Properties of Metakaolin Based Geopolymer Concrete Made With Recycled Concrete Aggregate

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Abstract: **Construction industry is a major consumer of materials in large quantities and a producer of large quantity of waste which had led to the gradual decrease of natural resources. Many researchers have utilized natural aggregates in the production of geopolymer concrete but few researches have been carried out producing geopolymer concrete using Recycled Concrete Aggregate (RCA). The research evaluates properties of metakaolin based geopolymer concrete (MKGPC) made with RCA. MKGPC was produced and cured at 60^oC in the oven for 24hrs after which they were left to air dry in the laboratory. Conventional Portland cement concrete (PCC) was produced to serve as control. MKGPC and PCC specimens containing RCA at varying percentages of 0%, 20%, 30%, and 40% were produced. Cube moulds of size 100mm x 100mm x100mm was used to cast a total of 96 concrete and properties such as compressive and tensile strength, absorption and abrasion resistance were evaluated after curing ages of 7, 14, 28 and 56days. The average compressive strength obtained at 28 days of curing for PCC specimens with 0%, 20%, 30% and 40% RCA are 24.23N/mm^2, 21.09N/mm^2, 19.81N/mm^2 and 19.37N/mm^2, while for MKGPC specimens with same replacement of RCA are 31.54N/mm^2, 31.17N/mm^2, 28.55/mm^2, 26.40N/mm^2 respectively. The average split tensile strength of MKGPC specimen was 4.66%, 11.11% and 14.69% while PCC specimen had 15.38%, 23.49% and 25.90% respectively. Water abrasion resistance was found to be higher than the PCC specimens though its absorption capacity was higher than the PCC specimens. This shows that properties of MKGPC containing RCA is higher when compared to that of PCC containing RCA though it has high absorption capacity. The research recommends that metakaolin based geopolymer concete containing RCA up to 40% RCA could be used to produce concrete for structural use.**

Keywords: **Geopolymer; Recycled Concrete Aggregate; Metakaolin; Alkaline Solution; Ordinary Portland cement, Portland cement Concrete.**

I. INTRODUCTION

Over the years, there have been environmental concerns about the increasingly evident ecological consequences due to human activities which have come to global attention and as such, the call to decrease the global anthropogenic carbon-dioxide (CO_2) has encouraged researchers to search for supplementary cementitious materials to replace or completely remove cement which is the second most consumed product in the world. Example of such material is geopolymer. Geopolymer is an amorphous binder synthesized from a source material of geological origin, industrial or agricultural waste with alkaline material and is considered as a more eco-friendly alternative to Ordinary Portland Cement (OPC) (Davidovits, 1991). Irfan *et al.*, (2014) explains that this chemosynthetic material has many applications such as binders, green and durable cements, encapsulating agent for hazardous waste, active catalyst and thermal resistant coating. Geopolymer concrete (GPC) is a concrete produced when aggregate is mixed with the geopolymer binder.

Valerie and Assia, (2013) opines that construction industry consumer of materials such as aggregate in large quantities and at the same time produces large amount of waste and as such, there tend to be scarcity of natural aggregate and at the same time accumulation of aggregate as waste created due to demolition activities. Adejo, (2012) described recycled concrete aggregate (RCA) as aggregate that form the main component of old concrete obtained from demolition activities. In attainment of sustainability, emphasis is made on circular pattern of consumption as against the linear pattern of consumption meaning that it helps in discouraging vast consumption of natural aggregate and reducing the disposal of demolished waste from old concrete. This concept fit into the motto of sustainability of 'Reducing, Reusing, Recycling and Regenerating' as described by (Swapna *et al.*, 2011).

The problem of these waste prompted researchers to develop a means of incorporating it in the production of Portland cement concrete. According (Ryu, 2002; Chen *et al*., 2003; Khalaf and DeVenny, 2004; Khalaf and DeVenny, 2005; Hottmann *et al.*, 2012) in Valerie and Assia (2013) the quality of concrete made with RCA are different, these aggregates tend to have influence on the properties of concrete which they are made of. According to Swapna *et al.*, (2011), RCA have lower specific gravity, higher water absorption, lower level of compressive strengths and durability when used to produce concrete. George (2014) observed that the amount and quality of adhered mortar affect the physical properties of recycled aggregates, because the adhered mortar is porous, and its porosity depends on the w/c ratio of the recycled concrete employed. The presence of recycled concrete aggregate and the porous nature of the old cement mortar affect the bond between the RCA and the cement paste when used in the production of new concrete as established by (George 2014). This has therefore limited the use of RCA in the production of new concrete.

Researchers have been carried out utilizing natural aggregate in the production of geopolymer concrete but few researches have been carried out producing geopolymer concrete using RCA. Incorporating RCA partially or fully in the production of geopolymer concrete contribute immensely to the concept of sustainability because it reduces the pressure placed on natural aggregate, utilize the waste obtained from construction and demolition activities which is commonly used for landfill (Benjamine and Natelie, 2013). Sata *et al.,* (2013) utilized crushed concrete and crushed bricks to replace natural coarse aggregates in the production geopolymer concrete made with different concentrations of sodium hydroxide solution and compared it with geopolymer concrete made with natural aggregate. They found that there was a general increase in compressive and indirect tensile strengths of specimens, but it was also discovered that the compressive strength and tensile strength of geopolymer previous concrete made with crushed concrete and crushed bricks when compared with geopolymer concrete made with natural aggregate are lower. Anuar *et al.*, (2011) used waste paper sludge ash (WPSA) as the source material for production of geopolymer concrete and discovered that from 7 to 28curing days, an increment in compressive strength of 10% was experienced and the higher the molarity of NaOH the higher the compressive. Posi *et al.*, (2013) used recycled lightweight aggregate to produce geopolymer concrete and found out that as the percentage replacement of recycled lightweight aggregate increases, compressive strength of geopolymer concrete decreases. This paper is aimed at exploring the properties of metakaolin based geopolymer concrete (MKGPC) made with recycled concrete aggregate.

II. MATERIALS AND METHODS

Materials

Dangote brand of Ordinary Portland cement was used. The matakaolin used as source was obtained by heating raw kaolin obtained from kankara local government area in Kastina State. After grinding, it was calcined at a temperature of 650^{o}C for 90mins and the chemical compositions were determined using XRF test. The result is presented in Table 1.0. Fine aggregate and natural coarse aggregate (NCA) and recycled coarse aggregate (RCA) made from demolition activates were obtained and used. The combination of Sodium Silicate (Na_2SiO_3) and Sodium Hydroxide (NaOH) were used as the alkaline activator. Na_2SiO_3 solution having composition of Na_2O = 13.71%, SiO_3 = 29.4% and H_2O = 55.9%. NaOH which is in pallet form was dissolved in water to make solution for the research, 16molar concentration of NaOH was used which means tmolarity of NaOH multiplied by the molecular weight of NaOH which is 40 therefore (16 x 40 = 640g).

III. METHODOLOGY

Four mixes of MKGPC specimens having replacement of 0%, 20%, 30% and 40% of RCA were produced. The mix ratio used to produce the GPC specimen is given in table 2.0. Sieve analysis was carried out for NCA and RCA as shown in figure 1.0. The NCA and RCA that fell between 20mm up to 4.75mm were used in its saturated surface dry condition. Physical properties for RCA and NCA such as specific gravity, aggregate bulk density, aggregate moisture content and absorption capacity, aggregate impact and crushing values were determined and the result presented in table 2.0. The method adopted by Anuradha *et al.*,(2011) and Ramujee and Potharaju (2014a), was used for the mix design as shown in table 3.0. The alkaline solution used was a combination of of NaOH and Na_2SiO_3 in the ratio 1:2.5. NaOH pallet of 16molar concentration was dissolved in water to make a solution after which it was mixed with Na_2SiO_3 a day before its useage. This was done to allow the heated s to cool at room temperature before use. Metakaolin and the aggregates were mixed together. The alkaline solution was added and the MKGPC specimen mixed for about 8mins. In order to improve the workability of the mixes, extra water was added and mixed thoroughly. Grade 25 Portland cement concrete (PCC) specimens were also produced to serve as control using British Research Establishment (BRE) method of concrete design. The mix ratio is presented in table 4.0. After mixing, slump value of each fresh MKGPC and PCC specimens was measured to determine their workability. The fresh MKGPC and PCC were cast into 100mm x 100mm x 100mm moulds in 2 layers. Each layer was compacted by rodding with a tapping rod in order to achieve compaction of the specimen. The MKGPC specimens were kept for 24hrs rest period after casting. They were then de-moulded, wrapped in a polythene bag and cured in the oven at 60^{o}C for 24hrs. After curing for 24hrs in the oven, it was then removed, unwrapped and left to cure continuously in the laboratory until the days required for testing. The PCC specimens were also cured in a pool of water tank until the day required for testing. Properties such as compressive strength, tensile strength, absorption and abrasion resistance were tested at 7, 14, 28 and. 56 days curing period.

IV. RESULTS AND DISCUSSIONS

Table 1.0: Chemical composition of Metakaolin

Oxides	Percentage Composition (%)	Summation of Oxide for Metakaolin (%)	ASTM C-618 Requirement (%)
Aluminium oxide (Al_2O_3)	45.6	(SiO_2) = 50.5	
Silicon oxide (SiO_2)	50.5	+ +	(SiO_2)
Potassium oxide (K_2O)	0.734	(Al_2O_3) = 45.6 97.54	+
Titanium oxide (TiO_2)	0.0582	+ +	(Al_2O_3) 70
Vanadium oxide (V_2O_5)	0.003	(Fe_2O_3) =1.440	+
Manganese oxide (MnO)	0.047		(Fe_2O_3)
Iron trioxide (Fe_2O_3)	1.440	Sulfur trioxide (SO_3)	
Copper oxide CuO	0.014	= Nill	Sulfur trioxide (SO_3)= 4.0
Germanium oxide (Ga_2O_3)	0.039		
Selenium dioxide(SeO_2)	0.14		Moisture Content
Silver oxide (Ag_2O)	0.737	Moisture Content	= 3.0
Antimony trioxide (Sb_2O_3)	0.070	=Nill	
Praseodymium (III) Oxide (Pr_2O_3)	0.036		
Neodymium (II) Oxide (Nd_2O_3)	0.060		
Europium(III) oxide (Eu_2O_3)	0.039		
Rhenium(VII) oxide (Re_2O_7)	0.089		
Titanium(III) oxide (Ti_2O_3)	0.31		LOI = 10.0
LOI	1.22	LOI = 1.22	

Figure 1.0 present the grading curve for NCA and RCA for aggregates with 20mm nominal size. It can be observed that NCA and RCA fall between zones 1 and 4. This means that the aggregate is suitable for general construction work.

Figure 4.1: Sieve analysis of NCA and RCA

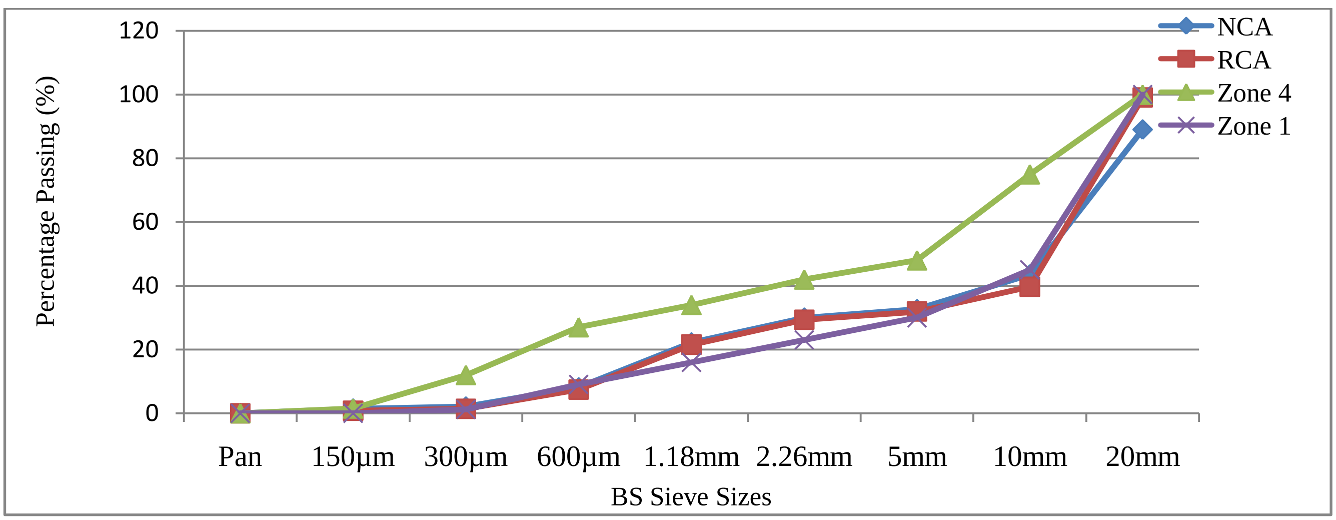

Table 2.0: Physical and Mechanical Properties of NCA and RCA

Sample	Specific Gravity Kg/m^3	Aggregate Moisture Content(%)	Aggregate Absorption Capacity(%)	Aggregate Bulk Density(Kg/m^3)	Aggregate Crushing Value (%)	Aggregate Impact Value(%)
NCA	2.5	0.10	1.5	1554	25.32	15.40
RCA	2.4	1.26	4.5	1475	32.24	25.52

Table 3.0: Mix ratio for Grade 25 MKGPC Specimen

Sodium Silicate	Sodium Hydroxide	Extra Water	Metakaolin	Fine Aggregate	Coarse Aggrgate
208.1 kg/m^3	83.3 kg/m^3	85 kg/m^3	470 kg/m^3	577.17 kg/m^3	932.35kg/m^3

Table 4.0 Mix ratio for Grade 25 PCC Specimen

Cement	Fine Aggregate	Coarse Aggrgate	Water
0.42 kg	0.88 kg	1.17 kg	0.25kg

Workability

Table 5.0 presents the slump tests result for PCC and MKGPC. Workability of MKGPC specimens containing 0%, 20% and 30% RCA was between low slump (25-50mm) while MKGPC specimen with 40% RCA fell within very low slump (0-25mm). For PCC specimen though the workability is higher compared with MKGPC specimen, the slump values obtained for PCC specimen containing 0%, 20%, 30% and 40% RCA was within medium slump (25-100mm). The decreases in workability of MKGPC specimens can be attributed to the molar concentration of NaOH used because according to Reddy *et al.*, (2010), increase in the molar concentration of NaOH solution result to decrease in workability of the concrete.

For MKGPC and PCC specimens containing 20%, 30% and 40% RCA, the decrease in workability noticed when compared to MKGPC and PCC with 0% could be due to the introduction of RCA. This agrees with Smith and Tighe, (2008) report that concrete produced with RCA may have less slump value compared with that made with NCA at the same water/cement ratio, Roesler and Hunley, (2008) attributed the decrease in workability of the concrete made with RCA to the angularity of RCA, rough surface texture and higher water absorption capacity.

Table 5.0: Slump values for MKGPC and PCC specimens

Specimen	0% RCA (mm)	20% RCA (mm)	30% RCA (mm)	40% RCA (mm)
MKGPC	37	35	27	20
PCC	80	65	50	40

Compressive strength

Figure 2.0 presents result for average compressive strength of MKGPC and PCC specimens containing 0%, 20%, 30% and 40% RCA cured at 7, 14, 28 and 56days respectively. From the figure, there was general increase in compressive strength from 7 to 56days curing period for the PCC and MKGPC specimen; however 22.29% increase in compressive strength at 56 days curing age was notice between PCC and MKGPC specimens containing 0% RCA. The MKGPC specimen attained a higher compressive strength of 32.43N/mm^2 than the PCC specimen; this could be as a result of the metakaolin based gropolymer used as binder in the production of the MKGPC specimen. Bachhav and Dubey, (2016) affirm that compressive strength of PCC is less compared to GPC because the compressive strength of GPC specimen increases with increase in molarities of NaOH solution.

Percentage decrease in compressive strength at 56 days curing occurred for PCC and GPC specimen containing 20%, 30% and 40% RCA when compared to PCC and MKGPC specimen with 0% RCA. 10.71%, 16.03%, 22.61% percentage decrease was noticed for the PCC while the GPC specimen had 1.54%, 12.24%, 15.08% decrease respectively. This may be due to the RCA introduced because James, (2009) affirms that concrete produced with RCA has decrease in compressive strength compared to those of NCA. According to Verien *et al.*, (2013), the higher the percentage replacement of RCA, the greater the reduction in strength

Split tensile strength.

Figure 3.0 present the average split tensile strength of PCC and MKGPC specimens tested at 7, 14, 28 and 56days. 15.96% increase in the split tensile strength occurred between PCC and MKGPC specimen containing 0% RCA at 56days curing period. This perhaps could be as a result of type of binder used in the production of the concrete specimen for Preethy *et al.*, (2015) discovered that the split tensile strength increases with increasing the molarity of sodium hydroxide as in the case of compressive strength. Higher concentration of NaOH solution gives higher split tensile strength of MKGPC specimen because it makes good bonding between aggregate and paste of the concrete

However PCC and MKGPC specimen containing 20%, 30% and 40% RCA when compared with PCC and MKGPC specimens containing 0% RCA had 4.66%, 11.11% and 14.69% decrease for the PCC specimen while MKGPC specimens had 15.38%, 23.49% and 25.90% decreased respectively. This could possibly be due to the introduction of RCA because Sherif *et al.*, (2015) explain that reduction of up to 10 % in split tensile strength could be when NCA was substituted with RCA.

Abrasion resistance

Figure 4.0 represent average abrasion resistance of PCC and MKGPC specimens tested at 28 and 56days curing periods. The result show that MKGPC specimen containing 0% RCA has less percentage loss in weight of about 0.05% compared to PCC with the same replacement which has 0.06% weight loss. This perhaps could be as a result of the type of binder used because Ramujee and Potharaju, (2014b) compared the abrasion resistance of PCC and MKGPC specimen by placing an abrasive charge on the surface of the specimen for the paddle to rotate at a required speed for 12hrs duration and discovered that MKGPC specimen had better resistance to abrasion than PCC specimen because the depth of wear in MKGPC specimen smaller compared to PCC specimen.

Water Absorption capacity

Figure 5.0 shows the average water absorption capacity of the PCC and MKGPC specimens cured at 28 and 56days. The MKGPC specimen containing 0% RCA has the high absorption capacity of 8.44% at 56days curing period compared to PCC specimens with 0% RCA. This possibly could be due to the release of water contained in the GPC specimens when cured in the oven. It therefore justifies the claims by Rangan, (2010) that water is released during the formation of geopolymer (i.e. during curing and further drying period of the matrix) leaving behind nano-pores. The implication of this is that it could make MKGPC specimen susceptible to attack.

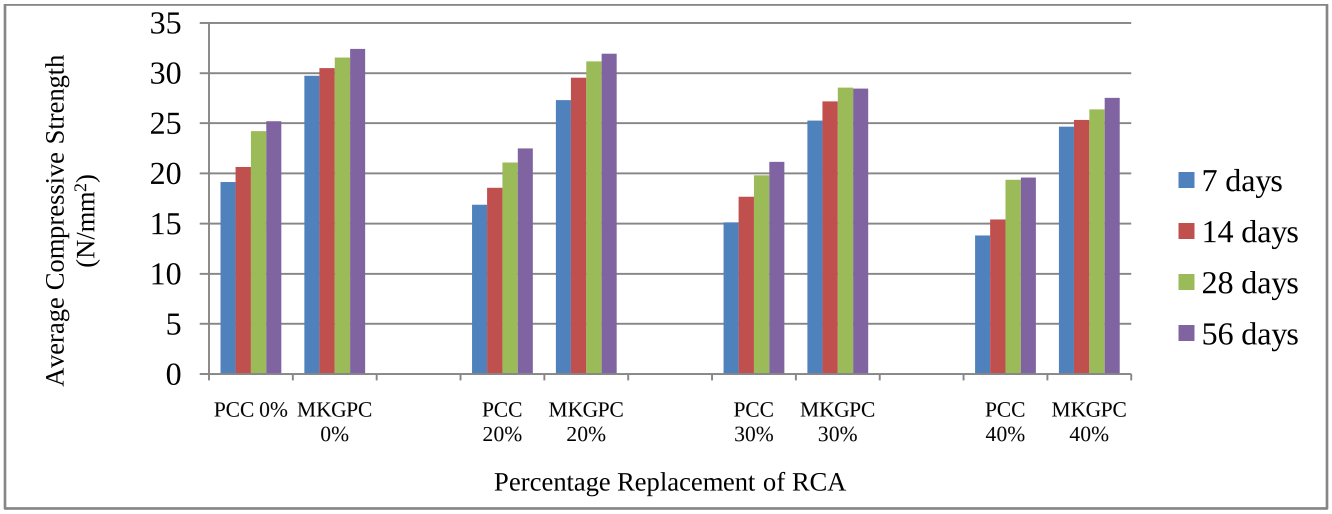

Fig. 2.0: Average Compressive Strength of Hardened Concrete Specimen

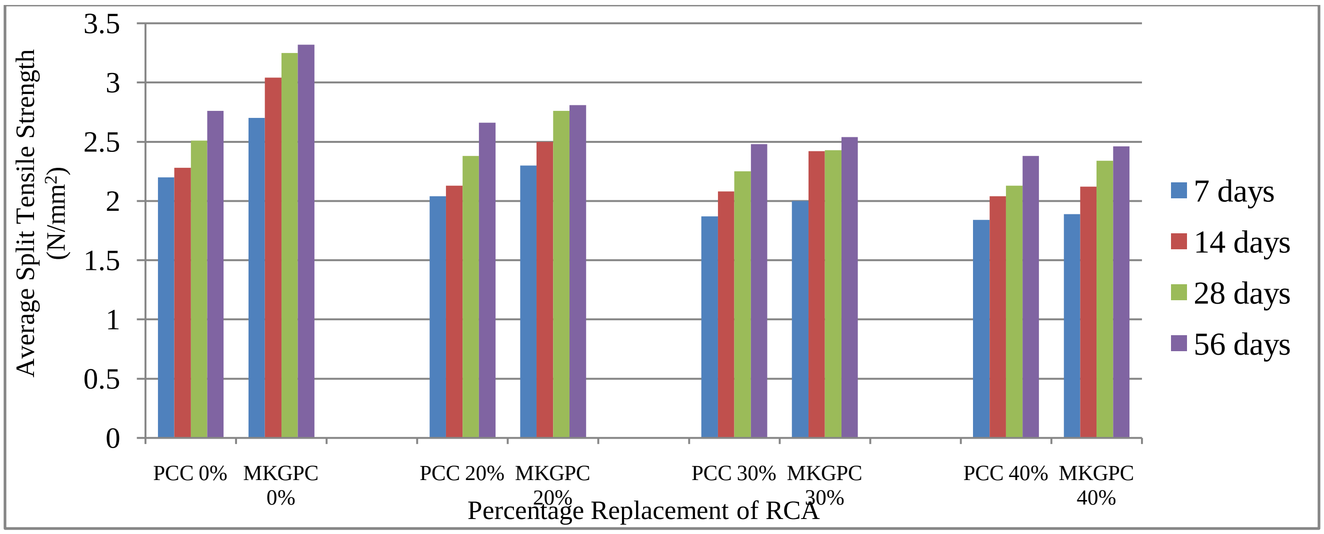

Fig. 3.0: Average Split Tensile Strength of Hardened Concrete Specimen

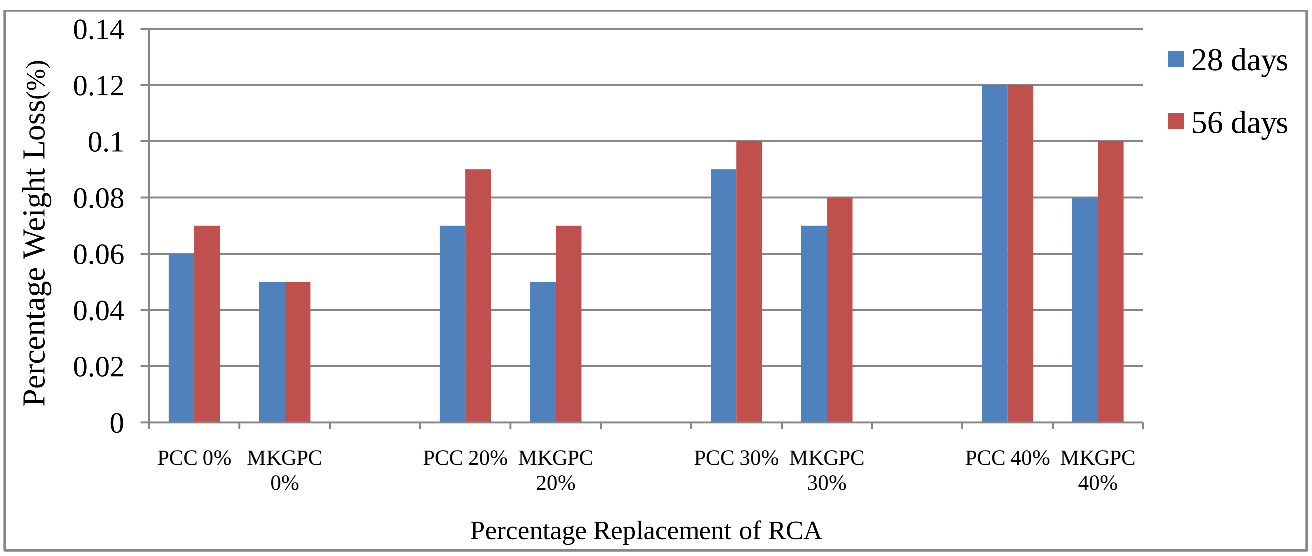

Figure 4.0: Average Abrasion Resistance of Hardened Concrete Specimen

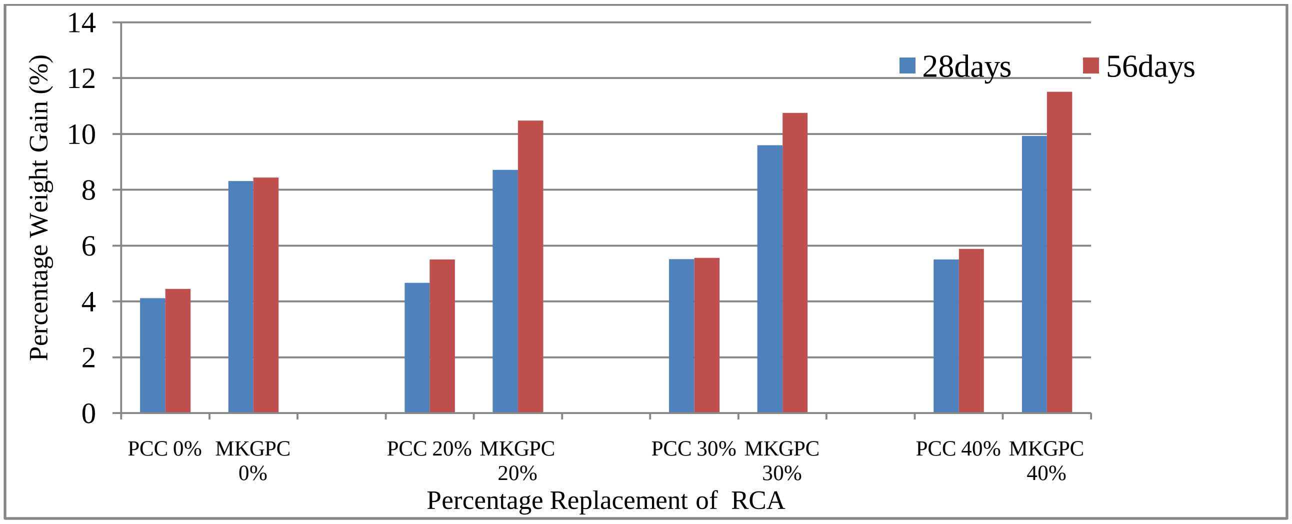

Fig. 5.0: Average Water Absorption Capacity of Hardened Concrete Specimen

V. CONCLUSION

This paper studied the properties of metakaolin based geopolymer concrete made with recycled concrete aggregate. Physical and mechanical properties of the aggregate was determined and Properties such as compressive and tensile strength, absorption capacity and abrasion resistance were measured at 7, 14, 28 and 56 days. Based on the test carried out, the following conclusions were made:

1. The physical and mechanical properties such as specfic gravity, bulk density, moisture content and absortion capacity, aggregate crushing and impact values for NCA were found to be higher than that for RCA.
2. The workability of MKGPC specimen is less than that of PCC with the same replacement of RCA.
3. MKGPC with various replacement of RCA upto 40% have higher compressive strength than the PCC specimen so it can be used for structural concrete
4. The split tensile strength obtained for MKGPC specimen containing the various replacement of RCA is higher than PCC specimes containing the same replacement of RCA.
5. MKGPC specimens with various replacement of RCA have high abrasion resistance than PCC specimes with the same replacement of RCA, but absorption more water than the PCC specimen .

REFERENCES

[1] Adejo, J. (2012). Comparison of the Properties of Concrete made with Natural Aggregate with Properties of Concrete Made with Recycled Aggregate. *Unpublished Undergraduate Project*, Department of Building, Ahmadu Bello University, Zaria.

[2] Anuar K. A., Ridzuan, A. R. and Ismail, S. (2011). Strength Characteristic of Geopolymer Concrete Containing Recycled Concrete Aggregate. *International Journal of Civil & Environmental Engineering*, 11(01).

[3] Anuradha, R., Sreevidya, V., Venkatasubramani, R. and Rangan, B. V. (2011). Modified Guidelines for Geopolymer Concrete Mix Design Using Indian Standard.Curtin University of Technology, Perth, Australia. 354-364.

[4] Bachhav, S. S. and Dubbey, S. K. (2016). Effect of Geopolymer on Strength of Concrete. *SSRG International Journal of Civil Engineering*. 3(1), 34-41.

[5] Benjamin, G. and Natelie, L. (2011). Fly Ash Based Geopolymer Concrete with Recycled Aggregate. In: *Proceeding of Concrete 2011 Conference*, Perth, WA. The Concrete Institute of Austrelia.

[6] Davidovits, J. (1991). Geopolymers. *Journal of Thermal Analysis*, 37, 1633-1656.

[7] George, O. (2014). A Solution to the Problem of Recycled Concrete Aggregate. *International Journal of Engineering and Technology Research*, 2(4), 1-6.

[8] Irfan, K. M., Khairun, A., Suriati, S., Ahmer A. S., Zakaria M, and Hafeez, U. (2014). Sodium Silicate Free Geopolymer As Coating Material: Adhesion To Steel. In: *proceedings of 1st international conference on material*. Retrieved from http://sciforum.net/conference/ecm-1. 1-8.

[9] James, S. T. (2009). Recycled Concrete Aggregate—A Viable Aggregate Source For Concrete Pavements. *PhD Thesis*, University of Waterloo, 1-206.

[10] Posi, P., Teerschanwit, C., Tanutong, C., Limkamoltip, S., Lertnimoolchai, S., Sata, V. and Chindaprasirt, P. (2013). Lightweight geopolymer concrete containing aggregate from recycled lightweight block. *Material Design*, 52, 580–586.

[11] Preethy, K. T., Binu, M. I. and Deepak, J. P. (2015). Assessment of Demolished Concrete as Coarse Aggregate in Geopolymer Concrete. In: *2nd International Conference on Science, Technology and Management*. University of Delhi, Conference Center, New Delhi India. 2229-2241.

[12] Ramujee, K. and Potharaju, V. K. (2014a). Abrasion Resisatnce of Geopolymer and its Composites. In: *Proceeding Material Science for 3rd International Conference on Materials Processing and Characterization (ICMPC)*, 6, 1961-1966.

[13] Ramujee, K. and Potharaju, M. (2014b). Development of Low Calcium Flyash Based Geopolymer Concrete. *LACSIT International Journal of Engineering and Technology*. 6(1), 1-4.

[14] Reddy, B. S., Varaprasad, J. and Reddy, K. N. K., (2010). Strength and Workability of Low Lime Fly-Ash Based Geopolymer Concrete. *The Indian Journal of Science Technology*, 3(12), 1188.

[15] Rangan, V. B. (2010). Fly Ash-Based Geopolymer Concrete. In: *Proceedings of the International Workshop on Geopolymer Cement and Concrete*. Allied Publishers Private Limited, Mumbai, India. 68-106.

[16] Roesler, J. R. and Hunley, J. G. (2008). Performance of I-57 Recycled Concrete Pavement. *Research Report*, Illinois Center for Transportation, 48.

[17] Sata, V., Wongsa, A. and Chindaprasirt, P. (2013). Properties of pervious geopolymer concrete using recycled aggregates. *Constriction Building Material*, 42, 33–39.

[18] Sherif, Y., Kareem, H., Annam, A., Amani, Z. and Hiba, I. (2015). Strength and Durability Evaluation of Recycled Aggregate Concrete. *International Journal of Concrete Structures and Materials.* 9(2), 291-239.

[19] Smith, J. T. and Tighe, S. L. (2008). Recycled Concrete Aggregate-A Viable Aggregate Source for Concrete Pavements. In: *Report of 87th Annual Transportation Research Board Meeting*. Washington, D.C.

[20] Swapna, K., Sarkar, A. k. and Rajamane, N. P. (2011). Nanosilica Improves Recycled Concrete Aggregate. Retrieved from: http://www.nbmcw.com/articles/admixtursadditives/20929-nanosilicate-improves-recycled-concrete-aggregate.html. On 20/03/2015.

[21] Valerie, S., and Assia, D. (2013). Improvement of recycled concrete aggregate properties by polymer treatments. *International Journal of Sustainable Built Environment*, 2, 143 – 152.

[22] Verian, K. P., Whiting, N. M., Olek, J., Jain, J. and Snyder, M. B. (2013). Using Recycled Concrete as Aggregate in Concrete Pavements to Reduce Materials Cost. *Joint Transportation Research Program*, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana. Publication FHWA/IN/JTRP-2013/18