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EXPLORING THE SUITABILITY OF NIGERIAN-BASED RICE HUSK ASH FOR HIGH STRENGTH CONCRETE PRODUCTION FOR USE IN CONSTRUCTION

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***Abstract*: This study investigates properties of Nigerian-based RHA as a partial replacement for cement in HSC for sustainable and economic construction. Rice husks were obtained from Ire Ekiti, calcined to ash in a furnace under the range of 600 - 800°C, sieved and milled to improve the surface area and composition test was done. Two samples of RHA (milled and unmilled) were prepared and RHA-Cement blends using 0%,10%,20%,30%,40% and 50% by weight of cement. 72 cubes were prepared with an expected compressive strength of 60 MPa with each percentage replacement respectively having 12 cubes each for 7, 14, 21 and 28-days compressive strength to obtain the optimum percentage replacement. In the RHA produced, combined proportion of (SiO_2), (Al_2O_3), and (Fe_2O_3) gives 91.48% with loss of Ignition (LOI) of 3.79%, thus, satisfying ASTM 70% minimum requirement for the combined proportion of these oxides and 6% maximum Loss of Ignition. From the compressive strength test, the unmilled RHA -Cement blends performed poorly with respect to the control mix while the milled RHA -Cement shows an increase in strength and peaked at 10% with an average 28 days compressive strength of 63.70 MPa while 20% RHA gives 59.85 MPa. The close result of the average compressive strength of the 20% RHA to the target strength of 60 MPa, 10% and 20% RHA mixes were chosen as the likely optimum RHA replacement. With respect to these findings, Nigerian-based RHA shows promises for use in construction activities.**

***Keywords:* rice husk ash, sustainable, Nigerian, High strength concrete, construction.**

I. INTRODUCTION

The construction industry is one of two largest producers of carbon dioxide (CO_2), creating up to 5% of worldwide man-made emissions of this gas, of which 50% is from the chemical process and 40% from burning fuel [15], [6]. The CO_2 emission from the concrete production is directly proportional to the cement content used in the concrete mix; 900 kg of CO_2 is emitted from the production of every ton of cement, accounting for 88% of the emissions associated with the average concrete mix [9], [12].

Cement manufacture contributes greenhouse gases both directly through the production of carbon dioxide when calcium carbonate is thermally decomposed, producing lime and carbon dioxide, [5], [6] and also through the use of energy, particularly from the combustion of fossil fuels. The world's annual consumption of Portland cement (1880 – 1996), rose from 2 million tons to 1.3 billion tons. The major environmental impact associated with the production cement is CO_2 which contribute over 50% of all industrial CO_2 emissions (for every 1 ton of cement produced 1.25 ton of CO_2 is released in the air). Also, 1.6 ton of natural resources is consumed to produce 1 ton of cement [10], [7].

Beyond the environmental impact of cement manufacture and consumption, [14] noted the continuous rise in cost of building construction in developing countries as direct implication of high cost of cement (one of the essential ingredients in concrete production) and advised on the use of alternative materials with aim of lowering the overall cost of construction. In his report, he advocated for the use of some industrial and agricultural by-products as a possible supplementary cementitious material (SCM) with the aim of reducing the amount of cement used in concrete production while also protecting the environment.

Given these concerns over the environmental impact of cement production coupled with the ever-increasing cost of construction of concrete structures, research has been geared towards finding environmentally and cost-friendly alternative materials that can serve as a partial replacement for cement in concrete without compromising its structural performance. Based on available literature, various locally available materials have been viewed as a possible supplement for cement in concrete such as; Sugarcane ash, Groundnut ash, Corn cob ash, Rich husk ash and many others. While such materials offer promising sustainability practices in concrete production, they fail to offer significant cost benefit in concrete production on their own merit. However, research has indicated that these materials can serve as an excellent natural admixture in high strength concrete (HSC), which is more cost-friendly given its ability to bear more load per unit area. Thus, it offers direct cost savings on construction cost in form of concrete volume savings. In addition, HSC has been said to possessed improved characteristics in form of enhanced performance, thus, offers significant cost savings in form of lower maintenance cost.

Thus, this research has been focused on the possible use of Nigerian-based Rice Husk Ash (RHA) given its high pozzolanic properties (containing 75-90% organic matter such as cellulose, lignin etc., while mineral components such as silica, alkalis and trace elements accounting for the rest.) as a partial replacement for cement in High Strength Concrete (HSC) production. Thus, aimed at addressing the environmental issues resulting from rice production in Nigeria while reducing the amount of cement in concrete production.

II. MATERIALS AND METHODS

In this study, the following materials were used:

a. Cement: In concrete production, strength development is a function of both cement characteristics and cement content. Thus, in high-strength concrete production, proper choice of cement (with consideration to type and source) is one of the important steps [3]. In view of this, the cement used was Ordinary Portable Cement OPC (Grade 42.5R). This cement satisfies international standards of OPC and it ensures the cement passes the test for which its properties may be determined.

b. Fine and coarse aggregate: The fine aggregate used for this experiment was obtained from the Lagos lagoon bed located at Oworoshoki, Lagos. The sand particles were sieved to reduce the clay, loam, dirt and organic or chemical matter. The particles passed through BS sieve No. 4 (aperture 4.75mm) but retained on sieve 1 (aperture 0.06mm) ensuring that the dust particles were removed from the sand. While the coarse aggregate used were crushed granite of igneous origin with sizes varying from 2.36 – 12.70 mm

c. Rice husk ash (RHA): The rice hush waste was obtained from Ire Ekiti in southwest Nigeria. The husk was burnt within the temperature range of 500- 800 degree Celsius in the furnace, after which the sample was sieved and milled.

d. Superplasticizer: Given the high fine content in the mixture and the extremely low water content, *conplast 430* was employed as high range water reducer (HRWR) with aim to improve the workability of the concrete mix.

e. Portable water: The water used was obtained from the laboratory taps. The water was portable and did not contain sulphate, ferric, alkaline, oils, vegetation or salt that could affect the properties of materials concrete in the fresh or hardened state [4]. Also, the water should be colourless, tasteless, odourless and free from decaying organic matters.

Materials selection and concrete design mix:

The study is aimed at developing a high strength concrete (HSC) with a strength of 60 MPa using a Nigerian sourced RHA. Given the unconventional nature of HSC and the high sensitivity of it to the materials used for its production,

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known concrete mixes such as 1:2:4 and other well-established concrete mix ratios will not be adequate for its production. As such, a trial mix approach was adopted using the ACI committee 211 High strength concrete design guide [1] was used in arriving at the appropriate mix ratio for the specified concrete strength (60 MPa).

Before the proportion of materials needed for the HSC production, preliminary tests were carried out to investigate the physical and chemical properties of the RHA, granite, sand and the cement. Based on this result, the appropriate specifications where followed as laid down in the ACI committee 211 guides [1] in arriving at the first trial mix using pure concrete without RHA (control mix). The concrete was casted to cubes and tested for 7, 14, 21 and 28 days respectively for compressive strength and necessary adjusted are made to initial mix design by adjusting the water/cement ratio to arrive at the final design mix.

With the derived control mix for 60 MPa HSC, RHA was introduced into the mix by varying percentages from 10-50% with respect to the cement weight to give 5 different sample. Each sample was casted into 12 sets of cubes and tested for 7, 14, 21 and 28 days respectively for compressive strength and compared with the control mix.

III. RESULTS AND DISCUSSION

The experimental works started with a preliminary test of RHA, fine and Coarse aggregate properties. The figure 1 and 2 shows the sieve analysis for both fine aggregate and coarse aggregate. This was carried to check the compliance of aggregate particle size distribution with respect to ACI 363R-10 [3]. With reference to the figure 1, highest amount of aggregate retained to be at seize size 1.18mm with a percentage retaining of 37.08% of the total weight. Thus, the soil sample used was well graded. In figure 2, The particle sizes between 10 – 20mm account for 83.04% of the sample weight with a negligible fine aggregate content. As such, the impact of the fine aggregate on the concrete property is highly negligible. Although, a considerable amount of fine aggregate in the coarse aggregate will impact the water requirement of the mix, thus, impacting the strength of the concrete.

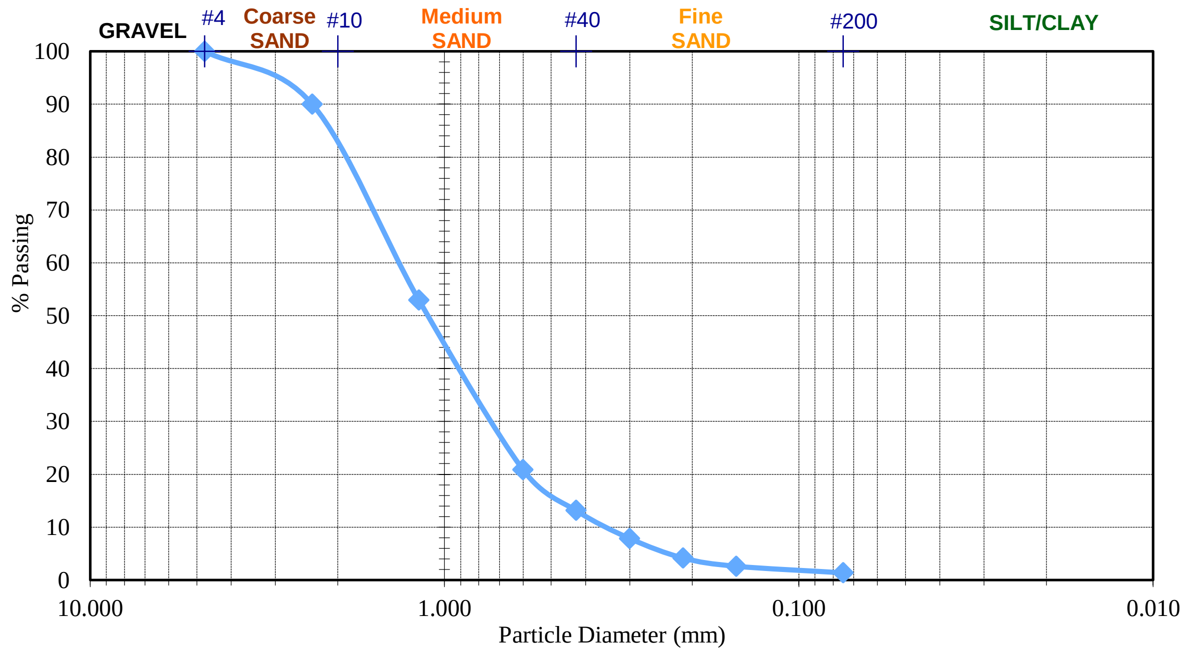

Fig. 1: Fine aggregate Sieve analysis

The RHA used for this experiment was sourced from rice milling factory in Ire, Ekiti state as noted earlier. Given the direct correlation between combustion temperature and nature of the ash formed, the RHA was further subjected to *X-ray Diffraction* test to ascertain the internal chemical structure of the ash. With reference to the results as shown below in Figure 3 and 4 below, prior to the milling operation, the XRD result indicated there is a mixture of amorphous and crystalline RHA in the ash. As such, the RHA was further milled to improve the available effective surface area for necessary chemical reaction between the silicate in the RHA and the hydroxyl ions in the cement solution during hydration reaction. Thus, cement was replaced by weight with RHA at 0-50% at 10% increment in order to determine an optimum replacement. The concrete mix proportioning and materials selection steps are shown Table 1.

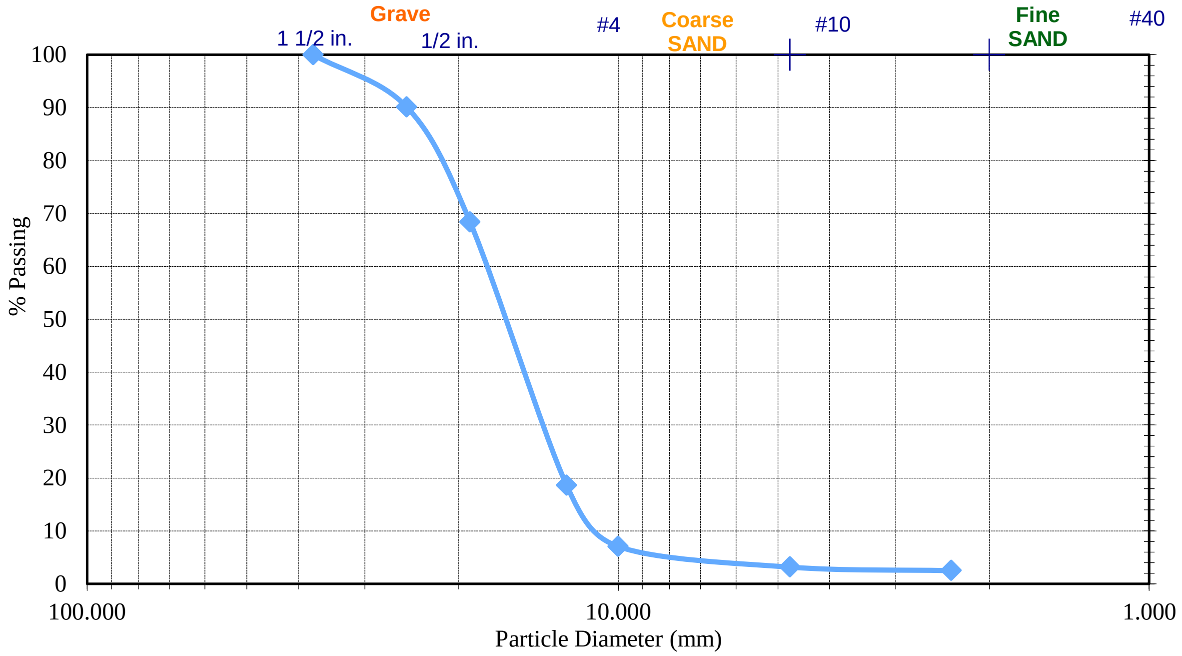

Fig. 2: Coarse aggregate Sieve analysis

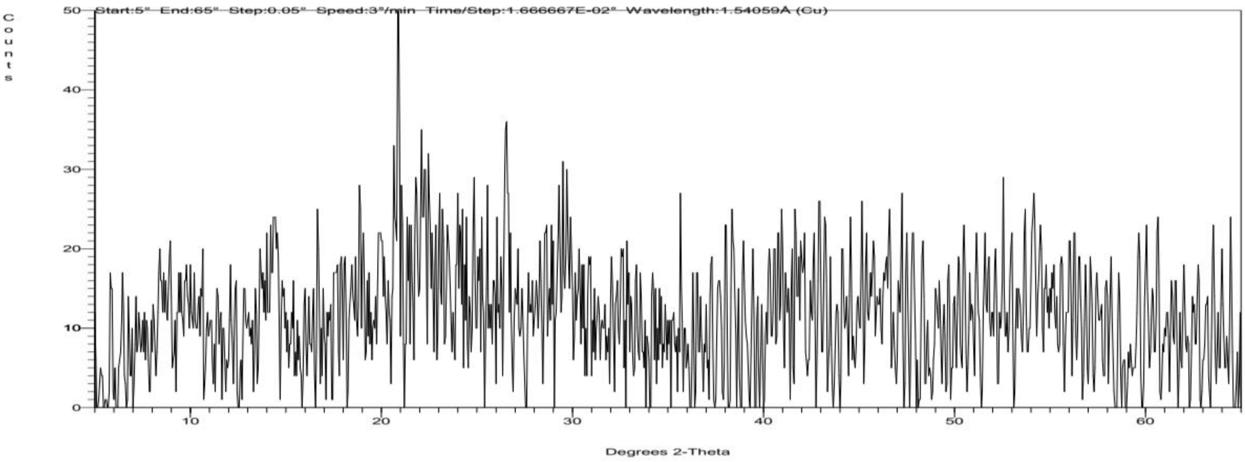

Fig. 3: X-Ray Diffraction (XRD) analysis for RHA before milling

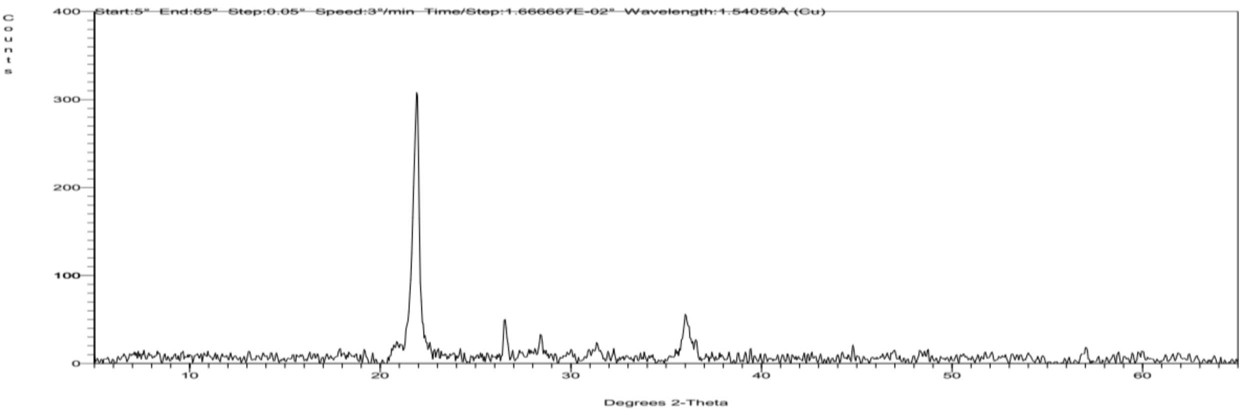

Fig. 4: X-Ray Diffraction (XRD) analysis for RHA after milling

Table I: Concrete Mix design

A. Design Specification	
Target strength (MPa)	60
Max size of aggregate used(mm)	12.7
Specific gravity of Cement	3.15
Specific gravity of fine aggregate (F.A)	2.63
Specific gravity of coarse aggregate (C.A)	2.58
Dry Rodded Bulk density of F.A (Kg/m3)	1693
Dry Rodded Bulk density of C.A (Kg/m3)	1619
Water-cementitious ratio	0.3169
Specific gravity of RHA	1.56

B. Control mix design Calculation	**Volume**	
Fractional volume of oven dry rodded C.A for 12.5mm size aggregate	0.68	
Based on slump of 25 - 50mm estimated mixing water content (kg/m3)	174	
Void content of FA %	35.59	
Adjustment in mixing water	2.8	**Volume**
Total water required(kg)	176.8	0.1768
Cementitious materials content(kg)	557.84	0.1771
Coarse aggregate content (kg)	1100.65	0.4267
Entrapped air content	2	0.02
Fine aggregate content(kg)	524.1	0.1994
HRWR Dosage as per manufacturer recommendation:	1Ltr/100kg cementitious content	

Table II: Lab Trial Mix (0.05062m3) 15 cubes per mix with 25% allowance for wastage

Constituents	**Control Mix(kg/m3)**	**Percentage Replacement (%)**				
		10	**20**	**30**	**40**	**50**
Cement	35	32	28	25	21	18
RHA	0	4	7	11	14	18
Sand	33	30	27	24	21	18
Stone	70	70	70	70	70	70
Water (plus HRWR)	11	11	11	11	11	11
HRWR (ml)	353	353	353	353	353	353
Total(kg)	149	146	143	140	137	134

NB: The design mix was based on ACI-211.4R-08 recommendation for High Strength Concrete (HSC)

Six batches of concrete were prepared for the compressive test with the first batch being the controlled mix without rice husk ash as a reference mix while the other five concrete mixes with a different percentage of unmilled rice husk ash at 10%, 20%, 30%, 40% and 50%. Figure 5 shows the comparisons of the compressive strength test between the control mix and concrete with different percentage of unmilled RHA in room temperature at 28 days. Figure 5 below (1st compressive test) shows the relationship between the control mix and concrete with different percentage of RHA in room temperature at 28 days. From the results obtained, it is clear that the compressive strength of unmilled RHA concrete reduces as the percentage of RHA replacement increases while strength of the cube increase as the number of days increases. This unusual behavior of the mix was as a result of the low pozzolanic activities given the high crystalline content of the ash in the mix. As noted by [8], [11], the internal lattice structure of the ash has a significant effect on the pozzolanic properties of the ash, thus, having a strong influence on the compressive strength of the concrete.

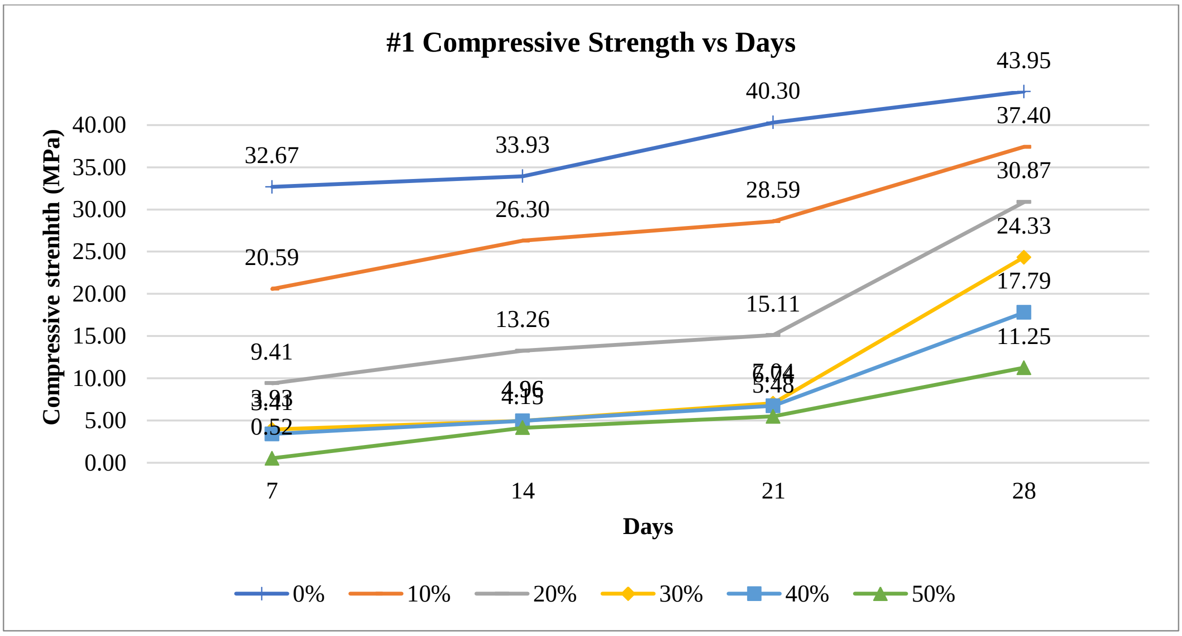

Fig. 5: unmilled RHA compressive strength

Thus, a second compressive test was carried out using a milled RHA in place of the unmilled one and the whole test was repeated. Figure 6 shows the comparisons of the compressive strength test between the control mix and concrete with different percentage of milled RHA in room temperature at 28 days. The compressive strength increased progressively and peaked at 10% and began to decrease from 10% to 20%. However, 20% result is very close to our target strength. The result shows that strength increases as the number of days increase for every batch. Also, the results of unit weight for different percentage replacement of RHA concrete are presented in Figure 7 and 8 below.

IV. CONCLUSION

As discussed above, there is an increase in compressive strength of the cubes with respect to the increase in percentages of RHA in the mix until 20% where a slight decrease in strength was observed. Although, the 20% RHA replacement is slightly below the 60 MPa target strength but with more quality control during concrete mixing, 20% RHA replacement can be used successfully for the production of HSC within acceptable compressive strength. While RHA use in concrete production offers interesting environmental

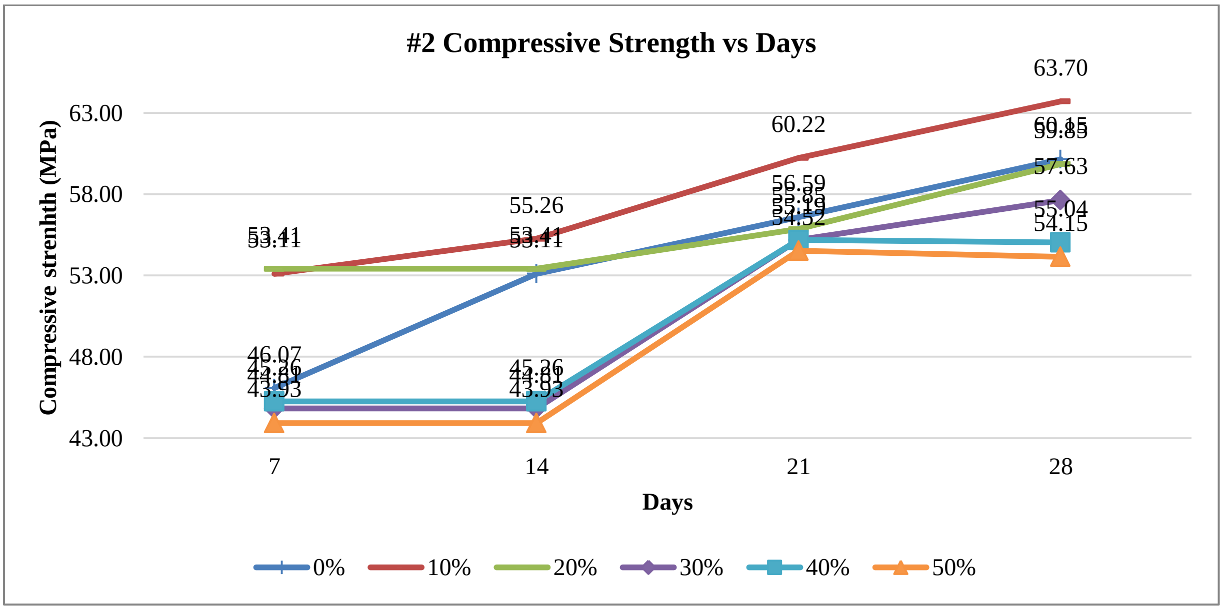

Fig. 6: milled RHA compressive strength

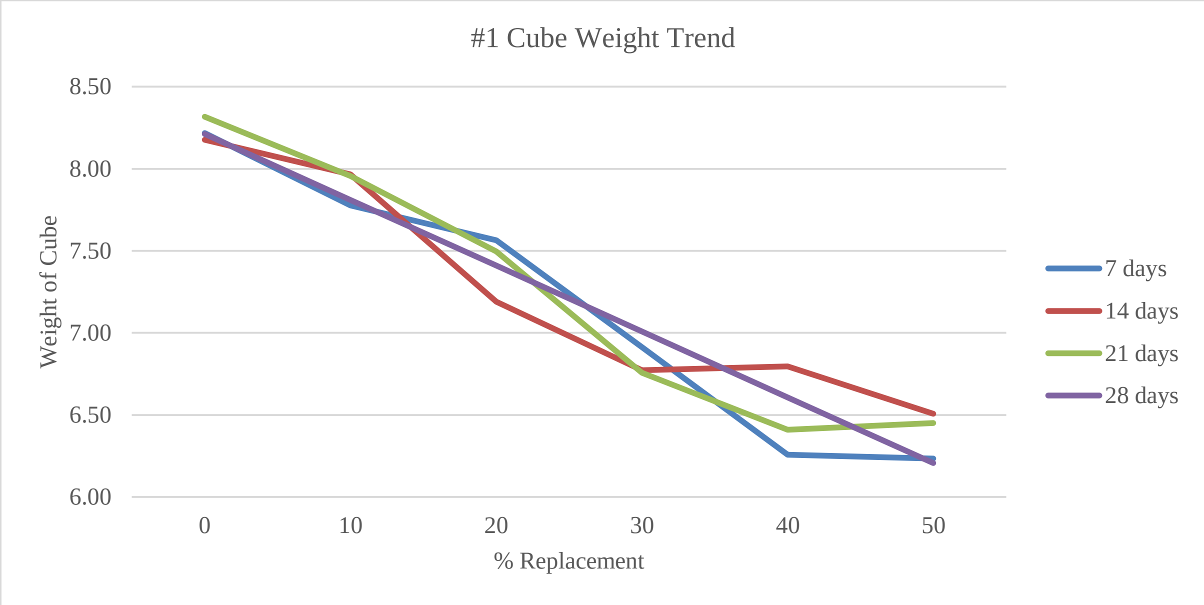

Fig. 7: unit weight for unmilled RHA concrete

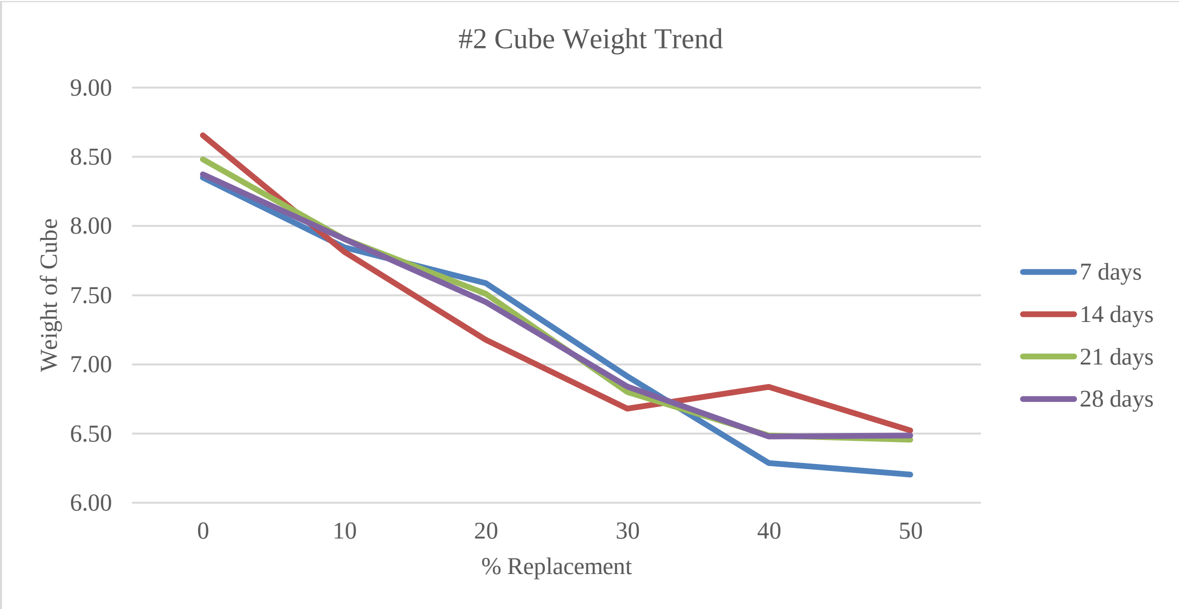

Fig. 8: unit weight for milled RHA concrete

benefits, its cost benefits has been stated to be negligble in comparison to the overall construction cost. However, the use adoption of RHA in HSC has shown to offer better cost benefit given the strength – volume advantage of HSC. Thus, the adoption of RHA-based HSC in construction activities gives both economical and environmental benefits.

Thus, 20% replacement cement in HSC production can offer opportuntiy for lower construction cost and help tp boost low cost housing estate development in the country to catering for the ever growung population.

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