The effect of partial replacement of Nigerian Portland limestone cement with rice husk ash agricultural waste in concrete

U T Igba*, S O Ehikhuenmen2, J O Akinyele1, M O Osaghale2 and S O Oyebisi3

1 Department of Civil Engineering, Federal University of Agriculture Abeokuta, Ogun, Nigeria
2 Department of Civil and Environmental Engineering, Faculty of Engineering, University of Lagos, Akoka, Lagos, Nigeria
3 Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria.

*Corresponding Author Email: igbaut@funaab.edu.ng

Abstract. Rice Husk is an agricultural waste which when burnt under controlled temperature, produces an ash Rice Husk Ash (RHA) owing to its rich content in silica, which is used as a super-pozzolanic material for the partial replacement of Cement in concrete. Presently, large amounts of RHA are generated in both Rural and Small-Scale Industries which has a high impact on the environment. In this work, Portland limestone cement (PLC) was partially replaced at 0%, 5%, 10%, 15%, 20%, 25% and 30% with RHA. A control of 0% PLC replacement was adopted. Compressive strength was investigated A mix ratio of 1: 1.12 : 3.07 with water-cement ratio of 0.5 was adopted for a curing period of 7, 14, 28, 60 & 90 days. The result showed that the compressive strength decreased as the percentage of RHA increased. At 90 days, compressive strength of 34.12, 29.70, 28.30, 26.67, 24.48, 23.96 and 23.42N/mm$^2$ was recorded for 0, 5, 10, 15, 20, 25 and 30% replacement level respectively. It was recommended that further work should be investigated to check for the suitability of partial replacement of other grades of Nigerian cement with RHA in concrete.

Keywords Portland limestone cement (PLC); Rice husk ash (RHA); Concrete; Compressive strength.

1. INTRODUCTION
Rice husk is a waste product from rice mill. Rice is a major food source for billions of people all over the world. An approximate of hundred million tons of rice paddy are planted annually. Rice husk contains cellulose, lignin and silica in percentage of about 50%, 25%-30 and 15-20% respectively [1]. Rice mills uses rice husk for the boilers for processing paddy. Rice husk is used in energy generation in small power plants [2]. Rice husk has approximately 75% organic volatile matter which burns up the weight remaining of this husk which is 25% is converted into ash during the firing process, which will eventually become Rice husk ash (RHA) [3].

RHA is a by-product of combustion of rice husk at rice mills. RHA is a term used to describe the ash produced from burning rice husk [4]. Carbonized rice husk is produced when the burning process is incomplete. At a burning temperature range of 550°C to 800°C amorphous ash that is black in colour is produced while at higher temperatures crystalline ash having grey to white colour is produced [5].

Researchers are currently investigating the use of ash for composite production since ash is an abundant agricultural waste, it is renewable and has low bulk density. Rice husk ash had been applied
in other areas like manufacturing insulating powder, production of refractory bricks, cement production and sandcrete block production. However, there are limited applications of rice husk ash in composite production.

Cement replaced with RHA up to 20% volume in the matrix, improved the mechanical properties of the concrete. The researcher posited that using pozzolans like RHA reduced the utilization of cement and lowered the cost of buildings [6].

The partial replacement for ordinary Portland cement with RHA in concrete was investigated. OPC was replaced with RHA by weight at 0%, 5%, 10%, 15%, 20% and 25%. The control was at 0% replacement. 1:2:4 concrete mix proportion by weight in a mixture of cement, sand and gravel was adopted. The hardened concrete was made from 150 mm x 150 mm x 150 mm concrete cubes and tested for the compressive strength after 7, 14 and 28 days curing in water. The result concluded that as the percentage replacement of OPC with RHA increased, the Compressive strength and Compacting factor decreased [7].

The Effect of Rice Husk Ash on Properties of Concrete was studied. The main objective was to study the suitability of the rice husk ash as a pozzolanic material for cement replacement in concrete. Result showed from the experimental work that mix M2 (M0+20% RHA) was the best combination among all mixes, which gave maximum tensile, flexural and compressive strength over normal concrete [8].

The use of RHA will contribute not only, to the production of concrete of a higher quality and lower cost, but also the reduction of carbon dioxide (CO2) emissions from the production of cement. The partial replacement of cement by RHA will result in lower energy consumption associated with the production of cement [9].

The effect of using Rice Husk Ash (RHA) as a partial cement replacement material based on an experimental study of mortar made with Ordinary Portland Cement (OPC) at replacement of 10%, 15%, 20%, 25% and 30% was investigated.

The RHA used was obtained from an uncontrolled auto combustion of rice husk, in a chamber, without control of temperature and burning. The porosity and compressive strength of mortar were investigated. The result showed that the porosity and compressive strength of mortar incorporating the percentage of RHA were better majorly for RHA replacement of up to 20% replacement with cement [10].

The rice industry produces wastes on a daily basis which are usually dumped in the open thereby impacting the environment negatively without any economic benefits. In Nigeria, rice husks have not been accepted in its usage for construction. In order to make efficient use of locally available materials, this study investigated the maximum strength gained in terms of the compressive strength properties of RHA as a binding material replacing partially Portland limestone cement in concrete production considering a long term of 90 days.

2. MATERIAL AND METHODS

Rice Husk Ash

The Rice Husk used was obtained from the rice threshing floor at Ifo Local Government Area, Ifo, Ogun State. The RHA was made in the laboratory by burning the husk using an Electric furnace, with the temperatures of the furnace at about 700°C. The resulting ash was grey in colour which was collected and sieved through a BS standard sieve with size of 45 μm.
Cement
Portland Limestone Cement (PLC) manufactured by Dangote Cement Plc in Nigeria was used. It was purchased in sealed 50kg bags with its properties conforming to Standard [11]. A BS standard sieve size of 75μm size was used in sieving the cement. Fineness test was carried out in accordance with [12]. The specific gravity, initial and final setting of PLC 43 grade were 3.06, 156 and 240 minutes respectively.

Fine Aggregate
The fine aggregate was free from clay/silt content. Sharp Sand of sizes that pass-through sieve size 4.75mm was used as fine aggregates will be used with the specific gravity of 2.63.

Coarse Aggregate
Granite was used as the coarse aggregate. It was free of deleterious organic matter and passed through 20mm maximum sieve size.

Water
The potable water used for this experiment was obtained from the taps available in the laboratory. Casting and curing of specimens were done with potable water that was available in the department of Civil Engineering building, Federal University of Agriculture Abeokuta.

Mix Proportion
The control concrete was designed to achieve Grade 30 using [13]. Based on this design method, Cement measured by weight was replaced with RHA in the range of 0%, 5%, 10%, 15%, 20%, 25%, and 30%, to estimate the residual strengths of RHA replaced concrete.
The mix design proportion used in this study was (see Table 1):

| S. No | RHA Replacement % | Cement Replacement % | Fine Aggregate | Coarse Aggregate | Water to binder ratio |
|-------|-------------------|-----------------------|---------------|-----------------|----------------------|
| 1     | 0                 | 100                   | 1.12          | 3.07            | 0.5                  |
| 2     | 5                 | 95                    | 1.12          | 3.07            | 0.5                  |
| 3     | 10                | 90                    | 1.12          | 3.07            | 0.5                  |
| 4     | 15                | 85                    | 1.12          | 3.07            | 0.5                  |
| 5     | 20                | 80                    | 1.12          | 3.07            | 0.5                  |
| 6     | 25                | 75                    | 1.12          | 3.07            | 0.5                  |
| 7     | 30                | 70                    | 1.12          | 3.07            | 0.5                  |

Casting and Testing of Specimens:
All the ingredients were first mixed mechanically in dry condition in the concrete mixer. The concrete mix proportion is shown in Table 1. The calculated amount of water was added to the dry mix and mixed thoroughly to get a uniform mix. Oil was smeared on the inner surface of the mould and the concrete was poured in to the mould. After 24 hours of casting, the specimens were demoulded and cured for a period of 7, 14, 28, 60 and 90 days in a water tank. After the curing, the specimens were tested.
3. Results and Discussion

3.1 Chemical properties of RHA and PLC

The results of the chemical properties are presented in Table 2 below.

**Table 2. Chemical properties of RHA and PLC**

| S/No | Chemical components       | RHA % | Portland Limestone cement (Dangote 3x cement) % |
|------|---------------------------|-------|-----------------------------------------------|
| 1    | Silica Oxide (SiO$_2$)    | 88.29 | 19.16                                         |
| 2    | Sodium Oxide (NaO$_2$)    | 0.10  | 0.40                                          |
| 3    | Potassium Oxide (K$_2$O)  | 2.90  | 0.35                                          |
| 4    | Calcium Oxide (CaO)       | 0.63  | 64.2                                          |
| 5    | Magnesium Oxide (MgO)     | 0.46  | 2.17                                          |
| 6    | Aluminium Oxide (Al$_2$O$_3$) | 0.44 | 4.92                                          |
| 7    | Iron Oxide (Fe$_2$O$_3$)  | 0.65  | 0.75                                          |
| 8    | Sulphur Oxide (SO$_2$)    | 0.00  | 1.02                                          |
| 9    | Loss of ignition(Loi)     | 5.35  | 0.005                                         |

From the result, the silica content of the RHA was found to be 88.29% which indicate higher silica content than in cement. This value was higher than the minimum required value of 70% for the combined proportion of silica oxide, aluminium oxide and iron oxide for natural pozzolanas [14]. On the other hand, the alumina content in cement (4.92%) was higher than that in the RHA sample. The potassium oxide in the RHA (2.90%) was higher than that in cement. Also, the loss on ignition obtained for RHA was found to be 5.35% and the cement was 0.005%.

3.2 Compressive strength of RHA and PLC blended concrete

The compressive strength for different replacements of grade 30 concrete are shown in Table 3. The results of the compressive strength of the concrete cubes with variation in percentage replacement are presented in figure 1 for 7, 14, 28, 60 and 90 days curing respectively showing the average of compressive strength test.

**Table 3. Compressive strengths for different replacements of grade 30 concretes.**

| RHA (%) | Average Compressive strength of cube (N/mm$^2$) |
|---------|-----------------------------------------------|
|         | Age of curing in days                         |
|         | 7 days | 14 days | 28 days | 60 days | 90 days |
| 0       | 22.37  | 23.26   | 32.12   | 33.18   | 34.12   |
| 5       | 21.70  | 22.67   | 28.15   | 28.89   | 29.70   |
| 10      | 20.67  | 20.96   | 26.82   | 27.41   | 28.30   |
| 15      | 17.08  | 19.26   | 22.37   | 25.04   | 26.67   |
| 20      | 17.07  | 18.67   | 20.44   | 23.41   | 24.48   |
| 25      | 15.60  | 17.78   | 18.67   | 23.11   | 23.96   |
| 30      | 14.34  | 17.41   | 18.22   | 22.00   | 23.42   |
Figure 1. Compressive Strengths of Weight-Batched RHA Concrete

The compressive strength test was conducted on three concrete cube samples for each of the percentage replacement of cement with RHA at the ages of 7, 14, 28, 60 and 90 days respectively. It was observed that the compressive strengths reduced as the percentage replacement of RHA increased from 0%, 5%, 10%, 15%, 20%, 25% and 30%. However, the compressive strengths increased as the number of days of curing increased for each percentage RHA replacement.

For the 5% RHA replacement, it showed an increase in compressive strength from 21.70 N/mm$^2$ at 7 days to 28.15 N/mm$^2$ at 28 days (29.72% increment). The 28-day strength was less than the specified value of 30 N/mm$^2$ for the characteristic’s strength of grade 30 concrete. The strength of the 10% RHA replacement showed an increase in compressive strength from 20.67 N/mm$^2$ at 7 days to 26.82 N/mm$^2$ at 28 days (29.75% increment). The 28-day strength was also lower than the specified value of 30N/mm$^2$ for the characteristic strength of Grade 30 concrete. However, the 28-day strength for the 15%, 20%, 25% and 30% RHA replacement gave 22.37 N/mm$^2$, 20.44 N/mm$^2$, 18.67 N/mm$^2$ and 18.22 N/mm$^2$ respectively.

4. Conclusion

From the investigations carried out, the following conclusion can be made: There exists a high potential for the use of rice husk as a binder in partial replacement of cement for the production of reinforced concrete. It was observed that the average compressive strength of grade 30 concrete without RHA at 90 days was 34.12 N/mm$^2$ which was higher than the specified value of 30 N/mm$^2$ for the characteristic’s strength of grade 30 concrete.

It was observed that the compressive strengths reduced as the percentage replacement of RHA increased. However, the compressive strengths increased as the number of days of curing increased for each percentage RHA replacement.

At the end of the experiment, it was observed that RHA with 5% replacement had the optimal compressive strength of 29.70 N/mm$^2$ which is approximately the same strength as the target strength of 30 N/mm$^2$ for grade 30 concrete, which makes 5% RHA replacement suitable for concrete production and utilization. The results of the experimental investigation indicate that Rice Husk Ash (RHA) can be adopted as partial replacement material for the Portland Cement in the construction of low-cost housing.
References

[1] Abubukar B, Ramadhanbugh P and Abdulaziz H Malaysian Rice Husk Ash improving the Durability and corrosion Resistance of concrete preview. Concrete Research letters. 2010, 1: 280-285.
[2] Cook DJ 1996 Rice Husk Ash increment replacement material. Concrete technology and design vol.3 Ed.R.Swamy, Surrey University, UK. IS code books - 10262, 456.
[3] Mahmud HB, Chia BS and Hamid NBA Rice husk ash: An alternative material in producing high strength concrete. Proceedings of International Conference on Engineering Materials, CSCE/JSCE, Ottawa, Canada. 1997, 2: 275-284.
[4] Zemke N and Woods E Rice Husk Ash. California statepolytechnic University. 2009, 30-35.
[5] Bronzeoak Ltd. Rice Husk Ash Market Study. ETSU U/00/00061/REP DTI/Pub URN 03/668. 2003.
[6] Ahmadi MA, Alidoust O, Sadrinefad I and Nayeri M Development of Mechanical properties of Self Compacting Concrete Containing Rice Husk Ash. World Academy of Science, Engineering and Technology. 2007, 34: 64 -71.
[7] Obilade IO Experimental Study on Rice Husk as fine aggregates in Concrete. The International Journal of Engineering and Science (IJES). 2014, 3: 09-14.
[8] Makarand SK, Paresh G, Prajyot PB, and Tande SN Effect of Rice Husk Ash on Properties of Concrete. Journal of Civil Engineering and Environmental Technology, 2014, 1(1): 26-29.
[9] Velupillai L, Mahin DB, Warshaw JW and Wailes EJA Study of the Market for Rice Husk to Energy Systems and Equipment. Louisiana State University Agricultural Center, USA, 1997.
[10] Alireza NG, Suraya AR, Farah NA and Mohamad AMS The effect of rice husk ash on the strength and durability characteristics of concrete. 2010, 10: 60-78.
[11] British Standard, BS 12 1996 Specification for Portland cement. British Standards Institution, London.
[12] British Standard BS 4550-Part 3 1978 Methods of testing cement. British Standards Institution, London.
[13] American Society for Testing Materials. ASTM C618-94a. Standard specification for fly ash and raw or calcined natural pozzolan for use as a mineral admixture In: Portland Cement Concrete. American Standards Testing Materials Annual Book of ASTM Standards. 1995, 4.02, 304-306.