

# Mechanical Properties of Geopolymer Concrete Produce with Peanut Husk Ash Blended Metakaolin

Wabalong Klakoye Desire

*Department of building ATBU Bauchi/ Nigeria*

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## ABSTRACT

Concrete is one of the most widely used construction material in the world. It is a fundamental construction material used to fulfill the housing and infrastructural need of the society having the basic constituent of conventional fine and coarse aggregate, cement and water. It has proven to be a leading construction material for more than a century and it is estimated that the global production rate annually is at 1m<sup>3</sup>. This research is aimed at investigating the Mechanical Properties of Geopolymer Concrete Produce with Peanut Husk Ash blended Metakaolin. The research aim was achieved through the following objectives: to determine the physical properties of the constituents, to determine the workability of fresh geopolymer concrete produced with peanut husk ash and metakaolin, to determine the strength properties of geopolymer concrete produced with peanut husk ash and metakaolin. In this research, an attempt is made to study strength properties of geopolymer concrete using Peanut Husk Ash (PHA) blended Metakaolin (MK) replacing Ordinary Portland cement in 5 different (100%MK, 80%MK+20%PHA, 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA) percentages. Sodium silicate (212.57 Kg/m<sup>3</sup>) and sodium hydroxide of 16 molarity (85.03 Kg/m<sup>3</sup>) solutions were used as alkalis in all 5 different mixes. With maximum (28.57%) replacement of 80%MK+20%PHA (Mix no2), achieved a maximum compressive strength of 28.2N/mm<sup>2</sup> for 28 days. The same mix (Mix no2) is shown 27.3 N/mm<sup>2</sup> after cured in Magnesium Sulphate attack. The study conclude that Strength properties hardened concrete specimen shows that 80%MK+20%PHA have higher compressive and flexural strengths than others mixes. The compressive Strength of concrete has been increase by 9% for 16M solution in 1:2.5 alkaline liquid ratios. The research recommends by using these

replacements we are trying to reduce cost, energy savings, and superior products and fewer hazards to environment.

**Keywords:** Fly Ash, Geopolymer concrete, sodium silicate, sodium hydroxide, Peanut Husk Ash, Metakaolin, Compressive strength, Flexural strength, Water Absorption, Abrasion Resistance and Magnesium Sulphate.

## I. INTRODUCTION

Concrete is one of the most widely used construction material in the world. It is a fundamental construction material used to fulfill the housing and infrastructural need of the society having the basic constituent of conventional fine and coarse aggregate, cement and water. It has proven to be a leading construction material for more than a century and it is estimated that the global production rate annually is at 1m<sup>3</sup> (approximately 2.5 ton) per capita (Neville, 2003).

The construction industry searches the alternatives to satisfy the increasing need for the cement necessary for concrete production. The current cement production rate worldwide is approximately 1.2 billion tons/year. This consumption is expected to grow to about 3.5 billion tons/year by 2015 (Adesanya & Raheem, 2009). However, high consumption of concrete results in high demand of cement. It was estimated that 125liters of fossil fuel and 118KWH of electricity is consumed in the production of 1tonne of cement (Vazinram & Khodaparast, 2009).

This means the production of cement requires the burning of fuel which results in significant release of large amount of carbon-dioxide (CO<sub>2</sub>). Patricija, Aleksandrs & Valdemars (2013), noted that cement does not only consume energy during its production, it is also accountable for a substantial part of man-made CO<sub>2</sub> emission,

which leads to global warming. The problems associated with cement are in two folds. First, the negative environmental impact and secondly, the high cost of the production process. Cement is used as a major material in concrete; the composition of world-cement consumption in the year 2010 was measured at 3,313 million metric tons, which shows that it is the mostly used material (Vignesh, Devi, Manohari & Santha, 2014). During the manufacturing of 1 ton of cement, 1 to 1½ ton of earth resources like lime stone is used up and at the same time, an equivalent amount of CO<sub>2</sub> is released into the atmosphere (Srinivasan, Sathiya & Palanisamy, 2010). According to Jindal & Kamal (2015), production of Portland cement currently exceed 2.6 billion tons per year worldwide and it increases at 5% rate each year thereby generating nearly 7% of atmospheric carbon-dioxide (CO<sub>2</sub>) which contributes largely to the global warming. Priya & Partheeban (2013), explain that the CO<sub>2</sub> constitute up to 65% of global warming. Because of these, efforts have been made by researchers to reduce the problem created when using Portland cement in concrete production.

The search for alternative binder or cement replacement materials led to the discovery of the potentials of using industrial by-products and agricultural wastes as cementitious materials whereby its quantity of these cement is partially replaced with these supplementary cementing materials such as fly ash, ground granulated blast furnace slag, rice husk ash, metakaolin etc. If these fillers have pozzolanic properties, they impart advantages to the resulting concrete and also enable larger quantities of cement replacement to be achieved (Biricik et al., 1999)

Another way of developing alternative environmentally friendly concrete is to replace Ordinary Portland Cement (OPC) with a binder known as geopolymer which is presented herein. Tavor, Wolfson, Shamaev & Shvarzman (2007) defined geopolymer as an amorphous polymer formed through the ionic bonding reaction between an aluminosilicate (Al - Si) materials and strong alkaline solution. It results into polycondensation of silica and alumina from a source material rich in silica (Si) and alumina (Al) like fly ash, metakaolin, silica fume and other pozzolana to attain structural strength instead of forming calcium-silicate-hydrates (CSH) as in the case of OPC (Rajamane, Lakshmanan & Nataraja, 2009). This binder shows a promising application for use in concrete production because according to Priya

& Partheeban (2013), it could reduce CO<sub>2</sub> emission caused by cement industry by 80%.

## II. STATEMENT OF THE PROBLEM

Cement is used as a major material in concrete. The composition of world-cement consumption in the year 2010 was measured at 3,313 million metric tons, which shows that it is the most used material (Vignesh et al, 2014). Despite the conventionally known materials for producing concrete and following that cement is the most important, and due to the increasing cost of cement and rigorous process of obtaining cement, it is necessary for an alternative and partial replacement to cement in concrete production (Adole, Dzasu, Umar & Oraegbune, 2011). 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 emission of CO<sub>2</sub>. The emission of CO<sub>2</sub> is such that for every ton of cement produced almost a ton of CO<sub>2</sub> is emitted Shoubi et 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.

The use of waste materials for partial replacement of cement provides for greater economic and environmental benefits Nazir et al (2009). A considerable amount of work has been reported in the literature on how to use agricultural waste products as supplementary cementitious materials Mehta (2000). Ideally, the development of such materials serves three separate purposes simultaneously. 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 emission of CO<sub>2</sub>. The emission of CO<sub>2</sub> is such that for every ton of cement produced almost a ton of CO<sub>2</sub> is emitted Shoubi et al., (2013)

As the demands for concrete continue to increase due to rapid infrastructural development, so is the demand of OPC. Liew, Kamarudin, Mustafa, Luqman, Khairul & Heah, (2011), explains the growing concerns on environmental impact caused by the extraction of raw materials for cement and CO<sub>2</sub> emission during cement

manufacturing. In view of this, the concept of geopolymer which is environmentally friendly was developed to be used as an alternative to OPC in concrete production. Many researchers have utilized different materials in the production of geopolymer concrete but few researches have been carried out producing concrete using blended peanut husk ash and metakaolin geopolymer. Result on the study of mechanical properties of geopolymer concrete at different replacement shows that compressive, tensile strength and elastic modulus shows favourable increase in concrete properties (Anuar et al., 2011; Shuang et al., 2012; Posi et al., 2013; Seta et al., 2013). Currently very few researches have been carried out exploring the properties of peanut husk ash and metakaolin blend geopolymer concrete.

### III. AIM AND OBJECTIVES

This research is aimed at investigating the Mechanical Properties of Geopolymer Concrete Produce with Peanut Husk Ash blended Metakaolin.

The research aim was achieved through the following objectives:

- i. To determine the physical properties of the constituents.
- ii. To determine the workability of fresh geopolymer concrete produced with peanut husk ash and metakaolin.
- iii. To determine the strength properties of geopolymer concrete produced with peanut husk ash and metakaolin.

### IV. LITERATURE REVIEW

#### Concrete

Concrete is an ubiquitous material and its versatility and ready availability have ensured that it has been and will continue to be of great and increasing importance for all types of construction throughout the world (Donome & Illston, 2010). Various definitions of concrete were suggested as a result of various researches carried out across the world. 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. 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. Furthermore, concrete was also defined by Al-Kourid & Hammad, (2010), as a mixture of cement (11%), fine aggregate (26%), coarse aggregate (41%), water (16%) and air (6%). 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 admixtures.

#### Constituents of concrete

##### Cement

The early history of cement has originated from the Egyptians who burn gypsum to obtain cementing materials. According to Shetty (2005), the investigation conducted by L. J. Vicat led the research 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 to 1200 to 1500<sup>0</sup>C, the resulting product “clinker” is then ground to the consistency of powder (Al-Kourid & Hammad, 2010). According to ASTM 150, Standard Specifications for Portland cement, Portland cements are classified as:

Type I: General purpose. For use when the special properties specified for any other type are not required.

Type II: For general use, more especially when moderate sulphate resistance or moderate heat of hydration is required.

Type III: For use when high early strength is desired. (Limit the C<sub>3</sub>A content of cement to maximum 15%)

Type IV: For use when low heat of hydration is desired.

Type V: For use when high sulphate resistance is desired. (Maximum limit of 5% on C<sub>3</sub>A)

##### Portland cement

Portland cement is obtained by mixing together calcareous materials like limestone or chalk and argillaceous materials such as shale or clay or other silica and iron oxide bearing materials burning them at a clinkering temperature and grinding the resulting clinker (Neville & Brooks, 2010). According to Shetty (2009) the manufacturing process of cement involves grinding of raw materials and mixing them thoroughly in a certain proportion which depend upon their purity and composition and burning them in a kiln at about 1300<sup>0</sup>C – 1500<sup>0</sup>C. At this temperature, the

materials bond together and partly fused into clinker (Neville & Brooks, 2010). It is then cooled and ground to a fine powder with some gypsum added. The process of Portland cement manufacturing is grouped into two and according to Shetty (2009), they are the wet and dry process. In the wet process, limestone after crushing into small fragment is taken to a ball or tube mill where it is mixed with clay or shale and ground to a fine consistency of slurry with the addition of water. The slurry is pumped to a slurry tank or basin and kept in an agitated condition with the aid of rotating arms with chains or blowing compressed air from the bottom to prevent setting of lime stone and clay particle. In the dry process, the raw materials are crushed and fed in correct proportions into the grinding mill where they are dried and reduced to a very fine powder. The dry powder is then further blended and corrected for its right position and mixed by means of compressed air.

#### Types of Portland cement

Portland cement clinker is made by sintering a precisely specified mixture of raw

materials (raw meal, paste or slurry) containing elements, usually expressed as oxides, CaO, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub> and small quantities of other materials. The raw meal, paste or slurry is finely divided, intimately mixed and therefore homogeneous. Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates (3CaO, SiO<sub>2</sub> and 2CaO, SiO<sub>2</sub>), the remainder consisting of aluminium and iron containing clinker phases and other compounds. The ratio by mass (CaO)/(SiO<sub>2</sub>) shall be not less than 2.0. The content of magnesium oxide (MgO) shall not exceed 5.0 % by mass (Hewlett, 1998).

#### Chemical composition of Portland cement

Materials used in Portland cement manufacturing consist mainly of lime, silica, alumina and iron oxide. At high temperature, the materials interact with one another to form a more complex compound (Shetty, 2009). The proportions of oxide composition for Ordinary Portland Cement (OPC) are shown in Table 1.

Table 1: Chemical Composition of Oxides in Ordinary Portland cement

Name of Constituent Oxides	Percentage by weight		Value of Compounds (%)
	Range	Average	
1. Lime, CaO	60 - 67	63	C3S = 54.1
2. Silica, SiO <sub>2</sub>	18 - 25	20	C2S = 16.6
3. Alumina, Al <sub>2</sub> O <sub>3</sub>	3 - 8	6	C3A = 10.8
4. Magnesia, MgO	0.5 - 6	3	C4AF = 9.1
5. Iron, Fe <sub>2</sub> O <sub>2</sub>	0.1 - 4	1.5	
6. Sulphur-Trioxide, SO <sub>3</sub>	1 - 3	2	
7. Alkalis, K <sub>2</sub> O; Na <sub>2</sub> O	0.2 - 1.3	1	
8. Calcium Sulphate (Gypsum- CaSO <sub>4</sub> )	3 - 5	4	

Source: Fredrick and Jonathan, 2001

#### Cementitious Reactions of Portland cement

Calcium combination with silica, aluminum and iron oxide are essentially crystalline compounds cement is made of. These compounds are essentially regarded as the major constituent's Portland cement. The actual quantities of the

various compounds vary considerably from cement to cement, and in practice different types of cement are obtained by suitably proportioning these materials. Along with the major compounds there exist minor compounds such as SO<sub>3</sub>, MgO, K<sub>2</sub>O, Na<sub>2</sub>O, which normally amount to not more than a

few percent by weight of the cement. The compounds of the Portland cement clinker are anhydrous, but when water is added they begin to ionize, and the ionic species form hydrated products of low solubility that precipitate out of the solution. The main product of the hydration of silicates mineral is calcium hydrate silicate (C-H-S) of colloidal dimension, that at an early age, under scanning electron microscope, usually shows up as an aggregation of very fine grains partly intergrown together. The structure of C-H-S is not constant in space and time. It adopts a variety of morphologies, some based on thin sheets to give fibrous or honey comb structure at an early age, while others have a more complex structure (Reinhardt, 1995). It is highly cementitious and constitutes about 60 to 65 percent of the total solids of the hydrated cement. The other product of the hydration of the silicate minerals is about 20 percent calcium hydroxide (CH) which usually occurs as large hexagonal crystals, and contributes little to the cementitious properties of the system. Also, being relatively soluble and alkaline than the other products of hydration, it is easily subjected to attack by water and other acidic solution. This reduces the durability of Portland cement systems in such environments Mehta (1983).

#### **Aggregate**

Aggregates are the important constituents in concrete; they give body to the concrete, reduce shrinkage and effect economy (Shetty, 2005). Aggregates are rocklike materials used in most civil and construction engineering works. They can be classified in to two major types: coarse and fine aggregates.

#### **Pozzolana**

Pozzolanas have been used to improve properties of cement mortar and concrete. Pozzolanas, by their diverse and varied nature, tend to have widely varying characteristics. The chemical composition of pozzolanas varies considerably, depending on the source and the preparation technique. Generally, a pozzolana will contain silica, alumina, iron oxide and a variety of oxides and alkalis, each in varying degrees. Pozzolanic materials do not harden in themselves when mixed with water but, when finely ground and in the presence of water, they react at normal ambient temperature with dissolved calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) to form strength-developing calcium silicate and calcium aluminate compounds. These compounds are similar to those which are formed in the hardening of hydraulic materials. Pozzolanas consist essentially of reactive silicon

dioxide ( $\text{SiO}_2$ ) and aluminium oxide ( $\text{Al}_2\text{O}_3$ ). The remainder contains iron oxide ( $\text{Fe}_2\text{O}_3$ ) and other oxides. The proportion of reactive calcium oxide for hardening is negligible. The reactive silicon dioxide content shall be not less than 25% by mass BS 197 part 1(2000). The American Society for Testing and Materials (ASTM) is probably the most widely recognized and used national standards-setting organization in the United States for engineering-related materials and testing. The ASTM C618 (1992) specification is the most widely used because it covers the use of fly ash as a pozzolan or mineral admixture in concrete. The three classes of pozzolans are Class N, Class F, and Class C. Class N is raw or calcined natural pozzolan such as some diatomaceous earths, opaline cherts, shales; tuffs, volcanic ashes, and pumicites; and calcined clays and shales. Class F is pozzolanic fly ash normally produced from burning anthracite or bituminous coal. Class C is pozzolanic and cementitious fly ash normally produced from burning lignite or sub-bituminous coal.

#### **Pozzolanas and Lime-pozzolanas**

In general, pozzolanas are classified into two groups: natural and artificial. A pozzolana is a material which, on its own, is not cementitious but, with the addition of lime, reacts to form a material which sets and hardens. Thus, for the purpose of construction, a pozzolana is not an end in itself but, rather, a means of achieving the ultimate product - lime-pozzolana. Lime-pozzolana is a low-strength binder used in the same manner as lime, to prepare mixtures for mortars, plasters and building blocks and for soil stabilization. Normally, a mixture of one part of lime to two parts of pozzolana is adequate for lime-pozzolana binders, and, even if a ratio of 1:1 is applied, considerable savings of about 50 per cent of the available supply of lime is achieved. In this way, where pozzolana is obtained at a lower cost than lime, lime-pozzolana becomes an attractive material for low-cost construction.

#### **Natural pozzolanas**

Natural pozzolanas are basically of volcanic origin and are usually found in areas which have experienced volcanic activities. For example, in Africa, natural pozzolana deposits can be found in six countries -Burundi, Cameroon, Caper Verde, Ethiopia, Rwanda and the United Republic of Tanzania. Pozzolanas of this type occur either in a pulverized state or in the form of compact layers, and this, in turn, determines the production process which the pozzolana has to undergo before being mixed with lime to produce a binder. Where volcanic tuff occurs as a naturally

fine-grained material, it requires no preparation apart from ensuring that it is sufficiently dry prior to mixing with lime. Sun-drying is feasible, even though a small-scale, locally fabricated kiln can be used for this purpose. For example, the Arusha-Moshi area of the northern part of the United Republic of Tanzania is volcanic, and large deposits of fine-grained pozzolanas are widely available. These deposits which require no grinding after quarrying can be mixed with lime to prepare mortars, plasters and building blocks.

Where the natural pozzolana occurs in a coarse-grained form, it is desirable to dry the material, either in the sun or a kiln, and, thereafter, grind it in a ball-mill to the desired fineness, ready for mixing with lime. In some instances, the grinding of coarse grained pozzolanas is restricted to the preparation of mortars and plasters, while the preparation of blocks is feasible without any grinding. For instance, in Lembang, Indonesia, unground coarse-grained pozzolana is mixed with 20 per cent lime and sufficient quantities of water to produce solid blocks for building construction.

#### **Artificial pozzolanas**

Unlike natural pozzolanas, artificial pozzolanas are obtained only after the basic materials undergo some basic production processes. The raw materials from which artificial pozzolanas are obtained are extensive in scope, covering materials of geological origin and agricultural and industrial residues (Ahmed, 1993). However, the most common raw materials used for production of artificial pozzolanas are as follows:

- Clay products: Suitable clay deposits can be quarried, fired and ground into fine powder in a ball-mill, for use as a pozzolana. Basically, most soil groups containing the common clay minerals can be used for this purpose, but plastic clays, as those used for pottery, are most likely to produce good pozzolanas. The firing of the clay should be under controlled temperatures, and a locally fabricated kiln or incinerator can be used for this purpose. The desired temperature for firing is around 600°C. As an alternative to firing raw clays, pozzolanas can be produced by grinding bricks or tiles obtained as residual products in the production of fired-clay bricks and tiles. Here, the only equipment required is a ball-mill or a hammer-mill to grind the material. Sometimes, the pozzolana and the lime are mixed and ground together in the ball-mill.

- Rice-husk-ash: Rice-husk is the residual product from milling rice. It often has no commercial value but, rather, poses a problem of disposal. The ash which results from burning rice husk is a pozzolana

which reacts with lime and water to produce a binder suitable for low-strength masonry application. Normally, about 20 per cent of the volume of rice husk results in ash, and, because rice is grown in several countries, rice husk ash is potentially an important cementitious material. In Africa alone, there are about 40 countries where rice is grown, and, even though the quantity of output is not high enough in all the countries to justify commercial-scale production of rice-husk-ash, the potential that exists for promoting the material is encouraging. As a pozzolana, rice husk ash is produced under controlled temperatures of about 600°C in a kiln or incinerator. The incinerator for burning rice-husk can be locally fabricated, and, in countries where production has been commercialized, the scale of production is often as small as 1 ton per day. Apart from the incinerator, which can be locally built in bricks, the main capital item required for rice-husk-ash pozzolana manufacture is a ball-mill to grind the ash or ash and lime into a homogenous fine mix. In some countries, the ball mill may have to be imported but, in a country such as India, it is readily available on the market.

- Fly-ash: Fly-ash is the residual product obtained when coal is fired and, thus, occurs as a waste product from coal-fired power stations. It is desirable for the fly-ash to be in a dry state prior to use. Often, fly-ash occurs in a coarse form and will have to be pulverized before mixing with lime to produce a binder, so that the main capital item required in preparing fly-ash pozzolanas is a ball-mill for pulverizing the ash to the desired fineness.

#### **Environmental issues related to concrete production**

Approximately 80% of total embodied greenhouse gas emissions in concrete is attributable to the production of Portland cement (Flower & Sanjayan, 2007). The contribution of Portland cement production to worldwide greenhouse gas emissions is 1.6 billion tons or estimated to be about 7% (Mehta, 2001, Berry et al., 2009). This is directly as a result of the calcinations of limestone in the kiln during the manufacturing process and fossil fuel combustion (Roy, 1999). In addition, the process of Portland cement manufacture is an energy intensive process (Berry et al., 2009). In Australia, the total greenhouse gas emissions from the production of Portland cement increased by 5.2% between 1990 and 2005 (Australian Greenhouse Office, 2007). Global cement production is expected to rise 4.1% yearly through 2013 and expected to reach 3.5 billion metric tons, with the Asia/Pacific accounting for 69%,

Africa/Middle East 12%, Western Europe 6%, North America 5% and other regions 8% (Freedonia Group, 2010). The highest growth of demand is expected to be in Asian countries where investment in infrastructure is still lagging behind other regions. According to the U.S. Geological Survey (U.S. Geological Survey, 2012), China accounted for 56% of global cement consumption in 2010, approximately 28 times the consumption of the U.S. The cement consumption in China alone accounts for as much as the combined consumption of the other top ten countries as shown in Figure 1. It is even exceeding India, which has a comparable population to China, possibly due to the deficit of the availability of raw materials. The need to reduce the environmental impact of concrete production has been recognized by the industry. The U.S. concrete industry has developed plans to address these issues in a report "Vision 2030: A Vision for the U.S. Concrete Industry" (Mehta, 2001). The report states that 'concrete technologists are faced with the challenge of leading future development in a way that protects environmental quality while projecting concrete as a construction material of choice. Public concern will be responsibly addressed regarding climate change resulting from the increased concentration of global warming gases'. In this report, strategies to maintain concrete as a construction material and simultaneously to consider the impact of concrete on the environment are discussed (Mehta, 2001, Plenge, 2001).

In order to reduce the environmental impact of the concrete industry, Mehta (2002) suggests two approaches, a short term and a long term approach. The short term approach would be to practice "industrial ecology" which involves the use of industrial by-products as cement replacement materials. The long term approach would be to lower the rate of material consumption. The environmental impact of the concrete industry may also be reduced by improving the durability of concrete products and by conserving materials and energy in concrete production (Mehta, 2002).

Likewise, in order to meet the environmental challenge in concrete production, Meyer (2009) suggests replacing as much Portland cement as possible with supplementary cementitious materials, especially those that are by-products of industrial processes, such as fly ash, ground granulated blast furnace slag, and silica fume. In addition, McCaffrey (2001) proposed three mechanisms to reduce the amount of carbon dioxide (CO<sub>2</sub>) emissions by the cement industries, i.e. to decrease the proportion of calcined material in cement, to decrease the proportion of cement in

concrete, and to decrease the number of buildings using cement.

### Geopolymer

The concept of geopolymer concrete is as old as ancient Egyptian and Roman Empire, but was not known until recently. The mystery behind the ancient Egyptian and Roman mortars which has resisted deterioration and chemical attack for many decades gave rise for search of a new material binder that is more durable than the present ordinary Portland cement binder (Davidovits, 1996). The way in which these ancient concretes and mortars has resisted deterioration for many years when compared with the present Portland cement mortar and concretes prompted the search into the mystery behind the composition of these ancient compounds (Van-Jaarsveld et. al., 1996). In 1978, Davidovits, a French Scientist proved that the pyramid of Egypt was not built with OPC mortar being used in the present time, but with some aluminium silicate materials which he called "geopolymer". He noted that the durability of ancient mortars used in construction of pyramid of Egypt gave credence to the fact that the present Portland cement was not used in its construction. It is a known fact that the pyramid has lasted more than 4000 years and has resisted physical and chemical attack. Moreover, Glukhovskiy (1959), after investigation on the properties of ancient construction materials, proved that the presence zeolite or compounds of "aluminosilicate calcium hydrates" which are not different from the ones found in OPC must have been responsible for the durability of ancient concretes. Following the investigation, a binder emerges which he called "soil cement" which was named partly because of its resemblance to earthy rock and partly due to its pozzolanic activity. The discovery triggered the interest of other research scholars (Eitel 1966, Krivenko 1994). Therefore the presence of calcium silicate hydrates (C-S-H) which is present in OPC was not the only compound responsible for the durability of ancient mortars as assumed by (Langton et. al 1984). The long term durability of ancient mortars and concretes as seen in the Pyramid of Egypt in figure 2 triggered the interest of many other researchers. In his work on the resistance of ancient mortars to chemical attack, Malinowsky (1979) noted that the canals of underground and elevated aqueducts" which were built without joints by ancient builders were impermeable to water, without cracks and free from shrinkage. Campbell et. al. (1991), therefore proved that the resistance of ancient mortars to

deterioration were as a result of zeolitic and amorphous compounds present in them.

#### Reaction of Geopolymer with Binders

According to Hadjito & Rangan (2005), Joseph Davidovits in 1987 proposed that an alkaline solution could react with silicon (Si) and aluminum (Al) contained in a source material of geological or by-product; example of such are metakaolin (MK), fly ash (FA), rice husk ash (RHA), etc, to produce a binder which he termed geopolymer because of the polymerization process that takes place between them. Srinivas, Prathap & Prema (2015), explained that geopolymer are characterized by a three-dimensional aluminosilicate (Si-O-Al); they represent a broad range of materials characterized by a network of inorganic polymer. Geopolymer provides a comparable performance to traditional cementitious binder in a range of application with the added advantage of significantly reducing greenhouse gas (GHG) emission (Duxson, Fernandez-Jimenez, Provis, Lukey, Palomo, & Van-Deventer, 2007).

#### Source Materials

As earlier stated, the two main ingredients of geopolymer are the source materials and alkali. The source materials are industrial waste products which have abundance of silicon (Si) and aluminum (Al) in amorphous form example fly ash (FA), Kaolin (MK), blast furnace slag (BFS), silica fume (SF) are good for geopolymer materials (Hadjito et.al., 2005). A lot of minerals of natural origin and industrial waste products are looked into by many scholars. The use of metakaolin as a geopolymer source material was studied by (Gourley 2003; Pinto et. al., 2002; Davidovits, 1999; Barbosa et. al., 2000).

The following research scholars (Palomo et. al., 1999; Swanepoel et. al., 2002), investigated the use of low calcium fly ash as geopolymer source material, others looked into natural Al-Si minerals (Xu & van Deventer 2002) and further insight into combination of ground granulated blast furnace slag (GGBFS) and metakaolin (MK). The blending of blast furnace slag and metakaolin to produce fire- resistance geopolymer was studied by Chengs & Chiu (2003). High rate of dissolution of metakaolin in the reaction and color, coupled with

easy control of Si/Al ratio made its usage in geopolymer concrete a priority (Gourley 2003). The limitation posed on the use of metakaolin as a source material for geopolymer is cost implications. Materials for geopolymer concrete achieve better result when the molarity ratio of Si-Al is 2 (Davidovits 1999). Higher compressive strength is usually obtained when source materials are calcined unlike using non- calcined material example. Kaolin, clay, mine tailings and naturally occurring minerals (Barbosa, 2000). In their research study, Xu & Deventer (2000), made a significant input when they discovered in their result a great improvement in compressive strength and less reaction time in blending calcined and non- calcined material.

#### Chemistry of Geopolymer

Some research scholars have proposed the fundamental chemistry of alkali-activated binders which are referred for some time now (Glukhorskyy et. al., 1980; Krivenko 1994). A Ukrainian scientist, Glukhorskyy (1957), undertook a research into the differences between the durability of ancient cement and modern concretes, which metamorphosed into the synthesis of materials of geological origin like from clay, feldspar, volcanic ashes, metallurgical slags and fly ash (Glukhorskyy 1980). He noted the superior properties of these new materials compared with existing cementitious materials. Krivenko (1994) currently continues the pioneering work undertaken by Glukhorskyy. Several scholars have studied the use of wastes such as fly ash, slags, clay in the synthesis of geopolymer (Rahier et. al., 1997; Van-Jaarsveld et. al., 1997, 1998, 1999; Khahil & Merz 1994).

#### Source of Kaolin in Nigeria

Gabriel (2007) describes kaolin as a soft, lightweight and often chalk-like sedimentary rock that has an earthy odor with plate-like crystal morphology. It contains quartz and mica and less frequently feldspar, illite, montmorillonite, ilmenite, anastase, haematite, bauxite, zircon, rutile, kyanite, silliminate, graphite, attapulgitite and halloysite (Gabriel, 2007). It can be found in abundance in many parts of Nigeria as shown in Table 2.

**Table 2: Sources of kaolin in Nigeria and their chemical composition**

Deposit	chemical composition (%)										
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	SO <sub>2</sub>	Loi	Colour
Ozubulu 60	26	5	5	trace	trace	trace	trace	-	-		white greylight and dark brown



Nahuta white	47	32	1.3	2.4	trace	trace	trace	trace	0.55	12-18	
Jagalwa River	50	30	1.4	2.4	trace	trace	trace	trace	-	-	-
Darazo white	51.9	32.9	2.9	-	0.39	0.29	trace	0.89	0.13	-	
Kankara 43.3	36.7	0.21	Nil	trace	1.49	trace	0.7	-	11.10	white	
Onibode 43.1	36.1	3.1	1.9	trace	trace	trace	trace	-	12.65	-	
Ifon	48	33.2	0.006	1.72	trace	trace	trace	trace	-	-	Pink
Okitipupa	50	29	5	5	trace	trace	trace	trace	-	10	-
Major Poter	45.6	35.2	2.7	-	trace	trace	trace	trace	-	-	-

Source: Alabi and Omojola, (2013)

## V. MATERIALS AND METHOD

### Materials

Materials used in this research include the following: Cement, metakaolin as the source material and peanut husk ash as by-product, coarse aggregates, fine aggregate, alkaline solution, which include Sodium Hydroxide (NaOH), Sodium Silicate and (Na<sub>2</sub>SiO<sub>3</sub>); water.

### Cement

Ordinary Portland Cement (OPC) was used for this research as the binder for the control specimen and it is assumed to conform to the minimum requirement as provided by BSEN Standard. The OPC was Dangote brand of cement.

### Metakaolin

Metakaolin used for this research was obtained from kaolin sourced from Alkali Bauchi State, Nigeria. The sample was pound using mortar and then sieved in the Department of Building Laboratory, Abubakar Tafawa Balewa University Bauchi. It was sieved through 150microns sieve after which, it was calcined in the Industrial Design Department of the University at a temperature of 700°C for about 90 mins.

### Peanut Husk Ash

Peanut husk ash used for this research was obtained from peanut sellers in Kangere Gombe Road in Bauchi state, Nigeria. After obtaining the sample it was placed on the floor to sundry for at least 3 weeks. After sun drying it was placed on iron sheet and burnt at an uncontrolled temperature. The burnt peanut husk was then grounded and the burnt ash was sieved through British Standard sieve of 75 microns. The portion passing through the sieve had the required degree of fineness of 63 microns and below while the residue was thrown away as opined by Kolawole & Mbachu (1998).

### Coarse aggregate

The coarse aggregate was obtained within Bauchi, Bauchi State. Sieve analysis was carried out in accordance with BSEN Standard to distribute the aggregate into various sieve sizes. The aggregate requirement was comprised of 20mm as its maximum and 4.75mm as its minimum size and they were used in the Saturated Surface Dry (SSD) condition.

### Fine aggregate

River sand was obtained within Bauchi and used. It was kept in the SSD condition prior to use in the laboratory of the Department of Building, ATBU Bauchi. Sieve analysis was carried out in accordance with BSEN Standard to distribute the particles in their required sieve sizes and also to remove impurities and bigger size aggregates.

### Alkaline solution

A combination of sodium hydroxide (NaOH) and sodium silicate (Na<sub>2</sub>SiO<sub>3</sub>) were used as the alkaline activator. The process is described as follows:

#### Sodium hydroxide (NaOH)

NaOH which is in pallet or flake form with 97%-98% purity was obtained from a supplier and dissolved in tap water to make a solution. For this work, 16 Molar concentration was used which means that the molarity multiplied by the molecular weight of NaOH (40). This means (16 x 40 = 640) gives the quantity in grams of NaOH solids per liter of water.

#### Sodium silicate (Na<sub>2</sub>SiO<sub>3</sub>)

The sodium silicate solution (Na<sub>2</sub>O = 13.7%, SiO<sub>3</sub> = 29.4%, and H<sub>2</sub>O = 55.9% by mass) was

purchased from a supplier within Bauchi and used for this work.

### **Water**

Portable water fit for drinking was used for this research. It was used for mixing and dissolving the alkaline activator and also used for the production of the concrete specimens. The water used conforming to BS EN 1008-2 (2002).

### **Production of Concrete Specimens**

#### **Production of geopolymer concrete specimen (GPC)**

##### **Mix design**

Currently, no standard mix design is available for the production of GPC (More, 2013). This means that the mix design for the production of geopolymer concrete is based on trial and error. For this reason, the method adopted by Anuradha, Sreevidya, Venkatasubramani & Rangan (2011), in designing fly ash based geopolymer concrete was used to design grade 25 metakaolin based geopolymer concrete. In designing for the quantity of alkaline, Ramujee and Potharaju (2014b), method was adopted after series of trial and error.

##### **Preparation of alkaline solution**

A combination of NaOH and Na<sub>2</sub>SiO<sub>3</sub> were used as the alkaline solution for this research. For the purpose of this research, the 16 molar concentration of NaOH pallet was dissolved in water to make a solution. The alkaline solution was mixed together a day before its usage to produce the geopolymer concrete.

##### **Mixing and casting of geopolymer concrete**

The method used for mixing the GPC specimens was similar to that used when producing ordinary Portland cement concrete. All the aggregates used for the casting were kept in the saturated surface dry condition (SSD). Peanut, Metakaolin and the aggregates (both fine aggregate and coarse aggregate) were mixed together thoroughly, after which the alkaline solution was added and the geopolymer concrete specimen mixed together. After mixing, the fresh geopolymer concrete was casted into 100mm x 100mm x 100mm moulds in 2 layers while each layer was compacted by rodding with a tapping rod in order to achieve a smooth compaction of the specimen.

### **Production of Control Specimens**

##### **Mix design**

Grade 25 concrete was designed for the ordinary Portland cement concrete. This was done to create a basis for comparison with geopolymer concrete specimens. In this case, Building Research

Establishment (BRE) method of mix design was used for designing the grade of concrete. (Details in Appendix)

##### **Mixing and casting of Control Specimens**

The same method used in mixing the geopolymer concrete specimens was also used in mixing the ordinary cement concrete. After mixing, the fresh ordinary cement concrete specimen was casted into 100mm x 100mm x 100mm mould in 2 layers; while each layer was compacted by giving it 25 blows with a tapping rod in order to achieve a smooth compaction of the specimens.

### **Curing of GPC specimens**

After casting, the specimens were kept for 24hrs rest period. The peanut and metakaolin geopolymer concrete specimens were then de-moulded, wrapped in a polythene bag and cured in the oven at 60°C for 24hrs according to Suresh & Manojkumar (2013) heat curing assists the chemical reaction in the geopolymer paste. After heat curing for 24hrs, it was then removed from the oven and unwrapped from the polythene bag and left to cure at the room temperature in the laboratory until the days required for testing which is 7, 14, 28 and 56 days.

### **Curing of Control Specimens**

Specimens were allowed to set for 24hrs before de-moulding and were immersed in portable water tank for ages 7, 14, 28 and 56 days to allow for effective curing by using BSEN Standard.

### **Testing of Fresh Concrete Specimens**

#### **Workability Test**

Before casting the fresh geopolymer concrete and ordinary Portland cement specimen into moulds, the slump value of each fresh concrete were measured to determine the workability of the mix. This was done as recommended by BSEN Standard. The apparatus used in carrying out the slump test includes steel tamping rod, base plate, hand scoop, trowel and metal cone.

### **Testing of Hardened Concrete Specimens**

After curing the geopolymer and ordinary Portland cement specimens, they were subjected to the following test at the end of each curing ages which include:

#### **Compressive strength test**

Compressive test was carried out after different curing ages of 7, 14, 28 and 56 days for geopolymer concrete and ordinary Portland cement specimens. A total of 72 specimens were tested for

compressive strength and it was done as stipulated by BSEN Standard. Three (3) cubes each were tested to failure for all specimens. The maximum failure load was then recorded and the compressive strength calculated using the relation:

$$\text{Compressive Strength} = \frac{\text{maximum load RN}}{\text{Cross-sectional Area (mm}^2\text{)}} \quad \text{---(3)}$$

#### Resistance to magnesium sulphate (MgSO<sub>4</sub>) attack test

After casting, the geopolymer and ordinary Portland cement specimens were kept for a rest period of 24hrs at room temperature after which they were de-moulded. The geopolymer concrete specimens were cured in the oven for 24hrs, while the ordinary Portland cement concrete specimens were cured in water for 24hrs. The specimens were then cured in Magnesium Sulphate (MgSO<sub>4</sub>) for the required hydration period of 28 and 56 days before testing. A total of 36 cubes were immersed in MgSO<sub>4</sub> solution with each specimen. Three (3) cubes were tested and their compressive strength determined at the end of 28 and 56 days curing age. The concentration of MgSO<sub>4</sub> used was 2.5%, which was categorized by Gupta and Gupta (2012) as a severe attack. The relationship adopted by Ibrahim (2015) was used to achieve the quantity of MgSO<sub>4</sub> that gives the concentration. The relationship is thus: If 50 liters of water = 5000g by weight 5000g of water = 100% concentration

Using 2.5% concentration, the quantity of water = Xg Therefore, mathematically,

$$Xg = 5000g \times \frac{2.5}{100} \quad \text{---(4)}$$

Therefore, for every 5000g of water, 125g of MgSO<sub>4</sub> was dissolved in the water.

#### Flexural strength test BSEN Standard

The Flexural strength test was determined at curing ages of 28 and 56 days on the geopolymer and ordinary Portland cement concrete specimens. A total of 36 specimens were tested for flexural strength. The mean value of the failure load for each was taken as the flexural strength. The flexural strength of the concrete specimen was determined using the equation adopted by (Gambo, 2014).

$$\text{Flexural Strength } f_b = \frac{PL}{bd^2} / f_b = \frac{3Pa}{bd^2} \quad \text{---(5)}$$

Where:

P = Load at failure (N)

b = Width of the beam in millimeters

d = Failure point depth in millimeters

L = Supported length in millimeters

a = Distance between the line of fracture and nearest support

#### Abrasion resistance test

Abrasion resistance is used to measure the resistance of concrete to surface wear by abrasion. It is aimed at determining the abrasion resistance of a material through sliding or scraping, thus causing a wearing down by friction. Gupta & Gupta (2012) explained that abrasion value should not be more than 30% for wearing surface and 50% for other surfaces. A total of 36 specimens were tested after 28 and 56 days of curing. Three (3) cubes each for geopolymer and ordinary cement concrete specimens were tested for abrasion resistance after different curing ages. On the day of testing, the initial weight of each concrete sample was determined before brushing and recorded as W<sub>1</sub>, after which a weight of 3.5kg was mounted and tightly fixed to the wire brush. It was then used to brush the surface of concrete specimen 36 times and the specimen was then re-weighed while the value was recorded as W<sub>2</sub>. The relation used to determine abrasion resistance of the concrete sample is given as

$$\text{Abrasion Resistance} = \frac{W_1 - W_2}{W_1} \times 100 \quad \text{---(6)}$$

Where W<sub>1</sub> = Initial weight of a concrete specimen

W<sub>2</sub> = Final weight of a concrete specimen

#### Water absorption capacity test

This test was conducted at the curing ages of 28 and 56 days on geopolymer and ordinary cement concrete specimen in accordance with BS 1881-122:(1983). A total of 36 specimens were tested for absorption capacity and on each day of testing, three cubes each were placed in the electric oven to dry the specimens at 105<sup>0</sup>C for 24 hours. The specimens were then removed from the oven and allowed to cool at room temperature before determining the initial weight which was recorded as (W<sub>1</sub>). The final weight was determined after the concrete specimen was immersed in water for 24hrs. It was then removed and dried with a piece of cloth; then re-weighed and recorded its weight as W<sub>2</sub>. The equation used to compute the absorption capacity for the specimens is given as:

$$\text{Water Absorption Capacity} = \frac{W_2 - W_1}{W_1} \times 100 \quad \text{---(7)}$$

Where: W<sub>1</sub> = Weight of the concrete sample after oven dry

W<sub>2</sub> = Weight of the saturated surface dry concrete sample

## VI. DATA PRESENTATION AND ANALYSIS

### Presentation of Result

Cement is completely replaced with metakaolin and Peanut Husk ash and alkaline activators are used in this study for the polymerization is the solutions of sodium hydroxide (NaOH) and sodium silicate (Na<sub>2</sub>SiO<sub>3</sub>) for binding of materials to prepare Geopolymer Concrete. Which is an eco-friendly construction material and it gains compressive strength rapidly faster than OPC.

The results presented in this chapter are obtained from the test carried out on the type of materials and concrete samples used in the research. Physical

properties and chemical analysis for the materials used in the experiment as well as the test for both fresh hardened properties of concrete are discussed in this chapter.

### 4.3 Fresh Properties of Concrete Specimens Workability Test of fresh geopolymer concrete produced with PHA and MK

From Table 16 present the result for slump and compacting factor test made with Peanut husk ash - Metakaolin as partial replacement of OPC.

**Table 16: the result for slump and compacting factor**

Mixes	Slump	Degree of workability	Compacting Factor	Degree of workability
Control (0%)	44	Low workability	0.90	Medium workability
100% MK	44	Low workability	0.90	Medium workability
80%MK+20%PHA	40	Low workability	0.91	Medium workability
60%MK+40%PHA	34	Low workability	0.89	Low workability
40%MK+60%PHA	24	Low workability	0.88	Low workability
20%MK+80%PHA	14	Low workability	0.86	Low workability

From the values of the six different mixes, the degree of workability for slump test is low according to Neville & Brooks (2010) and as specified by BS 812. Mixes with percentage replacement were more workable than 0% replacement (control) as shown in Figure 6. 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 & Brooks (2010). Mixes with 0% - 100% MK, 80% MK+20% PHA, 60% MK+ 40% PHA and 40% MK+60% PHA shows higher workability while 20% MK+80% PHA shows low workability as presented in Figure 7.

### 4.4 Presentation of Results of Tests on Hardened Concrete Strength Properties of Geopolymer Concrete produced with PHA and MK

Details off all the figures used to present the results for compressive, Flexural strength, abrasion resistance and water absorption test were attached at appendices. However compressive strength is an important property of concrete and thus, cements concrete and aggregate Australia (CCAA, 2006) stated that concrete achieved about 80 – 100% of its strength at 28 days. For this

reason 28 days compressive, flexural and split tensile strength results were picked and discussed while all other curing days analyzed and presented.

### Compressive Strength of Geopolymer Concrete Cured in Water (H<sub>2</sub>O)

Figure 11 shows compressive strength of Portland cement/Peanut husk ash-Metakaolin concrete specimens cured in water (H<sub>2</sub>O) and crushed at 7, 14, 28 and 56 days hydration periods. Samples of concrete with 100%MK, 80%MK+20%PHA, 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA replacement of OPC/PHA-MK achieved 28.8 N/mm<sup>2</sup>, 28.2 N/mm<sup>2</sup>, 25.6 N/mm<sup>2</sup>, 25.1 N/mm<sup>2</sup> and 23.6 N/mm<sup>2</sup> respectively while 0% replacement achieved 28.9 N/mm<sup>2</sup> at 28 days. This represents 3.8% increase of 100%MK and 80%MK+20%PHA replacement over 0% in compressive strength. The result is in range with the work carried out by Gambo, Ibrahim, Aliyu, Ibrahim & Abdulsalam (2020). The compressive strength achieved for both control and percentage replacement were below the BS EN 197-01 (2000) requirement which stated that concrete sample should achieved 32.5 N/mm<sup>2</sup> at 28 days. (Sa1, Juma, Prakash, Haider & Rao, 2012) reported that, at all ages, cement partially replaced with Peanut husk ash significantly increased the strength

properties of concrete. This could be due to the method of compaction used during the concrete

production. However, the standard requires the use of mechanical compaction to achieve this result.

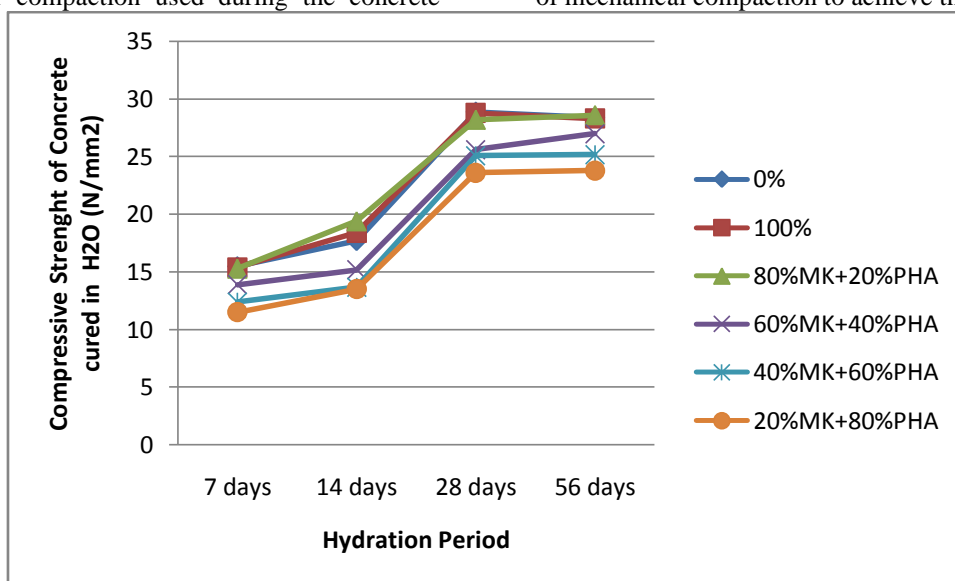


Figure 11: Compressive Strength of Hardened Geopolymer Concrete cured in H<sub>2</sub>O

#### Compressive Strength of Geopolymer Concrete Specimens Cured in MgSO<sub>4</sub>

Figure 12 shows compressive strength of OPC/PHA-MK specimens cured in MgSO<sub>4</sub> and crushed at 28 and 56 days hydration periods. Concrete samples with 100%MK and 80%MK+20%PHA replacement of OPC withstand magnesium sulphate medium better than 0% replacement. It achieved 27.3 N/mm<sup>2</sup>, 27.3 N/mm<sup>2</sup>, 25.3 N/mm<sup>2</sup>, 16.8 N/mm<sup>2</sup> and 14.5 N/mm<sup>2</sup> respectively at 28 days for 100%MK, 80%MK+20%PHA, 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA as against 0% replacement which is 26.3 N/mm<sup>2</sup>. This represents 2.640 decrease of 0% control concrete from 80%MK+20%PHA cement replacement concrete. This means that MgSO<sub>4</sub> Curing medium is injurious to concrete samples in control samples than at 100%MK and

80%MK+20%PHA cement replacement with PHA-MK. This has occurred due to the fact that the curing medium (MgSO<sub>4</sub>) is a deleterious material to concrete that can damage concrete and alter strength development in concrete. This also could be that the magnesium salt reacted with the cement mortar in the concrete specimens. Gupta and Gupta (2012) affirm that magnesium sulphate (MgSO<sub>4</sub>) decomposes calcium hydroxide Ca(OH)<sub>2</sub> and hydrated tricalcium aluminate (C<sub>3</sub>A) present in cement which eventually form hydrated magnesium silicate that has no binding properties. Replacement percentages retard the action or concrete damage which may be as a result of pozzolanic activity in the material, that is filler or binder present in Peanut husk ash and Metakaolin which tally with the assertion made by Srinivasi, Padmakar, Brhmalah & Vijaya (2020); Gambo, Ibrahim, Aliyu, Ibrahim & Abdulsalam (2020)

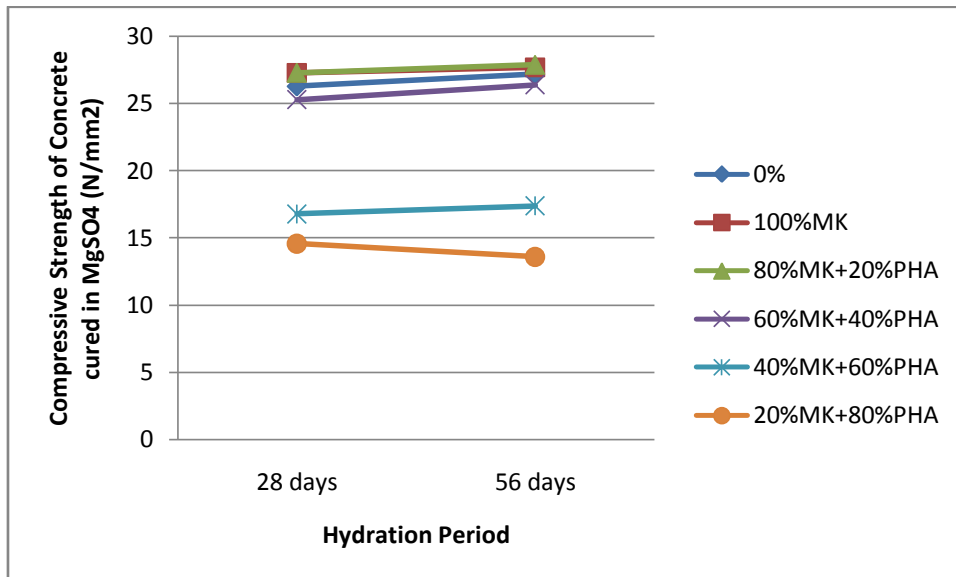


Figure 12: Compressive Strength of Hardened Geopolymer Concrete cured in MgSO<sub>4</sub>

### Flexural Strength of Geopolymer Concrete

Figure 13 present the Flexural strength of OPC/PHA-MK specimens tested at 28 and 56 days hydration periods. Concrete specimens with 0% replacement achieved 5.30 N/mm<sup>2</sup> while 100%MK, 80%MK+20%PHA, 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA replacement of Portland cement with 5.26 N/mm<sup>2</sup>, 5.29 N/mm<sup>2</sup>, 4.66 N/mm<sup>2</sup>, 4.28 N/mm<sup>2</sup> and 3.92 N/mm<sup>2</sup> at 28 days. This represents 0.01% decrease of 0% from

80%MK+20%PHA in flexural strength. The increase in strength of percentage replacement in concrete could be as a result of the type of pozzolana used in the production of the concrete specimen. However the flexural strength increases with increase curing days. Replacement of cement with Peanut husk ash and Metakaolin gives higher Flexural strength because it makes good bonding and excellent filler between the aggregates and paste of the concrete.

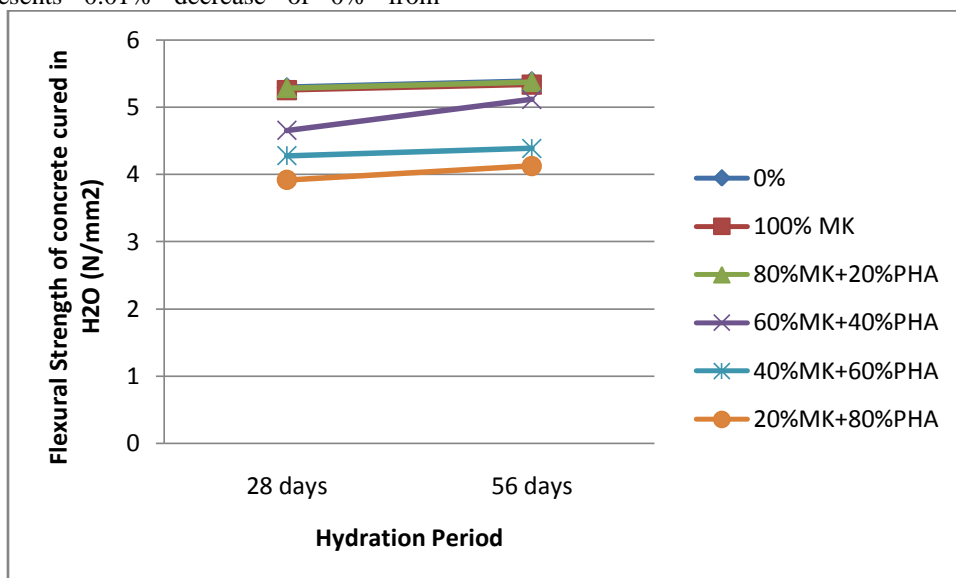


Figure 13: Flexural Strength of Hardened Geopolymer Concrete

### Water Absorption Test

#### Water absorption Tests of Geopolymer Concrete Cured in H<sub>2</sub>O

Figure 14 presents the water absorption test of OPC/PHA-MK concrete cured in water (H<sub>2</sub>O) and tested at 28 and 56 days hydration periods. The degree of sorption of the concrete tally with the work carried out by Shah (2014) which stated that the average absorption of the concrete test specimens shall not be greater than 5%. For cubes cured in H<sub>2</sub>O at 28 days 0% replacement absorbed more curing agent than 100%MK and 80%MK+20%PHA replacement while other replacement level absorb more curing agent than the control concrete. Concrete samples with 0% replacement absorbed 2.27% while 100%MK, 80%MK+20%PHA, 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA replacement absorbed 2.10%, 2.14%, 2.29%, 2.41% and 2.46% respectively. Also at 56 days Concrete samples with 0% replacement absorbed 2.28% while 100%MK, 80%MK+20%PHA, 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA replacement absorbed 2.14%, 2.15%, 2.31%, 2.40% and 2.42% respectively. However this means that replacement percentages above 80%MK+20%PHA absorbed more amount of curing agent than 0% replacement which can be attributed to the concrete specimen.

#### Water Absorption Tests of Geopolymer Concrete Cured in MgSO<sub>4</sub>

Figure 15 presents the water absorption test of OPC/PHA-MK concrete cured in magnesium sulphate (MgSO<sub>4</sub>) and tested at 28 and 56 days hydration periods. For sample cured in MgSO<sub>4</sub> at 28 days 0% replacement absorbed more curing agent than 100%MK, 80%MK+20%PHA, 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA replacement. Concrete cubes with 0% replacement absorbed 2.35% while 100%MK, 80%MK+20%PHA, 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA replacement absorbed 2.20%, 2.22%, 2.31%, 2.34% and 2.38% respectively. Also at 56 days concrete samples with 0% replacement absorbed 2.80% while 100%MK, 80%MK+20%PHA, 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA level replacement absorbed 2.35%, 2.17%, 2.56%, 1.76% and 2.38% respectively. However concrete samples present Slight difference as compared to other curing medium with higher absorption of curing agent in both replacement levels and control at 56 days curing age. This means that

80%MK+20%PHA replacement level absorbed less amount of curing agent than 0% replacement.

### Abrasion Resistance Test

#### Abrasion Resistance Test of Geopolymer Concrete Cured in H<sub>2</sub>O

Figure 16 presents the abrasion resistance of OPC/PHA-MK concrete cured in normal water (H<sub>2</sub>O) and tested at 28 and 56 days hydration periods. There was high loss of weight 0.05% for 100% MK and 80%MK+20%PHA replacement as compared to 0% replacement while control and 0% have 0.04% respectively at 28 days. Thus at 28 days control concrete, 60%MK+40%PHA and 20%MK+80%PHA replacement with 0.08% resist abrasion impact more than 40%MK+60%PHA replacement levels 0.07% respectively. Also at 56 days it was discovered that 0% and 100%MK has 0.05% while 80%MK+20%PHA and 60%MK+40%PHA resist more abrasion impact with 0.07% while 40%MK+60%PHA and 20%MK+80%PHA replacement has 0.08% and 0.08% respectively. Thus 80%MK+20%PHA replacement resists abrasion impact than 0% replacement in H<sub>2</sub>O curing.

#### Abrasion Resistance Test Geopolymer Concrete Cured in MgSO<sub>4</sub>

Figure 17 presents the abrasion resistance of OPC/PHA-MK Concrete cured in MgSO<sub>4</sub> and tested at 28 and 56 days hydration periods. 0% replacement has high loss of weight of 0.12% than 100%MK replacement with 0.10% at 28 days while it has same value with 80%MK+20%PHA and 60%MK+40%PHA of 0.12% but better than that with 40%MK+60%PHA and 20%MK+80%PHA which have 0.13% and 0.14% respectively. Also at 56 days it was discovered that 0% replacement present same loss of weight of 0.12% as compared to 100%MK and 80%MK+20%PHA replacement, but resist abrasion better than 60%MK+40%PHA, 40%MK+60%PHA and 20%MK+80%PHA with 0.15%, 0.15% and 0.16% respectively. Thus control concrete, 100%MK and 80%MK+20%PHA replacement has same resistance to abrasion impact in MgSO<sub>4</sub> curing media generally.

## VII. SUMMARY, CONCLUSION AND RECOMMENDATIONS

### Summary of Findings

Based on the results of the experiments carried out on the characterization (physical and chemical properties) of the alternative binders, harden properties tests were carried on concrete specimens with percentage replacement of Peanut Husk Ash and Metakaolin in variable percentages

of 20, 40, 60, 80 & 100. Mechanical properties of concrete specimens were studied and were compared with control mix results, the following findings were made:

- 1- The experimental study is conducted for mix proportion of 1:2.5
- 2- Test on the Physical Properties of Coarse Aggregate and Fine Aggregate revealed specific gravities of 2.71 and 2.64 respectively, result of void percentages of 25.15% and 15.19% respectively, also the bulk density of coarse aggregate & fine aggregate is 1729 kg/m<sup>3</sup> and 1550 kg/m<sup>3</sup> respectively. The Fineness modulus of 2.74 was obtained or Fine aggregate and grading of this sample belong to zone 2 category. While the nominal size of Coarse Aggregate was 20 mm.
- 3- Test on physical properties of Peanut husk ash and Metakaolin revealed specific gravities of 2.10 and 2.51 respectively, which indicates that it is suitable for use in replacement and falls within range for specific gravity of pozzolana. Also results of void percentages of 19.36% and 13.619% respectively and Bulk densities of 1604 kg/m<sup>3</sup> and 1803 kg/m<sup>3</sup> respectively were obtained.
- 4- The Workability of Peanut husk ash and Metakaolin concrete above 100%MK has the same value that of control concrete for slump while 80%MK+20%PHA concrete has higher workability than control concrete sample for compacting Factor.
- 5- Concrete samples with 80%MK+20%PHA of cement replacement leads to compressive strength by 5.26%, 7.95% and 15.94 at 28 days in normal and MgSO<sub>4</sub> environment respectively.
- 6- The Flexural Strength results revealed that the concrete with all replacement levels at 28 days surpassed both the 4.2N/mm<sup>2</sup> flexural strength of control mix and the expected 40N/mm<sup>2</sup> flexural strength of concrete at 28 days.

### Conclusion

Peanut Husk Ash and Metakaolin are used as the source material, instead of the Portland cement, to make concrete. From the various tests, discussions and analysis carried out in this study, the following conclusion can be drawn.

- Physical properties such as bulk density, specific gravity of Peanut husk ash and Metakaolin were found to be in conformity with ACI E1-99, Setting time and consistency OPC/Peanut husk ash and metakaolin satisfied the BS EN 197-1 (2000) requirements.

- The Workability of Peanut husk ash and Metakaolin concrete 100%MK has the same value that of control concrete for slump while 80%MK+20%PHA concrete has higher workability than control concrete sample for compacting Factor.
- The Strength properties hardened concrete specimen shows that 80%MK+20%PHA have higher compressive and flexural strengths than others mixes. The compressive Strength of concrete has been increase by 9% for 16M solution in 1:2.5 alkaline liquid ratios.

### Recommendations

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

- ✓ The research recommends the use of Peanut husk ash and Metakaolin to replace cement concrete production due to its availability.
- ✓ The research recommends by using these replacements we are trying to reduce cost, energy savings, and superior products and fewer hazards to environment.
- ✓ The use of 80% MK+20%PHA replacement level is the optimum replacement level that can be used to produce concrete with required strength for general construction purposes.
- ✓ It is recommended that concrete specimens with 80% MK+20%PHA should be used in areas exposed to magnesium sulphate attack.

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