates has a large range of particle size distribution compared to that of coarse aggregates. A well graded soil has a co-efficient of concavity ranging from 1 to 3, and the values of co-efficient of concavity obtained in this research work are 1.30 for fine aggregate 1.29 for coarse aggregate, which shows that the samples are well graded.

4.5.5 Slump test of concrete.

The test primarily measures the consistency of plastic concrete and workability. It only detect changes in workability, the slump test for mix ratio 1:2:4 shows true slump and shear slump was exhibited by the aggregate in the fresh concrete mix.

4.5.6 Compacting factor test of concrete.

The test measures the degree of compaction of work and reasonably applicable for assessment of workability of concrete work. BS 1981: part 103: specified that for normal range of concrete, the compacting factor lies between 0.80 and 0.92. The result obtained fall between 0.80 and 0.92. The result obtain lies within this range.

4.5.7 Compressive Strength.

The resulst of strength development when cured for 28 days and subsequent subjection to varying temperature are given in table 4:11

The result shows that the compressive strength of concrete cubes at ambient temperature was retain even when subjected to 50°c and 100 °c, 200 °c, 250°c and 300°c respectively but start falling when 300°c was exceeded. This shows the concrete structure will maintain the stability of the structure for as long as possible which is obviously desirable for survival, escape and fire fighting.

CHAPTER FIVE

5.1.0 CONCLUSION AND RECOMMENDATION

5.1.1 CONCLUSION

According to the results obtained in chapter four table 4.11 compressive strength of concrete after been subjected to varying temperature shows that there was reduction in weight and density.

The concrete is non-combustible and due to its low thermal conductivity most of its strength was retained in a typical fire/temperature. Concrete as a load bearing element when subjected to temperature up to 30°c (≤300°c) retain it integrity. It was noticed that concrete strength after 28days curing under ambient condition was retained even when subjected to 50°c and 100°c for one hour each. Beyond these temperature the concrete strength increases when subjected to 150°c, 200°c, 250°c and 300°c. The strength start falling when the temperature start exceeding 300°c to 350°c and 400°c as show in table 4.11 and 4.12.

Concrete excellent and proven fire resistance properties deliver protection of life, possessions and environment in the case of fire. It responds effectively to all of the protective aims set out in European legislation and fire protection criteria in Euro code 2; Resistances ® Separation(E) and Isolation(I). form this research work it could be seen that in the event of fire, concrete structure will maintain the stability of the structure for as long as possible which is obviously desirable for survival, escape and fire fighting. This excellent performance is due in the main to concrete's constituent materials (i.e cement and aggregates) which when chemically combined within concrete, form a material that is essentially inert and, importantly for fire safety design, has relatively poor thermal conductivity. It is this slow rate of heat transfer (conductivity) that makes it retain it's compressive strength and will act as an effective fire shield not only between adjacent but also to protect itself from fire damage.

5.2 Recommendations

Based on the experiment carried out, I hereby recommend that concrete elements should be mostly use in structures, especially where the structure is prone to fire outbreak, because it is non-combustible and due to its low thermal conductivity most of its strength is retained in a typical fire (structural integrity retain for temperature up to $300^{o}c$).

Concrete element not only does it have superior fire resistance properties, but it also provides thermal mass and acoustic insulation for this additional reason I strongly recommend that concrete structure be use in most of our structures for its long-term fire safety advantage.

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