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Effects of Source Materials on Mechanical Properties of Geopolymer Concrete

Oke O. L., Ayeni I. S.
Civil Engineering Department, Ekiti State University, Ado-Ekiti, Nigeria,
Civil Engineering Department, The Federal Polytechnic, Ado-Ekiti, Nigeria,
Corresponding Author: Oke O. L.,

ABSRTACT: *This work aims at studying the effects of source materials on the mechanical properties of geopolymer concrete. Three source materials were used which were Rice Husk Ash (RHA), Saw Dust Ash (SDA) and Cow Dung Ash (CDA) and the amount of Alumina and Silica oxides in them were determined to be RHA (81.28%), SDA (72%) and CDA (71.2%). They were used with Alkaline solution in ratio 0.4 to produce binding medium for other constituents. The Alkaline solution was a combination of Sodium Silicate and Sodium Hydroxide in ratio 2.5. Compressive and Flexural strengths of geopolymer concrete produced with RHA, SDA and CDA were determined after heat curing for 24 hours, 48 hours and 72 hours at temperature of 100^{o}C. Both compressive and flexural strengths increased as the curing age increased. RHA-geopolymer concrete gave the highest compressive and flexural strengths followed by SDA and CDA in that order.*

KEY WORDS: *source, materials, geopolymer, concrete, compressive, flexural, strength*

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I. INTRODUCTION

Cement is the largest source of CO_2 emissions from decomposition of carbonates and these emissions are in two categories; namely emission from chemical reaction involved in the production of cement clinker and combustion of fossil fuels required to generate energy which is used to heat the raw materials. The total emission of CO_2 from cement industry is put at 8% of global CO_2 emissions (Andrew, 2018). The United Nations Intergovernmental Panel on Climate Change (IPCC) has identified the unmindful pumping of CO_2 into the atmosphere as the main culprit for the climate change and highlighted that the "largest mitigation potentials are in the steel, cement and pulp and paper industries." (IPCC, 2007). Carbon emission data is alarming; the 2007 carbon emission estimate was an all times high and a 1.7 percent increase from the previous year alone (Boden, 2010).

In view of the serious impact of carbon dioxide on the environment and the continued anticipated growth of industrialization and urbanization, there is a need to redirect the building industry away from its overwhelming reliance on Portland cement by developing alternative binder systems. The two options which have attracted attention as alternative binders are; (i) the partial replacement of cement with industrial byproducts such as fly ash, slag etc. and; (ii) the use of geopolymer binders. The first alternative has been widely researched and abundant information on the fresh and hardened properties of concrete with partial replacement of cement has led to the use of such blended cements (Mehta, 2004, Stevenson & Panian, 2009, Poon et al, 2000, Padadikis, 1999, Malhotra, 2002, Oyedepo, Oluwajana & Akande, 2014, Omoniyi, Duna & Mohammed, 2014). In one such application, a post-tensioned structure with 50 -70 percent replacement of cement by slag resulted in an estimated reduction on carbon dioxide emissions for the project by 4500 tons (Poon et al, 2000). Partial replacement of cement in binders has been found to comply with standards for masonry cement and could be used up to 25 percent partial replacement without deleterious effect on strength (Singh & Grary, 1999). The second alternative, geopolymer binder, is an emerging area of technology. Davidovits (1991) first proposed that an alkaline liquid could be used to react with the silicon (Si) and aluminum (Al) in a source material of geological origin or in by -product materials such as fly ash, rice husk ash etc to produce cementitious binders. Because the chemical reactions that take place in this case is a polymerization process and the source materials are of geological origin, he coined the term "geopolymer" to represent these binders.

Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that results in a three-dimensional polymeric chain and a ring structure consisting of Si -O-Al bonds (Davidovits, 1994).
The schematic formation of geopolymer material can be shown as described by equations (i) (Davidovits, 1994).

$n(Si_2O_5,Al_2O_2)+2nSiO_2+4nH_2O+NaOH$ or KOH $Na^+,K^+ + n(OH)_3\text{-Si-O-Al--O-Si-}(OH)_3$
(Si-Al materials) $(OH)_2$
(Geopolymer precursor)----- (i)

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumina -silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. The alkaline liquids are from soluble alkali metals that are usually Sodium or Potassium based. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate (Jeyasehar et al, 2010).

Lloyd and Rangan (2009) conducted a study on geopolymer concrete with fly ash. For their study, they used low calcium (ASTM Class F) fly ash as their base material. The effect of water was observed on geopolymer solids. They concluded that geopolymer possess excellent properties and is well suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after disaster.

Hardjito and Rangan (2005) studied fly ash based Geopolymer Concrete. The material used was low calcium ASTM class F dry fly ash obtained from power station. The calcium content of the fly ash was about 2 percent by mass. They observed the compressive strength data and concluded that fly ash based geopolymer concrete has good compressive strength and is suitable for structural application. The fly ash based geopolymer concrete also showed excellent resistance to sulphate attack and the elastic properties of hardened concrete and the behaviour and the strength of reinforced structural members are similar to the Portland cement concrete. The behavior and failure mode of fly ash-based geopolymer concrete in compression is similar to that of Portland cement concrete. Test data showed that the strain at peak stress was in the range of 0.0024 to 0.0026 (Hardjito & Rangan, 2005). They also worked on the unit weight of geopolymer concrete. The unit-weight of concrete primarily depends on the unit mass of aggregates used in the mixture. Their results showed that the unit-weight of the low-calcium fly ash-based geopolymer concrete is similar to that of Portland cement concrete. When granite-type coarse aggregates were used, the unit-weight varied between 2330 and 2430 kg/m^3 (Hardjito & Rangan, 2005).

The fresh geopolymer concrete was easily handled up to 120 minutes after mixing without any sign of setting. The addition of high range water reducing admixture improved the workability of concrete. They concluded that higher concentration of sodium hydroxide solution and curing temperature in the range of 30ºc to 90ºc results in a higher compressive strength of geopolymer concrete. Higher concentration (in terms of molar) of sodium hydroxide solution results in a higher compressive strength of geopolymer concrete. The rest period between casting of specimens and the commencement of curing up to 60 minutes has no effect on the compressive strength of geopolymer concrete (Djwantoro et al., 2009).

Most of previous researches have focused mainly on the used fly ash as source material in geopolymer concrete production due to its availability and suitability. This fly ash is not available in our study area unlike rice husk ash, saw dust ash and cow dung ash which are available. The availability of the listed source materials and environmental nuisance they constitute necessitated this research work. The study was aimed at studying their effects on mechanical properties of geopolymer concrete.

II. MATERIAL AND METHODS

Materials

The following materials were obtained and used for the research work:

Fine Aggregate (River Sand): The fine aggregate used was river sand retained on a 600microns sieve acting as fillers. It was obtained from a local supplier in Ado – Ekiti, Ekiti State, Nigeria.

Coarse Aggregate: The coarse aggregates used was Granite of 20 mm size. It was sourced from a quarry site in Ikere-Ekiti, Ekiti State, Nigeria.

Source Materials: Three different source materials which are agricultural wastes were used. They are; Rice Husk Ash (RHA), Saw Dust Ash (SDA) and Cow Dung Ash (CDA). Rice Husk was obtained from a rice mill factory in Igbemo – Ekiti, Ekiti State, Nigeria, while Saw dust and Cow dung were obtained from Saw mill and

Cattle farm in Ado-Ekiti Ekiti State, Nigeria. They were all subjected to open burning in order to obtain them in ash form. The ratio of alkaline solution to source material used was 4:10 as suggested by Rangan, (2014). Open burning was opted for since this is the normal practice for disposing these agricultural wastes where they were obtained from.

Alkaline Solution: A combination of sodium silicate solution and sodium hydroxide solution was used as the alkaline activator. The alkaline solution was prepared by mixing both solutions together at least 24 hours prior to use. The ratio of sodium hydroxide to sodium silicate solution used was 10:25 as suggested by Hardjito and Rangan (2005) and Rangan (2014). The ratio of water to sodium hydroxide solids was 0.262 and that of water to sodium silicates solids was 0.559.

Methods

Chemical analysis: This was conducted in accordance with ASTM C311-12. It was performed on the three source materials (rice husk ash, saw dust ash and cow dung ash) using AAS Buck scientific 210VGP and Flame Photometer FP 902GP at Chemistry Department of Afe Babalola University, Ado-Ekiti. Nigeria. This was done to determine the amount of silicon and alumina oxides present in the source materials.

Compressive strength: This was conducted in accordance with BS 1881-116 (1983). It was done at the Civil Engineering Department of Afe Babalola University, Ado-Ekiti. Nigeria.

Flexural strength: This was conducted in accordance with BS 1881-116 (1983). It was done at the Civil Engineering Department, Federal Polytechnic, Ado-Ekiti, Nigeria

III. RESULTS AND DISCUSSIONS

Chemical Analysis of Source Materials

The amount of Alumina and Silicon oxides present in RHA, SDA and CDA were 81.28%, 72% and 71.2% respectively and are as shown in Table 1. They are classified as source materials because they are rich in Alumina and Silica oxides.

Table 1: Result of chemical analysis for source materials

Source materials	AL_2O_3 (%)	SiO_2 (%)	(AL_2O_3 + SiO_2) (%)
RHA	2.68	78.6	81.28
SDA	5.25	66.75	72.00
CDA	6.88	64.32	71.20

Compressive Strength of Geopolymer Concrete

The rice husk ash, sawdust ash and cow dung ash which are the selected source materials were used to produce rice husk ash geopolymer concrete, sawdust ash geopolymer concrete and cow dung ash geopolymer concrete. The geopolymer concretes produced were subjected to curing at a constant temperature of 100^oC for 24hrs, 48hrs and 72hrs and their compressive strengths were determined. Effects of source materials on compressive strengths were determined. The compressive strengths increased as curing ages increased. RHA gave highest compressive strengths at each curing age, followed by SDA and CDA in that order as shown in Figure 1. The performance of RHA geopolymer concrete may be attributed to the amount of Alumina and Silica oxides in it being the highest recorded in the study.

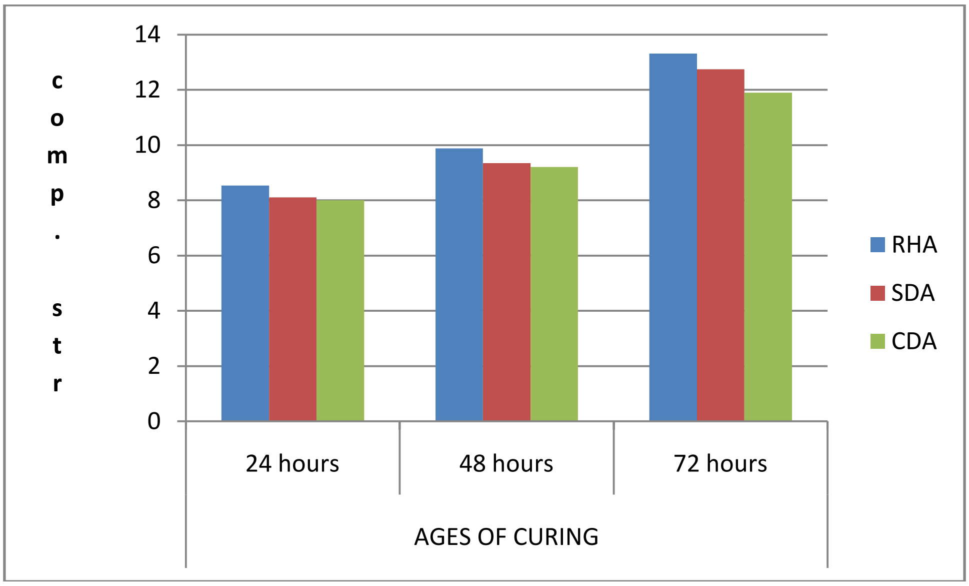

Fig. 1. Compressive Strength of Geopolymer Concrete

Flexural strength of geopolymer concrete

Flexural strength is a measure of tensile strength of concrete which is a fractional part of compressive strength of concrete varying between 15% - 20% (Hardjito & Rangan, 2005). The three source materials were used to produce geopolymer concretes and the flexural strengths were determined. RHA gave highest flexural strength at each curing age, followed by SDA and CDA in that order as shown in Figure 2. The performance of RHA geopolymer concrete may be attributed to amount of Alumina and Silica oxides in it being the highest recorded in the study.

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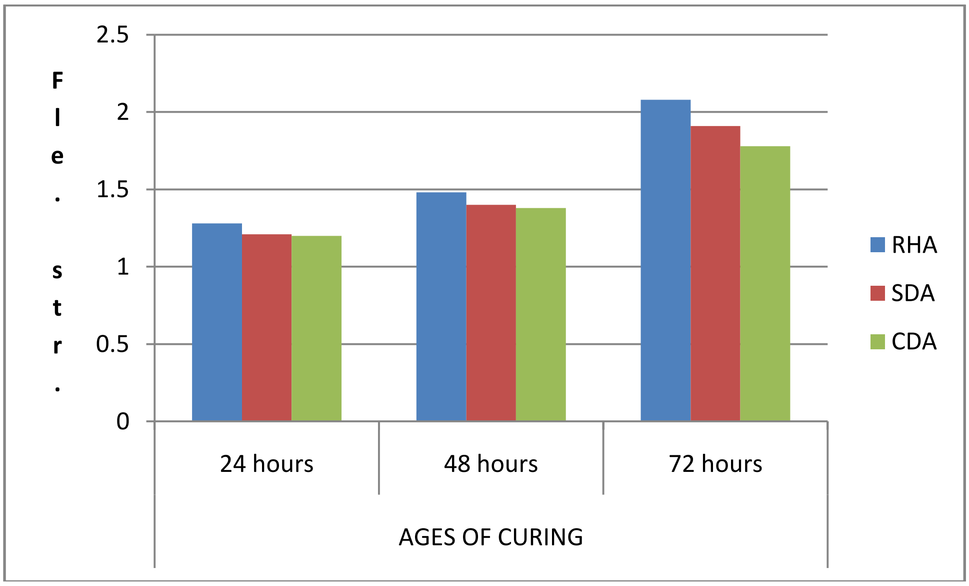

Fig. 2. . Flexural Strength of Geopolymer Concrete

IV. CONCLUSION

From this study the following conclusions are:

- The mechanical properties increase as the curing period increases
- RHA had largest amount of Alumina and Silica oxide among the three source materials
- Geopolymer concrete produced with RHA gave highest compressive and flexural strengths
- Fine aggregates other than river sand should be used for future research
- Heat curing method was used for this research work other methods of curing should be used for further research

- Compressive and flexural strengths obtained were generally low, this may be as result of molar concentration of sodium hydroxide, curing temperature and curing age, ratio of sodium silicate and sodium hydroxide used. Higher values of the listed parameters should be used for further research

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