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Effect of Composite Corn Cob Ash and Metakaolin on the Durability Properties of Concrete Exposed to Chemically Aggressive Enviroment

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ABSTRACT

The Portland cement industry is a highly energy intensive process requiring about 112 Kw of energy-per ton of finished product. Therefore, efforts should be made to find alternatives for cement. Supplementary cementing materials (SCM) play an important role in the production of high strength and high performance concrete. The negative environmental impact and high cost of cement are reasons for research efforts which drive me into discovering suitable replacements for cement in concrete production. Efforts have been made to eliminate the problem associated with cement usage and its production by partially replacing cement with a binder known as Pozzolana. This research evaluates the effect of composite corn cob ash and metakaolin on the durability properties of concrete exposed to chemically aggressive environment. A total of 360 specimens were cast. Out of 360 samples 216 were of 100mm x 100mm x 100mm cubes were cast with each sample containing 0%, 10%, 15%, 20%, 25% and 30% percentage replacement of cement, cured in different environmental condition of H_2O, $MgSO_4$ and H_2SO_4 used for compressive strength test. 36 concrete cubes were used for flexural strength, for absorption capacity and abrasion resistance, 108 concrete specimens were used. The average compressive strength obtained at 28 days of curing for concrete specimens with 0%, 10%, 15%, 20%, 25% and 30% in H_2O are 27.6N/mm^2, 27.6N/mm^2, 27.3N/mm^2, 25.1N/mm^2, 24.6N/mm^2 and 23.9N/mm^{2}repectively, while in $MgSO_4$ are 24.9N/mm^2 25.7N/mm^2, 24.9N/mm^2, 23.9N/mm^2, 23.1N/mm^2, 22.2N/mm^2 respectively, also in H_2SO_4 it includes 26.7N/mm^2, 27.0N/mm^2, 26.8N/mm^2, 25.5N/mm^2, 23.7N/mm^2, 23.1N/mm^2 respectively. The result obtained showed that concrete samples with 10% Corn Cob ash-Metakaolin replacements cured in $MgSO_4$ and H_2SO_4 withstood the medium better with 0% replacements as indicated by 3.11% and 1.11% increase in compressive strength at 28days. Concrete produced with 10% composite corn cob ash and metakaolin have high resistance to abrasion and less sorptivity than 0% replacements in both normal and aggressive chemical environments at 56days. In conclusion corn cob ash and metakaolin are pozzolanic material having satisfied the requirement of ASTM C618-05. Therefore, this research, recommends the use of 10% replacement of cement in concrete with corn cob ash and metakaolin, it will lead to a strong and durable concrete which can be used in both normal and aggressive environments

Key words: metakaolin, compressive Coarse Aggregate, Fine Aggregate (River Sand), Corn Cob AshandWater absorption

I. INTRODUCTION

Concrete is a mixture of cement, aggregates and water, with any other admixtures which may be added to modify the placing and curing processes or the ultimate physical properties (Arthur, 2007). Concrete is widely used construction material for more than a century for the rapid development of the built environment all over the world. New forms of concrete have been evolved through many advances via dedicated research and development over many decades. For example, in the first evolution cycle, researchers focused on increasing the compressive strength, and now the focus has changed to improve the functional characteristics and performance of concrete. Concrete has been used for many years in civil and construction engineering works because of its strength, durability and affordable price. In the earlier time, problems were faced in the use of concrete such as workability, earlier strengths and the later strengths of concrete. A lot of research works have been carried out in order to overcome such problems and as such the technology of concrete have been improved tremendously. According to Mohammad (2010) cement is one of the essential ingredients of concrete that both contributes to the construction industries and environmental problem. However, the production of cement emits carbon dioxide to the surroundings which result to environmental pollutions. For each tonne of cement, there is between 0.5 to 1 tonne of carbon dioxide emitted into the atmosphere (Rubenstein, 2012). It is expensive to buy when compared to other concrete materials such as gravel, sand, water etc. The problems of pollution and cost have led to researches on cement alternatives or substitutes that will fully or partially replace cement in the construction industry (Ogunbode and Hassan, 2011). Dadu (2011) reported that the global move currently is to reduce the amount of Portland cement contents used in the concrete mixtures with cheaper Supplementary Cementitious Material (SCM)/pozzolans to improve certain durability properties of concrete.

The American Society for Testing and Material (ASTM C125-06) defined pozzolan as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. The word “pozzolana” according to Jackson (2003), is derived from the Latin words “PulvisPuteolamus”, meaning the powder from Puteolior the dust of Puteoli.Parhizkaret al (2010) has also defined Pozzolanas as materials containing reactive silica and/or alumina, which, alone have little or no binding property, but when mixed with portland cement, react with calcium hydroxide (produced from the hydration of the cement) to form a strong gel.Shetty (2009) classified pozzolans as either natural or artificial pozzolan. Natural pozzolans include; clay and shales, opalinccherts, diatomaceous earth, volcanic ash, volcanic tuffs and pumicites, Artificial pozzolans include; fly ash, blast furnance slag, silica fume, rice husk ash, metakaoline and surkhi. Volcanic ash, being one of the classifications of natural pozzolans, is environmentally friendly, economical and accessible than artificial pozzolan.

Out of the many different materials used in concrete is metakaolin and corn cob ash which are economically, environmental-friendly, sustainable, easy to obtain and locally produced material.

The use of corn cob ash as partial cement replacement of cement in concrete is one potential means of generating affordable binder for construction and is a way of effectively converting the waste to wealth. However, corn cob is one of the major wastes littering the environment in Nigeria especially in the summer when corn/ maize is harvested in large quantity. Corn cob is the hard thick cylindrical central core of maize (on which are borne the grains or kernels of an ear of corn). Raheem (2010) described Corn cob as the agricultural waste product obtained from maize or corn, which is the most important cereal crop in sub-Saharan Africa. According to Food and Agriculture Organization (FAO) data, 589 million tons of maize were produced worldwide in the year 2000 (FAO Records; 2002). The United States was the largest maize producer having 43% of world production. Africa produced 7% of the world’s maize (IITA Records; 2002). Nigeria was the second largest producer of maize in Africa in the year 2001 with 4.62 million tons. South Africa has the highest production of 8.04 million tons (FAO Records; 2002).

Metakaolin is one type of calcined clay and it comes from the calcination of kaolin clay and there have been some interests in the use of Metakaoline in recent years (Siddique & Klaus, 2009). Metakaoline differs from the other cement replacement materials (SCMs) in that it is not a waste product resulting from industrial activities nor is it completely natural. It is originated from kaolinite clay mineral and is processed for different uses and applications including cementitious systems. Metakaoline is mainly produced by calcination (i.e. thermal treatment) of kaolin clays within a temperature ranging from about 600 to 800̊C (Biljana, 2010). The treatment process of calcination is important for the production of highly reactive pozzolanic material. The water is driven off from the kaolinite clay and the material structure collapses, resulting in an amorphous alumino-silicate referred to as metakaolin or metakaolinite.

The most important single property of concrete is strength this is because the major aim of structural design is that the structural elements must be capable of carrying the loads imposed on it. The maximum value of stress in a loading test is usually taken as the strength, even though under compressive loading the test piece is still whole (but with substantial internal cracking) at this stress, and complete breakdown subsequently occurs at higher strains and lower stresses. Strength is also important because it is related to several other important properties that are more difficult to measure directly, and a simple strength test can give an indication of these properties such as durability (Peter and John, 2010)

The durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desiredengineering properties (Jamaludinet al, 2012). It can also be defined as the ability of a material to remain serviceable for at least the required lifetime of the structure of which it forms a part. Standards and specifications increasingly include requirements for a design life, which can typically be 50 or 100 years, but for many structures this is not well defined, so the durability should then be such that the structure remains serviceable more or less indefinitely, given reasonable maintenance. For many years, concrete was regarded as having an inherently high durability, but experience in recent decades has shown that this is not necessarily the case. Degradation can result from the environment to which the concrete is exposed, for example freeze–thaw damage, aggressive chemical environment or from internal causes within the concrete, as in alkali–aggregate reaction (Peter and John, 2010). One of the most important aspects of durability is chemical attack which results in volume change, cracking of concrete and the consequent deterioration of concrete. Some of the chemicals that are harmful to concrete include acids and bases. Concrete is not fully resistant to acids, most acids solution will slowly or rapidly disintegrate Portland cement concrete depending on the type and concentration of acid.

These days, concrete is being used for wide varieties of purposes in different conditions. In these conditions ordinary concrete may fail to exhibit the required quality performance or durability. However, it has now been recognized that compressive strength of concrete alone is not sufficient to judge the quality of concrete, the degree of aggressiveness of the environment to which the concrete is subjected to, is equally important to look upon. Therefore, both strength and durability have to be considered thoroughly at both the research and design stage (Shetty, 2009). This research work therefore assesses the effect of composite corn cob ash and metakaolin on the durability properties of concrete.

Statement of Problem

Cement as an important constituent of concrete is becoming gradually expensive compared to other ingredients of concrete. The mining of its raw materials leads to depletion of natural resources and degradation of environment. Its production pollutes the environment due to the high energy demand emission of CO_2 which is responsible for global warming, the depletion of lime stone deposits are disadvantages associated with cement production. The emission of CO_2 is such that for every ton of cement produced almost a ton of CO_2 is emitted Shoubiet al., (2013); (Dahiru, 2010). In view of this and other problems associated with production and use of cement, a lot of research efforts were made to find an alternative material that will partially or fully replace cement in concrete production.

According to Babu and Rao (Badur, S. and Chaudhary, R 2008) about 7% CO_2 is released into the atmosphere during cement production, which has a negative influence on ecology and future of human being arising from global warming. Research on alternative to cement, has so far centered on the partial replacement of cement with different materials. The challenges associated with the application of Portland cement includethe excessive high heat generated in early hydration which results in cracking as a result of rapid volume changes, the poor durability performance in some environments especially chloride and Sulphate rich environments and the high cost of service life cycle of structures (Lawrence, 1998). As part of such efforts research has looked into the use of corn cob ash as supplementary materials for partial replacement for cement in the construction industry Sabiret al. (2000). Likewise, to satisfy the future demand and termly requirements for suitable and sustainable environment, there is a need to examine further on benefit of application of corn cob ash in concrete. Secondly, while considering a suitable replacement for cement, it is important not to compromise the integrity of cement in concrete. Therefore, metakaolin was introduced to solve the problem of the optional chemical requirement lacking in corn cob ash. As part of such effort Taylor (1997) carried out research on metakaolin and recommend that it can be used to partially replace cement in concrete because of its high pozollanic property.

However, durability properties such as exposing such composite corn cob and metakaolin concrete to aggressive or hostile environment like sulphate attack, acid attack, fire resistance etc. we're not assessed J D Bapat,(2012). In addition, Shetty (2009) stated that earlier concrete was deemed to be very durable material which demands less or no maintenance but at later age it was discovered that when exposed to aggressive environment where there is presence of chemicals, failures would occur and this can cost huge amount of money to renovate the affected concrete structure. Therefore, the impression that concrete is a durable and sustainable material is being threatened and hence the durability properties need to be considered.Therefore, the research is undertaken to determine the effect of composite corn cob ash and metakaolin on the durability properties of concrete.

Aim and Objectives of the Study

The aim of this research is to determine the effects of composites corn cob ash and metakaolin on the durability properties of concrete, with a view to determining the feasibility of its usage in aggressive chemical environment. The following objectives are proposed to achieve this aim.

1. To determine the chemical properties of individual constituents of corn cob ash and metekaolin.
2. To determine the fresh properties of concrete made with composite corn cob ash and metakaolin.
3. To determine the harden properties of concrete made with composite corn cob ash and metakaolin.

II. LITERATURE REVIEW

Concrete production

The word "concrete" as opined by Li (2011) is derived from the Latin, concretus, meaning "to grow together." The ASTM C125-06 defines concrete as a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate; in hydraulic-cement concrete, the binder is formed from a mixture of hydraulic cement and water. Various definitions of concrete were suggested as a result of various researches carried out across the world. According to Donome and Illston, (2010), Concrete is a ubiquitous material and its versatility and ready availability have ensured that it will continue to be of great and increasing importance for all types of construction throughout the world. Concrete is a freshly mixed material which can be moulded into any shape. According to Harris (2006), concrete is a stone like material formed by mixing an aggregate (such as stones of irregular shape or crushed rock) with cement (which act as a binding material) and water, then allowing the mixture to dry and hardened. It is a relatively new construction material when compared to stone, timber, steel etc. and the most widely used building and civil engineering construction material (Garba, 2008). According to Neville, (2010), concrete is any product or mass made by the use of cementing medium, generally, this medium is the product of reaction between hydraulic cement and water. While cement contributes to the hardening of certain materials into an artificial rock, the other components used to produce concrete enhance its strength properties, ensure the workability of the new substance produced and guarantee durability. The durability of concrete has been observed to last over decades, centuries and millenniums. For instance, the Romans used concrete extensively from 300 BC to 476 AD, a span of more than seven hundred years (http://matse1.matse.illinois.edu/concrete/history.html, 2013). During the Roman Empire, Roman Concrete (Opus Caementicium) was made from quicklime, pozzolana and an aggregate of pumice (Lancaster, 2005). Furthermore, concrete was also defined by Al-Kourd and Hammad, (2010), as a mixture of cement (11%), fine aggregate (26%), coarse aggregate (41%), water (16%) and air (6%). Reed (2008) stated that concrete as a manufactured material has various properties that are determined not only by the component materials, but also by the manufacturing process of the cement, the design of the structure to be build and the construction procedures followed on site. As a versatile material, concrete can be cast in any desired shape and hence can be applied for most building purposes. Concrete has also been defined as a composite material composed of aggregate bonded together with fluid cement which hardens over time (Zongjin, 2011). The simplest representation of concrete is: Concrete = Filler + Binder. The word binder refers to several substances that have been developed over the years. Therefore, according to the type of binder used, there are many different kinds of concrete. For instance, Portland cement concrete, asphalt concrete, and epoxy concrete. Today, Concrete has become a major component of most of our infrastructural facilities in the 21st century because of its versatility in use. Concrete is used more than any other man-made material in the world (NRMCA, 2013). Approximately 919 million tons of concrete were produced in 2007 (EPA, 2009), about 7.5 cubic kilometers of concrete was made each year; more than one cubic meter for every person on Earth. The importance of concrete in modern society cannot be underestimated. In concrete production, Portland cement is the most widely used binder. In Nigeria, the use of other cement or binder types is practically nonexistent. Thus, the term concrete usually refers to Portland cement concrete, which is usually adequate for most construction works within the country. For this kind of concrete, the composition can be presented as follows; Portland cement (plus Admixture including pozzolans) + fine aggregate + coarse aggregate = concrete. Concrete production within the country is missing an essential component of modern concrete production that can greatly improve the properties and quality of concrete.

Classification of concrete

Concrete as a construction material can be made based on the binding materials that are available or manufactured within an area (e.g. pozzolanic, cement etc.) or based on specifications. Requirement of concrete can be specified either by its perspective, performance, density or method of casting. Hence Duggal (2008) classified concrete as follows:

1. Based on Cementing Material: This class of concrete depend on cementing material that would be used to bind the aggregates together and it is classified as lime concrete, gypsum concrete and cement concrete.
2. Based on Specification Perspective: The cement concrete is specified by proportions of various constituents, e.g., 1 (cement): 1.5 (fine aggregate): 3 (coarse aggregate). It is believed that by obeying such specifications view, satisfactory performance may be achieved. The usual mix proportions of cement concrete are given in table 1

Table 1: Mix Proportion of Cement Concrete

Grade of concrete	M10	M15	M20	M25
Mix proportion	1:3:6	1:2:4	1:1.5:3	1:1:2
Perspective characteristic strength	10	15	20	25

Source: Duggal (2008)

Where M refers to the mix and this type of concrete mix is also known as nominal mix.

3. Based on Performance Oriented Specifications: For a concrete that is specified based on performance, the required concrete properties such as strength, water-cement ratio, compaction factor, slump, etc., are specified by the contractor.
4. Based on Grade of Cement Concrete: This class of concrete is specified depending upon the strength (N/mm2) of the concrete cubes (100 or 150 mm) at 28 days required. The strength specification can be low strength concrete (< 20 N/mm2), medium strength concrete (20–40 N/mm2) and high strength concrete (>40 N/mm2).
5. Based on Bulk Density: Density of concrete is considered for this classification as super heavy (over 2500kg/m3), dense (1800-2500 kg/m3), light weight (500–1800 kg/m3) and extra light weight concrete (below 500 kg/m3).
6. Based on Place of Casting: This class of concrete are; in-situ concrete and precast concrete. When concrete is produced and placed in position on site it is known as in-situ concrete and when produced as a prefabricated unit in a factory it is known as precast concrete.

Cement Concrete and Aggregate Australia, CCAA, (2004) opined that concrete properties are its characteristics which entails; workability, cohesiveness, strength and durability. Concrete has various properties at fresh state; when it's wet and at hardened state when it's completely dry. The variation of these properties tends to affects its end use or functional requirements.

Constituent of concrete

Concrete have four major constituents which are: cement, fine aggregate, coarse aggregate and water. Other materials may be added in the mix to alter the properties of the concrete; these materials are called additives or admixtures.

Cement

The early history of cement originated from the Egyptians who burn gypsum to obtain cementing materials, the Egyptians used lime and gypsum as cementing materials in constructing the famous pyramids. Romans have also used calcareous cements which is either lime stones burned in kilns or were mixtures of lime and pozzolanic materials (volcanic ash, tuff) combining into a hard concrete (Duggal, 2008). According to Shetty (2005), the investigation of L. J. Vicat led him to prepare an artificial hydraulic lime by calcining an intimate mixture of limestone and clay. This process may be regarded as the leading knowledge to the manufacture of Portland cement. The raw materials required for the manufacture of Portland cement are calcareous materials such as lime stone or chalk, and argillaceous materials such as shale or clay (Shetty, 2005). Portland cements are hydraulic cements, meaning the react and hardened chemically with the addition of water. Cement contains limestone, clay, cement rock and iron ore, blended and heated from 1200 to 1500^{0}C, the resulting product “clinker” is then ground to the consistency of powder (Akourd and Hammad, 2010). Merrit and Ricketts (2001) defines cementitious materials as any material which when mix with either water or some other liquid or both form a cementing paste that may be formed or molded while in plastic but will set into a rigid shape. When sand is added to this paste, mortar is formed and when coarse aggregate (crushed stone) and fine aggregate (sand) added to the paste forms the concrete. Use of cementitious material increases the chemical and physical binding capacity, influence the pore system as well as the composition of cement pastes (Ytterdal, 2014). Cement as one of the construction materials may be define as adhesive or sticky-substances capable of clinging fragments or masses of solid matter to a compact whole. It can be made from a mixture of elements that are found in natural materials such as limestone, clay, sand and shale (Mays (2003); Isah, (2014); Oluwatuyi and Olayemi (2012). According to Mays (2003) cement generally are artificial chemicals which, when mixed with water, undergo a chemical reaction that is given the special name ‘hydration’. The mass hydration products together with the unhydrated parts of cement age granules are called the ‘cement paste’ and this paste maintains this name in dry, aged hardened concrete. However hydraulic cementis made by replacing some of the cement in a mix with activated aluminium silicates, pozzolanas, such as fly ash. The chemical reaction results in hydrates that are not very water-soluble and so are quite durable in water and safe from chemical attack. This allows setting in wet condition or underwater and further protects the hardened material from chemical attack (e.g., Portland cement). The chemical process for hydraulic cement found by ancient Romans used volcanic ash (activated aluminium silicates). Presently cheaper than volcanic ash, fly ash from power stations recovered as a pollution control measure, or other waste or by-products are used as pozzolanas with plain cement to produce hydraulic cement. This pozzolanas can constitute up to 40% of Portland cement.

Characteristics of Portland cement

Cement paste is an important part in concrete and thus; Rasa, Katabchi, Afsher, (2009) stated that the mechanical properties of concrete are highly influenced by the density and compressive strength of concrete cement paste. The density and compressive strength of concrete cement paste are affected by several parameters; water cementitious materials ratio, pozzolan contents, percentage of super-plasticizer, curing, cement type, etc. Strength and durability of any building to be constructed depends solely on the characteristics of cement to be use, and for this reason Garba (2008) described the characteristics of Portland cement as:

Fineness: Fineness of cement as one of it characteristics influences the rate of reaction with water because of the fact that finely ground cement has more exposed surface area than a coarsely ground one. If the rate of reaction of cement is affected, the rate of setting and hardening of that cement will also be affected and therefore this characteristic facilitate in completing the chemical reaction between cement and water within short time. When powder cement is too fine the particles may become pre-hydrated by moisture (water vapour) from air and result to losing it is cementitious power (bad cement). This characteristic of cement can be measured from specific surface of the cement which can be determined in an air permeability apparatus where the typical value of OPC specific surface is 300m^2/kg. Sieving an estimated amount of 0.11kg of cement sample through no. 170 sieve (0.09 mm) in 15 minutes and the residue should not exceed 10% is another method that used to measure the fineness of cement. For a material of similar features with cement like pozzolanic material the second method can also be used to determine the fineness of that material.

Chemical composition: This is the basis of characterization of cement which can affects all properties of cement except the fineness of cement. High content of certain cement constituents compound in proportion to others may lead to retardation or acceleration of the rate of setting and hardening, thus the constituents need to conform to standard specification. Excess of any compound could affect the rate of heat evolution as the cement hydrates, and to guide against this the ratios of lime, silica, alumina, iron oxide, alkali and sulphur contents should be maintained base on the standard specification. Calcium chloride and calcium sulphate (gypsum) are used as additives to accelerate or retard the rate of setting of cement paste. Some of the methods that can be used for checking the chemical composition of cement are; Energy Dispersive X-Ray Fluorescence test (EDXRF), wet chemistry method, Neutron Activation Analysis (NAA) etc.

Soundness: A mixture of cement and water also known as cement paste. When it sets and hardens without any cracking or disintegrating such cement is said to be sound cement. Hydration of free lime (CaO), magnesia (MgO) and sulphates (SO_4) surrounded by cement particles caused unsoundness of cement by preventing easy hydration of free lime (uncombined lime) and other materials during the normal setting period. For a cement to be free from unsoundness it should be thoroughly mixed, burnt and ground. Selecting too much lime which may combine with acidic oxides during manufacture, too much magnesia and too much sulphate were the errors usually made responsible for the production of defective (unsound) cement. Le chartelier apparatus is the instrument widely used for checking the unsoundness of cement in the laboratory.

Hydration: The chemical reaction that occurred between cement and water is called hydration of cement which is an exothermic process and the heat liberated is known as heat of hydration. OPC can liberate heat as high as 85-100 cal./g. and low heat cement liberates up to about 60-70 cal./g. When this heat is release in large amount it could be harmful but at times could be useful for a huge concrete structure (e.g. dam, bridge etc.). It causes cracking and disintegration of the structure due to the high insulation properties of concrete and does not allow heat to dissipate easily thereby causing restrained thermal expansion.

Setting and Hardening: Setting is the state of rigidity of cement paste over time and the process after final setting is the hardening of cement paste. When water is poured on cement, hydration begins, at the same time cement starts to stiffen thereby losing its plasticity to become a bit rigid and hence the cement paste is said to have set. Setting time of cement can be determined in the laboratory by the use of Vicat apparatus, cylindrical mould, initial and final setting time of cement paste. Setting times of cement paste is a highly variable property of cement which should neither be too slow nor too fast and it does depend on the type of cement used. It should be long enough (not less than 45 minutes and not more than 10 hours for initial and final setting time) to enable mixing, transporting, placing and compaction of concrete or mortar to be completed before final setting starts.

III. MATERIALS AND METHODS

Materials

For this research, the basic materials for concrete production was used. These materials include cement, fine aggregate, coarse aggregates and water. Two other materials used as partial replacement for cement are Corn cob ash (from maize waste) and Metakaolin. The properties of all the materials mentioned above that facilitated the determination of the required quantities of concrete constituents in various mixes was tested in the laboratory and recorded. These properties are specific gravity, bulk densities, sieve analysis and volumes of the various materials.

.1 Coarse Aggregate

Coarse aggregate may be either gravel or crushed stone comprised of particles greater than 0.25 inch (6.35mm) diameter. Single sized crushed granite stone that conformed to BS EN 933-5 (1998) was used for this research and was obtained from aggregate suppliers within Bauchi town. It was in saturated surface dry condition before it was used in the research. It was sieved to pass through 20mm sieve and retained on 10mm sieve.

2 Fine Aggregate (River Sand)

Fine aggregate (sand) was clean and saturated surface dried sharp river sand which was obtained from suppliers within Bauchi town. It was subjected to sieve analysis which passed through a sieve size of 4.75mm conforming to BS EN 933-1 (1997).

3 Cement

Cement used in this research was Ordinary Portland Cement grade 42.5 of Dangote brand because is the most widely used cement for construction in Nigeriaand is assumed to conform to BS 12.

4 Corn Cob Ash

The corn cob used for this experiment was obtained from a big farm in DisinaShira local government Bauchi state, Nigeria. The Corn Cob

Ash was obtained by the burning of the corn cobs. The corn cobs were dried and broken down to smaller pieces and burned using open air burning. The ash resulting from the combustion was passed through a number 200nm sieves and used in the experiment. The Corn Cob ash was examined using an x-ray fluorescence (XRF) test to determine the oxide composition of the ash.

5 Metakaolin

Metakaolin, a supplementary cementitious material used for this research work, was obtained from Alkaleri local government area of Bauchi state, Nigeria in sufficient quantities from calcination of locally sourced kaolin clay. The Kaolin was ground to powder using a stone crusher then metal mortar and pestle to fine powder. The kaolin powder was fired (calcined) in the laboratory at controlled temperature of 700°C in a Kiln (furnace) and soaked (maintained) for one hour, and the resulted metakaolin was brought out and allowed to cool at room temperature, this produced a highly reactive alumino-silicate pozzolanic material rich in silica and alumina. After cooling, the resultant metakaolin powder was sieved through a 15μm sieve.

6 Water

Water that was used for this research work was portable water, which was obtained from a tap located at phase 1 faculty of environmental technology ATBU Bauchi.

7 Curing Method

The concrete samples were cured by completely immersing them into the curing media. Three types of curing media was used which includes; 0% concentration of H_2O, 1.2% concentration of $MgSO_4$ and 1.2% concentration of H_2SO_4. 1.2% concentration of $MgSO_4$ and H_2SO_4 used for this research can be said to be of severe concentration range as indicated by Monteiro (Anonymous). Suphuric acid (H_2SO_4) was procured in liquid form and magnesium sulphate ($MgSO_4$) in powdered form from chemicals vendor in TafawaBalewastreet Jos in Plateau State.

METHODS

Chemical properties

Chemical analysis was carried out on corn cob ash and metakaolin using XRF test to determine the oxide composition of the materials, these include; Silicon Oxide (SiO_2), Aluminum Oxide (Al_2O_3), Iron Trioxide (Fe_2O_3) and others. In order to investigate if they are in line with the ASTM C 618-94: (1994) classes of pozzolana. This chemical analysis was carried out at Sodexmines in Jos. The ASTM standard stipulates that for any material to be used as pozzolana, it should fall within the following classes; Class N, Class F or Class C.

Sieve Analysis of fine and coarse aggregates

Sieve analysis refers to the grading of aggregates into fractions, each containing particles of the same sieve size (Neville, 1981). The grading of an aggregate has major effect on the workability of a concrete mix and forms significance factors to be considered in concrete mix design. The grading of aggregates was determined using standard BS Sieve sizes by procedure specified in BS Codes such as BS 812:1975. In sieve analysis, instruments and apparatus used in this research for this procedure involves a series of standard sieve sizes arranged in a descending order of five (5) different sizes, a scoop, weighing balance and a brush.

Specific Gravity

Specific gravity is given as the ration of the weight of a given volume of substance to the weight of an equal volume of water and it is used in determining the absorption of aggregate fine and coarse aggregates.

Apparatus: In determining the specific gravity of aggregate a pycnometer (a vessel of 1 litre capacity with a metal conical screw top and a 5mm diameter hole at it apex, giving a water tight connection), tray, scoop, drying cloth and weighing balance were used. The test procedure was carried out in accordance to BS 812. 1975.

Bulk Density and Voids

Bulk density is the mass of the particles and material divided by the total volume they occupy. This test involves determination of the bulk density and the amount of voids in a sample of both fine and coarse aggregates.

Apparatus: Apparatus to be adopted in this procedure include; weighing balance, metal cylinder of $7dm^3$ capacity, scoop, straight edge and a drying duster (towel). The test was carried out according to BS 812: 1975.

Procedure

The procedure followed in determining the bulk densities and voids of the samples involves: - clean and weigh the metal cylinder, then the cylinder was filled with water to the brim and weighed. Then the water was poured out of the cylinder and dried with a towel. For the compacted bulk density test, the cylinder was filled in three layers, each layer was compacted with the rod by tamping using the rod 25 times before the next layer is added and then finally weighed. The obtained net weight of the material was then divided by the volume of the metal cylinder to give the appropriate bulk density.

Setting Time Test

As described in BS EN 196-3 (1995) setting time test was conducted in which consistency, initial setting time and final setting time were carried out using Vicat apparatus with the plunger and needle. Five different mixes with 0%, 10%, 15%, 20%, 25% and 30% replacement of Portland cement with composite corn cob ash-metakaolin paste was prepared for setting time test.

Consistency

Consistency was determined using equation 1

$$\text{Consistency} = \frac{\text{water consumed}}{\text{weight of cement cement sample}} \times 100\% \quad \text{- -- - - - - - - - - - - - - -}(1)$$

For all the replacement levels.

3 Workability

Workability of each mix of concrete was assessed using the slump test in accordance with the provision of BS1881: part 2:1970.

Slump test

Slump test is an empirical test that measures the workability of fresh concrete and was done in accordance to BS EN 12 350- 2:2009.

Apparatus: A slump cone 300mm high with base plate and tapping rod, a weighing balance, trowel, scoop and ruler were used in checking the slump of the concrete cone.

Procedure

The concrete mixes were prepared for slump test using a water-cement ratio of 0.55 for all the replacement levels. The constituents of concrete were then mixed together manually until a uniform mix and consistency is obtained.

The slump conical mould was placed on the base plate with the smaller opening at the top and held firmly down into position. The mould was then filled in 3 three layers of approximate0ly equal depth and each layer tamped 25 times with a standard 16mm diameter steel rod, and the top of the cone stroke off with a trowel. The mould was then slowly lifted vertically from the concrete cone and slump measured as the difference between the height of the concrete in mould (300mm) and the greatest height of it after lifting the mould and measured to the nearest 5mm.

Compacting Factor Test

Compacting factor test was done in accordance to BS EN 12 350- 4:2009

Apparatus: A Compacting factor apparatus, scoop, two floats, shovel, head pan, a weighing balance and a straight edge for leveling the top.

Procedure: The upper hopper was filled with of 0%, 10%, 15%, 20%, 25%, and 30% concretes and was leveled to the brim without any compaction of the concrete. The door at the bottom was then released to allow the concrete to fall into the second hopper. The door at the bottom of the second hopper was also released to allow the concrete fall into the cylinder. The excess concrete was then cut off by the use of a straight edge. The weight of the concrete in the cylinder was determined to the nearest 10g which constitute a partially compacted weight. The corresponding weigh of fully compacted concrete was then determined by refilling the cylinder with concrete in 3 layers, each tampered with a tamping rod 25 times. The compacting factor was then determined as the ratio of partially compacted weight to the ratio of the fully compacted weight.

Mixes

Optimum water cement ratio (w/c) was determined by producing three different types of concrete samples with different w/c; 0.45, 0.50 and 0.55 for each of the replacement leels. The test shows that 0.50 w/c is the most suitable and was used for this research. In achieving the mix design, a mix ratio was designed, 20mm coarse aggregate size was used. Ordinary Portland Cement (OPC) was replaced with composite Corn Cob Ash (CCA) and Metakaolin (MK) proportion at different ratios as shown below:

i. 5% CCA: 5% MK
ii. 7.5% CCA: 7.5% MK
iii. 10% CCA : 10% MK
Iv. 12.5% CCA: 12.5% MK
iv. 15% CCA : 15% MK

Concrete Tests

The concrete samples produced was cured in three curing media which are; 0% concentration of H_2O (control), 1.2% concentration of $MgSO_4$ and 1.2% concentration of H_2SO_4. The concrete specimens was crushed after 7, 14, 28, and 56days

1 Density test

The concrete specimens were removed from the curing container at 7,14,21,28 and 56days and placed outside to surface dry, then weighed using weighing balance to determine the mass of the samples in accordance to BS EN 12390-7 (2000). The density of concrete specimens was calculated, using equation (2).

D = M/V - 2.

Where D is the density of the concrete specimen in kg/m^3

M is the mass of the concrete in kg

V is the volume of the concrete in m^3

2 Compressive Strength Test

In respect to the determination of compressive strength, which is before crushing of cubes, the cubes were brought out of water at 7,14,21,28, and 56days and kept for about 20 – 30 minutes for the water to drip off. They were taken to the crushing machine in accordance with BS 1881: Part 116 (1983)

Method for determination of compressive strength of concrete cubes:

After the cubes are crushed, the result of the load applied by the crushing machine was recorded by taking the reading. The compressive stress was obtained by the ratio of applied load to the cross sectional area of the specimen.

Apparatus/ Materials: Compression Testing Machine/ concrete cubes

Procedure:

i. The specimens were removed from water after the specified curing age and excess water was allowed to drip off from the surface for some minutes.
ii. The dimension of specimens was taken.
iii. The specimen was then placed in the machine in such a manner that the load is applied to the opposite sides of the cube, with the cubes centrally placed on the base plate of the machine.
iv. The load was then gradually applied continuously and without shock until the specimen failed.
v. The maximum load was then recorded.
vi. The results were then calculated as the ratio of the maximum load applied to the area of the cube as: [Load (N) ÷ Surface Area (mm^2)]

Abrasion Resistance Test

The concrete samples (cubes) were removed from the container at 28 and 56days and allowed to surface dry. The surface of the concrete cubes was subjected to brushing by means of a wire brush. The brushing consists of one forward and backward motion per second for one minute i.e. 60 cycles. The mass of the cubes before brushing was recorded and named W_1 and after brushing the mass was recorded and named W_2. The mass of the detached matter i.e. $W_1 – W_2$ was recorded and the percentage weight loss of all the specimens were recorded and compared as stated by Gambo (2014) using equation(3).

Abrasion resistance test = (w1 – w2) / w2 x 100% - 3

Water Absorption Test

The concrete samples (cubes) were removed from the curing tank at 28 and 56days and allowed to dry, and then placed in the electronic oven to oven dry at 105^{0}C for 72 hours. The samples were removed from the oven and allowed to cool at room temperature then weighed to determine the initial weights. The final weights were determined after immersing the concrete samples in the curing medium for 30 minutes then was removed to cloth dry and re-weighed again. The values obtained was recorded and the results calculated to assess the rate of absorption of the concrete specimens in accordance to BS 1881-122 (1983).

Flexural Strength Test

In the determination of flexural strength of concrete beams, certain procedures were followed.

Apparatus/ Materials: Flexure Testing Machine and concrete beams

Procedure:

i. The specimens were removed from water after the specified curing age and excess water, allowed to drip off from the surface.
ii. The dimension of specimen was taken
iii. The specimen was placed in the machine correctly centered with the longitudinal axis of the specimen at right angles to rollers.
iv. The load was gradually applied continuously and without shock until the specimen failed.
v. The maximum load was recorded.
vi. The results were then calculated as: R= [Mc ÷ I] = [PL ÷ bd^2]--------equation 4

R= flexural strength (N/mm^2), I= moment of inertia (mm^4), P= failure load (N)

M= max. Bending moment (Nmm), L=length (mm), b= average width (mm)

c= d/2 (mm), d= average depth (mm)

IV. RESULTS AND DISCUSSIONS

Presentation of Test Results

The results of preliminary tests conducted on this research work were; chemical composition of corn cob ash and metakaolin. Others were; specific gravity and bulk density, sieve analysis of the aggregates, of materials used in the experiment.

Physical properties of material

Sieve Analysis of Fine Aggregate

Table 4 shows results of sieve analysis of fine aggregates which was used to determine the fineness modulus and calculated as 2.84. The fineness modulus of fine aggregates should be within the range of 2.0 – 3.5 (± 0.2) and hence it conforms to BS812 and also satisfied the literature reviewed Garba (2008).

Sieve analysis of coarse aggregate

Table 5 presents results of sieve analysis of coarse aggregates which was used to determine the fineness modulus calculated as 6.81. The fineness modulus of coarse aggregates should fall within the range of 5.5 – 8.0 (± 0.2), therefore the coarse aggregates used for this research was in conformity with BS812 and the literature reviewed Garba (2008).

Specific Gravity of Fine Aggregate

Table 6 shows the computation of the Specific gravity of fine aggregate (sand) and which was determined to be 2.58. This falls within the specified range specified by BS882 of specific gravities of fine aggregate, as 2.4 to 2.9.

Specific Gravity of Coarse Aggregate

The average specific gravity of rocks used as aggregate varies from 2.6 to 2.8 (Shetty, 2005). Table 7 presents the result on specific gravity of coarse aggregate used to be 2.71. Result obtained falls within the specified range of specific gravities for coarse aggregates. **5 Specific Gravity of Corn Cob Ash**

Specific gravity of Corn Cob Ash (CCA), as shown in Table 8 was determined to be 2.07. This value is close to the values determined in the study done by Egbe-Ngu and Abdulkareem (2017), who state the specific gravity as 2.05. The result determined in this research is consistent with works done by previous researches.

Specific Gravity of Metakaolin

From Table 9, the specific gravity of metakaolin (MTK) was determined to be 2.39; this value is related to the work done by Manikandan, Subalakshmi, Manikandan, KarthikRaja, Kumar (2015) who report a value of 2.50. The result determined in this research is consistent with works done by previous researches.

Bulk Density for Fine Aggregate

From Table 10, the range of values obtained for un-compacted and compacted bulk densities are 1340kg/m^3 and 1525kg/m^3. These fall within the BS 1881 specified range of 1200kg/m^3 – 1800kg/m^3 which shows the bulk density specifies the requirement for normal aggregate.

Bulk density for Coarse Aggregate

The range of values obtained for un-compacted and compacted bulk densities are 1398kg/m^3 and 1727kg/m^3. These fall within the BS 1881 specified range of 1200kg/m – 1800kg/m^3 which shows that the bulk density specifies the requirement for normal aggregate.

Setting Time and Consistency Test of Materials

The setting time and consistency of Portland cement and composite corn cob ash-metakaolin paste. The setting time and consistency test correspond with ASTM 187 (1986) and conforms to the test carried out by Ogunbiyi, Olawale, Alabi and Thanni (2017).According toAmbroise, Maximilien and Pera, (1994); and Moseley, (1999), Metakaolin slightly reduces the initial and final setting times of cement paste.

Chemical Composition of Materials

Chemical Composition of Corn Cob Ash

The chemical composition of Corn Cob Ash used for this research indicated that silica, alumina and iron contents were 74.48% as presented in Table 13 which is in line with the findings of Adesanya et. Al., (2009) andEgbe-Ngu, Abdulkarim, (2017) and satisfies requirement by the ASTM C618-05 which state that for a material to be a pozzolan the summation of Aluminum Oxide (Al_2O_3), Silicon Oxide (SiO_2) and Iron Oxide (Fe_2O_3) must be 70.0 % minimum.

Table 13: Chemical Composition of Corn Cob Ash in Comparison ASTM Requirement.

Elements	% Composition	ASTM C618-05 limits
Aluminum Oxide (Al_2O_3)	17.23	Al_2O3
Silicon Oxide (SiO_2)	52.38	+
Iron Oxide (Fe_2O_3)	4.87	SiO2
Potassium Oxide (K_2O)	3.64	+
Calcium Oxide (CaO)	7.97	Fe2O3
Sodium Oxide (Na_2O)	3.49	
Magnesium Oxide (MgO)	1.21	=
Vanadium Oxide (V_2O_5)	0.001	70.00%
Manganese Oxide (MnO)	0.16	
Sulphur trioxide (SO_3)	1.53	
Titanium oxide (TiO_2)	0.52	
Chromium Oxide (Cr_2O_3)	0.04	
Zinc Oxide(ZnO)	0.06	

Source: Laboratory Work (2020)

Chemical Composition of Metakaolin

The chemical composition of metakaolin used for this research indicated that the silica, alumina and iron contents sum up to 98.13% as presented in Table 14 which is in line with Hani, (2017) and Gambo, Mohamed, Abdel Rahman and Mohamed (2015); Ibrahim, Aliyu, Ibrahim and Abdulsalam, (2020)and satisfies requirement by the ASTM C618-05 which state that for a material to be a pozzolan the summation of Aluminum Oxide (Al_2O_3), Silicon Oxide (SiO_2) and Iron Oxide (Fe_2O_3) must be 70.0 % minimum.

Table 14: Chemical Composition of Metakaolin in Comparison ASTM Requirement.

Elements	% Composition	ASTM C618-05 limits
Aluminum Oxide (Al_2O_3)	43.77	Al_2O_3
Silicon Oxide (SiO_2)	53.25	+
Iron Oxide (Fe_2O_3)	1.11	SiO_2
Potassium Oxide (K_2O)	0.22	+
Calcium Oxide (CaO)	0.17	Fe_2O_3
Sodium Oxide (Na_2O)	0.11	
Magnesium Oxide (MgO)	0.14	=
Vanadium Oxide (V_2O_5)	0.004	70.00%
Manganese Oxide (MnO)	0.07	
Titanium oxide (TiO_2)	0.16	

Source: Laboratory Work (2020)

Fresh Properties of Concrete Specimens

Workability and Compacting Factor test

Table 15, present the result for slump and compacting factor test of concrete made with corn cob ash-metakaolin as partial replacement of OPC. From the values of the six different mixes, the degree of workability for slump test is medium to low according to Neville and Brooks (2010) and as specified by BS 812 as shown in figure 1. The slump test value for Percentage replacement of cement decrease with increase pozzolana. For compacting factor test value, the degree of workability ranges from low to medium which falls within the range specified by BS 812 and Neville and Brooks (2010). Mixes with 0% - 15% shows higher workability while 20% - 30% shows lower workability. Kamau, Ahmed, Hirst, and Kangwa, 2016). The result is presented in Figure 2.

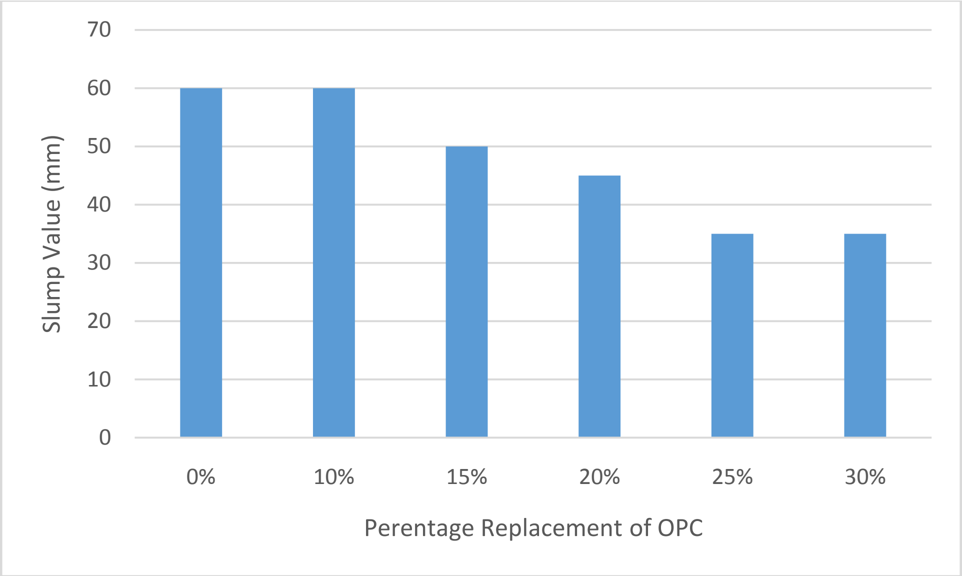

Figure 1: Slump heights of Composite CCA-MTK in (mm) versus percentage replacement of OPC

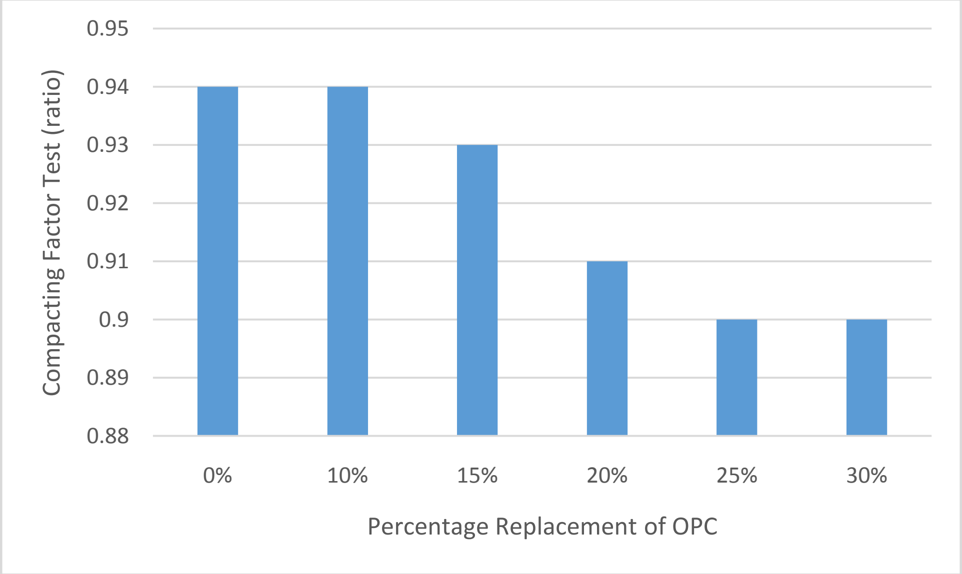

Figure 2: Compacting Factor of Composite CCA_MTK versus percentage replacement of OPC

Density of cubes

1 Density of Cubes Cured in H_2O

Figure 3 present the average density of concrete samples produced with ordinary Portland cement with metakaolin and corn cob ash as partial replacement of cement, cured in normal water (H_2O) and weighed at 7, 14, 28, and 56 curing days. The density of concrete cube samples varies from 2205 kg/m^3 to 2567 kg/m^3 and it increase with increase curing periods. Concrete samples with density higher than 2600kg/m^3 are called as higher density concrete samples (Kazjonovset al., 2010). Values obtained at 28 days exceeded the 2400 kg/m^3 expected for a normal weight concrete. Therefore, concrete produced with metakaolin and corn cob ash is a concrete with ordinary density, though samples with pozzolanic material replacements were denser than the control samples. Adesanya (1996) reported a decrease in weight with higher CCA replacement. The result from this study is similar with that of Kamau, Ahmed, Hirst, and Kangwa (2016); Olafusi and Olutoge, (2012) and Udoeyo and Abubakar, (2003), who reported that the densities of CCA-replaced specimens at higher percentage above 10% were below those of the control. Olafusi and Olutoge (2003), however reported that density increased with curing age, but decreased with further CCA replacement above 10%.

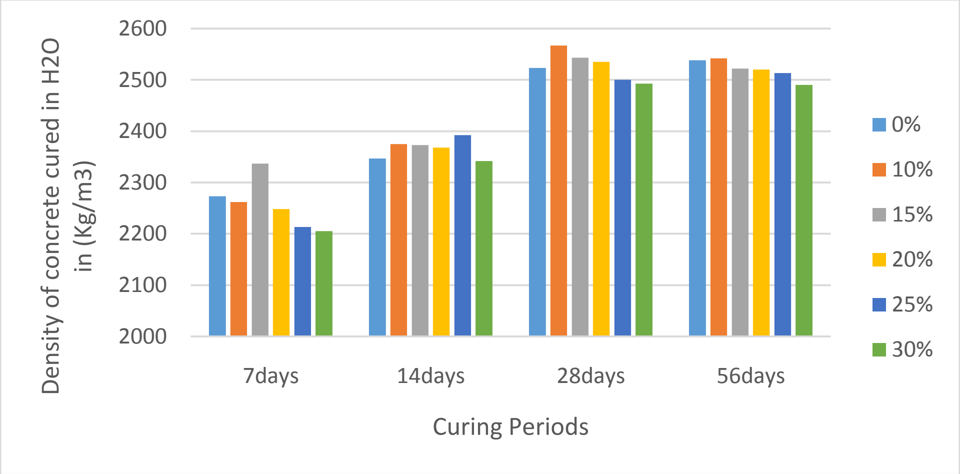

Figure 3: Density of concrete Specimen cured in H_2O

Density of Cubes Cured in $MgSO_4$

Figure 4 shows the average density of Portland cement/corn cob ash-metakaolin concrete samples cured in $MgSO_4$ curing condition and weighed at 7, 14, 28, and 56 curing days. The density of concrete cube samples varied from 2155 kg/m^3 to 2513 kg/m^3 and it decreased with increase in curing periods. There was more loss of density in 30% CCA-MTK cement replacement concrete samples of about 2.52% that in control sample at 56 days curing. Concrete subjected to magnesium sulphate curing environment suffers more loss in weight than in other curing condition, as such magnesium sulphate is more deleterious to concrete samples. The result is close to the work of Olafusi and Olutoge (2003), who reported that density increased with curing age, but decreased with further CCA replacement.

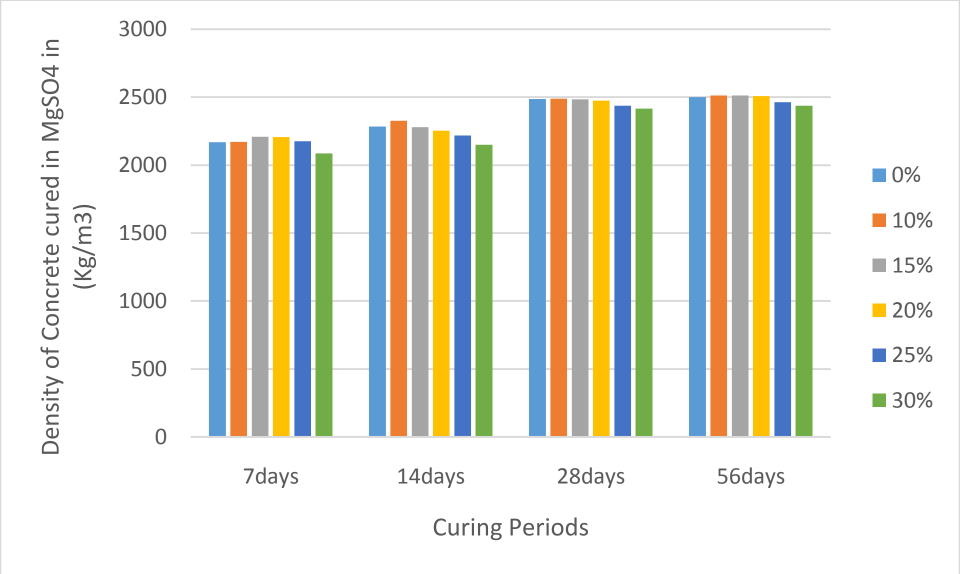

Figure 4: Density of concrete cubes cured in $MgSO_4$

Density of Cubes Cured in H_2SO_4

Figure 5 presents the average density of Portland cement/CCA-MTK concrete samples cured in H_2SO_4 and cured at 7, 14 28 and 56 hydration periods. The density of concrete cube samples varies from 2203 kg/m^3 to 2512 kg/m^3 and it decreases with increase in curing periods. Generally, the higher the density of concrete the lesser its porosity which ensures greater durability of concrete under heavy loads and harsh conditions. The result is close to the work of Olafusi and Olutoge (2003), who reported that density increased with curing age, but decreased with further CCA replacement. The result is similar to the work carried out by Abdulazeez (2019) who stated that concrete produced with pozollanic material and cured in H_2SO_4 possess better density than the control concrete and also withstand chemical environment better.

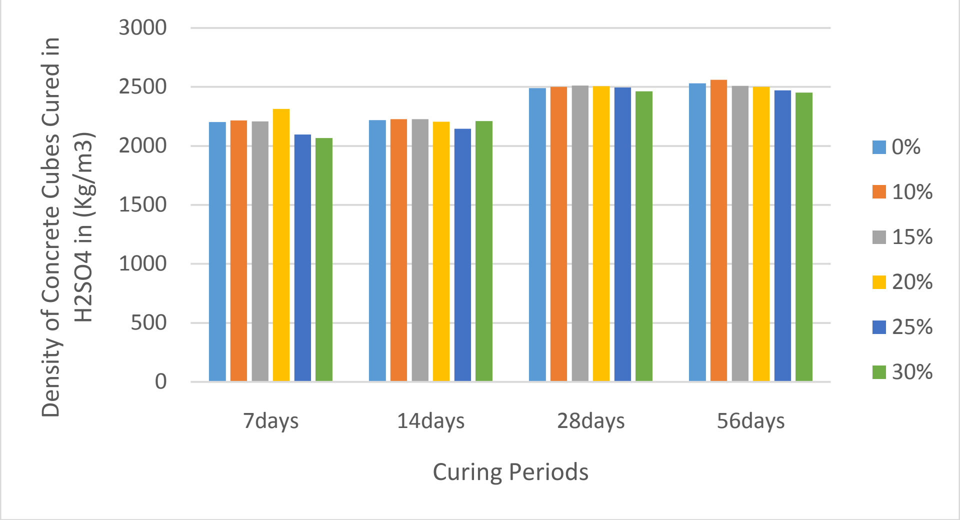

Figure 5: Density of concrete Specimen cured in H_2SO_4

Beam Density Specimenn

From the results shown in Figure 6, the density of concrete cube samples varies from 2480 kg/m^3 to 2580 kg/m^3 and it increases with increase in curing periods. The research is in line with the work carried out by (Kazjonovset al., 2010) and Abdulazeez (2019) with concrete produced in the researches possess increase in density as curing days' increases. Values obtained at 28 and 56 days exceeded the 2400 kg/m^3 expected for a normal weight concrete. Analysis can be drawn that the concrete beams produced conform to the density of normal-weight, and favor higher durability due to the higher values than 2400 kg/m^3 value recorded for beam sample. Therefore, concrete produced with metakaolin and corn cob ash is a concrete with ordinary density, though the samples with pozzolanic material replacements were denser than the control samples. The result is also close to the work of Muhammad and Gomathi (2017) who stated that density of beam increase with curing period. According to Olafusi and Olutoge (2003), however reported that density increased with curing age, but decreased with further CCA replacement.

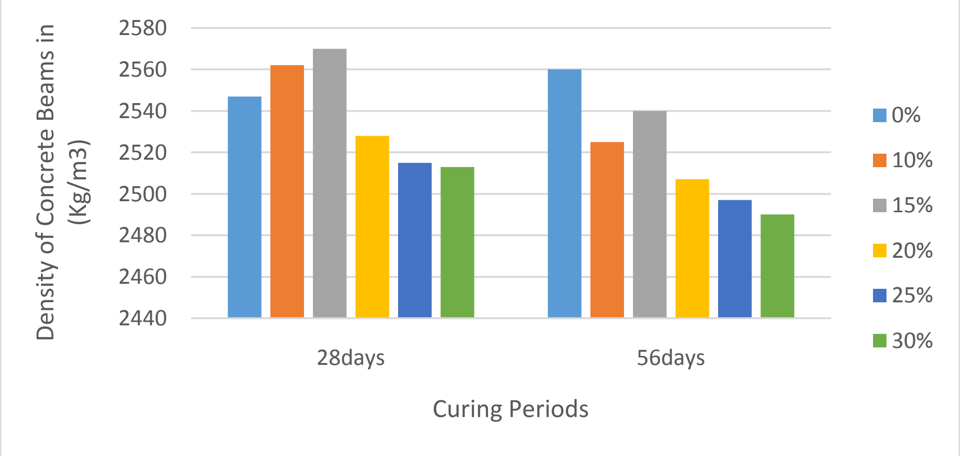

Figure 6: Density of beam Concrete Specimen

Strength Properties of Concrete

Compressive Strength of Concrete specimen Cured in H_2O

Figure 7 shows the compressive strengths of Portland cement/corn cob ash-metakaolin concrete specimens cured in water (H_2O) and crushed at 7, 14, 28 and 56 days' hydration periods. Concrete samples with 10%, 15%, 20%, 25% and 30% replacements of Portland cement with corn cob ash and metakaolin concrete achieved 27.6 N/mm^2, 27.3 N/mm^2, 25.1 N/mm^2, 24.6 N/mm^2 and 23.9 N/mm^2 respectively while 0% replacement achieved 27.6 N/mm^2 at 28 days. The result shows that the control concrete has same strength index with 10% cement replacement in concrete. At 56days concrete produced with 10%, 15%, 20%, 25% and 30% replacements of Portland cement with corn cob ash and metakaolin achieved 28.2 N/mm^2, 27.7 N/mm^2, 25.5 N/mm^2, 25.1 N/mm^2 and 24.2 N/mm^2 respectively while 0% replacement achieved 27.9 N/mm^2 This represents 1.06% increase for 10% replacement of cement over the control concrete in compressive strength. The result is in range with the work carried out by Jehad and Kemal (2014). The compressive strength achieved for both control and percentage replacement were below the BS EN 197-01 (2000) requirement which states that concrete sample should achieve 32.5 N/mm^2 at 28 days. This could be due to the method of compaction applied (manual compaction) during the concrete production. The standard requires the use of mechanical compaction to achieve this result. Price, Yeargin, Fini, and Abu-Lebdeh, (2014) reported that compressive strengths increased above those of the control with the addition of CCA up to the 10% replacement, after which they decreased with further replacement, whereas Adesanya (1996) reported strengths that were above those of the control at 28 days. Adesanya and Raheem (2009) reported compressive strengths that were above those of the control for replacements of up to 8%, with compressive strengths capable of use for structural applications as per BS-EN 1992-1-1-2000 (2004) being reported for all replacements. Udoeyo and Abubakar (2003) reported high compressive strengths suitable for structural applications for the 10% replacement, whereas Olafusi and F. Olutoge, (2012) reported 10% as the level of replacement by the volume of cement that was satisfactory in compressive strength so as not to compromise structural integrity. However, the compressive strengths reported by Adesanya and A. A. Raheem, (2009) from all replacements were below the classes that are specified by BS-EN 1992-1-1-2000 (2004) as being suitable for structural applications. According to Dhiret al. (1999), Ryle (1999), Sabir (1998) and Wild et al (1999) made numerous studies have shown that metakaolin increases the compressive strength of concrete. The magnitude of the effect is sensitive to water/ binder ratio. Poon et. al. (2001) reported increased in compressive strength at 10% replacement of cement with metakaolin content with increase in water-binder ratio.

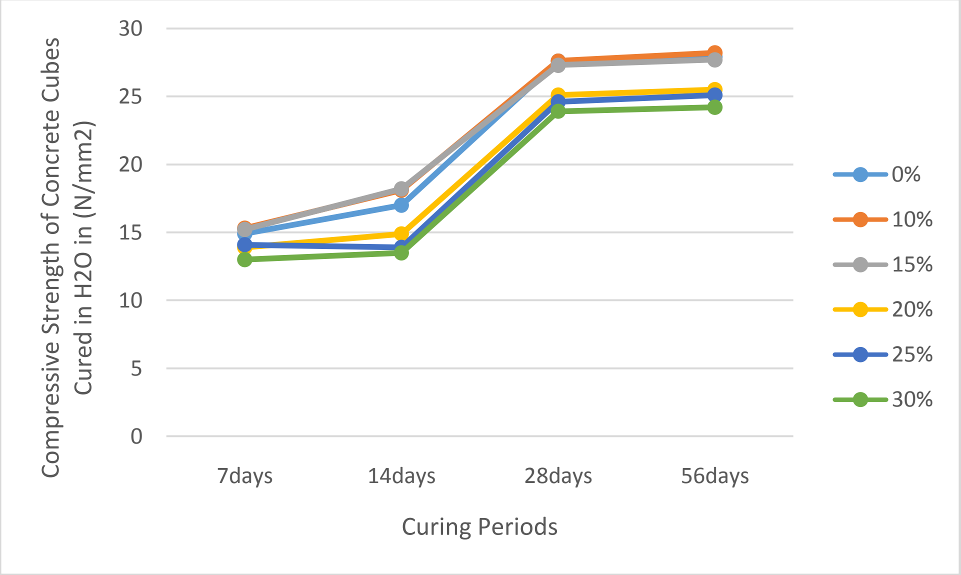

Figure 7: Average compressive strength of Concrete Specimen Cured in H_2O

Flexural Strength

Figure 8 presents the flexural strengths of Portland cement corn cob ash-metakaolin specimens tested at 28 and 56 days' hydration periods. Concrete specimens with 0% replacement achieved 5.18 N/mm^2 while 10%, 15%, 20%, 25 and 30% replacement of Portland cement metakaolin-corn cob ash achieved 5.20 N/mm^2, 5.10 N/mm^2, 4.55 N/mm^2, 4.36 N/mm^2 and 4.13 N/mm^2 at 28 days. This represents 0.38% decrease of 0% concrete from 10% corn cob ash-metakaolin replacements in compressive strength. The result is close to the research work of Muhammad and Gomathi (2017) which shows highest flexural strength at 10% metakaolin. This perhaps could be as a result of the type of pozollana used in the production of the concrete specimen as posited by Vijayakumaret al. (2013) that the flexural strength increases with increase curing days. Percentage replacement of corn cob ash-metakaolin up-to 15% gives higher flexural strength because it makes good bonding and excellent filler between the aggregates and paste of the concrete. Metakaolin has a beneficial effect on flexural strength, although the magnitude of the effect is less than that observed for compressive strength (Kalaignan& Siva, 2016).

V. SUMMARY OF FINDINGS

1. The Chemical properties of metakaolin (MTK) and corn cob ash (CCA) where investigated and the result showed that MTK has high SiO_2 percentage of up to 53.25% which meets the necessary minimum chemical requirements for a good pozzolan ($SiO_2 + Al_2O_3 + Fe_2O_3 = 98.13\%$), with $Al_2O_3 = 43.77\%$ and $Fe_2O_3 = 1.11\%$. On the other hand, corn cob ash met the minimum requirement ($SiO_2 + Al_2O_3 + Fe_2O_3 = 74.48\%$) with a considerable percentage of $Al_2O_3 = 17.23\%$ and $Fe_2O_3 = 4.87\%$. The higher percentage of Al_2O_3 in metakaolin became the basis to justify developing a composite CCA-MTK replacement ratio for cement in concrete. The test on the Physical Properties of fine aggregate and coarse aggregate revealed specific gravities of 2.58 and 2.71 respectively. The results of void percentages of coarse aggregate and fine aggregate is 17.57% and 12.55% respectively, also the compacted bulk density of CA and FA are 1727 kg/m^3 and 1525 kg/m^3 respectively, while that of un-compacted bulk density of coarse aggregate and fine aggregate is are 1398 kg/m^3 and 1340 kg/m^3 respectively. Also, Test on physical properties of metakaolin (MTK) and corn cob ash (CCA) revealed specific gravities of 2.07 and 2.39 respectively; which indicates that it is suitable for use in replacement of cement and falls within range for specific gravity of pozzoloans.
2. The workability of concrete with metakaolin (MTK) and corn cob ash (CCA) for all percentages of replacements using a water-cement ratio of 0.55 revealed a medium to low degree of workability for 0% - 30% replacement of cement with respect to slump test, with values of 60mm, 60mm, 50mm, 45mm, 35mm, and 35mm for Slump test and 0.94, 0.94, 0.93, 0.91, 0.90, 0.90, for the compacting factor test which indicated low to medium degree workability. These Results suggest that concrete made from MTK and CCA are suitable for mass concrete, reinforced concrete, foundation sections and roads.
3. There were visible surface deterioration or wear but no tear observed for concrete samples cured in $MgSO_4$ and H_2SO_4 medium though the concrete samples cured in $MgSO_4$discoloured to white and those cured in H_2SO_4 turned to brown. The compressive strength results revealed that the concrete with 0% replacement level at the age of 28 but 10% replacement of cement with corn cob ash and metakaolin have better strength at 56days. Also the flexural strength results revealed that the concrete with 10% replacement level at the age of 28 and 56days surpassed that of control concrete and the expected 4.0N/mm^2 flexural strength of concrete at 28 days.

VI. CONCLUSION

After carrying out the experiments, observations, analysis and discussions, on effect of composite corn cob ash and metakaolin on the durability properties of concrete exposed to chemically aggressive environments, the following conclusions were drawn:

1. The XRF chemical analysis of corn cob ash and metakaolin showed that it satisfied the ASTM C618-05 requirement as a pozzolanic material, also physical properties such as bulk density, specific gravity and were found to be in conformity with ACI E1-99. Setting time and consistency test of Portland cement/corn cob ash-metakaolin satisfied the BS EN 197-1 (2000) requirements.
2. The workability of concrete at all levels of replacement was higher than that of ordinary Portland cement concrete (control) specimen

for slump while concrete with 10% and 15% cement replacements had higher workability than control concrete samples for the compacting factor.

3. Strength properties of hardened concrete specimen showed that concrete with 10% replacement of cement with metakaolin and corn cob ash composite have higher compressive and flexural strengths than ordinary Portland cement specimen (control).

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VII. RECOMMENDATIONS

From the results of this research, the following recommendations were made:

1. The research recommends the use of composite corn cob ash and metakaolin to replace cement in concrete production due to its accessibility, usability and availability.
2. The use of 15% replacement of cement with composite corn cob ash and metakaolin is the optimum OPC/MTK-CCA replacement level that can be used to produce durable concrete for construction purposes in both normal and aggressive chemical environments.
3. Partial Replacement of ordinary Portland limestone cement with corn cob ash and metakaolin should be used in roads and bridges due to its increased tensile strengths.

1. It is recommended that the concentration of the chemical curing media for Portland cement/corn cob ash-metakaolin concrete samples be increase to up- to more than 2.0% and 3.0%, then tested to up-to 90 curing days to further assess the severity of the deterioration on the concrete samples.
2. Durability properties are many and varied, therefore further research should be carried out to assess the effect of this material on shrinkage, creep, fire resistance, chloride penetration, freezing and thawing resistance and others.
3. Research should be carried out on the effects of a different water-cement ratio on the porosity of corn cob ash–metakaolin concrete.

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