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GEO-POLYMERISATION OF AGRO-WASTES AS ADDITIVES FOR CONCRETE PRODUCTION

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ABSTRACT: *This research work focused on the effects of source materials, aggregate type and size on mechanical performance of geopolymer concrete. Three source materials (i.e. Rice Husk Ash (RHA), Sawdust Ash (SDA) and Cow Dung ash (CDA))were used. The sums of alumina and silica oxides in them were determined as 81.28%, 72% and 71.2% respectively. The mixing ratio of material constituents used in producing geopolymer concrete was 1:2:4. The source materials were used with alkaline solution to produce a binder for geopolymer concrete. The alkaline solution was a combination of sodium hydroxide and sodium silicate in ratio 10:25 and the ratio of alkaline solution to source material was 4:10. 20mm granite was used and the grading properties of the source materials and coarse aggregates were obtained. The workability of all the concrete produced was determined at different curing hours of 24hrs, 48hrs, 72 hrs and at a constant temperature of 100oC. The geopolymer concrete produced were subjected to sulphate attack and sulfuric acid resistance in order to determine their durability The results obtained revealed that both compressive and flexural strengths increased as curing hours and aggregate sizes increased for all source materials and aggregate types used but RHA-geopolymer concrete produced with 20mm granite gave better performance with the highest compressive and flexural strengths at each curing hour. Its durability is better in comparison with conventional concrete. The use of geopolymer concrete should be encouraged because of its high resistance to sulphate attack, environmental protection and high workability.*

KEYWORDS: *Geopolymer concrete, Rice Husk Ash, Saw Dust Ash, Cow Dung Ash, Flexural strength, Compressive strength*

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I. INTRODUCTION

Concrete is the most often used material in construction besides wood. Concrete which is a main building material is broadly used in the construction of infrastructures such as buildings, bridges, highways, dams, and others facilities. The increasing of the human population leads to the increasing the demand for the building constructions. One of the materials that is usually used as a binder in the manufacture of concrete is the ordinary Portland cement (OPC) Izzat et al.,(2013)

One of the needs to reduce the high cost of OPC in order to provide accommodation for the populace has intensified research into the use of some locally available materials that could be used as partial replacement for OPC. Supplementary cementitous materials have been proven to be effective in meeting most of the requirements of durable concrete and blended cements are now used in many parts of the world (Kachwalaet al., 2014).

The term “geopolymer” was first coined by Joseph Davidovits, the inventor and developer of geopolymerization in the late 1970’s, the aim is to classify the newly discovered geosynthesis that produces inorganic polymeric materials now used for a number of industrial applications.

Geopolymer is a new inorganic polymeric material that has undergone a marked development in the pastyears. The geopolymer term was first used by Davidovits in its research which represents the activation of sodium hydroxide produced alumina-silicate components which was found to be as an alternative binder to the OPC (Sivakuma and Srinivasan, 2014). Hardjito and Rangan (2005) stated that the most frequent alkaline liquids used in geopolymerisation are mixture of sodium hydroxide and sodium silicate solution. The addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquids will enhance the reaction between base materials and the solution. Alkaline concentration is a huge element for controlling the leaching of alumina and silica from fly ash particles, geopolymerisation process and mechanical properties of solidified geopolymer. Duchesne et al., (2010) also affirm that the presence of NaOH in the alkaline activators solutions can make the reaction that takes place more briskly and the gel is less smooth. The most common sodium hydroxide concentration used by many researchers is 12g. (Suriya & Senthil, 2015) proved that the suitable molarity used for mixing of NaOH is 12.

Fiber reinforced concrete (FRC) is a composite materials made with Portland cement, aggregates and incorporating discrete discontinuous fibers. Plain and unreinforced concrete is known as a brittle material with a low tensile strength and a low strain capacity (Nguyen, 2004). The bond between the concrete and the reinforcing steel fibers is a significant mechanism for the performance of reinforced geopolymer concrete as a composite material (Prabir, 2011). Several experimental done by previous researchers pointed that the utilization of fibers especially steel fibers enhanced the impact resistance of the geopolymer concrete (Murali et al., 2014)

Concrete is a broadly used construction material and the construction industry exploit the natural resources greatly (Mehta, 2002.) OPC plays a vital function in the production of concrete and the manufacturing of cement involves burning of huge quantities of fuel and breakdown of limestone, which results in large emission of carbon dioxide to the atmosphere (Kong &Sanjayan, 2008). In manufacturing one ton of cement, one ton of carbon dioxide is released to the atmosphere (Davidovits, 1994). Due to these environmental issues, attempts were made to reduce the use of Portland cement. Cement is used as a binder which can be replaced by the use of source material containing high amount of Silica (Si) and Aluminium (Al) to react with an alkaline liquid or a by-product material like fly ash and RHA (Davidovits, 1988) and the chemical reaction is of polymerisation process and the binders were termed as Geopolymers. The curing temperature or the temperature at which the initial reaction takes place plays a vital role in the development of strength and can be achieved by curing it above ambient temperature (Barbosa & MacKenzie, 2003). The strength was improved at a curing temperature of 50 – 80°C rather than at room temperature (Khalil &Merz, 1994). The setting time of Geopolymer Concrete (GPC) decreases with increases in curing temperature (Chanhetal., 2008). The polymerisation reaction becomes very rapid with increase in curing temperature and the concrete can gain strength of 70% within 3-4 hours of curing and the higher early strength was achieved when curing at 65°C and there was no significant increase in the strength after 28days (Davidovits, 1994). The aggregate not prepared to saturated-surface-dry condition were found to produce Geopolymer with high strength and good workability. The flexural behaviour of GPC beams were studied and reported that the conventional reinforced concrete theory can be used for GPC beams under flexure study for the computation of moment capacity, deflection and crack width within reasonable limits (Dattatreya et al., 2010).

Xu et al. (2008) reported the performance of samples cast between 1964 and 1982 how it was and subjected to service conditions. They concluded that all samples demonstrate high compressive strengths significantly higher than when initially cast and excellent durability over a service life of up to 35 years in aggressive conditions". There are numerous examples of the use of geopolymer concrete in different applications in Australia.

The cost of building materials nowadays is so high in some parts of the world particularly developing countries like Nigeria that only the government, industries, business cooperation and few individual can afford it. This high and still rising cost can however be reduced to a minimum by use of alternative building materials that are cheap, locally available and bring about a reduction in the overall dead weight of the building. Some industrial and agricultural products that would otherwise litter the environment as waste or at best be put into only limited use could gainfully be employed as building material (Owolabi, 2005).

Rice Husk Ash (RHA), Saw Dust Ash (SDA) and Cow Dung Ash (CDA) which are agricultural by products and natural pozzolans have been reported to be good pozzolans by numerous researchers. In this research, geopolymer concretes were produced with RHA, SDA and CDA as the source materials with fine and coarse aggregates. Alkaline solutions (i.e. mixture of sodium silicate and sodium hydroxide solution) were used to react with aluminum and silica in the selected source materials to form the paste that bind the constituents together to yield the geopolymer concrete.

II. MATERIALS AND METHODS

A. MATERIALS

The Rice Husk, Cow Dung and Saw Dust were locally sourced from a rice mill in Igbemo Ekiti, Cattle ranch of the Federal Polytechnic, Ado-Ekiti and Ureje Saw Mill respectively. They (Rice Husk, Cow Dung and Saw Dust) (Fig. 2.1a, c and e) were subjected to open air burning to achieve the ashes (Fig. 2.1b, d and f). The resulting ashes were then sieved through BS sieve (90microns) to obtain a finer particle. In order to achieve geo- polymerization, alkaline solution of Sodium hydroxide and Sodium Silicate solution (Fig. 2.1g and h) were added to the mix at a ratio of 2:5. The aggregates (fine and coarse) were locally sourced and subjected to sieving to ensure they conform with appropriate standards.

Fig. 2.1a: Rice Husk (Before Burning)

Fig. 2.1b: Rice Husk (After Burning)

Fig. 2.1c: Saw Dust (Before Burning)

Fig. 2.1d: Cow Dung Ash

Fig. 2.1e: Saw Dust (After Burning)

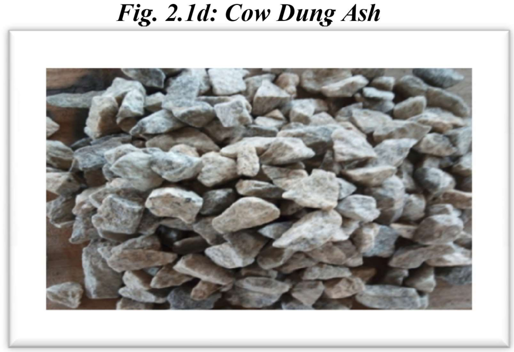

Fig. 2.1f: Granite

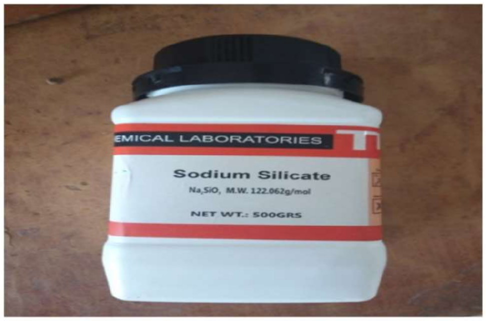

Fig. 2.1g: Sodium Silicate (Na2SO4)

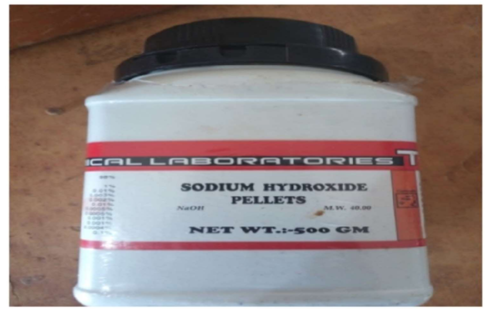

Fig. 2.1h: Sodium Hydroxide Pellets (NaOH)

B. METHODS

a. Sieve Analysis

This test was done to determine the percentage of different grain sizes contained in source material and aggregate. It was done at Civil Engineering Department of Civil Engineering, Federal Polytechnic, Ado-Ekiti.

b. Chemical Composition

This test was done to determine the amount of alumina and silica oxides present in source materials. It was done at Civil Engineering Department of Civil Engineering, Federal Polytechnic, Ado-Ekiti. The Apparatus used in this test method includes balance weight, Laboratory Glasswares and containers, filter papers, crucibles and muffles finance and the reagent used includes distilled water, concentrated acids, ammonium hydroxides and indicator solutions which were introduced so as to determine the insoluble residue, silicon oxide, Aluminum oxides, Ferric Oxide, calcium oxide, etc. either by color change, precipitation of insoluble residue or the production of gasses.

c. Compressive Strength

Thistest was done to determine the compressive strength of concrete. It was conducted in accordance with BS 1881-116 (1983). It was done at Civil Engineering Department of Afe Babalola University, Ado-Ekiti, Nigeria.

d. Flexural Strength:

The tensile strength of concrete, which is a fractional part of compressive strength of concrete varying between 15% - 20% (Hardjito & Rangan, 2005). For this research three source materials (RHA, SDA, CDA) were used with different aggregate types and sizes to produce geopolymer concrete and its flexural strength was determined. This was conducted in accordance with BS 1881-116 (1983). It was done at Civil Engineering Department Federal Polytechnic, Ado-Ekiti, Nigeria.

III. RESULTS AND DISCUSSION

A. Particle size distribution for Source materials

Grading properties of the source materials (i.e. RHA, SDA and CDA) used as fine aggregates are shown in Table 3.1 and Fig. 3.1. It is observed that the coefficient of uniformity (***Cu)*** and curvature (***Cc)*** for RHA, SDA and CDA were 1.2 and 0.98 respectively. The grading coefficients indicate that the source material is suitable for concrete mix. According to the unified soil classification system (ASTM D6913-04(2009)) for $Cu > 4$ and $1 < Cc < 3$. The Granite is therefore classified as well graded. The fines (i.e. ≤ 0.075mm) in the source materials were in descending order of SDA > RHA > CDA, while the sand (i.e. $0.106 \leq S \leq 2.36$mm) was in descending order of CDA > RHA > SDA.

Table 3.1: Particle size distribution for the source materials

Sieve size (mm)	% PASSING		
	RHA	SDA	CDA
2.36	92.1	99.4	99.8
1.18	85.3	97.3	98.8
0.6	76	90.9	78.4
0.425	69.4	85.9	53.4
0.3	62.5	77.3	37.3
0.212	55.9	63.9	25.9
0.15	34.8	41.8	15.5
0.106	18.5	28.1	10.8
0.075	9.8	17.9	5.9

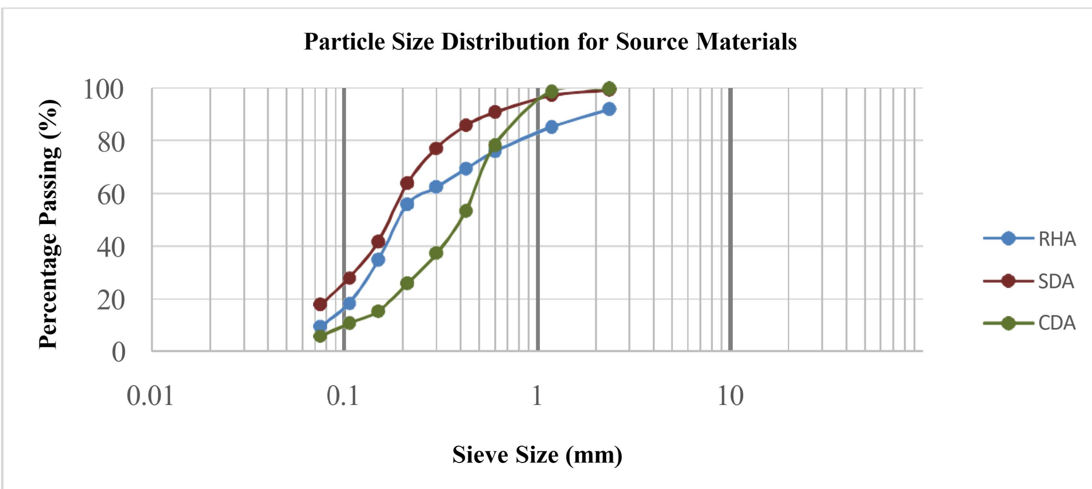

Fig. 3.1: Graph of Particle Size Distribution for Source Materials

B. Particle size distribution for Coarse Aggregates

The Table 3.2 and Fig. 3.2 shows the grading properties of the coarse aggregate used for this research. Larger percentage of 20mm was retained on sieve size 20mm. From the obtained result, the coefficient of uniformity (***Cu)*** and curvature (***Cc)*** for 20mm Granite were 1.2 and 0.98 respectively. The grading coefficients indicate that the source material is suitable for concrete mix. According to the unified soil classification system (ASTM D6913-04(2009)) for Cu>4 and 1 < Cc < 3. The Granite is therefore classified as well graded.

Table 3.2: Particle size distribution for Coarse Aggregate (Granite)

GRANITE (20mm)			
Sieve size (mm)	Weight retained (g)	% weight retained	% Passing
30.0	178.50	17.85	100
25.0	141.80	14.18	85.82
20.0	736.40	73.64	12.18
16.0	109.60	10.96	1.22
12.0	0.00	0.00	1.22
11.2	0.00	0.00	1.22
8.0	0.00	0.00	1.22
6.5	0.00	0.00	1.22
5.6	0.00	0.00	1.22
2.0	0.00	0.00	1.22

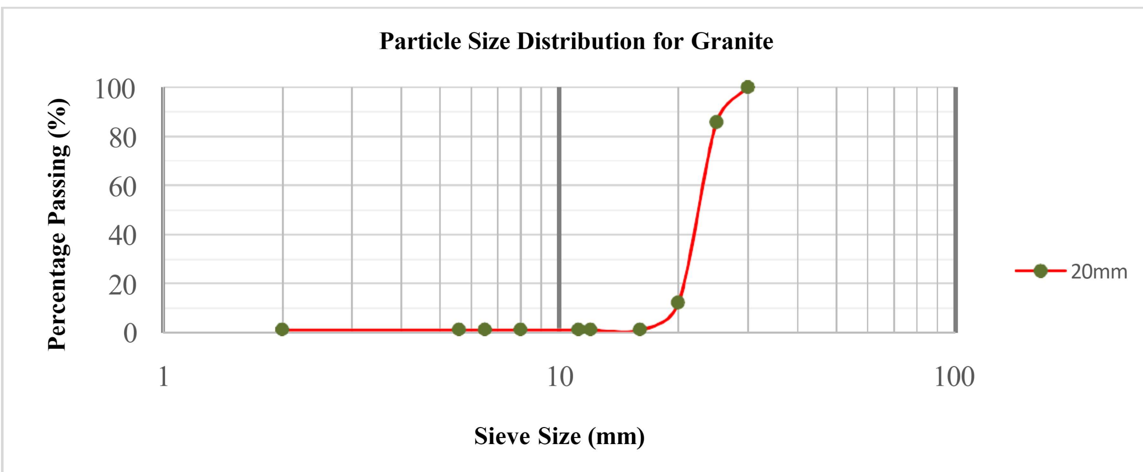

Fig. 3.2: Particle size distribution graph for the Coarse Aggregates (20mm Granite)

C. Chemical analysis of the source materials

The amount of Alumina and Silica oxides present in RHA, SDA and CDA are 81.28%, 72% and 71.2% respectively as shown in Table 3.3 and Fig. 3.3. The RHA and CDA give the highest and lowest percentages of Alumina and Silica Oxides respectively. This may influence the performance of the source materials in Geopolymer concrete production.

Table 3.3: 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
CDA	6.88	64.32	71.2

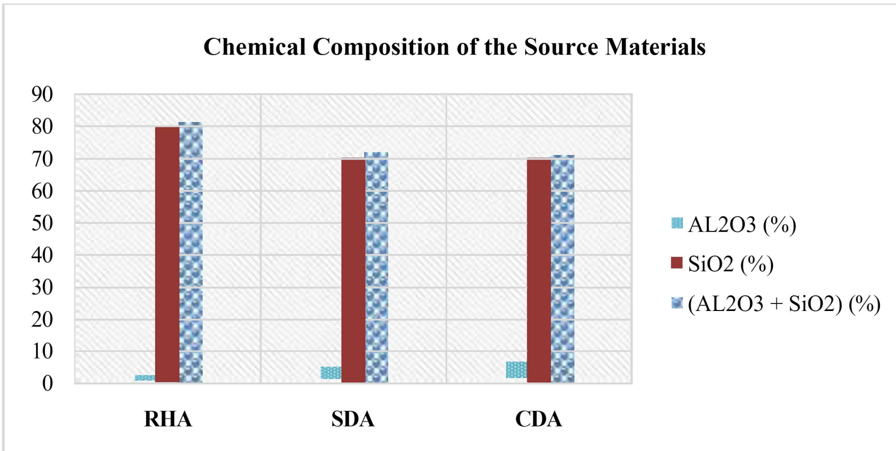

Fig. 3.3: Chemical Composition of the Sources Materials

D. Compressive strength

The RHA, SDA and CDA were used as source materials with a 20mm Coarse Aggregate (Granite) to produce geopolymer concrete. The compressive strength increases as the curing hour increases; longer curing time improved polymerization process resulting in higher compressive strength of geopolymer concrete (Rangan, 2008).The compressive strength was in descending order of RHA > SDA>CDA for all curing ages as shown in Table 3.4 and Fig. 4.4.

Table 3.4: Effect of Source materials and curing age on compressive strength of concrete

Aggregates + Source Materials	**Age of curing**		
	24hrs	**48hrs**	**72hrs**
RHA + GRANITE	2.2	2.9	4.4
SDA + GRANITE	2.1	2.5	4.2
CDA + GRANITE	1.95	2.3	3.0

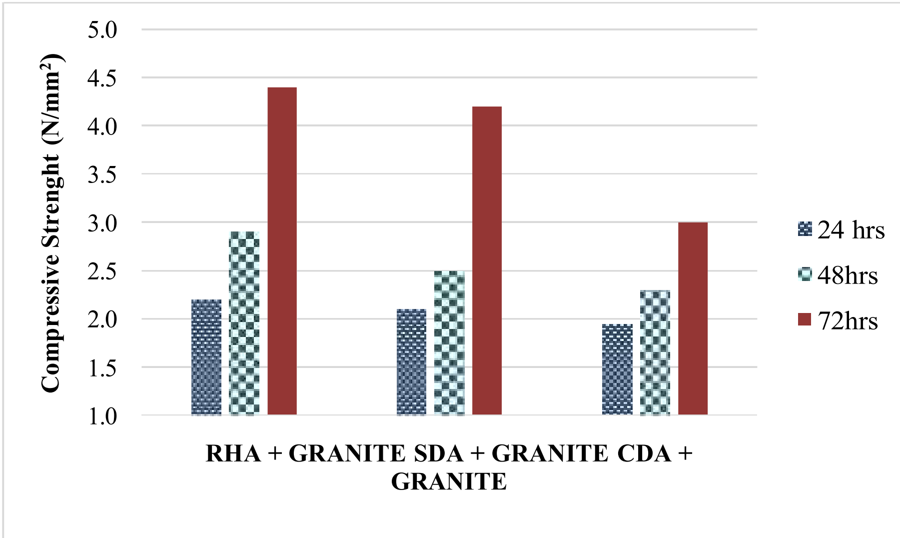

Fig. 3.4: Effect of Source materials and curing age on compressive strength of concrete

E. Flexural Strength

The RHA, SDA and CDA were used as source materials with a 20mm Coarse Aggregate (Granite) to produce geopolymer concrete. From the result obtained, the Flexural (tensile) strength increased as the curing hour increase, longer curing time improved polymerization process resulting in higher flexural (tensile) strength. RHA has the highest flexural strength, while CDA has the least as shown in Table 3.5 and Fig. 3.5.

Table 3.5: Effect of Source materials and curing age on Flexural (tensile) strength of concrete

Aggregates + Source Materials	Sizes	Flexural (Age of curing)		
		24 hrs	48hrs	72hrs
RHA + GRANITE	20	0.39	0.51	0.77
SDA + GRANITE	20	0.37	0.44	0.74
CDA + GRANITE	20	0.34	0.40	0.53

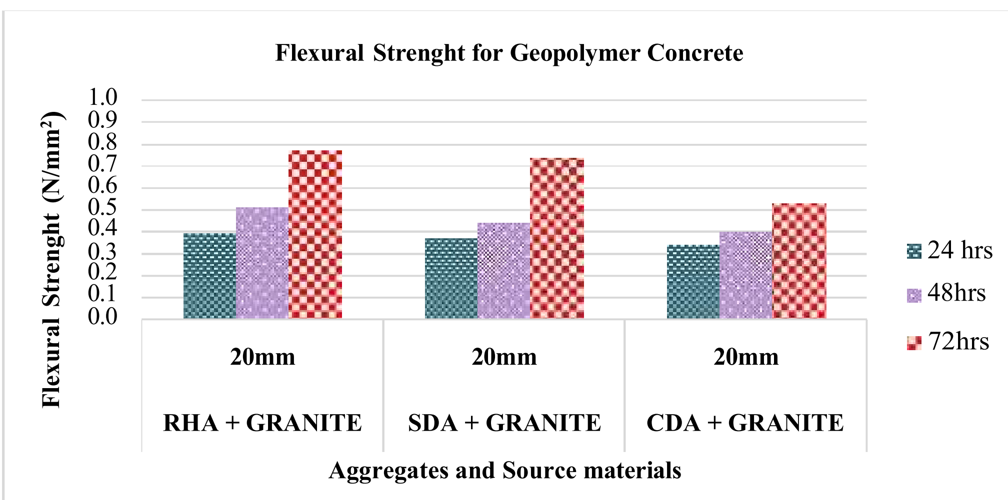

Fig. 3.5: Effect of Source materials and curing age on Flexural strength of concrete

IV. CONCLUSION

The conclusions were drawn based on the results obtained on mechanical properties (compressive and flexural strength) and durability of RHA, SDA and CDA geopolymer concretes produced with 20mm granite aggregate. The mechanical properties increase as the curing age increases. RHA geopolymer concrete produced with 20 mm granite gave the highest compressive and flexural strengths. The workability is in descending order of RHA
> SDA > CDA. The best workability in RHA may be attributed to its higher silica and alumina oxides composition. Geopolymer concrete offers environmental protection by means of recycling wastes up to high value construction materials needed for infrastructural development.

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