DEVELOPMENT OF PROTOTYPE MOULD FOR CURING IN-SITU CONCRETE ELEMENTS

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ABSTRACT

This research presents the development of prototype curing mould for curing in-situ concrete elements. It focuses on improving concrete curing on-site when using water in compliance to BS 1881-PART-111, in other to achieve the same flexural and compressive strength of concrete cured in the laboratory. Beam specimens of size 150mm × 150mm × 700mm were casted. Also, column specimens of size 100mm × 100mm × 300mm were casted. The flexural strength of the beams and the compressive strength of the columns cured by full immersion method using some developed water curing moulds after 7, 14, 21, and 28 were determined using the appropriate equipment and formulas in each case. Also, the flexural strength of the beams and the compressive strength of the columns cured by sprinkling water twice daily were determined. Flexural strength of 3.1N/mm^2 obtained by immersing concrete fully in water poured in the curing moulds for 7 days, was seen to be greater than the 2.5N/mm^2 obtained by the same concrete when it was sprinkled with water twice daily for 28days. Variations in results proved the need for development of better curing options on-site to enhance the achievement of optimal strength. Moulds designed for this experiment proved to be 70% efficient in minimising water loss during curing, and they are easy to assemble together. These curing moulds were designed as prototypes for producing better and more economical samples to be used on-site. Hence, they can be further enhanced in terms of design and materials for production to accommodate specific conditions on-site. Structural Engineers usually rely on specified compressive strength to be achieved from concrete cured under ideal conditions, to produce structural designs. Due to poor curing, such compressive strengths are rarely achieved on-site and this can reduce the overall performance of such structures.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

On a visit to each of the five different building construction sites around the Federal Capital Territory (FCT) Abuja and five other sites in Kaduna State, it was observed that all ten sites adopted the water sprinkling technique for curing in situ concrete elements. Though sprinkling water on concrete can be an adequate method for curing if done properly, it requires constant spraying of water at regular intervals to maintain the needed temperature for the concrete during the entire hydration period, especially on sunny days. The resource expenditure in form of water required for this process proved to be uneconomical and thus most of the construction sites reduced the interval between sprinkling water on the concrete to two times only on a daily basis, throughout the required number of days for curing. Usually this was done early in the morning and later in the evening. A period was observed at noon when all or part of the surface of the concrete was visibly left dry, hence undermining the curing process.

Improper curing is considered as one of the significant reasons for concrete failures in structural members of a building such as columns, beams, slabs and foundation. These failures are most times visible in the form of cracks on the surface or invisible in the form of internal cracks. Vertical members like the columns in particular are the most victimized. A Column requires optimal strength because it supports the entire load from the slabs and beams and transfers the loads to the foundation. Unfortunately adequate curing of the column is rarely done and this leads to a reduction of the durability of such structures. The compressive strength of hardened concrete is one of the most important and useful properties of concrete. In most of its structural uses, concrete is used mainly to resist compressive stresses thus making the properties of concrete ingredients measured in terms of the compressive strength. Also compressive strength of concrete is used as a qualitative measure of other properties of hardened concrete. Concrete develops more strength (both compressive and flexural) over a period of time after final setting has occurred and this strength can only be maximised if the concrete is properly cured and full hydration of cement is achieved at a controlled temperature. This implies that a secondary factor which helps to increase the final strength achieved, is the curing of the concrete. This forms the background of this work.

1.2 Statement of the Research Problem

As part of the specifications of the British Standard BS 8110-1997, Structural Engineers are to adopt specified compressive strength to be achieved from concrete cured under ideal conditions, to produce structural designs. Due to poor curing, such compressive strengths are rarely achieved on site and this can reduce the overall performance of such structures. Also, the presence of cracks in reinforced concrete allows percolation of water and hence causes rust in the steel reinforcement which reduces the durability of the reinforced concrete.

There are some disadvantages of not curing concrete properly, these include:

a) Increased permeability
b) Development of visible cracks
c) Development of defective microstructure
d) Development of poor strength

1.3 Aim and Objectives of the Study

The aim of this research is to develop prototype curing moulds with water retaining ability, for curing in situ concrete structural elements, and to determine their importance.

1.3.1 Objectives

The objectives of this research are to:

1. Determine the physical and mechanical properties of the aggregates.
2. Determine the workability of the fresh concrete.
3. Construct suitable prototypes of moulds that can be used for the curing of concrete elements, and determine the rate of loss of water from the joints of these moulds when in use.
4. Determine the compressive and flexural strength of all the specimens, and compare differences in terms of compressive and flexural strength of the concrete elements cured using the curing moulds, to those cured using water sprinkling technique.

1.4 Justification for the Study

Curing of concrete is a method by which freshly prepared concrete that has undergone final setting is protected from rapid loss of moisture required for complete hydration. Concrete curing helps to increase the compressive strength of the concrete and to decrease the permeability of hardened concrete. Curing also aids partial or total prevention of visible cracks and enable the formation of a perfect microstructure within the concrete elements, thus enhancing the flexural and compressive strength of the concrete. The difference in flexural and compressive strength observed between concrete cured on site to that cured in the laboratory creates the need to design a mould to be used on site to balance this difference.

1.5 Scope of the Study

This research focuses on improving concrete curing on site when using water in compliance to BS 1881-PART-111, in other to achieve the same flexural and compressive strength of concrete cured in the laboratory. How can water tight moulds be used to provide ideal conditions for adequate and efficient control of temperature? In what ways can they be used to improve the efficiency of using water for curing concrete on site?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concrete

According to Edward (2008), Portland Cement Concrete is a composite material made by combining cement, supplementary cementing materials, aggregate, water, and chemical admixtures in suitable proportions and allowing the resulting mixture to set and harden over time. It is the basic material used in most civil engineering structures because it provides a high compressive strength to such structures and it last longer when compared to other construction materials. It is an important construction material and used mainly to resist compressive stresses. It is an extremely versatile material being used in the production of anything from nuclear radiation shields to playground structures and bridges. It is able to be used in such a wide variety of applications because it can be poured into any shape easily, reinforced with steel or glass fibres, precast, coloured, has a variety of finishes and even set under water. Concrete in a freshly mixed state can be moulded into any shape. This is its main advantage as a construction material. It proves to be a universal construction material because it can be easily manipulated to suit the environment and prevailing climatic conditions. After concrete has hardened, it can be used as a structural (load bearing) element. Users may be involved in the factory production of pre-cast units, such as panels, beams, road furniture, or may make cast-in-situ concrete such as building superstructures, roads, dam. These may be supplied with concrete mixed on site, or may be provided with "ready-mixed" concrete made at permanent mixing sites.

Engineers are constantly trying out various mix design to get better and more improved concrete for construction, in order to minimise or totally prevent failure when in use. The major properties of concrete that are taken into consideration for design are the compressive and flexural strength of the concrete. Tensile strength of concrete is usually not considered directly in design (normally assumed to be zero) though its value is still needed because cracking in concrete tend to be of tensile behaviour (Zain *et al*., 2002). The various constituents of concrete can be varied or in some situations substituted with other materials to suit the construction to be undertaken. According to Shetty (1982), strength of concrete is its resistance to rupture. The ratio of water to cement in any concrete mixture determines the strength of the hardened concrete as proposed in Duff Abram's law (1918). This theory holds true before setting of fresh concrete. Beyond this point, what affects the final strength achieved by concrete? Strength is also affected by the quality of the constituent materials and the mixing and curing methods (Zain *et al*., 2002). Increase in strength with age continues as long as any un-hydrated cement is still present, the relative humidity in the concrete is approximately 80% or higher, and the concrete temperature is favourable. To maintain this increase in strength, concrete must be properly cured. (Edward, 2008).

Curing of concrete is a method by which freshly prepared concrete that has undergone final setting is protected from rapid loss of moisture required for complete hydration. Concrete curing helps to increase the compressive strength of the concrete and to decrease the permeability of hardened concrete.

Concrete failures at site are caused by one or more of the following reasons.

a) Wrong concrete mix design
b) Use of substandard materials
c) Inadequate mixing, placing and compaction
d) Poor curing

A study by Omenilu *et al*. (2016) on building collapse in Nigeria (1971-2016), showed that the leading causes of building collapse within this period are structural failures (24.9%), substandard materials (13.2%), poor workmanship (12.2%), faulty design (8.8%), use of quacks (7.3%), and inappropriate foundation (6.8%). All these are clearly man-made conditions and can be avoided if there is strict adherence to building regulations and codes.

Cement; Cements may be defined as adhesive substances capable of uniting fragments or masses of solid matter to a compact whole (Lea, 1971). Cement can also be described as a material with adhesive and cohesive properties which makes it capable of bonding mineral fragments into a compact whole. For constructional purposes, the meaning of the term cement is restricted to the bonding materials used with stones, sand, bricks, building blocks, etc. the principal constituents of this type of cement are constituents of lime. The cement of interest in construction have the property of setting and hardening under water by virtue of chemical reaction with it and are therefore called hydraulic cement. According to Neville (1987), Portland cement clinker is a hydraulic material which should consist of at least two-third by mass of calcium silicates ($3CaO.SiO_2$ and $2CaO.SiO_2$), the remainder consists of Aluminium and Iron containing clinker phases and other compounds. The ratio of CaO to SiO_2 shall not be less than 2.0. The magnesium contents (MgO) shall not exceed 5.0% by mass. In order to achieve the desired setting qualities in the finished product, quantity (2-8%, but typically 5%) of calcium sulphates (usually gypsum or anhydrite) is added to the clinker, and the mixture is finely ground to form the finished cement powder. This is achieved in a cement mill.

On adding water to cement, a reaction starts and forms spongy mass known as gel. During this process, a large quantity of heat is liberated. In cement, C_2S and C_3S are responsible for hydration of cement; C_3A is responsible for immediate stiffening of cement paste; C_4AF with gypsum accelerates silicates hydration which facilitates initial setting of concrete while Sclerenchyma material and Parenchyma material, "pith fibre" makes bagasse particularly problematic as an admixture/retardant component. The most common use for Portland cement is in the production of concrete. Portland cement is also used in mortars (with sand

and water only) for plasters and screeds, and in grouts (cement/water mixes squeezed into gaps to consolidate foundations, road-beds, etc.). When water is mixed with Portland cement, the product sets in a few hours and hardens over a period of weeks. These processes can vary widely depending upon the mix used and the conditions of curing of the product, but a typical concrete sets in about 6 hours and develops a compressive strength of 8 MPa in 24 hours. The strength rises to 15 MPa at 3 days, 23 MPa at 1 week, 35 MPa at 4 weeks and 41 MPa at 3 months. In principle, the strength continues to rise slowly as long as water is available for continued hydration, but concrete is usually allowed to dry out after a few weeks and this causes strength growth to stop.

There are five types of Portland cements with variations of the first three according to ASTM C150.

Type I Portland cement is known as common or general purpose cement. It is generally assumed unless another type is specified. It is commonly used for general construction especially when making precast and precast-prestressed concrete that is not to be in contact with soils or ground water. The typical compound compositions of this type are:

55% (C3S), 19% (C2S), 10% (C3A), 7% (C4AF), 2.8% MgO, 2.9% (SO3), 1.0% Ignition loss, and 1.0% free CaO.

A limitation on the composition is that the (C3A) shall not exceed fifteen percent.

Type II is intended to have moderate sulphate resistance with or without moderate heat of hydration. This type of cement costs about the same as Type I. Its typical compound composition is:

51% (C3S), 24% (C2S), 6% (C3A), 11% (C4AF), 2.9% MgO, 2.5% (SO3), 0.8% Ignition loss, and 1.0% free CaO.

A limitation on the composition is that the (C3A) shall not exceed eight percent which reduces its vulnerability to Sulphates. This type is for general construction that is exposed to moderate sulphate attack and is meant for use when concrete is in contact with soils and ground water especially in the western United States due to the high sulphur content of the soil. Because of similar price to that of Type I, Type II is much used as a general purpose cement, and the majority of Portland cement sold in North America meets this specification.

Type III is has relatively high early strength. Its typical compound composition is:

57% (C3S), 19% (C2S), 10% (C3A), 7% (C4AF), 3.0% MgO, 3.1% (SO3), 0.9% Ignition loss, and 1.3% free CaO.

This cement is similar to Type I, but ground finer. Some manufacturers make a separate clinker with higher C3S and/or C3A content, but this is increasingly rare, and the general purpose clinker is usually used, ground to a specific surface typically 50-80% higher. The gypsum level may also be increased a small amount. This gives the concrete using this type of cement a three day compressive strength equal to the seven day compressive strength of types I and II. Its seven day compressive strength is almost equal to types I and II 28 day compressive strengths. The only downside is that the six month strength of type III is the same or slightly less than that of types I and II. Therefore the long-term strength is sacrificed a little. It is usually used for precast concrete manufacture, where high 1-day strength allows fast turnover of moulds. It may also be used in emergency construction and repairs and construction of machine bases and gate installations.

Type IV Portland cement is generally known for its low heat of hydration. Its typical compound composition is:

28% (C3S), 49% (C2S), 4% (C3A), 12% (C4AF), 1.8% MgO, 1.9% (SO3), 0.9% Ignition loss, and 0.8% free CaO.

The percentages of (C2S) and (C4AF) are relatively high and (C3S) and (C3A) are relatively low. A limitation on this type is that the maximum percentage of (C3A) is seven, and the maximum percentage of (C3S) is thirty-five. This causes the heat given off by the hydration reaction to develop at a slower rate. However, as a consequence the strength of the concrete develops slowly. After one or two years the strength is higher than the other types after full curing. This cement is used for very large concrete structures, such as dams, which have a low surface to volume ratio. This type of cement is generally not stocked by manufacturers but some might consider a large special order. This type of cement has not been made for many years, because Portland-pozzolan cements and ground granulated blast furnace slag addition offer a cheaper and more reliable alternative.

Type V is used where sulphate resistance is important. Its typical compound composition is:

38% (C3S), 43% (C2S), 4% (C3A), 9% (C4AF), 1.9% MgO, 1.8% (SO3), 0.9% Ignition loss, and 0.8% free CaO.

This cement has a very low (C3A) composition which accounts for its high sulphate resistance. The maximum content of (C3A) allowed is five percent for Type V Portland cement. Another limitation is that the (C4AF) + 2 (C3A) compositions cannot exceed twenty percent. This type is used in concrete that is to be exposed to alkali soil and ground water sulphates which react with (C3A) causing disruptive expansion. It is unavailable in many places although its use is common in the western United States and Canada. As with Type IV, Type V Portland cement has mainly been supplanted by the use of ordinary cement with added ground granulated blast furnace slag or tertiary blended cements containing slag and fly ash.

Types IA, IIA, and IIIA have the same composition as types I, II, and III. The only difference is that in IA, IIA, and IIIA an air-entraining agent is ground into the mix. The air-entrainment must meet the minimum and maximum optional specification found in the ASTM manual. These types are only available in the eastern United States and Canada but can only be found on a limited basis. They are a poor approach to air-entrainment which improves resistance to freezing under low temperatures.

Types II (MH) and II (MH)A have recently been added with a similar composition as types II and IIA but with a mild heat.

Water: water is a fluid used for various purposes. When it is to be used for hydration of cement, it is required to be free from all materials that could results in weakness of concrete. Certain oxides contained in water from sources such as rainfall can result in corrosion of reinforcement used in concrete and hence weaken the concrete. Water is majorly a compound formed from the mixture of hydrogen and oxygen.

Aggregates: aggregates make up about 75% of the volume of concrete, so their properties have a large influence on the properties of the concrete (Alexander and Mindess, 2005). Aggregates usually have specific gravities in the range of 2.6 to 2.7. They are granular materials, most commonly natural gravels and sand or crushed stone, although occasionally synthetic materials such as slag or shale are used. While selecting the aggregate for a particular concrete, the following requirements should be kept in mind.

a) Economy of the mixture

b) Strength of the hardened mass and

c) Durability of the structure

Aggregates are made up of coarse and fine aggregates. Coarse aggregates comprises of stones, gravels, and boulders. While fine aggregates comprises of sand and filler. Generally, aggregates are classified as follows:

i) According to source

ii) According to mineralogical composition

iii) According to size

iv) According to mode of preparation

i) According to Sources: this is further classified into;

a) Natural aggregates

b) Artificial aggregates

a) Natural aggregates: these aggregates are formed from natural occurring material. The natural aggregates such as gravel and sand are the product of weathering and action of running water. These are derived from rocks.

b) Artificial Aggregates: these aggregates are usually produced for some special purposes as burned clay aggregates for making light weight concrete. Some of artificial aggregates are the by-product of an unrelated industrial process such as blast furnace, slag, cinder etc.

ii) According to Mineralogical Composition: this may be classified according to siliceous or calcareous.

iii) According to Mode of Preparation: here, distinction is made between aggregates reduced to its present size by natural agents and crushed aggregates obtained by a deliberate fragmentation of rock.

iv) According to Size of Aggregate Particles: this is subdivided into coarse and fine aggregate.

The effect of aggregates on the properties of concrete depends mainly on:

i) Shape and texture of particles

ii) Size of particle

iii) Quantities of impurities in aggregates

iv) Crushing strength of aggregates

v) Grading of aggregate

The following factors affect the grading of aggregates and they are:

a) Surface area of the aggregates: for a maximum size of aggregates, the larger size of the aggregates particles, the lesser the surface area of aggregate in a given mix, which will require less amount of water to wet its surface and greater proportion of the water will be available for imparting workability to the mix for a particular water/cement ratio.

b) Relative volume of space occupied by the aggregate: A satisfactorily workable mix must contain smaller materials smaller than 300 micron size including cement particles. Thus a richer mix requires a lower content of fine aggregates than a lean mix.

c) Workability of Mix: This is improved when there is an excess of paste above that required to fill the voids in the fine aggregates and also likewise to the coarse aggregate.

d) Segregation of Mix: This is defined as the separation of the constituents of a heterogonous mixture so that their distribution is no longer uniform.

The deleterious substances seen in aggregates are:

a) Impurities which interfere with the process of hydration of cement.

b) Coating on aggregates which prevent the development of good bond between aggregates and the cement paste.

c) Unsound or weak particles.

The bond strength of aggregate is the resistance developed to shear the aggregate particle from the hardened cement paste. The bonding between the cement paste and the aggregates is an important factor in the strength of concrete specially the flexural strength. Thus, the rougher the surface as that of a crushed stone, the better the bond. Greater number of crushed aggregate particle suggests weaker aggregate. Usually, aggregate used in cement concrete should be at least 10 times the strength of the hardened cement paste.

Admixtures: admixtures may be defined as the materials other than the basic ingredients of concrete added to the concrete mixture immediately before or during the mixing process to modify one or more specific properties of the concrete in fresh or hardened state. It also includes cement replacement by some materials depending on its percentage replacement.

The uses of admixtures do offer improvement or new discoveries in the properties of concrete by adjusting the proportion of cement and aggregates. Its effect on concrete is always used only at intense situations. Also, admixtures are not substitutions for a good workmanship.

There are different types of admixtures according to their characteristic effects on concrete mixture. These include;

i. Accelerating admixtures
ii. Retarding admixtures
iii. Plastics
iv. Super plastics
v. Pozzolanic admixtures
vi. Workability admixtures

2.2 Hydration of Cement

Anhydrous cement does not bind fine and coarse aggregate. It requires adhesive property only when mixed with water. The chemical reaction that takes place between cement and water is referred to as hydration of cement. The chemistry of concrete is essentially the chemistry of the reaction between cement and water. On account of hydration, certain products are formed. These products are important because they have cementing or adhesive value. The quality, quantity, continuity, stability and the rate of formation of the hydration products are important. Anhydrous cement compounds when mixed with water, reacts with each other to form hydrated compounds of very low solubility. The hydration of cement can be visualised into two ways. The first is "through solution" mechanism. In this the cement compounds dissolve to produce a supersaturated solution from which different hydrated products get precipitated. The second possibility is that water attacks cement compounds in the ‘’solid state" converting the compounds into hydrated products starting from the surface and proceeding to the interior of the compounds with time. It is probable that both "through solution" and "solid state" types of mechanism may occur during the course of reactions between cement and water. The former mechanism may predominate in the early stages of hydration in view of large quantities of water being available, and the latter mechanism may operate during the later stages of hydration.

2.3 Workability of Concrete

Road Research Laboratory U.K., who have extensively studied the field of compaction and workability, defined workability as the property of concrete which determines the amount of useful internal work necessary to produce full compaction (Neville, 1987). This property allows concrete to be transported and placed without segregation and bleeding. Thus it is defined as the physical property of concrete alone without reference to the circumstances of a particular type of construction. A good workable concrete must overcome the following;

a. Internal Friction: this is the friction between the individual particles in the concrete.
b. Surface Friction: this is the friction between concrete and the surface of the mould or reinforcement.

Factors affecting the workability of concrete are;

i. Water constant

ii. Size of aggregate particles

iii. Coarse and fine aggregate ratio

iv. Particle interference

v. Particle interlocking

vi. Admixtures

According to Gupta and Gupta (2004), Evans (a concrete technologist) found out from laboratory test that in a hot day, the water content of particular mix would have to be increased for a constant workability to be maintained. Also Sharon (a concrete technologist too) observed that upon a temperature of 104^0F (40^0C) and relative humidity between 20%-70%, no effect on slump was observed. But at 122^0F (50^0C) and below 20% humidity, the slump falls off rapidly. Also, he observed that at temperature rise from 40^0F to 100^0F, slump falls from 16cm to 7.0cm. Also, freshly mixed concrete stiffens with time due to the fact that some water from mix is absorbed by the aggregates while some is lost by evaporation particularly if the concrete is exposed directly to the sun or wind".

2.4 Setting Time of Concrete

The term setting is used to describe the stiffening of the cement paste. It is the change from a fluid to a rigid state. On adding sufficient quantity of water to cement, a paste is formed which gradually becomes plastic and finally stiff and hard. This paste is said to have set when it becomes rigid and can withstand some pressure. The setting process is accompanied by temperature changes in cement paste. The setting time of cement is found to decrease in temperature, but at 30^0 (85^0f), the setting time increases. Also, at low temperatures, setting time is retarded.

The setting period is divided into two groups;

i. Initial setting time and

ii. Final setting time

The initial setting corresponds to a rapid rise in temperature and the final setting corresponds to the peak temperature, other subdivisions include;

i. False set and
ii. Flash set

A false set is the abnormal premature stiffening of cement paste taking place in few minutes without evolving heat while flash set is that one involving evolution of heat of hydration and it's a violent reaction. Also flash set occurs when two types of cement are allowed to come in contact with each other such as in mixtures of ordinary Portland cement and high alumina cement, it also causes rapid setting.

2.5 Curing of Concrete

Curing of concrete is done to enable complete hydration of cement in hardened concrete. Ideal conditions are provided for curing concrete in the laboratory but in most cases such conditions are rarely ever met in the site. Arafah, *et al*. (1996), investigated the influence of non-standard curing on the strength of concrete in arid-areas and discovered variations in strength of cubes and cores cured by water sprinkling twice daily for 7days with and without burlap cover. The length of adequate curing time is dependent on the following factors:

a) Mixture proportions
b) Specific strength
c) Size and shape of concrete member
d) Ambient weather conditions
e) Future exposure conditions

There are several methods for curing concrete adopted on site and off site. These methods are adopted depending on the constraints, type of structure and materials available in abundance for curing. The following are the conventional methods accepted for curing concrete:

1. Water curing: water curing can be done in different ways including:-
    a) Sprinkling/Spraying/Fogging
    b) Ponding
    c) Wet covering
2. Steam curing: this method keeps concrete surface moist and raises the temperature of concrete to quicken the rate of strength achievement. It is done to speed up the early hardening of concrete by subjecting it to steam. This method is usually employed for curing precast concrete.
3. Membrane curing: this method is used to reduce moisture loss from the concrete surface by covering it with an impermeable membrane and using curing compounds such as acrylic and water base liquids. Curing in this method can be done using:-
    a) Plastic or Nylon sheeting
    b) Formwork
    c) Word chipping or Sawdust

Water curing if done properly can be the most efficient method and this makes it necessary to study and improve on its usage.

2.6 Importance of Concrete Curing

1. Increased Compressive Strength:

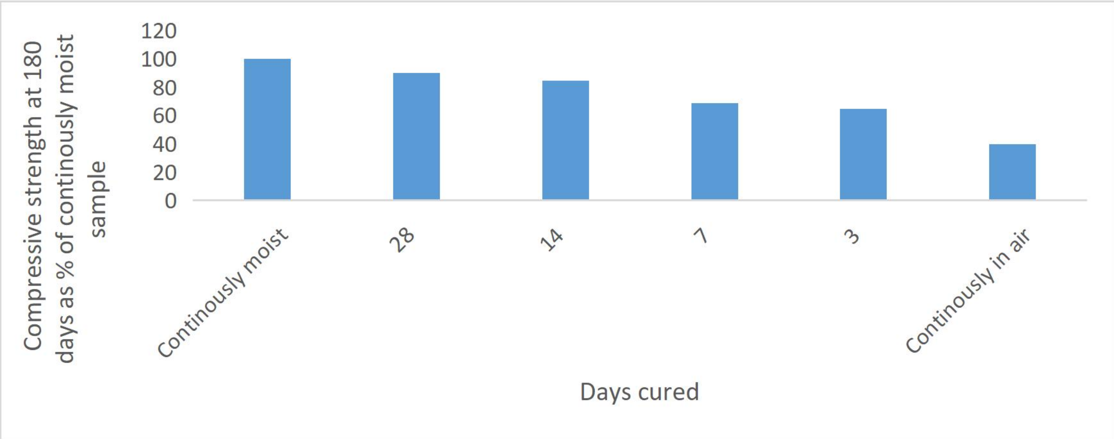

Figure 2.1: Effect of duration of water curing on strength of concrete

Source: CCAA datasheet April 2006, figure 1, page 1

An experimental investigation was conducted by Cement, Concrete and Aggregate Australia (CCAA) which gave the result in Figure 2.1. From Figure 2.1, it is observed that concrete allowed to dry out immediately, achieves only 40% of strength of the same concrete cured with water for the full period of 180 days.

2. Improved Durability of Concrete: durability of concrete is greatly affected by a few factors such as porosity, permeability and absorptivity. Proper curing of concrete helps to reduce the development of drying, thermal and plastic shrinkage cracks. This makes the concrete more water tight and thus preventing moisture and water borne chemicals from entering into the concrete and thereby increasing its durability.

3. Improved Microstructure: the properties of materials are directly related to their microstructure. Curing assists the cement hydration reaction to progress steadily and develop calcium silicate hydrate gel, which binds the aggregates leading to a rock solid mass. This development helps in make the concrete more dense and enhances the physical and mechanical properties of concrete.

4. Enhanced Serviceability: concrete that is allowed to dry out quickly undergoes considerable early age shrinkage. Inadequate curing contributes to weak and dusty surfaces having a poor abrasion resistance.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

1. Aggregates

   a. Fine aggregate (sand); conforms to the standard requirement of BS EN 12620 (2008).
   b. Coarse aggregate (crushed granite); this also conforms to the standard requirement of BS EN 12620 (2008).

2. Cement; the cement that was used for this experiment is the Dangote Ordinary Portland Cement which has a strength grade of 42.5N, which is in accordance to NIS 87:2007: part 1 and classified as CEM 1 of the standard. It was manufactured about two months before purchase.

3. Water; borehole water was used because it is considered to have less reactive chemicals. The water is clean, free from deleterious materials and fit for drinking as recommended by BS EN 1008 (2002).

4. Plaster of Paris (POP) Cement; the ABS POP was used for this work.

5. Wooden formwork; this was used to produce moulds for casting of the POP curing moulds.

6. Nylon; the nylon should be thick enough to prevent water percolation.

7. Adhesive tapes; the tapes possesses long lasting adhesive property for up to 30days.

8. Body filler Putty

9. Rope

3.2 Testing of Materials

During the period of the experimentation and testing with raw materials available for this work, all the precautions necessary were taken to minimise errors. The following tests were carried out on the materials for this work:

i. Sieve analysis.
ii. Specific gravity test.

iii. Bulk density test (compacted and un-compacted).

iv. Water absorption test.

v. Aggregate impact value test.

vi. Moisture content test

3.2.1 Sieve analysis

This was done to determine the nature of particle sizes distribution of granite and sand used.

Procedure

For the sieve analysis of the granite, the sieves were cleaned with the iron sieve brushes to remove all particles, after which they were weighed individually on the electronic weighing balance to determine their weights. The sieves were then stacked in ascending aperture size with the pan at the bottom and the largest sieve size at the uppermost top. The sample was dried, weighed (1500g) on the weighing balance and introduced into the arranged sieves from top (28mm) sieve and covered with the lid. The whole arrangement was placed on the electronic sieve shaker and the power turned on. The shaking process was done for 5minutes. The power was then turned off after shaking had been completed and the weight of the sample retained on the different sieve sizes were weighed and recorded. Results obtained from weighing the samples retained on the sieves were recorded;

Weight of aggregate retained = (weight of sieve + sample) - (weight of sieves)

$$\text{Percentage weight retained } \% = \frac{\text{weight of aggregate retained}}{\text{total weight of aggregate used}} \times 100 \qquad (3.1)$$

Cumulative percentage passing = 100 % – cumulative percentage retained.

For the sieve analysis of the sand, the sieves were cleaned with the iron sieve brushes to remove all particles, after which they were weighed individually on the electronic weighing balance to determine their weights. The sieves were then stacked in ascending aperture size with the pan at the bottom and the largest sieve size at the uppermost top. The sample was dried, weighed (123g) on the weighing balance and introduced into the arranged sieves from top (10mm) sieve and covered with the lid. The whole arrangement was placed on the electronic sieve shaker and the power turned on. The shaking process was done for 5minutes. The power was then turned off after shaking had been completed and the weight of the sample retained on the different sieve sizes were weighed and recorded. Results obtained from weighing the samples retained on the sieves were recorded; Equation 3.1 was then used to analyse this results.

3.2.2 Specific gravity test

According to ASTM (C127-15), specific gravity is defined as the ratio of mass (or weight in air) of a unit volume of material to the mass of the same volume of water at the stated temperature. It is made use of in design calculations of concrete mixes. With the specific gravity of constituent materials known, their weights can be converted in solid volume and hence a theoretical yield of concrete per unit volume can be calculated. It is also required in calculating the compacting factor in connection with the workability measurements.

Procedure

The empty measuring cylinder was weighed and placed on a levelled surface. The aggregate was gently poured into the cylinder and weighed. The cylinder was gradually filled with water to gauge mark and shaken until it was free from air bubbles. Weight of the cylinder with the mixture was taken and recorded. The cylinder was emptied and allowed to dry, and it was then filled with water to the gauge mark and weighed. The whole readings were recorded and used in determining the specific gravity of the aggregate using the equation below.

$$\text{Specific gravity (GS)} = \frac{W_2 - W_1}{W} \tag{3.2}$$

Where W_1 = Weight of cylinder

W_2 = Weight of cylinder + sample

W_3= Weight of cylinder + sample + water

W_4 = Weight of cylinder + water

W = (W_4-W_1) – (W_3-W_2)

W = Weight of water displaced by sample

(W_2-W_1) = Weight of sample

3.2.3 Bulk density test

Bulk density test 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. Bulk density depends on how densely the aggregate is packed and consequently on the size distribution and shape of particles. Thus the degree of compaction has to be specified. BS 812: part 2: 1975 recognises two degree: loose and compacted.

Procedure

The dimension of the sample divider was determined and recorded.

Un-compacted bulk density: the aggregate was gently poured into the sample divider to overflow and then levelled by rolling a rod across the top of the oven flowing sample to level it. The weight of the sample and the sample divider was recorded.

Compacted bulk density: the sample divider was filled in three layers and each one-third of the volume tamped 25 times with the tamping rod. The overflow was removed and the top levelled before it was weighed on the balance. The net weight of the aggregate was then determined using the equation below.

$$\text{Bulk density} = \frac{\text{weight of sample (un}-\text{compounded/compacted)}}{\text{volume of mould}} \qquad (3.3)$$

Weight of sample = (Mass of mould + sample) − Weight of mould

Volume of mould = $\pi r^2 h$

3.2.4 Water absorption test

Some aggregates are porous and absorptive. Porous and absorptive aggregates will affect the water cement ratio and hence the workability of concrete. The water absorption of aggregate is determined by measuring the increase in weight of an oven dry sample when immersed in water for 24 hours. The ratio of the increase in weight to the weight of the dry sample expressed as a percentage is known as absorption of water by aggregate. Absorption of water is also taken to be the weight of water absorbed by aggregate in reaching a saturated surface dry state expressed as a percentage of the weight of the dry aggregate. Water absorption is an important factor that control workability of a mix.

Procedure

The sample that was used was placed in one of the dry cloth and surface dried. When it was noticed that the cloth will remove no further moisture, the sample was then transferred to a second cloth, spread out and left exposed to the atmosphere, and away from direct sunlight for 20minutes. The sample was turned over once during this period of exposure. A can was weighed and taken as W, the sample was placed in the can and weighed and was taken as W_1, the can containing the sample was then placed in an oven at a temperature of 100^0c and left for 24 hours. After this time, it was removed and allowed to cool and weighed, this was taken as W_2. The same procedure was repeated and an average was taken and recorded.

$$\text{Water absorption} = \frac{\text{increse in weight}}{\text{weight of oven dry sample}} \times 100 \qquad (3.4)$$

$$= \frac{\text{weight of water}}{\text{weight of dry sample}} \times 100 \qquad (3.5)$$

$$= \frac{W_1 - W_2}{W_2 - W} \times 100 \qquad (3.6)$$

3.2.5 Aggregate impact value test

The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact. For the aggregates used, four samples were tested and their mean determined as the aggregate impact value.

Procedure

The sample that was tested was first surface dried. The measure cup was weighed on the weighing balance. The measuring cup was filled with the aggregate sample in three layers tampered with 25 strokes of the impact machine. The excess sample was removed and the measuring cup and sample in it weighed. The weight of the measured cup deducted from weight of the measure cup and sample, gave the weight of the sample S_1. The sample was then removed from the measure cup and placed on the set of BS sieves. The sample retained in the BS sieve size 2.36mm was weighed and recorded as S. The value obtained was used to determine the aggregate impact value using the following expression:

$$\text{Aggregate impact value} = \frac{S}{S_1} \times 100 \qquad (3.7)$$

Where S = weight of fraction retained in 2.36mm sieve size

S_d = weight of surface dried sample

3.2.6 Moisture content test

There are several methods available but accuracy depends on sampling so that it is important to have a representative sample. In the laboratory, the total moisture content can be determined by means of oven-drying method, prescribing by BS 812: part 109: 1990

Procedure

The open cans were cleaned and the mass of the empty cans determined and recorded (W_1). The moist soil was placed in the open cans and the mass of the open cans containing the moist soil determined and recorded (W_2). The open cans containing the moist soil were then placed in the drying oven and left for 24hours. The open cans were carefully removed from the oven and allowed to cool to room temperature. The mass of the open cans containing the dry soil were determined and recorded (W_3). The moisture content of the aggregate was also determined as follows;

Mass of soil solids $W_s = W_3 - W_1$ (3.8)

Mass of pore water $W_w = W_2 - W_3$ (3.9)

Moisture content MC (%) = $\frac{Ww}{Ws} \times 100$ (3.10)

3.3 Concrete Mix Ratio

This entails the process of selecting ingredients of concrete and determining their relative quantities. The weight measurement was applied in mixing raw materials such as cement, fine aggregate (sand), coarse aggregates (crushed granite of size 10mm), and water. Appropriate weighing of the raw materials was done and implemented systematically and accurately. Accurate batching is more important for higher grades of concrete.

The mix ratio that was used for this work is 1:2:4

3.3.1 Mix design

Mix design can be define as the process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability and workability as economically as possible. A standard mix ratio of 1:2:4 (cement and coarse aggregate) was adopted for the purpose of this research and water cement ratio of 0.5 for aggregates sizes of 12mm. For normal weight concrete mix design are usually established for trial mixes. The proportions of various ingredients and water requirement are estimated based on previous experiences with particular aggregate. According to Neville (1996) the degree of workability, density and compressive strength are the three properties for which concrete is designed. For the purpose of this research, the absolute volume method was employed to proportion the constituent materials. This method is based on the principle that the volume of fully compacted concrete is equal to the absolute volume of all the ingredients (ignoring air content).

With trial mix the amount of the concrete ingredients are summarized and specified in weight as well as in volume for 1 m^3 of compacted concrete.

Determination of Mix Proportions Using Absolute Volume Method

There are several methods used in determination of quantity of constituent materials of concrete, but for the purpose of this research work, the absolute volume method was used. The sizes of aggregates, mix ratio and water cement ratio will be considered in calculating the quantity of constituents used for this research work.

$$V_w + V_c + V_{sand} + V_{gravel} + V_{air} = 1 \quad (3.11)$$

$$\frac{Ww}{1000 \times SGW} + \frac{Wc}{1000 \times SGC} + \frac{Wsand}{1000 \times SGsand} + \frac{Wair}{1000 \times SGgravel} + 3\% = 1 \quad (3.12)$$

3% air (ACI 211.1-91)

Where,

Ww = weight of water (kg)

Wc= weight of cement (kg)

Wsand = weight of sand (kg)

Wgranite= weight of granite (kg)

SGw= specific gravity of water

SGc= specific gravity of cement

SGs= specific gravity of sand from result of specific gravity.

SGg= specific gravity of 12mm coarse aggregate from result of specific gravity table

- **For mix 1:2:4**

Water cement ratio 0.5

$\frac{W}{C} = 0.5 => W = 0.5C$ (3.13)

$\frac{1}{2} = \frac{C}{S} => S = 2C$ (3.14)

$\frac{1}{4} = \frac{C}{G} => G = 4C$ (3.15)

Substituting into equation (3.12)

$$\frac{0.5c}{1000 \times 1} + \frac{c}{1000 \times 3.15} + \frac{2c}{1000 \times 2.65} + \frac{4c}{1000 \times 2.75} + 0.03 = 1$$

$$\frac{0.5}{1000} + \frac{c}{3.150} + \frac{2c}{2650} + \frac{4c}{2750} + 0.03 = 1$$

$$0.0005c + 0.000315c + 0.000755c + 0.00145c + 0.03 = 1$$

$$= 0.003022c + 0.03 = 1$$

$$0.003022c = 1 - 0.03$$

$$C = \frac{0.97}{0.003022} = 321kg/m^3$$

Concrete Columns

Volume of concrete columns = 0.1 x 0.1 x 0.3

= $0.003m^3$

For 8 columns = 8 x $0.003m^3$

Allowing for 20% waste 8 x 0.003 x $1.2m^3$ = $0.0288m^3$

321kg required for $1m^3$

x kg required 0.0288m^3

x kg = $\frac{321x0.0288m^3}{1m^3}$ = 9.2448kg

Weight of cement required for 8 columns = 9.2448kg

Amount of water required for 8 columns = 9.2448 x 0.5 = 4.6224kg

From equation b above S = 2C

Weight of sand required = 2 x 9.2448kg = 18.4896kg

From equation c above G = 4c

= 4 x 9.2448 = 36.9792kg

Weight of granite required for 8 columns = 36.9792kg

Concrete Beams

Volume of concrete beams = 0.15 x 0.15 x 0.75

= 0.0158m^3

For 8 beams = 8 x 0.0158m^3

Allowing for 20% waste 8 x 0.0158 x 1.2m^3 = 0.1517m^3

321kg required for 1m^3

x kg required 0.1517m^3

x kg = $\frac{321x0.1517m^3}{1m^3}$ = 48.6957kg

Weight of cement required for 8 beams = 48.6957kg

Amount of water required for 8 columns = 48.6957 x 0.5 = 24.3479kg

From equation b above S = 2C

Weight of sand required = 2 x 48.6957kg = 97.3914kg

From equation c above G = 4c

= 4 x 48.6957 = 194.7828kg

Weight of granite required for 8 columns = 194.7828kg

3.3.2 Method of mixing

There are two methods of mixing concrete: mechanical (use of concrete mixer) and manual (hand) method. The manual method was adopted due to the small volume of concrete.

Procedure

Quantities of materials, coarse aggregates, sand, water and cement calculated was weighed on the weighing balance. The sand was weighed first and spread on a clean spread tray; cement was then weighed next and spread over the sand. The two materials were mixed with a shovel by turning them over from one end of the tray to the other, until the mix appeared uniform. The coarse aggregate was weighed and spread on the mixed sand and cement, a proper mixing of this was done. Water was then poured over the mixture gradually and mixed again until the mix appeared uniform and consistent. Care was taken to prevent foreign materials from mixing up with the concrete mix during the mixing process.

3.4 Workability

Road Research Laboratory United Kingdom, who have extensively studied the field of compaction and workability, defined workability as the property of concrete which determines the amount of useful internal work necessary to produce full compaction (Neville, 1987). Workability of concrete can be measured using slump test, compacting factor test, Vee Bee test, Kelly Ball test, and flow test. Few amongst these tests have found universal acceptance due to simplicity of operation with an ability to detect variations in the uniformity of a mix of given nominal proportions. For this work, the slump test and compacting factor test were used.

3.4.1 Slump test

The slump test is used to determine the workability of fresh concrete that is normally undertaken at the point of delivery to ensure the concrete is of adequate consistency for placement. There are three types of slump;

a. True slump: if the concrete slump evenly up to125mm, it is called true slump.

b. Shear slump: if one half of the concrete slides down up to 150mm, it is called shear slump. The shear slump of concrete indicates that the concrete is non-cohesive and shows the characteristics of segregation

c. Collapse slump: if the concrete slump between 150mm-250mm it is called a collapse slump.

Procedure

After proper mixing of the concrete, the slump cone was held down tightly to the base plate with the small opening at the top. The cone was then filled with fresh concrete in three layers and each layer tamped 25 times with the tamping rod. Top of the cone was levelled with the hand trowel and fresh concrete around the base was cleared. The cone was lifted slowly and placed by the side of the concrete. A slump (reduction in height) from the resulting behaviour of the material was noticed and the height of the mould measured against the height of the slumped mix with the metre rule was recorded.

3.4.2 Compacting factor test

In this test, the degree of compaction called the compacting factor is measured by the ratio of the density actually achieved in the test to the density of the same concrete fully compacted.

Procedure

The hinged door at the bottom of each hopper was shut and the upper hopper filled with fresh concrete mix gently to avoid compaction. The bottom door of the hopper was then released and the concrete fell into the lower hopper. The lower hopper was filled in excess since it is smaller than the upper hopper. The bottom door of the lower hopper was also released and the concrete fell into the cylinder. The top of the cylinder was levelled off using the hand trowel and wiped clean of any concrete on the cylinder. The weight of the concrete in the cylinder was determined. The cylinder was emptied and filled with concrete in three layers each layer tamped 25 times. The top surface was carefully struck off and the outside of the cylinder cleaned and weighed.

The compacting factor was determined using the following equation;

Compacting factor = un-compacted weight / compacted weight

3.5 Design, Construction and Testing of Curing Mould for Concrete Column and Beam

A design of suitable curing moulds for columns and beams was done to enable accurate fabrication of the moulds. The sawdust was glued to some of the interior edges of the wooden moulds to cater for angular connectivity of some parts of the moulds. This was allowed to dry completely. The POP cement was mixed thoroughly with water and poured into the different moulds and left to hardened. They were removed and then wrapped in nylon and taped properly to prevent water percolation as shown in Plate I. The different parts of the mould were assembled and some secondary element for water tightness applied on it. After which, the water was poured into the mould. A cap was then placed on the mould to minimise water lose by evaporation. A stopwatch was set for 24 hours. The water level was checked periodically at an interval of 2 hours and recorded. This was then used to calculate the percentage loss of water from the moulds

3.6 Casting and Curing of Concrete Columns using the Fabricated Moulds

Procedure

The freshly mixed concrete was poured into the 8 different (100 × 100 × 300) mm moulds in three layers and each layer was compacted with 16mm steel rod. Each layer was applied 25 strokes with the rode. The top of the specimen was then covered with nylon and stored in room temperature for 24 hours. The moulds were removed after 24 hours and the curing process for the specimen started as shown in Plate I. 4 of the specimen were selected for deep emersion into water using the fabricated curing moulds as shown in Plate II, and III, while the remaining 4 specimen were cured by sprinkling water on them twice daily (6am and 6pm) as shown in Plate IV.

Plate I: Concrete Curing Mould **Plate II:** Curing Mould Being Used for Curing

Plate III: Concrete Column in Mould **Plate IV:** Concrete Column for Water Sprinkling

3.6.1 Compressive strength test of concrete columns specimen cured by full emersion and those cured by sprinkling water after 7, 14, 21, and 28 days

Procedure

The concrete columns were measured and weighed. Then cube testing machine was then used to determine the load that will cause the failure of the concrete columns as shown in Plates V and VI. Care was taken to ensure the columns were placed centrally in the machine, and the machine was zeroed before the process was stated. The load at failure was then used to determine the compressive strength of the concrete using the following expression:

Strength = Load/Cross-sectional area

Plate V: Column Testing Machine **Plate VI:** Crushed Concrete Columns

3.7 Casting and Curing of Concrete Beams using the Moulds that were Fabricated

Procedure

The freshly mixed concrete was poured into the 8 different 150mm × 150mm × 700mm moulds in three layers and each layer was compacted with 16mm rode. Each layer was applied 25 strokes with the 16mm steel rode. The top of the specimen was then covered with nylon and stored in room temperature for 24 hours. The moulds were removed after 24 hours and the curing process for the specimen started. 4 of the specimen were selected for deep emersion into water using the fabricated curing moulds, while the remaining 4 specimen were cured by sprinkling water on them twice daily (6am and 6pm).

3.8 Flexural Strength Test

3.8.1 Flexural strength test on concrete beams that will be cured by full emersion and concrete beams that will be cured by sprinkling water after 7, 14, 21, and 28 days

Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending. This test can be conducted using either three point load test (ASTM C78) or centre point load test (ASTM C293). The configuration of each test is shown in Plate VII and Plate VIII respectively.

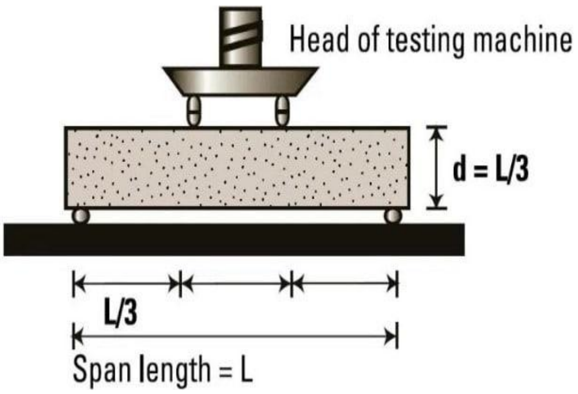

Plate VII: Three Point Load

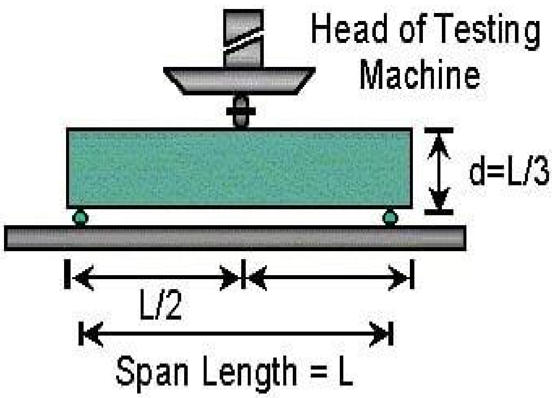

Plate VIII: Centre Point Load

Plate IX: Flexural Test Machine and Concrete Specimen

For the purpose of this research, the centre-point load test was done.

Procedure

The cross section and weight of the specimen to be tested were measured and recorded. The specimen was placed on the loading point and simple supported at a distance of 125mm from both ends. The hand finish surface of the specimen was not placed in contact with the loading point, as to ensure an acceptable contact between the specimen and loading point. The applying force was brought in contact with the specimen surface at the loading point as shown in Plate IX. Applying loads between 2 to 6% of the compute ultimate load, care was taken to ensure the loading was done at the middle of the clear span of the beam. Cap was used on the specimen surface to eliminate any gap in excess of 0.38mm in width. Loading of the specimen was done continuously without shock till the point of failure at a constant rate of 0.06+/-0.04N/mm^2.s according to British standard. The load at failure was recorded and used for calculation of the flexural strength of the beam.

3.8.2 Computation of modulus of rupture

The following expression was used for estimation of modulus of rupture:

$$\mathrm{MR} = \frac{3\mathrm{PL}}{2\mathrm{bd}^2} \quad (3.16)$$

Where:

MR: modulus of rupture

P: ultimate applied load indicated by testing machine

L: span length

b: average width of the specimen at the fracture

d: average depth of the specimen at the fracture

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Sieve Analysis Test

Table 4.1: Sieve analysis result for sand (sample size= 123g)

Sieve Sizes mm	Mass retained (g)	% Mass retained	% Cumulative mass retained	Percentage passing (%)
10.000	0	0.00	0.00	100.00
6.300	6.2	5.04	5.04	94.96
2.000	28.9	23.50	28.54	71.46
1.000	25.2	20.50	49.04	50.96
0.600	23.0	18.70	67.74	32.26
0.300	17.4	14.10	81.84	18.6
0.150	13.0	10.60	92.44	7.56
0.063	6.9	5.60	98.04	1.96
Pan	2.4	1.96	100	0

Table 4.2: Sieve analysis result for coarse aggregate size of 12mm (sample size= 1500g)

Sieve Sizes mm	Mass retained (g)	% Mass retained	% Cumulative mass retained	Percentage passing (%)
28.00	0	0.00	0.00	0.00
20.00	450.8	30.05	30.05	69.95
14.00	843.2	56.21	86.26	13.74
10.00	141.2	9.41	95.67	4.33
6.30	1.2	0.08	95.75	4.25
5.00	0	0.00	95.75	4.25
3.35	0	0.00	95.75	4.25
Pan	3.2	0.21	95.96	4.04

The reason for sieve analysis test is to determine the gradation (particle size) of the aggregate. From Table 4.1, the sieve analysis results for sand indicates grade sizes range in less than 10mm, and for effective sieve size of 0.063 the percentage passing is less than 10%. From Table 4.2, the sieve analysis test on coarse aggregate used, showed an open gradation of the aggregate due to the presence of very little fine aggregate.

4.2 Specific Gravity Test

Table 4.3 Result of specific gravity test for fine aggregate (sand)

No. Of Trials	1st Trial	2nd Trial	3rd Trial
Weight of cylinder W_1(g)	126.6	97.5	126.7
Weight of cylinder + sample W_2(g)	206.6	158.7	209.2
Weight of cylinder + sample + water W_3(g)	438.8	396.5	438.6
Weight of cylinder + water W_4(g)	388.9	358.7	386.7
Weight of sample W_2-W_1(g)	80	61.5	82.5
Specific Gravity = $\frac{W_2-W_1}{W}$	2.66	2.595	2.696
Average Specific gravity		2.65	

Table 4.4: Result of specific gravity test for 12mm coarse aggregate

No. Of Trials	1st Trial	2nd Trial	3rd Trial
Weight of bottle W_1(g)	129.7		116.8
Weight of bottle + sample W_2(g)	333.425		280.9
Weight of bottle + sample + water W_3(g)	618.9		537.6
Weight of bottle + water W_4(g)	502.8		434.4
Weight of sample W_2-W_1(g)	203.725		164.4
Specific Gravity = $\frac{\mathbf{W_2-W_1}}{\mathbf{W}}$	2.81		2.686
Average Specific gravity		2.75	

The results of specific gravity for fine and crushed aggregate from Tables 4.3 and 4.4 respectively are given as 2.65 and 2.75. According to ASTM C127-15, specific gravity of a normal aggregate ranges from about 2.5 to 3.0. According to Neville (1987), the majority of natural aggregates have specific gravity within the range of 2.6 – 2.7, though higher values indicates high strength.

4.3 Bulk Density Test

Table 4.5: Bulk density result for sharp sand (un-compacted)

No. of Trials	1st Trial	2nd Trial	3rd Trial
Mass of mould + sample (g)	3570	3567	3550
Weight of mould (g)	1071	1071	1071
Weight of sample (g)	2499	2496	2479
Average weight of sample (kg)		2.4913	
Volume of cylinder (m^3)		0.007159	
Bulk density (kg/m^3)		1416.32	

Table 4.6: Bulk density result for sharp sand (compacted)

No. of Trials	1st Trial	2nd Trial	3rd Trial
Mass of mould + sample (g)	3825	3845	3849
Weight of mould (g)	1071	1071	1071
Weight of sample (g)	2754	2774	2778
Average weight of sample (kg)		2.7687	
Volume of cylinder (m^3)		0.007159	
Bulk density (kg/m^3)		1574.02	

Table 4.7: Bulk density result for granite (un-compacted)

No. of Trials	**1st Trial**	**2nd Trial**	**3rd Trial**
Mass of mould + sample (g)	3440	3445	3406
Weight of mould (g)	1071	1071	1071
Weight of sample (g)	2369	2374	2335
Average weight of sample (kg)		2.359	
Volume of cylinder (m^3)		0.007159	
Bulk density (kg/m^3)		1348.19	

Table 4.8: Bulk density result for granite (compacted)

No. of Trials	**1st Trial**	**2nd Trial**	**3rd Trial**
Mass of mould + sample (g)	3805	3744	3735
Weight of mould (g)	1071	1071	1071
Weight of sample (g)	2734	2673	2664
Average weight of sample (kg)		2.690	
Volume of cylinder (m^3)		0.007159	
Bulk density (kg/m^3)		1537.34	

Bulk density depends on how densely the aggregate is packed and consequently on the size distribution and shape of particles. Thus the degree of compaction has to be specified. BS 812: part 2: 1975 recognises two degree: loose and compacted. Any aggregate with a particular density in the range of 1520kg/m^3 – 1680kg/m^3 is referred to as normal weight aggregate (ASTM C33/C33M, 2016). Results from Tables 4.5 and 4.7 for un-compacted sand and granite fall below this values but results from Tables 4.6 and 4.8 for compacted sand and granite fall within this values. The aggregates used thus can be classified as normal weight aggregates.

4.4 Water absorption test for granite

Table 4.9: Water absorption test

	Trial 1	Trial 2
Weight of can A_1 W(g)	43.4	43.9
Weight of can + wet sample W_1(g)	147.0	181.2
Weight of can + dry sample W_2(g)	143.1	179.1
Weight of water Ww(g)	3.9	2.1
Weight of dry sample Ws(g)	99.7	135.2
Water absorption %	3.9	1.6

Average water absorption = trial 1 + trial 2 / 2

$$= \frac{3.9 + 1.6}{2} = 2.75\%$$

From Table 4.9, the result obtained for water absorption of the coarse aggregate showed an average of 2.75%. This conforms to BS 882:1992, which suggests that the water absorption of aggregates should generally not be greater than 3%.

4.5 Aggregate Impact Value Test

Table 4.10: Aggregate impact value test result for 12mm

Weight of mould (g)	2632
Weight of can + sample (g)	3292
Weight of Sample (g)	661
Weight of sieved sample (g)	52.7
Impact value %	7.97

From Table 4.10, the result for aggregate impact value obtained was 7.97% for the coarse aggregate used. According to IS Code2386-4:1963, aggregates with impact values of <10% are classified as strong. Hence these aggregates are suitable for all structural works.

4.6 Moisture Content Test

Table 4.11: Moisture content test of fine aggregate

No of Trials	**Trial 1**	**Trial 2**	**Trial 3**
Weight of can W1(g)	24.9	24.6	23.1
Wt of can + sample W2(g)	70.5	56.5	66.7
Wt Can + dry Sample W3(g)	70.3	56.5	66.6
Weight of water Ww(g)	0.2	0.0	0.1
Weight of dry sample Ws(g)	45.4	31.9	43.5
Moisture Content (%)	0.44	0	0.23

$$\text{Average} = \frac{0.44 + 0 + 0.23}{2} = 0.34$$

From Table 4.11, the results for moisture content test of fine aggregate showed average moisture content of 0.34% thus this makes the aggregate to have low water absorption and by implication, the moisture content will have minimal effect in altering the water/cement ratio of the mix (Neville, 1987).

4.7 Slump Test

Table 4.12: Slump test

Trial 1 Slump (mm)	Trial Slump (mm)
32	30

From Table 4.12, the results for slump test showed a slump of 32 mm for trial 1 and 30 mm for trial 2. Both results fall within the range of (25 - 75) mm which indicates low workability according to BS EN 12350-2:2019

4.8: Water Loss from Curing Mould Test

Table 4.13: Water loss from curing mould test

Time (hours)	**Trial 1 % Water loss**	**Trial 2 % Water loss**	**Trial 3 % Water loss**
12	100	59.6	12.4
24	100	70.5	27.2

Validation of Curing Mould

Results from Table 4.12 on water loss from the curing moulds showed a 12.4 % water loss after 12 hours, and 27.2% water loss after 24 hours from trial 3 which indicate that little water will be added after every 24hours to the moulds for the entire curing process when using these curing moulds.

4.9 Flexural Strength Test

Table 4.14: Flexural strength of beams cured by water sprinkling and full immersion

Specimen	Method of Curing Concrete	Age of Concrete (Days)	Weight of Concrete (Kg)	Density of Concrete (Kg/m^3)	Flexural Strength (N/mm^2)
A1	Full Immersion	7	40.7	2584.13	3.1
B1	Water Sprinkling	7	39.1	2482.54	2.0
A2	Full Immersion	14	41.9	2660.32	3.4
B2	Water Sprinkling	14	39.4	2501.59	2.3
A3	Full Immersion	21	42.0	2666.67	3.7
B3	Water Sprinkling	21	39.1	2482.54	2.5
A4	Full Immersion	28	42.1	2673.02	3.8
B4	Water Sprinkling	28	39.3	2495.24	2.5

4.9.1 Compressive strength test

Table 4.15: Compressive strength of columns cured by water sprinkling and full immersion

Specimen	Method of Curing Concrete	Age of Concrete (Days)	Weight of Concrete (Kg)	Density of Concrete (Kg/m^3)	Compressive Strength (N/mm^2)
CI	Full Immersion	7	7.28	2426.67	19.1
D1	Water Sprinkling	7	6.70	2233.33	10.5
C2	Full Immersion	14	7.27	2423.33	19.6
D2	Water Sprinkling	14	6.71	2236.67	12.1
C3	Full Immersion	21	7.36	2453.33	19.5
D3	Water Sprinkling	21	6.84	2280.00	15.3
C4	Full Immersion	28	7.39	2463.33	19.8
D4	Water Sprinkling	28	6.96	2320.00	15.3

Results from Tables 4.14 and 4.15, showed that the mass, density, as well as its flexural and compressive strength increased gradually with age up to 28 days which was the maximum number of days for curing the specimen during this experiment. Flexural strength of 3.8 N/mm^2 obtained by immersing concrete fully in water was observed to be greater than the 2.5 N/mm^2 obtained by the same concrete when it was sprinkled with water twice daily for 28 days. Compressive strength of 19.8 N/mm^2 obtained by immersing concrete fully in water was observed to be greater than the 15.3 N/mm^2 obtained by the same concrete when it was sprinkled with water twice daily for 28 days. Results from these Tables shows that concrete cured fully in water develops better flexural and compressive strength than concrete cured by sprinkling method.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The physical and mechanical properties of the aggregates from the various test carried out, indicates that the fine and coarse aggregates were adequate.

The slump of 34mm and 35mm observed for trial 1 and trial 2 respectively falls within the range of concrete with low workability and this is ideal for beams and columns according to BS EN 12350.

The test results of the 3rd trial for the water retaining ability of the curing moulds recorded a 27.2% water loss after 24 hours, which indicates that little water will be added after every 24 hours to the moulds for the entire curing process when using these curing moulds. The curing moulds proved to be efficient for the experiment.

Flexural strength of 3.8 N/mm^2 obtained by immersing concrete fully in water contained in the curing moulds for 28 days, was observed to be greater than the 2.5 N/mm^2 obtained by the same concrete when it was sprinkled with water twice daily for 28 days. Compressive strength of 19.8 N/mm^2 obtained by immersing concrete fully in water was observed to be greater than the 15.3 N/mm^2 obtained by the same concrete when it was sprinkled with water twice daily for 28 days. The compressive strength obtained by sprinkling water on the concrete columns for 28 days, falls short of the requirements of the ACI, for a structural lightweight concrete which specifies a minimum compressive strength of 17 N/mm^2. This indicates the need for use of better techniques on-site for curing concrete, in order to achieve optimal strength of the concrete.

5.2 Recommendations

1. By using the curing moulds that were constructed, ideal conditions for complete hydration of cement in the hardened concrete was achieved. Hence, they can be considered for curing concrete elements, though extensive work might still be needed to fully develop these moulds into an economical and more efficient option to be used on-site for curing.
2. Alternatively, these moulds could be used as top covers to minimise loss of water by evaporation when using wet membranes for curing concrete in semi-arid or arid regions.

5.3 Contribution to Knowledge

The research was focused on improving concrete curing on-site when using water in compliance with BS 1881-PART-111. Structural members like columns and beams were the major focus due to high neglect in terms of curing on site. Curing moulds designed for this experiment proved to be 70% efficient in minimising water loss during curing. These prototype could be used for producing better and more economical samples to be used on-site.

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