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Comparison between the Compressive Strength of Binary and Ternary Alkaline-activated Pozzolanic Concrete

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ABSTRACT: This research compared the compressive strength of binary and ternary alkaline-activated pozzolanic concrete. Rice husk ash (RHA) and Metakaolin (MK) combined partially with Ordinary Portland Cement (OPC) each are the binary concrete while the combination of rice husk ash and metakaolin (RHA/MK) combined partially with OPC is the ternary concrete. The OPC was replaced at 15% each with RHA, MK and RHA/MK in ratios 0.33 (X), 0.5 (Y) and 1.0 (Z) of sodium silicate (NS) to sodium hydroxide (NH) as activator. A mix design ratio of 1:2:4 and water-cement ratio of 0.65 with alkaline liquid to pozzolan of 0.30 was used in the process of the study. Physical properties of the constituent materials as well chemical analysis of pozzolans were determined. Slump and compacting factor tests were done on the freshly mixed concrete to determine their workability while compression test was performed on the hardened concrete cube samples of side 150mm to obtain the compressive strength. Curing was done for 7 and 28 days inside water tank. The result of the compression test showed that the compressive strength of the ternary concrete continuously increased as the sodium silicate to sodium hydroxide ratio increased. At the maturity age of 28days, the values of the compressive strength were 14.2 MPa, 17.5 MPa and 20.3 MPa for sodium silicate (NS) to sodium hydroxide (NH) ratios of 0.33, 0.5 and 1.0 respectively. These values are higher than the compressive strength for the binary concrete of RHA and MK taken separately for the same NS to NH ratios which at 28days curing age were 10.9 MPa, 14.8 MPa, 16.2 MPa for RHA and 14.0 MPa, 15.3 MPa, 18.2 MPa for MK. The result of the research can be used in the construction industry for normal concrete work as well as serve for effective waste disposal of agricultural waste products such as RHA and MK to reduce environmental pollution.

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Concrete which is an important material in the construction of any engineering structure (buildings, dams, bridges, tunnels etc.) is relatively costly as a result of its constituent materials consisting of cement, fine aggregate, coarse aggregate and water being in huge demand. This results in the overall outcome of expensive buildings/shelters which the less privileged cannot afford (Feyidamilola *et al.*, 2022). Cement which is a very important constituent in concrete production is obtained from clinker. The use of clinker results in the emission of CO_2 (which is a greenhouse gas) leading to the depletion of the ozone layer thereby causing global warming and making cement used in concrete production to be less eco-friendly. This gives rise on the need to look out for local materials as alternatives for the construction of functional, but low-cost buildings in both the rural and urban areas (La Scalia *et al.*, 2021; Thomas *et al.*, 2022). Some of the local materials that have been used are earthen plaster (Hossain, 2003), lateritic interlocking blocks (Akeem *et al.*, 2012) and Palm kernel shell (Edmund *et al.*, 2014). Wastes accumulation occurring from industrial by-products and agricultural deposit create serious environmental problems both in terms of their

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treatment and in terms of disposal. The majority of such materials are used as fillers in concrete production in the construction industry (Antiohos *et al*., 2005). When fillers have pozzolanic properties, they add technical advantages to the resulting concrete and also makes it possible to achieve a larger quantities of cement replacement (Hossain, 2005). Pozzolana is a siliceous material which by itself contains no cementitious properties but when it reacts in the presence of water with lime it forms compounds of low solubility having cementitious properties (Tsado *et al*., 2014). The use of industrial and agricultural by-product in cement production is an environmentally friendly method of disposal of large quantities of materials that would otherwise pollute land, water and air thereby leading to social and environmental problems (Onwuka *et al*., 2013). The presence of mineral admixtures from agricultural waste is also known to add significant improvement in workability and durability of concrete. Although technological and economic benefits are the main reasons why mineral additions are used, it was observed that the prevention of environmental contamination by means of proper waste disposal is an added advantage (Ambika and Dash, 2015). An important role is played by alkaline solution in geopolymerization. The most frequently used alkaline solution in geopolymerization is an addition of sodium hydroxide (NaOH) or potassium hydroxide (KOH) with sodium silicate (Na_2SiO_3) or potassium silicate (K_2SiO_3). In this research, a combination of sodium silicate and sodium hydroxide was used as the alkaline liquid. Sodium based solutions were preferred because they are cheaper than Potassium based solutions. Sodium hydroxide and sodium silicate are readily available in market in the form of pellets and liquid (Sanni and Khadiranaikar, 2013). Therefore, the objective of this study is to investigate and compare the compressive strength of binary and ternary alkaline-activated pozzolanic concrete.

MATERIALS AND METHOD

The materials used in the experimental study include:

Ordinary Portland Cement (OPC): Ordinary Portland cement of grade 42.5 was used as the main binder throughout the study. This is because OPC is the most widely recommended material of its kind and widely available in Nigeria. Typical example of OPC in Nigeria is the Dangote Portland Cement which was used in carrying out this study. It was purchased from a local cement depot in Akure, Ondo state sealed in a 50kg bag and conforming to the quality of ordinary Portland cement as described by BS 12 (1996). Fineness test was carried out on the cement in accordance to BS EN 196-6 (1989) while soundness test and setting time (initial and final) test was carried out according to BS EN 196-3 (1994) to ensure its suitability for use in concrete production.

Rice Husk Ash (RHA) and Metakaolin (MK): Rice husk was collected from a neighbouring rice milling factory in Akure, Ondo state which was then incinerated in an incinerator at a controlled temperature of 650 °C for 8hours to obtain an amorphous silica which is the major constituent of geopolymer concrete while metakaolin was obtained from a commercial market in Akure, Ondo state. They were passed through a sieve 75µm as recommended for cement products. The chemical composition of the ash was conducted at Engineering Materials Development Institute (EMDI) in Akure, Ondo state by X-ray fluorescence (XRF) using Sky ray EDXRF 3600B energy dispersive x-ray fluorescence spectrometer. The stated procedures were done to ensure conformity to ASTM C618 (2012). The specific gravity of RHA was also determined in accordance with BS 812 (1990).

Fine Aggregate: Fine aggregate (natural sand) of maximum size of 4.75mm was collected from a local source in Akure, Ondo state which was clean, sharp, free from clay and inorganic materials and in conformity with the standard code of materials as described by BS 882 (1992). The tests conducted on fine aggregate include: sieve analysis, moisture content, specific gravity and bulk density test. The tests were carried out in accordance with BS 812 part 103.1 (1985); BS 812 part 109 (1990); BS 812 (1990) and BS 812 part 108 (1990) for sieve analysis, moisture content, specific gravity and bulk density tests respectively.

Coarse Aggregate

Coarse aggregate (granite) of size of 20mm was obtained from a nearby quarry plant in Akure, Ondo state which was in conformity with the provision of standard code of materials as described by BS 882 (1992). The tests conducted on coarse aggregate include: specific gravity, aggregate impact value and aggregate crushing value. The tests were carried out in accordance with BS 812 (1990); BS 812 part 112 (1990) and BS 812 part 110 (1990) for specific gravity, aggregate impact value and aggregate crushing value respectively.

Potable Water: Potable water was obtained from the borehole at the Federal University of Technology, Akure near the civil engineering laboratory which was free from dirt, harmful amount of acid, alkalis and organic materials and in conformity to BS 3148 (1980) which stipulates that water fit for drinking is suitable for concrete production.

Sodium Silicate (Na_2SiO_3) and Sodium Hydroxide (NaOH) Solution: Sodium silicate and sodium hydroxide (with a molarity of 12) were obtained from a chemical industry in Ogun State in a prepared solution form. The solutions were mixed in appropriate ratios and allowed to cool down for 24 hours at a room temperature to liberate heat from which the solution was then used for casting the geopolymer concrete.

Mix Design: A 15% replacement of OPC with RHA, MK and combination of RHA and MK was done with a mix ratio of 1:2:4 and alkaline liquid to geopolymer solid of 0.30. Eighteen cube samples of each of the pozzolans were cast and water curing was done for 7 and 28 days.

Preparation, Casting and Curing of Alkaline-activated Pozzolanic Concrete: The alkaline activator used was a combination of sodium hydroxide solution NaOH (sodium hydroxide pellets and distilled water) and sodium silicate solution (Na_2SiO_3). The role of NaOH is to dissolve the reactive portion of source materials Si and Al present in metakaolin and rice husk ash and provide a high alkaline liquid medium for condensation polymerization reaction while Na_2SiO_3 is to support NaOH to act as a binder, plasticiser or dispersant. To prepare sodium hydroxide solution of 12 molarity (12M), 480 g of sodium hydroxide pellet was dissolved in one litre of water because the mass of NaOH solids in a solution will vary depending on the concentration of the solution expressed in molarity; M. The pellets of NaOH are dissolved in one litre of water for the required concentration. In the laboratory, rice husk ash and the aggregates were first mixed together dry on pan for about three minutes. The addition of sodium silicate was to enhance the process of geopolymerization (Rangan, 2008). The varying ratio of Na2SiO3 / NaOH are 0.33, 0.5 and 1.0 for all the pozzolan replacements. The workability of the fresh concrete was assessed via slump and compacting factor tests. The rice husk ash and alkaline activator were homogeneously mixed together in the mixer until a uniform paste was obtained. This mixing process was done within 5 minutes for each mixture with different ratios of alkaline solution. After casting the samples, they were kept for twenty-four (24) hours before they were demoulded. Water curing was done for the period of 7 and 28 days. The procedure was repeated for metakaolin and the combination of rice husk ash and metakaolin.

RESULTS AND DISCUSSION

The fineness, soundness, initial and final setting time tests carried out on OPC gave 8%, 1.27mm, 29 minutes and 599 minutes for average fineness, average soundness, initial and final setting time respectively. A good cement should have less or equal to 10% of weight retained on the sieve to meet the requirement for fineness test according to BS EN 196-6 (1989) while increase in distance for the soundness of cement is limited to 10mm. Deformity occurs in cement that have any value extending beyond 10mm according to BS EN 196-3 (1994). Also, the initial setting time at which a good cement paste loses its plasticity should not be more than 30 minutes while its final setting time should not be more than 10 hours according to BSCEN 193-3 (1994). The above results show that the cement used for this research are in conformity with the required standards. The major oxides of composition obtained from the chemical analysis of RHA and MK were SiO2, Fe2O3 and Al2O3. The percentage of the major oxides of composition are 72.96% and 87.21% for RHA and MK respectively. These results were in conformity with ASTM C618 code requirement for a good pozzolanic material which must be at least 70% of the sum of SiO2, Fe2O3 and Al2O3.

The sieve analysis result for the fine aggregate used for this research is shown in the particle size distribution curve in figure 1. Uniformity coefficient Cu of fine aggregate is defined as: $Cu = \frac{D60}{D10}$ (1)

Coefficient of gradation Cc of fine aggregate is defined as: $Cc = \frac{D30^2}{D60 \ X \ D10}$ (2)

Where; D60 is Diameter of soil particles for which 60% are finer and 40% are coarser; D30 is Diameter of soil particles for which 30% are finer and 70% are coarser; D10 is Diameter of soil particles for which 10% are finer and 90% are coarser

From Figure 1,

D60 = 0.54 D30 = 0.28 D10 = 0.12

To obtain the uniformity coefficient from Equation 1,

$$Cu = \frac{D60}{D10} = \frac{0.54}{0.12} = 4.50;$$

To obtain the coefficient of gradation from Equation 2,

$$Cc = \frac{D30^2}{D60 \ X \ D10} = \frac{0.28^2}{0.54 \ x \ 0.12} = 1.21;$$

From the values of uniformity coefficient and coefficient of gradation obtained, they show that the soil is well graded because a soil sample classified as well graded is a value of Cu greater than 4 to 6 and a value of Cc ranges between 1 and 3. Table 1 presents the preliminary test results for moisture content, bulk density and specific gravity tests carried out on the fine sand used as well specific gravity, aggregate impact value (AIV) and aggregate crushing value (ACV) tests carried out on the granite used.

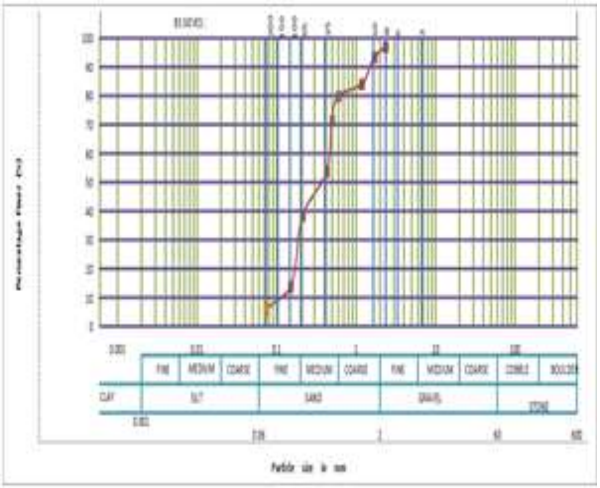

Fig 1: Particle size distribution curve for fine sand

Also, specific gravity of RHA and MK is presented therein. From the results presented in table 1, it can be seen that the average percentage moisture content obtained is 4.50% which is in conformity with the recommended 5% moisture content for fine sand. This implies that the moisture content obtained is adequate for effective development of strength and durability of concrete. Also, the bulk density of the fine sand used in this research falls within the normal range of 2500 – 2100 kg/m³ for fine sand. Furthermore, the specific gravity test result on fine sand, granite, rice husk ash and metakaolin show that they fall within the range specified by BS 812 (1990). Additionally, the result obtained from AIV test shows that the granite used in this research can withstand impact load as it falls within the stipulated range or 17 – 21% for percentage AIV. Also, the result obtained from ACV test shows that the granite used in this research can withstand crushing load as it falls within the stipulated range or 27 – 31% for percentage ACV.

Table 1: Preliminary Test Results

S/N	RHA	MK	Fine sand	Granite
Moisture Content (%)			4.5	
Specific Gravity	2.14	2.62	2.66	2.76
Bulk Density (kg/m³)			1733	
AIV (%)				17.45
ACV (%)				26.10

Workability: The slump and compacting factor test were conducted in accordance to BS 1881 part 102 (1983) and BS 1881 part 103 (1993) respectively. The result for the slump test for various ratios of sodium silicate to sodium hydroxide of different combinations of geopolymer concrete mixes is presented in figure 2. The result for the compacting factor ratio for various ratios of sodium silicate to sodium hydroxide of different combinations of geopolymer concrete mixes are 0.97, 0.91, 0.88, 0.98, 0.93, 0.93, 0.93, 0.95, 0.95 and 0.97 for CR, RHA X, RHA Y, RHA Z, MK X, MK Y, MK Z, RM X, RM Y and RM Z respectively. It can be seen from the result presented that all sample mixes met the recommended requirement for workable and usable concrete as they fall within the recommended values of 20 to 50 mm designated for mass concrete structures and pavement for slump test and 0.70 – 0.99 for compacting factor test, thus depicting that the concrete mixes are appropriate.

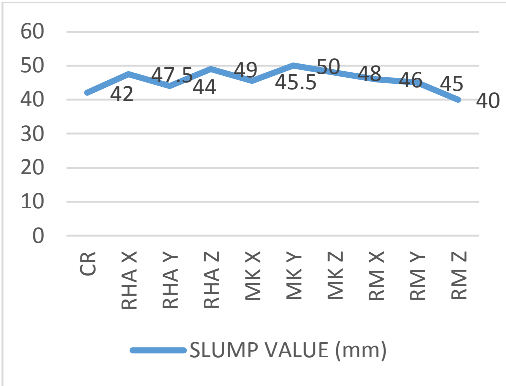

Fig 2: Slump Value Result

Compressive Strength: Compressive strength test was carried on the hardened pozzolanic concrete after water curing for 7 and 28 days respectively for various ratios of sodium silicate to sodium hydroxide of different combinations of geopolymer.

This test is often used for checking the adequacy of curing, quality control, estimating the strength of concrete in a structure, acceptance of concrete and so on. The procedure followed for this test was done in accordance to BS 1881 part 116 (1983).

The result of the compressive strength test is presented in figure 3. At 28 days curing age, the compressive strength obtained from the binary concrete mixture of RHA and OPC were 10.9 MPa, 14.8 MPa and 16.2 MPa for 0.33, 0.5 and 1.0 NS: NH ratio respectively. Also, for the binary concrete mixture of MK and OPC at 28 days curing age, the compressive strength obtained were 14.0 MPa, 15.3 MPa and 18.2 MPa for 0.33, 0.5 and 1.0 NS: NH ratio respectively. Also, at 28 days curing age, the compressive strength obtained from the ternary concrete mixture of the combination of RHA/MK and OPC were 14.2 MPa, 17.5MPa and

20.3 MPa for 0.33, 0.5 and 1.0 NS: NH ratio respectively.

Only the strength obtained from the ternary concrete mixture with ratio 1.0 of NS: NH can be compared with the control sample of 22.6 MPa at 28days curing age.

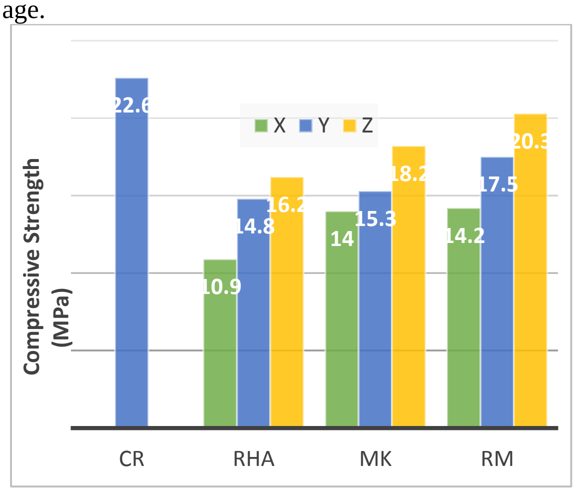

Fig 3: Compressive Strength Test Result for 28 days curing age

In figure 3; X, Y, Z represent the values of 0.33, 0.5, 1.0 for the sodium silicate (NS) to sodium hydroxide (NH) ratio. Additionally, RHA and MK combined partially with OPC each represent the binary concrete while the combination of RHA/MK combined partially with OPC represents the ternary concrete.

*Conclusion***:** Based on the experimental procedures done in this research work, it is concluded that the ternary concrete mixture can be used in the construction industry for normal concrete work.

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