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Cement Replacement by RHA in Concrete for Sustainable Development.

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ABSTRACT

Greenhouse gas and solid waste disposal are the major source of the environmental pollution. Cement industry and agricultural solid waste, namely rice husk contributes to CO_2 emissions and land fill problems. Thus, there is an immense need to arrange alternate method and reduce environmental impacts. The promising method of using rice husk as supplementary cementitious material in the concrete making process was examined. The characterization of unground rice husk ash and other building materials such as sand, gravel and cement was studied. In addition to this, the material quality test namely Proximate Analysis, Loss on Ignition for rice husk and rice husk ash were performed. From the experimental analysis, a remarkable increase of 11% concrete compressive strength was obtained for 10 wt% replacement of cement by rice husk ash. Further, the pozzolanicity has been studied.

Keywords: Rice husk ash, Compressive strength, Concrete, Sustainable development.

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1 INTRODUCTION

Increasing population, urbanization and technological innovation in living standards contributes to increase the environmental degradation. Excess environmental pollution, exhaustion of natural resources and generation of solid wastes by various activities are some of the major degradation observed at a larger scale. Population growth is accompanied by an increased demand for housing and infrastructure (Gastaldini et al. 2014). Production of construction materials becomes necessary to meet increasing housing demand that consumes electrical energy which leads to an environmantal degradation in terms of air, water and land pollution (Madurwar et al. 2013). Concrete is used as a construction material since the strutural stability and strength of the concrete is high (Rao & Tummalapudi 2012). The estimated concrete consumption per year per person is 1m^3 on the earth (Antiohos et al. 2013**).** Currently, more than 10 billion tons of concrete is produced annually. Thus, it depletes the natural resources and effects the ecosystems as well. Further, ordinary portland cement (OPC) manufacturing process emits large amounts of CO_2 into environment and it is been as about 7% of all the CO_2 gas emissions worldwide (Aprianti et al. 2015**)**.

Solid waste generation is another serious trouble in developing nations (Nabil Bouzoubaa and Benoit Fournier 2005, Guneyisi et al. 2012). In India, 600 metric tons of solid wastes have been generated from an agricultural resources alone (Pappu et al. 2007). Researchers are searching the way for effective usage of natural waste are endlessly advancing**.** The innovative way of incorporating these wastes as cement replacement into concrete production is promising.

RHA as cement replacement reduces the disposal problem and reducing building materials cost provides a acceptable solution to the waste management (Safiuddin. et al. 2010), saves energy and facilitates environmental protection**.** The advantages of using RHA in the concrete provides low heat of hydration, reduced creep and shrinkage, resistance to corrosive environment (Oyejobi et al. 2014). The characterization of various solid waste such as ash and silica fume, furnace slag have been reported by many researchers (Gurunaathan & Thirugnanam 2014; Khan et al. 2014; King 2012; Magudeaswaran & Eswaramoorthi 2013; Nikam & Tambvekar 2003). In another study, finely ground RHA increases the concrete strength since it has high pozzolanicity (Cordeiro et al. 2009). The experimental study of influence of RHA on the mechanical strength of concrete has also been reported in the literature (Suman et al. 2015; Kashyap et al. 2015; Ettu et al. 2013; Rego et al. 2015; Umapathy et al. 2014).

Present investigation includes to make use of agricultural biomass RHA as cement replacement for concrete making process. This study covers the preparation and characterization of RH, RHA, quality test for other building materials, namely sand, gravel and cement. Further, the experimental investigation on mechanical properties of concrete and pozzalonic activity of RHA were measured and discussed.

2 Experimental

2.1 Materials

2.1.1 Preparation of RHA

Rice husk was collected from local mill in Tamil Nadu, India was burnt to produce rice husk ash (RHA). About 25% of RHA was obtained after burning the rice husk. The RHA used has a specific gravity of 2.11, fineness modulus of 3.3, bulk density of 0.32 g/cc, loss on ignition of 2.27 wt % and has a pozzolanicity value of 567.72 mg/g of RHA.

2.1.2 Cement

OPC of 53 grade, with a specific gravity 3.12 from the local market conforming to IS 12269-1987(IS: 12269-1987) was used.

2.1.3 Aggregates

Natural sand of grading zone II with a fineness modulus 2.39, specific gravity 2.6 and absorption capacity 0.853 wt % was used as fine aggregate (FA). The coarse aggregate (CA) with a higher size of 20mm, specific gravity 2.79 and absorption capacity 0.518 wt % was used. The aggregates used were of IS 383-1970 (IS: 383-1970).

2.2 Methods

2.2.1 Characterization Studies

The characterization of RH and RHA such as particle size distribution (IS 2386 (Part 1) – 1963), specific gravity [IS 2386 (Part III) – 1963], bulk density [IS 2386 (Part III) – 1963], water absorption for fine [IS 2720 (Part II) – 1973] and coarse aggregates [IS 2386 (Part III) – 1963], proximate analysis [IS: 1350 (Part 1) – 1984] and loss on ignition (LOI) (IS 1727-1967) have been performed as per Indian Standards.

2.2.2 Experimental Analysis of Pozzolanic Activity

The pozzolanic activity of RHA was analyzed using the modified Chapelle's test (Ferraz et al. 2015). This test allows the quantification of $Ca(OH)_2$ consumed by 1g of RHA when it is mixed with 2g of Calcium oxide and 250 ml of distilled water. Then, the suspension was boiled at 90ºC for 16 hrs with a continuous stirrer. The portlandite content that was not consumed (free in solution) was determined by sucrose extraction and acid titration. The titration reactions are shown in Eq. (1) and (2).

$$CaO + 2HCl \rightarrow CaCl_2 + H_2O \quad (1)$$

$$Ca(OH)_2 + 2HCL \rightarrow CaCl_2 + 2H_2O \quad (2)$$

The pozzolanicity of RHA is calculated using Eq. (3).

$$PA = 2\left(\frac{V_1 - V_2}{V_1}\right)\left(\frac{74}{56}\right) \times 1000 \quad (3)$$

where, PA = pozzolanic activity of RHA (mg $Ca(OH)_2$ fixed/ g RHA); V_1 = volume of HCl 0.1 N (ml), necessary for titrate 25 ml of the final solution obtained without RHA (blank test); V_2 = volume of HCl 0.1 N (ml), necessary for titrate 25 ml of the final solution obtained with RHA.

2.2.3 Mix Proportion

The concrete was designed as per (IS: 10262-1982) to achieve M25 grade strength. The designed proportions of the raw materials in the concrete are given in Table 1.

Table 1. Design mix of concrete (for 1 m^3)

Water	Cement	Fine aggregate	Nominal coarse aggregate
186	413 Kg	548.6 kg	1025.78 Kg
0.45	1	1.3	2.4

2.2.4 Compression Test

The cube specimen was tested using compression testing machine as per (IS: 516 – 1959) at the completion of 7 days. The load was applied at constant rate till the specimen breaks down.

The maximum load on the specimen is recorded and the strength of concrete is calculated using Eq. (4).

$$f_{ck} = \frac{P}{A} \quad (4)$$

where, P = load (N) ; A = area (mm^2)

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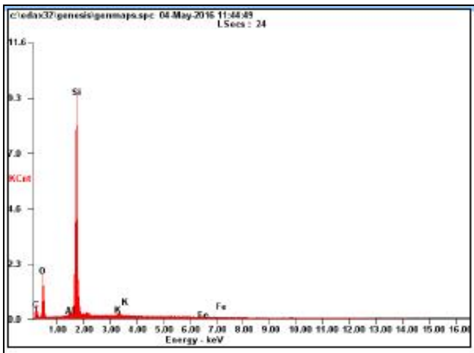
3 RESULTS AND DISCUSSION

The characterization of the building materials RH, RHA, cement, FA and CA which includes the particle size distribution, specific gravity, water absorption, bulk density, proximate analysis, loss on ignition and pozzolanic actvity are carried out and the results are discussed below.

3.1 SEM and EDX Analysis

The SEM and EDX analysis were performed to identify the surface morphology and an elemental composition of unground RHA, which are shown in Fig. 1. From the Fig. 1, the surface structure of unground RHA at 50 microns is similar to that of uniformly distribution of multiple adjacent layers, which is in node and anti node form. It is also observed that the composition of silica is found to be higher compared to other elements present in the unground RHA. This exhibits a similar behaviour as pozzolanic material that is suitable for replacing the cement in concrete.



Element	Wt%	At%
CK	3.64	5.73
OK	35.12	45.85
AlK	0.02	0.01
SiK	60.68	48.39
KK	0.44	0.17
FeK	0.1	0.03
Matrix	Correction	ZAF

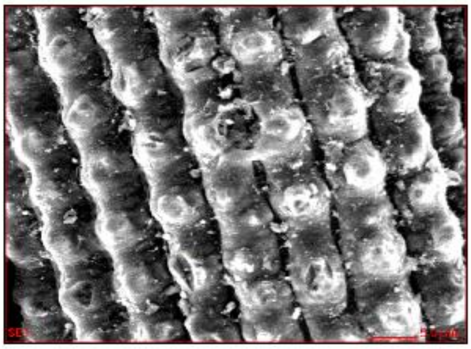


Fig. 1. SEM and EDX analysis of unground Rice Husk Ash (RHA)

3.2 Size Analysis

Size distribution analysis is essential for the characterization of RH, RHA, sand and gravel. The differential and cumulative analysis for various building materials namely RH, RHA, sand and gravel are shown in Fig. 2 - 5 respectively. The differential analysis is expressed in terms of the mass retained in each size and are shown in Fig.2 and Fig. 3. In the Fig. 2, the size range of RH was 1.29 - 1.55 mm and the maximum 0.075mm particle size of RHA was observed. Additionally, the maximum particle size of 0.45mm and 30mm for fine and coarse aggregates were also observed in Fig. 3. (Fig. 2- 5)

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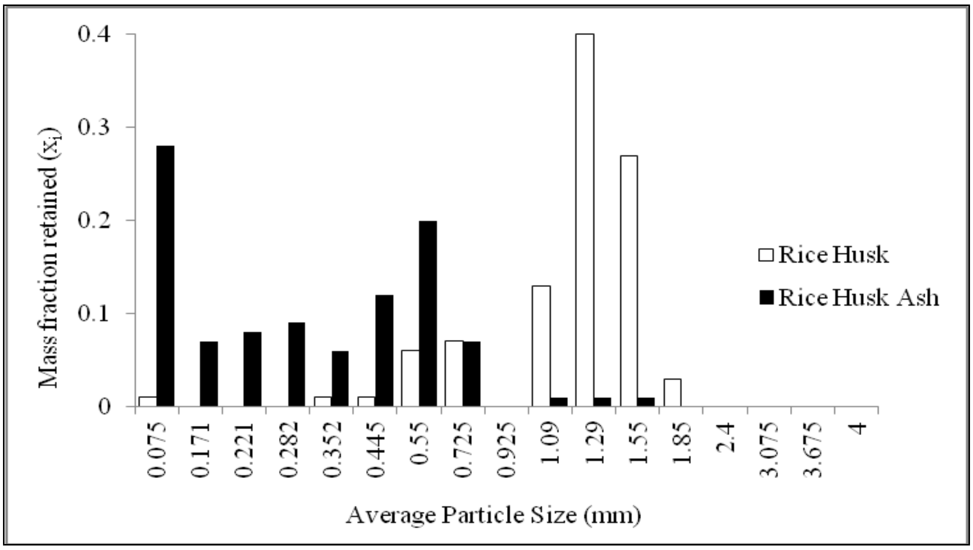

Fig. 2. Differential analysis of Rice Husk (RH) and Rice Husk Ash (RHA)

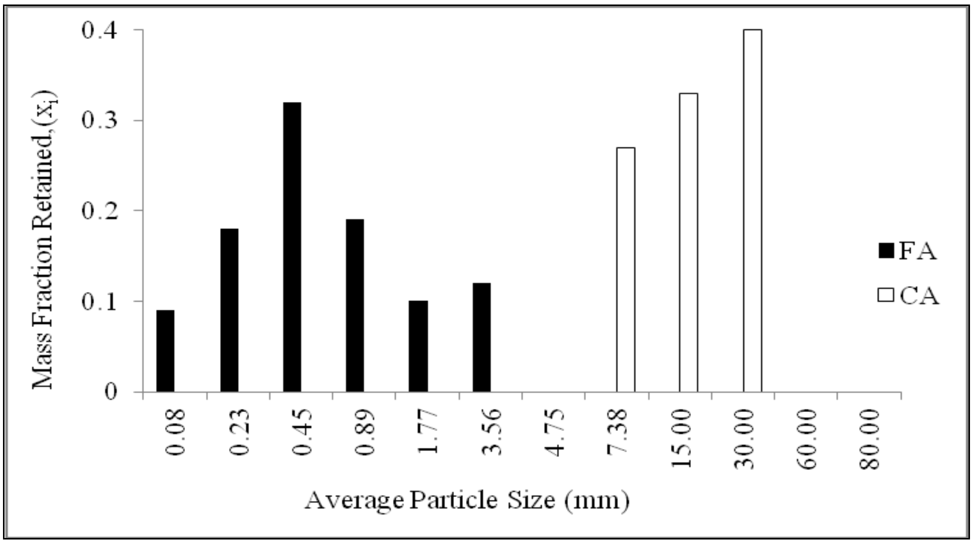

Fig. 3. Differential analysis of fine aggregate (FA) and coarse aggregate (CA)

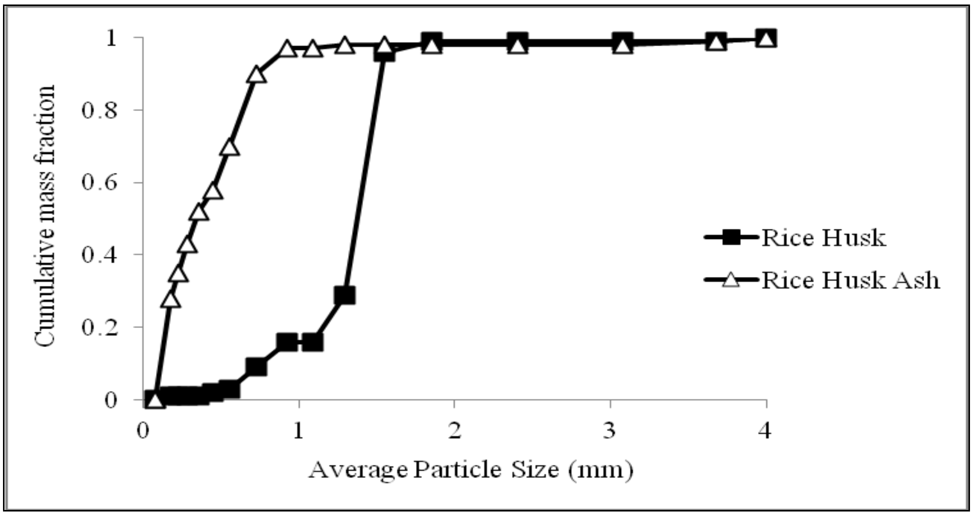

Fig. 4. Cumulative analysis of Rice Husk (RH) and Rice Husk Ash (RHA)

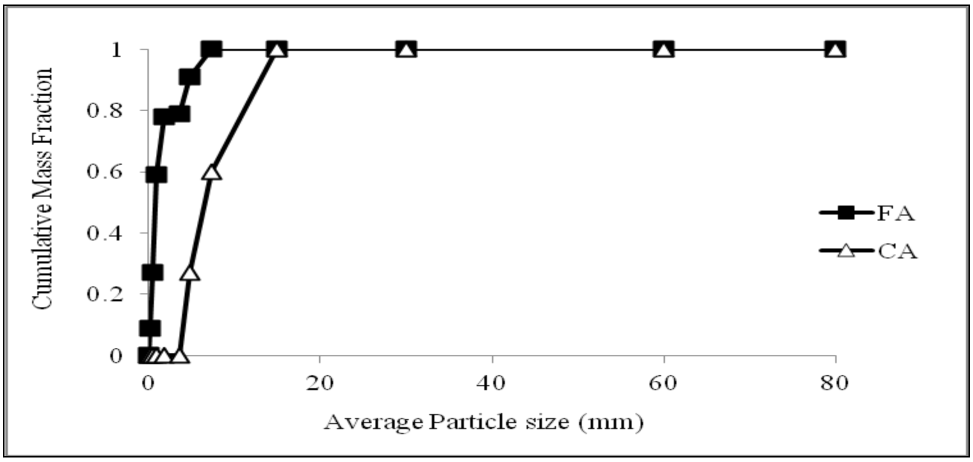

Fig. 5 Cumulative analysis of fine aggregate (FA) and coarse aggregates (CA)

From the above analysis, specific surface area, particle mean size and fineness modulus of the particle can be found. The specific surface area is calculated using the following Eq. (5).

$$A_w = \frac{6}{\varphi_s \rho_p} \sum_{i=1}^{n} \frac{x_i}{\bar{D}_{pi}} \tag{5}$$

where, A_w = Specific surface area (m^2/kg); φ_s = Sphericity (RHA = 0.45, Sand = 0.75, Gravel = 0.6) (Miller & Clesceri 2002; Chhabra & Richardson 2011); ρ_p = Density of the particle (kg/m^3); x_i = Mass fraction retained in each mesh; $\bar{D}_{pi}$ = particle mean size, taken as arithmetic average of smallest and largest particle diameter in increment (m); i = Individual increments; n = number of increments.

The specific surface area for RHA, sand and gravel are found to be 36.32 m^2/kg, 9.027m^2/kg and 0.257m^2/kg respectively. The average particle size is calculated using the Eq. (6).

$$\bar{D}_s = \frac{6}{A_w \varphi_s \rho_p} \tag{6}$$

where, $\bar{D}_s$ = Volume surface mean diameter (m); A_w = Specific surface area (m^2/kg); φ_s = Sphericity; ρ_p = Density of the particle (kg/m^3).

The building materials, namely RHA, sand and gravel has an average size of 0.174 mm, 0.342 mm and 13.9 mm respectively. The average particle size is inversely proportional to specific surface area. However, the higher average particle size was observed for gravel with a very less specific surface area.

From the Particle size distribution analysis, another important parameter, namely fineness modulus is obtained by Eq. (7).

$$\text{Fineness Modulus} = \sum \frac{\textit{cumulative \% retained}}{100} \tag{7}$$

Fineness modulus represents the size of the particle. The fineness modulus increases as increase in particle size. The respective magnitude of fineness modulus are 9.43, 3.3, 2.39 and 7.13 for RH, RHA, fine and coarse aggregates.

3.3 Specific Gravity

Specific gravity of the particle is used to design the concrete mixes and are shown in Table 2. From the known specific gravity of materials, theoretical yield of concrete per unit volume was determined. The standard specific gravity of materials considered in this study are 1.9-2.15 (RHA), 3.15 (cement), 2.6 (sand) and 2.8 (gravel). It was observed that if the specific gravity of cement is lesser than 2.9 or greater than 3.15 indicates adulterants of the particle. Thus, specific gravity is also an important factor to assess the quality of the building materials used (Table 2).

Table 2. Specific Gravity of Rice Husk Ash (RHA), cement, fine and coarse aggregates.

Sample	RHA	Cement	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.11 ± 0.03	3.12 ± 0.01	2.59 ± 0.02	2.79 ± 0.02

3.4 Water Absorption and its Bulk Density

The rate of water absorption of aggregates is of prime importance as it affects the hydration properties, workability and strength of the concrete. If the aggregates are porous and become more hydrated, which influences the workability and vice versa. However, the presence of moisture on the surface of the aggregates which further increases the ratio of water to cement in the concrete. Hence, both these conditions are essential to achieve the better strength of the concrete.

The coarse aggregate's standard absorption capacity is about 0.5 to 1 wt %. The materials, namely fine and coarse aggregates considered in the present study are given in Table 3. The RHA bulk density is found to be of 0.33 ± 0.02 g/c.c (Table 3).

Table 3. Water absorption of fine and coarse aggregates.

Sample	Fine Aggregates	Coarse Aggregate
Water content/ absorption (%)	**0.853 ± 0.051**	**0.518 ± 0.028**

3.5 Proximate Analysis

The proximate analysis of RH and RHA are shown in Table 4. The increased fixed carbon was found in RHA when compared to RH. This is attributed to the carbonation of RHA while burning it. Also, the significant loss of moisture was observed for RHA compared to RH. This may be due to the burning process of RHA (Table 4).

Table 4. Proximate analysis of Rice Husk (RH) and Rice Husk Ash (RHA).

Sample	Moisture (%)	VM (%)	Ash (%)	Fixed Carbon (%)
RH	12.25 ± 0.51	52.29 ± 1.04	20.88 ± 0.85	14.58 ± 0.29
RHA	7.11 ± 0.24	20.63 ± 0.23	50.25 ± 0.35	22.01 ± 0.31

3.6 Loss on Ignition (LOI)

Loss on Ignition (LOI) is generally referred as the quality test. This test is used to estimate the unburnt carbon present in the RHA. As per standards of IS: 1727-1967, the LOI should be less than 8 wt %. The observed value of RHA LOI is 2.26 ± 0.06 wt%, which is well below the specified standard.

3.7 Pozzolanic Activity of RHA

It is a measure of the reaction rate between a pozzolan and Ca^{2+} or $Ca(OH)_2$ in presence of H_2O. If material is said to be pozzolanic, it must have a minium reactivity 330 mg $Ca(OH)_2$/g of the sample. In the present wok, the pozzolanicity of the RHA was found to be 689.03 mg $Ca(OH)_2$/g, which is highly pozzolanic in nature.

3.8 Compression Test

The compressive strength of the concrete with and without RHA is shown in Fig. 6. This shows 11% increment in the compressive strength by 10 wt % replacement of RHA to the cement attaining 7 days curing period. This may be attributed due to the replacement of pozzolana in the pores of the concrete. Hence, the concrete becomes less permeable. In addition to this, the pozzolanicity of RHA is also increased since the formation of C-S-H (Calcium Silicate Hydrates) complex from the reaction between the $Ca(OH)_2$ and SiO_2 in the RHA. Hence the formation of $Ca(OH)_2$ was minimized and the maximum compressive strength was observed (Fig. 6).

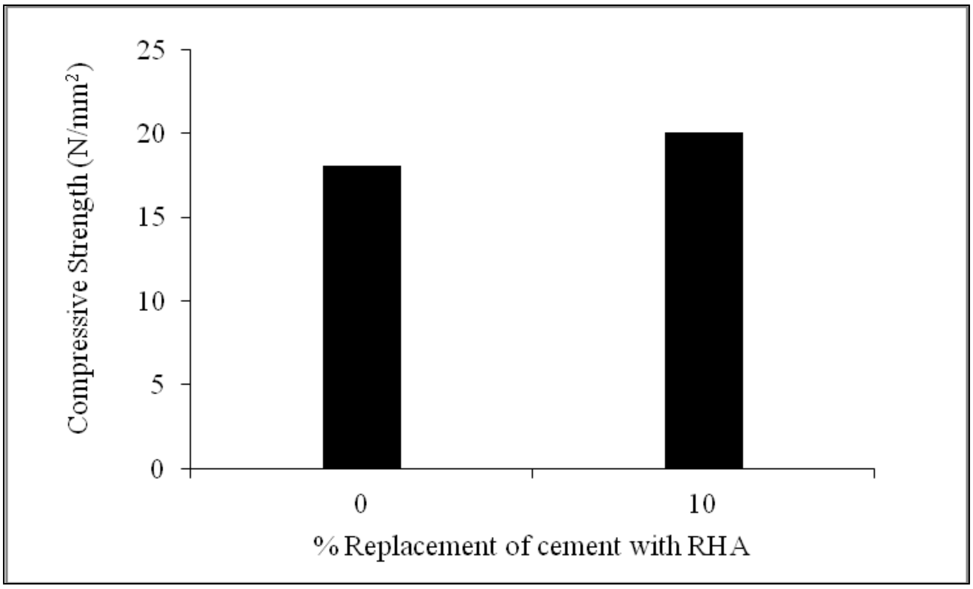

Fig. 6. Compressive strength of concrete with and without Rice Husk Ash (RHA)

4. CONCLUSION

Rice husk (RH) is an agricultural waste and its disposal leads to severe environmental pollution. The effective use of RH in the form of RHA as cement replacement in concrete making process was studied. The experimental characterization, SEM and EDX anaysis and quality test for RH, RHA and other buiding materials were performed. From the analysis, the replacement of cement with 10 wt% RHA exhibits 11% increment in compressive strength was observed. The pozzolanic activity of rice husk ash was estimated as 689.03 mg $Ca(OH)_2$/g and this shows that to achive a greater compressive strength of the concrete.

5. ACKNOWLEDGEMENT

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Nomenclature

The following notations are used in this paper.

A	=	Area
CA	=	Coarse Aggregate
C-S-H	=	Calcium Silicate Hydrates
FA	=	Fine Aggregate
LOI	=	Loss on Ignition
P	=	Load

RH	=	Rice Husk
RHA	=	Rice Husk Ash
SCM	=	Supplementary Cementitious Material

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