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Performance Investigation on Strength Properties of Metakaolin Based Geopolymer Concrete

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Abstract: Among the most commonly used construction materials worldwide is concrete. Cement is the main component used in the manufacturing of concrete. However, because cement manufacture uses natural resources, there are environmental issues due to the significant energy consumption and carbon dioxide (CO_2) emissions. This has increased the demand for using additional materials to make concrete instead of Portland cement. Therefore, this study aimed to investigate the strength properties of metakaolin based geopolymer concrete (MKGPC). Grade 25 MKGPC was given a mix design. Alkaline solutions containing 12 and 16 molars were used to cast the MKGPC specimens. They were then cured at ambient temperature as well as in a hot oven set at 100°C for 24 hours. The compressive strength and split tensile strength were investigated at 3, 7 and 28 days curing periods. The results from the investigation reveal that 16 molars and at ambient temperature had better results in terms of compressive strength and split tensile strength at all the curing periods. Therefore, this study concludes that the optimal molarity and cure regime for producing MKGPC are determined to be 16 molars and ambient temperature. As a result, the study suggests producing MKGPC using 16 molars and cured at an ambient temperature.
Keywords; Cement, concrete, geopolymer concrete, metakaolin, strength

I. INTRODUCTION

The most common and extensively used building material is concrete derived from ordinary Portland cement (OPC), which is readily available worldwide and can be easily prepared and fabricated into any shape that can be imagined. According to Anuar et al. (2011), the use of concrete in infrastructure, housing, and transportation has significantly accelerated the advancement of civilisation, economic growth, stability, and quality of life. Concrete is made up of inert mineral aggregates like sand, gravel, crushed stone, and cement. According to Neville and Brooks (2010), concrete is defined broadly as any product or mass created with a cementing medium. In general, this medium is formed by the reaction of hydraulic cement and water. When mixed in properly regulated proportions, they make a workable mass that can take the shape of any form work and harden.

Even though concrete is a great building material since it is hard, strong, weather-resistant, and durable in its finished state, some of the processes that go into making it have a detrimental impact on the environment. The ground surface has degraded due to processes like the extraction of limestone for cement production, which has caused erosion, leaching, uneven topography, etc. The inherent drawbacks of using Portland cement are nevertheless accepted despite the issues with the production procedures and the raw material extraction. OPC is the most often used binder in concrete, and in addition to its major limits in terms of durability in harsh settings, it is also a highly energy-intensive material with the most carbon dioxide (CO_2) emissions of any building material.

According to Meyer (2009), every tonne of cement produced emits around 0.9 tonnes of CO_2, and a typical cubic yard (0.7643 m^3) of concrete comprises approximately 10% cement by weight. A cubic yard of concrete weighs around 2 tonnes, and the CO_2 emissions from one tonne of concrete range from 0.05 to 0.13 tonnes. Approximately 95% of all CO_2 emissions from a cubic yard of concrete come from cement manufacture. According to Nurdeen and Shahid (2010), cement is one of the world's most essential and widely produced building materials. Because of its importance as a construction material and the geographic abundance of its raw material (limestone), cement is manufactured in almost every country and is mostly used to make concrete. Additionally, according to Dahiru (2010), cement is a very costly and unique component of concrete when compared to other components. The production process of cement depletes natural resources and degrades the environment, and the emission of CO_2 during production pollutes the environment. Because of the pressing need for a more environmentally friendly and energy-efficient concrete binder system, Davidovits developed a substitute binder consisting of silica and alumina that is activated by a highly alkaline solution known as geopolymer. According to Sabitha et al. (2012), geopolymer is the end product of a geosynthetic reaction between alumino-silicate minerals and strong alkalis. The amorphous alumino-silicate cementitious substance known as geopolymer, according to Abdullah et al. (2011), has a variety of uses in the automotive and aerospace, non-ferrous foundry and metallurgical, civil engineering, and plastic industries.

Alkali polysilicates and geopolymeric precursor undergo a polycondensation reaction, also referred to as the geopolymerization process, to create it. Additionally, Davidovits (2002) asserts that geopolymers have superior mechanical qualities as well as resistance to acidity and fire. Additionally, according to Prabu et al. (2014), geopolymer is the most effective way to lower the amount of cement used in concrete. While Hardjito and Rangan (2005) confirm that geopolymer is environmentally friendly, Shaik and Neeraja (2015) investigated the performance evaluation of metakaolin-based geopolymer concrete, and Najet et al. (2013) examined the impact of composition on the structure and mechanical properties of metakaolin-based pss-geopolymer. These are receiving more attention in a variety of study domains, including the engineering and construction sectors.

While the aforementioned researchers looked into how geopolymer concrete could be used to address the current issues of energy consumption and environmental pollution associated with the production of OPC, none of them conducted research on the effects of different molarities and curing regimes on metakaolin-based geopolymer concrete (MKGPC). The findings of numerous studies indicate that when burned, kaolin sourced from various locations contains a significant amount of silica and alumina in an amorphous form that can be used as a pozzolan. Therefore, this study aimed to evaluate the strength properties of metakaolin based geopolymer concrete using 2-molarities of alkaline (8 molars and 16 molars) solutions subjected to ambient temperature and oven temperature of 100^oC. The strength properties investigated include; compressive and split tensile strength at 3, 7 and 28 days curing.

II. MATERIALS AND METHOD

A. Materials

1) Metakaolin

Kaolin from Argungu Local Government, Kebbi State, Nigeria was used to make the metakaolin used in this study. In the Department of Chemical Engineering Laboratory at ABU Zaria, the kaolin sample was pulverised in a ball mill and then calcined for 90 minutes at 650 degrees Celsius. In the Concrete Laboratory of the Building Department, it was then sieved through a 150μm sieve.

2) Alkaline Solution

For Sodium hydroxide (NaOH), in order to prepare NaOH solutions with concentrations of 12 molars and 16 molars, 560 grammes of NaOH crystals were dissolved in one litre of water for 12 molars, while 640 grammes of NaOH crystals were dissolved in one litre of water for 16 molars. This was determined by multiplying the intended molarity for the NaOH solution by 40, which yields the quantity in grammes of NaOH solids per litre of water. Furthermore, for the preparation of Sodium silicate solution (Na_2SiO_3). According to the manufacturer's label, the Na_2SiO_3 solution was used, which has a SiO_2 to Na_2O by mass ratio of around 2, meaning that the solution contains 29.4% SiO_2, 14.7% Na_2O, and 55.9% water by mass. This suggests that there are twice as many silicate oxides than sodium oxides. This meets the requirements provided by Aleem and Arumairaj (2012) and Rangan (2010).

3) Aggregates

Clean, saturated, surface-dried sharp river sand from Dukku river Birnin Kebbi, Kebbi State, was used as the fine aggregate. In compliance with BS EN 933-1 (1997), it was sieved through 5mm to eliminate contaminants and bigger aggregates. Crushed granite (20 mm maximum size, retained on a 5 mm screen) from a quarry along the Birnin Kebbi, Kebbi State western bye-pass served as the coarse aggregate. To get rid of undesirable sizes, it was sieved.

B. Methods

1) Compressive Strength Test

The most popular test for hardened concrete is the compressive strength test, in part because it is simple to administer and in part because the majority of the concrete's desired characteristics are qualitatively correlated with its compressive strength. At 3, 7, and 28 days of curing periods, the concrete specimens were crushed. A crushing machine was used in the laboratory to measure compressive strength. This was carried out in compliance with BS EN 12390-3 (2000). The relationship in **equation 1** was used to calculate the compressive strength of the hardened concrete specimens.

$$Compressive\ strength = \frac{F}{A} ------------------------ (1)$$

Where; F = Failure Load (N) and A = cross-sectional area of the specimen (mm^2).

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2) Split Tensile Strength Test

The loading pieces were carefully positioned along the top and bottom of the loading system's plate, and the specimens were weighed and positioned diagonally at the central jig. The hardened concrete cubes in all were examined at 3, 7, and 28 days of curing. The concrete cubes failed as the load was applied and progressively increased. The machine's readings were noted. The following the formular in **equation 2**., which was cited by Garba (2014), was used to determine the tensile strength.

$$Split\ Tensile\ Strengt = \frac{0.518 \text{ X } P}{S^2} ------------------ (2)$$

Where: P = Failure load (N) and S= Surface area of the concrete specimen.

III. RESULTS AND DISCUSSION

A. Compressive strength

1) Compressive strength at ambient temperature

The average compressive strength of MKGPC specimens made with 12 molars and 16 molars that were cured for 3, 7, and 28 days at room temperature before crushing is shown in **Figure 1**. According to the findings, the compressive strengths of the 16 molars MKGPC specimens are higher than that of the 16 molars, increasing by 23.9%. It is consistent with the findings of Anuar et al. (2011) that the higher the concentration of NaOH, the higher the compressive strength of GPC that will be produced because a higher concentration of NaOH results in good bonding between the aggregate and the concrete paste. This could be due to an increase in molarity and a favourable curing temperature. Furthermore, the curing temperature satisfies the lowest temperature needed for heat curing GPC, which Rangan (2008a) explains can be as low as 30^{o}C.

2) Compressive strength at 100^{o}C temperature

The compressive strength of specimens that were cured at 100^{o}C is displayed in **Fig. 1.** When the molarity was increased at 3, 7, and 28 days after curing, a drop in compressive strength was also seen. The findings show that the compressive strength of the 12 molars and 16 molars specimens decreased by around 22.5% and 44.3%, respectively, at 28 days of curing age. Mohammed et al. (2014) found that elevated temperature curing beyond 12 hours causes decrease in compressive strength due to continuous evaporation of moisture from specimens because the water content in GPC is very small. This could be because longer curing times and increases in molarity and curing temperature caused cracks on the specimens, which in turn led to a reduction in strength as a result of lost in moisture, which causes cracks to form and reduces the GPC's strength.

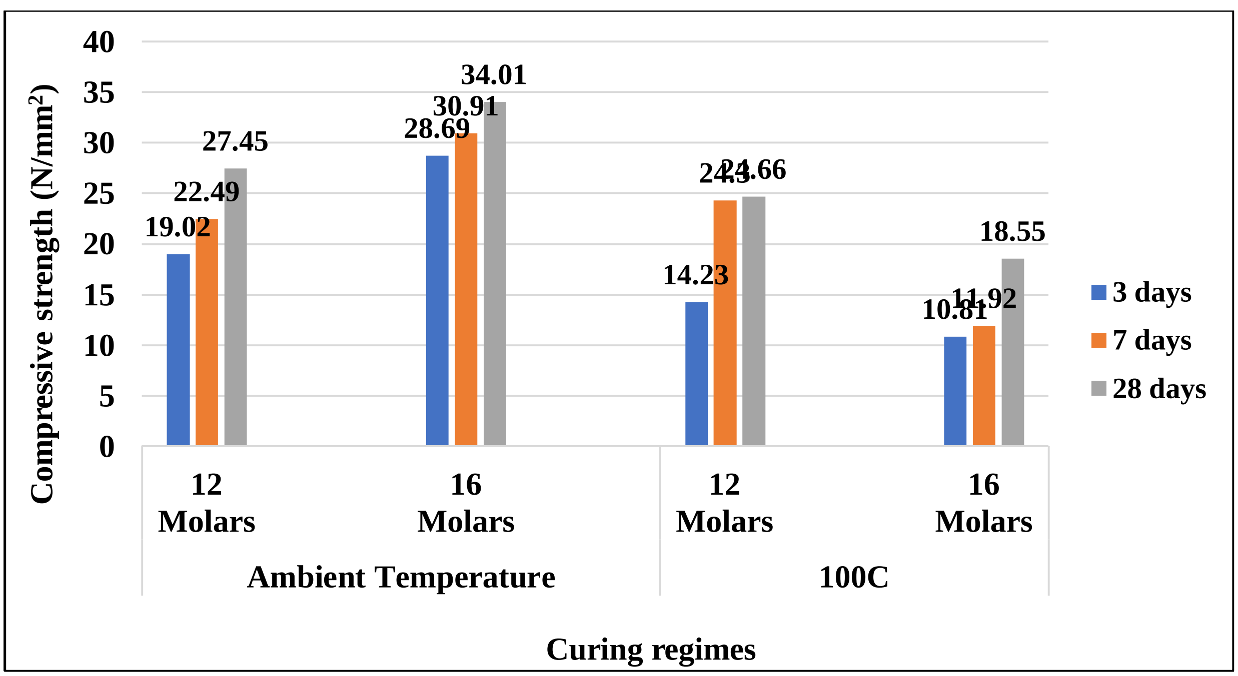

Figure 1 Compressive strength of MKGPC cured at ambient temperature and 100^{o}C

B. *Split Tensile Strength*

1) *Split tensile strength at Ambient Temperature*

The split tensile strength of the concrete specimens evaluated at 3, 7, and 28 days after curing at room temperature is displayed in Figure 2. All of the specimens showed an increase in tensile strength after three and seven days of curing. However, after 28 days of curing, the tensile strength of the 12 molars and 16 molars specimens decreased by 11.2% and 16.30%, respectively. This can be the consequence of inconsistent concrete cube sizes or mixing.

2) *Split tensile strength at 100^{o}c Temperature*

Fig. 2 depicts the split tensile strength of specimens treated at 100°C. Tensile strength decreased as molarity increased throughout the 3, 7, and 28-day cure periods. The results show that after 28 days of curing age, 12 molars and 16 molars had a 3.5% and 2.35% loss in tensile strength, respectively. This could be due to an increase in molarity and curing temperature, which resulted in a reduction in strength, as determined by Mohammed et al. (2014), who found that elevated temperature curing beyond 12 hours causes a decrease in compressive strength due to continuous evaporation of moisture from specimens because the water content in GPC is very low when subjected to high temperatures.

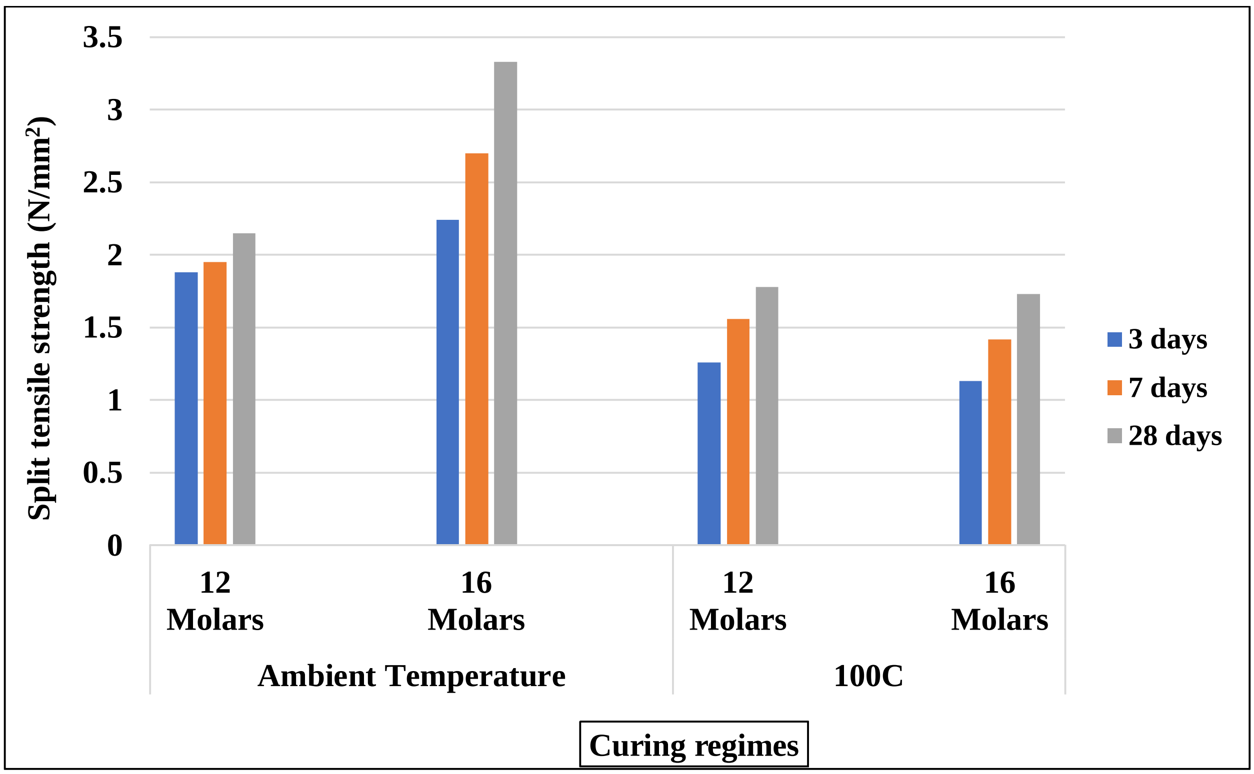

Fig. 2 Split Tensile strength of MKGPC cured at ambient temperature and 100^{o}C

IV. CONCLUSIONS

This study aimed to evaluate the strength properties of metakaolin based geopolymer concrete. The following can be inferred as conclusions from this study:

1) The hardening of geopolymer pastes was impacted by the curing temperature. Cracks appeared on metakaolin based geopolymer concrete (MKGPC) specimens as the curing temperature to 100°C.
2) The best curing regime for the production metakaolin based geopolymer concrete (MKGPC) is ambient temperature. This curing regime gives best results in terms of compressive strength and split tensile strength than 100^{o}C temperature.
3) The alkaline solution concentration has a major impact on MKGPC's strength characteristics. The compressive strength rose as the molarity concentration of 12 molars. However, at 16 molars, the specimens lost strength. As a result, the optimal molarity content for MKGPC is 12 molars.

V. ACKNOWLEGMENT

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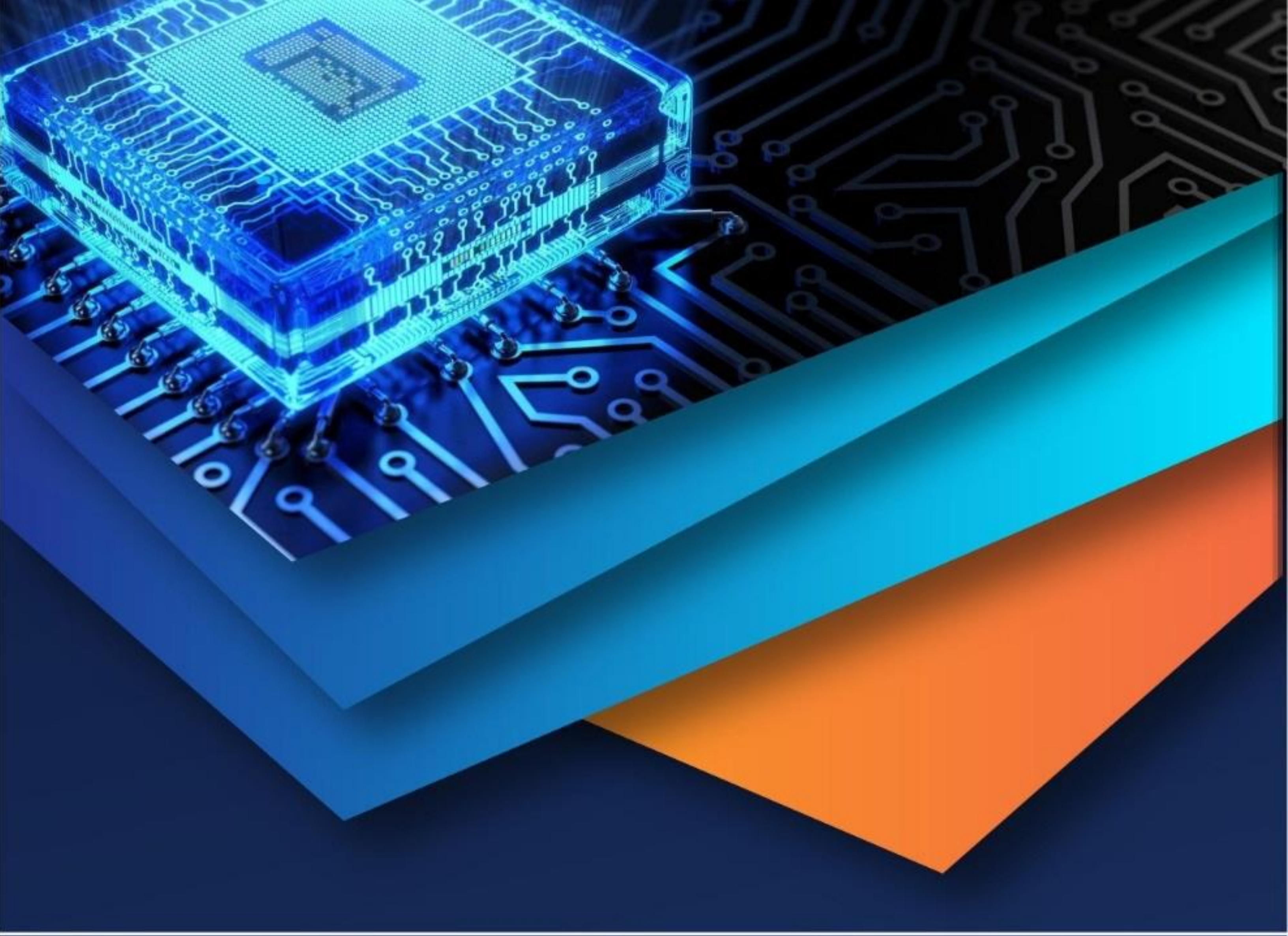
REFERENCES

[1] Aleem, M. I. A and Arumairaj, P. D., (2012). Optimum mix for the geopolymer concrete, Indian Journal of Sceince and Technology, Revised Advanced material science, 5(3), 90- 97.
[2] Abdullah, M. M. A. Hussin, K. Bnhussain, M. Ismail, K. N and Ibrahim, W. M. W (2011). Mechanism and Chemical Reaction of Fly Ash Geopolymer Cement- A Review, International Journal of Pure and Applied Sciences and Technology .
[3] Anuar, K. A., Radzuan A. R. M and Ismail S., (2011). Strength Characteristics of Geopolymer Concrete Containing Recycled Concrete Aggregates, International Journal of Civil and Environmental Engineering, 11(01), 82-84.
[4] British Standard European Norm, (2000). Testing Hardened Concrete; Compressive strength test. BS EN 12390-3, BSI, Linfordwood, Milton Keynes MK14 6LE, U.S
[5] Dahiru, D., (2010). Problem of Ready-mix Concrete Production in the Construction Industry in Nigeria and its Cost Implications, paper presented on West Africa Built An Environment Research (WABER) conference, July-27-28, 2010, Accra, Ghana, 445-457.
[6] Davidovits, J., (2002). 30 Years of Successes and Failures in Geopolymer Applications. Market Trends and Potential Breakthroughs, in Geopolymer 2002 Conference. Geopolymer Institute, Saint-Quentin, France: Melbourne, Australia.
[7] Garba, M. M (2014, May). Concreting: Materials, Design, Production and Assembly. Increasing the Core Practice Areas of Builders VI. Paper presented at the 7th annual Mandatory Continuing Professional Development Programme for Builders, Lagos, Nigeria.
[8] Hardjito, D. and Rangan, V., (2005). Development and Properties of Low- Calcium Fly Ash- Based Geopolymer Concrete. : Curtin University of Technology.
[9] Meyer, C., (2009). The greening of the concrete industry, Cement & Concrete Composites, 601-605.
[10] Najet, S., Basma, S., and Samir, B., (2013). Effect of Composition on Structure and Mechanical Properties of Metakaolin Based Pss-Geopolymer, International Journal of Material Science (Ijmsci) 3(4).
[11] Neville A.M and Brooks J.J, (2010). Concrete Technology. Longman Group United Kingdom Limited 8-178.
[12] Nurdeen, M. A. and Shahid, K., (2010). Green concrete structures by replacing cement with pozzolanic materials to reduce Green House Gas emissions for sustainable environment, American Society of Engineering, 209-277.
[13] Prabu, B. Shalini, A. and Kishore Kumar J.S., (2014). Rice Husk Ash Based Geopolymer Concrete – A Review, International Journal of Pure and Applied Science and Technology, 6(1), 35-44.
[14] Rangan, B. V. (2010). Fly Ash-Based Geopolymer Concrete .Proceedings of the International Workshop on Geopolymer Cement and Concrete, Allied Publishers Private Limited, Mumbai, India, pp 68-106.
[15] Rangan, B. V. (2008a). Low-Calcium Fly Ash-Based Geopolymer Concrete, Chapter 26, Concrete Construction Engineering Handbook, Second Edition, CRC Press, New York, 26.1-26.20; also available as Research Report GC4, Curtin University of Technologyat http://espace.library.curtin.edu.au
[16] Sabitha, D., Dattatreya, J. K., Sakthivel, N., Bhuvaneshwari, M. and Jaffer, S. S. A, (2012). Reactivity, workability and strength of potassium versus sodium activated high volume fly ash-based Geopolymers,current science, 103(11), 1320-1327.



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