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ВЛИЯНИЕ ПРИМЕНЕНИЯ ЗОЛЫ РИСОВОЙ Ш ЕЛУХИ НА УДОБОУКЛАДЫВАЕМОСТЬ И ПРОЧНОСТЬ ПРИ ИЗГИБЕ ЖЕЛЕЗОБЕТОНА, ПОДВЕРГАЕМОГО ПОВТОРНОЙ ВИБРАЦИИ

THE EFFECT OF APPLYING RICE HUSK ASH ON THE WORKABILITY AND FLEXURAL STRENGTH OF REVIBRATED AND NON-REVIBRATED REINFORCED CONCRETE

Рассмотрено влияние золы рисовой шелухи (ЗРШ) на удобоукладываемость и прочность при изгибе железобетона, подвергнутого повторной вибрации и без таковой. При подготовке бетона обычный портландцемент был частично (на 5, 10, 15 и 20 %) заменен ЗРШ. Исследовано 50 образцов балок, армированных стальными стержнями 12 мм, 35 из которых подвергались повторной вибрации. Проверка подвижности бетонной смеси по осадке конуса показала, что удобоукладываемость свежего бетона улучшается с увеличением содержания ЗРШ. По результатам испытаний отмечено, что добавление ЗРШ значительно повышает прочность железобетона при изгибе (наибольшая прочность получена при 5 %-ном содержании ЗРШ и 20 мин повторной вибрации).
Ключевые слова: бетон, прочность при изгибе, зола рисовой шелухи, повторная вибрация, время повторной вибрации, удобоукладываемость.

This study examines the influence of rice husk ash (RHA) on the workability and flexural strength of revibrated and non-revibrated concrete beams. Concrete production incorporated the replacement of Ordinary Portland Cement (OPC) with 0%, 5%, 10%, 15% and 20% of RHA. The design mix ratio of 1:2:4 and water-cement ratio of 0.5 was used in the process. Fifty test specimens reinforced with 12mm steel bars were cast. Thirty-five of the beams were revibrated after the initial mixing and placement, seven beams each at each percentage replacement of OPC with RHA. The remaining fifteen beams, three each per each replacement were not revibrated. The results of slump test indicates that the workability of fresh concrete is improved by increasing RHA content. Further, addition of RHA in reinforced concrete considerably increases the flexural strength for both revibrated and non-revibrated beams. Results show that the highest flexural strength is obtained at 5% replacement and at 20 minutes for revibration time-lag interval.
Keywords: concrete, flexural strength, rice husk ash, revibration, revibration time lag, workability.

1 INTRODUCTION

Finished products of cement and aggregates such as concrete, sandcrete blocks and beams are predominantly needed in large proportion for engineering structures such as buildings, bridges, dams and a number of others. Due to rapid industrialization throughout the world, the production of huge quantity of produced waste materials creates not only the environmental problem but also the depositional and waste management problems. In view of the current global emphasis on using waste for producing wealth described by Sridhar M. K. [1], and the need to preserve energy and resources, efforts are being made to burn the agro husks under controlled conditions and to utilize the resultant ash as a building material. When rice husk is burnt in an uncontrolled manner, the resulting ash, which is essentially silica, is converted into crystalline forms and becomes less reactive [2]. The most outstanding technical benefit of adding these mineral admixtures to concrete is the improved durability of concrete under various types of environmental influence or attack, mainly because of the reduced permeability arising from a pore size refining process [3].

Exploration of alternative materials to partially replace aggregates and cement in concrete production is becoming increasingly important due to the conventional materials` cost, environmental pollution caused by indecent ways of disposing agro-wastes such as rice husks, millet husks, groundnut shell, and sawdust among others [4].

Numerous works are devoted to the application of RHA as a supplementary cementitious material as a replacement of OPC in the production of lightweight concrete [5–13].

The objective of the present study is to examine the effect of RHA on workability and flexure strength of vibrated and non-revibrated concrete beams with varying percentage replacement of OPC at 0%, 5%, 10%, 15% and 20% respectively.

2 MATERIALS USED AND METHOD

2.1 Materials

The materials used in this study are cement, rice husk, fine and coarse aggregates, water and mild steel bars. The cement brand used is the Dangote Ordinary Portland Cement (OPC), Grade 43. Rice husk used was bought from a rice milling factory Minna, Nigeria. The Rice Husk was incinerated at a controlled temperature of about 600–800°C and pounded with mortar and pestle, after that it had to pass through 75microns B.S sieve in order to remove impurities and larger size particles. River sand obtained from an open market in Gidan Kwanu in Nigeria was used as fine aggregate in the laboratory experiments. The granite material with particle size between 18–20mm was used as coarse aggregate. It was provided from a local quarry in Gidan Mangoro in Nigeria. It was sand passing through 5mm British Standard test Sieves. The water used was collected at Gidan Kwano borehole, main campus of Federal University of Technology Minna, Niger State, Nigeria. This water is potable and can be used for making concrete as per laboratory records and conformed to [15] requirements. The physical and chemical characteristics of materials used are presented in Tables 4–7.

2.2 Methods

Preliminary tests such as sieve analysis, bulk density, specific gravity fine aggregate (sand), RHA and coarse aggregate were run. A sample of the rice husk ash was analysed in the laboratory to determine the oxides composition.

The concrete mix design of 1:2:4 and water cement ratio of 0.5 were used. Sump and compacting factor test on fresh concrete was conducted and results were presented on Table 9. The dimensions of the beams are 150mm × 150mm × 600mm. All beams were reinforced with 12mm tensile steel and concrete cover of 25mm provided. The size of the links provided were 8mm bar each at regular spacing of 125mm c/c.

As for the revibrated beams, 35 samples were produced in total. Seven (7) beams each were cast for each replacement of OPC with 0%, 5%, 10%, 15% and 20% RHA respectively. The beams were revibrated for 2 minutes at an interval of 10minutes for a total duration of 1 hour. For the non-revibrated process, 15 pieces were produced. Three (3) beams each were cast for each level replacement of OPC with 0%, 5%, 10%, 15% and 20% RHA respectively. Poker vibrator was used for both the initial vibration after mixing and placement and revibration process. The beams were demoulded, cured for 28 days, and tested for flexure using Magnus Flexural testing machine (MFUTM). The preparation and testing of concrete beams was conducted in accordance to specifications [14–27]. The design mix is presented in Tables 1–3.

3 RESULTS AND DISCUSSIONS

The results of aggregate characterization, laboratory tests of oxide composition of the RHA, as well as of compressive test, are presented in Tables 4–8 and Fig. 1, 2 and 3 respectively.

3.1 Aggregate Characterization

The results of particle size analysis of fine, coarse aggregates and RHA used in the study are presented in Fig. 1, 2 and 3 respectively.

Table 1

Mix constituent proportion for cubic meter (1m³) of concrete

% of RHA	Weight of cement (kg)	Weight of RHA (kg)	Weight of fine aggregate	Weight of coarse aggregate (kg)	Weight of water (kg)	Water to binder ratio (w/b)
0	316.53	0.00	633.06	1266.12	158.27	0.5
5	299.72	15.78	630.98	1261.96	157.75	0.5
10	283.01	31.45	628.92	1257.84	157.23	0.5
15	266.42	47.02	626.88	1253.76	156.72	0.5
20	249.94	62.48	624.84	1249.68	156.21	0.5

Table 2

Mix constituent proportion for seven revibrated concrete beams

Percentage of RHA replacement (%)	Weight of cement (Kg)	Weight of RHA (Kg)	Weight of fine aggregate (Kg)	Weight of coarse aggregate (Kg)	Weight of water (Kg)	Water to binder ratio (w/b)
0	35.89	0.00	71.79	143.58	21.11	0.5
5	33.98	1.79	71.55	143.11	17.89	0.5
10	32.09	3.57	71.32	142.64	17.83	0.5
15	30.21	5.33	71.09	142.18	17.77	0.5
20	28.34	7.09	70.86	141.71	17.71	0.5

Table 3

Mix constituent proportion for three non-revibrated concrete beams

Percentage of RHA replacement (%)	Weight of cement (Kg)	Weight of RHA (Kg)	Weight of fine aggregate (Kg)	Weight of coarse aggregate (Kg)	Weight of water (Kg)	Water to binder ratio (w/b)
0	15.38	0.00	30.76	61.53	7.69	0.5
5	14.56	0.77	30.67	61.33	7.67	0.5
10	13.75	1.53	30.56	61.13	7.64	0.5
15	12.95	2.29	30.47	60.93	7.62	0.5
20	12.15	3.04	30.37	60.73	7.59	0.5

Fig. 1 shows the distribution curve of fine aggregate. An initial weight of 500g of the fine aggregate sample used in this study was used for the analysis. The distribution curve shows that 97.97% of the sample passed through the 5mm British Standard sieve with only 2.03% retained. Therefore, the aggregate is a fine-grained soil (sand).

Fig. 2 shows the result of sieve analysis for the coarse aggregate with an initial weight of 1000g. The curve reveals that 16.45% of the initial sample was retained on the 20mm sieve.

The particle size distribution curve for 300g of RHA is shown in Fig. 3. Analysis reveals 0.83% of the sample was retained on a 5mm sieve. The sum of the cumulative percentage retained on selected sieve is 169.9.

Table 4 shows specific gravity, bulk density and fineness values of fine and coarse aggregates, which are in agreement with [22]. Specific gravity of RHA is 1.92, which less than the weight of cement with specific gravity of 3.15; as such, an inevitable reduction in the weight of OPC-RHA concrete cubes took place.

Fineness Modulus of the RHA is 1.57. This is similar to the Fineness Modulus result of 1.38 submitted by [30]. RHA is finer than fine aggregate. The fineness modulus of 1.69 for RHA is less than fineness modulus of 2.3–3.1 for fine aggregate suggested by [27].

3.2 Chemical composition of the Rice Husk Ash (RHA)

In Table 5 it can be seen, that the RHA used in this study consists of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3), which, when summed up together, is 105.3%. This is above the minimum of 70% specified by [27] for pozzolana.

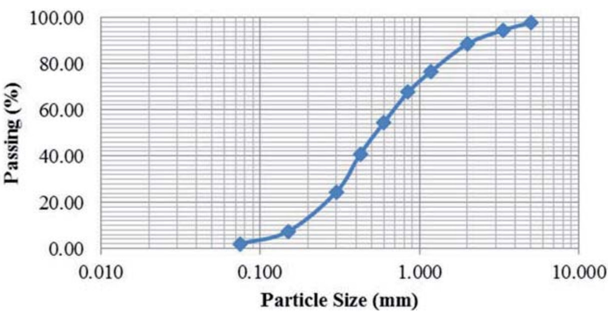

Fig. 1. Particle size distribution curve for fine aggregates

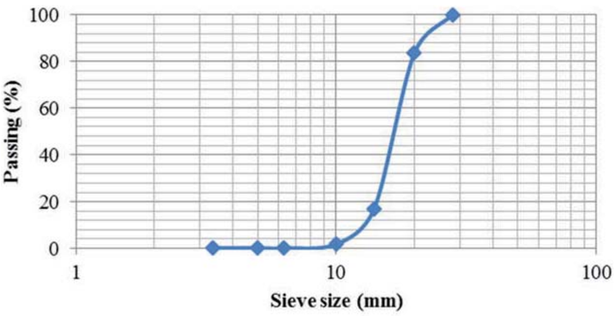

Fig. 2. Particle size distribution curve for coarse aggregates

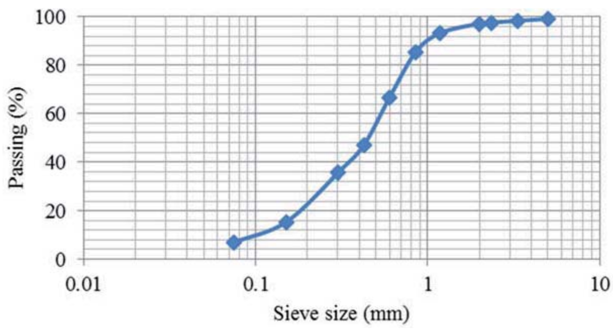

Fig. 3. Particle size distribution curve for RHA

Thus, it can be seen that the RHA is a very good pozzolana.

3.3 Workability

Workability is a function of water to cement ratio because too much mixing often caused reduction in strength of concrete mixture [29], [30].

Results of workability test on fresh concrete in terms of slump and compacting factor are presented in Table 6. It is evident that RHA, has influence on the workability of the freshly prepared RHA concrete,

Table 4

Characteristics of aggregates

Aggregate	Test	Result	Requirement
Fine	Sieve analysis: a. Coefficient of curvature, Cc b. Coefficient of uniformity, Cu	 2.41 6	 $1 \le Cc \le 3$ $Cu \le 6$ [16]
	Specific gravity	2.6	2.6–3.0 [22]
	Bulk density (kg/m^3) a. Compacted bulk density b. Un-compacted bulk density	 1570 1480	1500–1700 [23]
	Fineness modulus (FM) from standard sieves only	2.85	2.0–3.3 [18]
Coarse	Sieve analysis: a. Coefficient of curvature, Cc b. Coefficient of uniformity, Cu	 1.02 1.35	 $1 \le Cc \le 3$ $Cu \le 6$ [16]
	Specific gravity	2.65	2.4–2.8 [22]
	Bulk density (kg/m^3) a. Compacted bulk density b. Un-compacted bulk density	 1570 1480	1300–1800 [23]
	Fineness modulus (FM) from standard sieves only		
Rice Husk Ash	Specific gravity	1.92	3.15 [22]
	Bulk density (kg/m^3) a. Compacted bulk density b. Un-compacted bulk density	 780 610	
	Fineness modulus (FM) from standard sieves only	1.69	2.3–3.1 [27]

this is shown by the slump and compaction test which decreases from 20mm to 15mm corresponding to 0%RHA and 20%RHA respectively.

3.4 Effect of revibration on the flexural strength of RHA concrete

From Table 4, it is visible that the flexural strength increases at the initial stage of re-vibration for all specimens of the concrete beams with RHA at 10 minutes and 20 minutes against the control specimens without RHA (100% OPC). The early increase in flexural strength of the control beam is due to increase in the quantity of the tricalcium silicate (C_3S) in the OPC, but later there is a decline of flexural strength from 30minutes re-vibration due to debonding of chemical compound C_3S, which leads to decrease in strength from 30 minutes to the lap hour. This is especially visible for beams with 5%, 10% and 20% RHA respectively as shown in Figure 4. From the above discussion, it can be seen that early revibration of concrete improves the flexural strength of concrete and thereafter it causes the material to debond, thereby lowering the flexural strength.

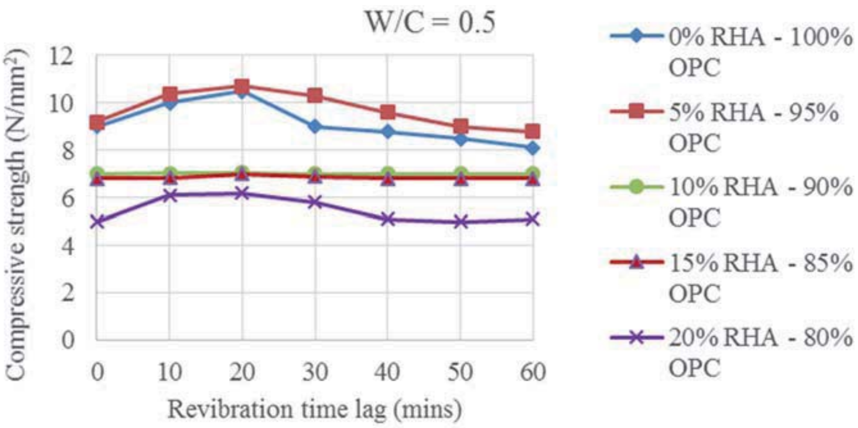

Fig. 4. Effect of re-vibration on the flexural strength with time for all percentages replacement

Table 5

Chemical composition of Ordinary Portland Cement and Rice Husk Ash

Elemental oxide	Percentage (%) of OPC	Composition percentage (%) of RHA
SiO_2	28.57	79.28
CaO	79.12	1.08
Al_2O_3	2.8	19.84
MgO	–	5.12
Fe_2O_3	4.28	6.52
Mn_2O_3	0.01	0.24
K_2O	0.24	2.62
P_2O_5	–	9.08
SO_3	1.6	0.00
TiO_2	0.16	0.61
ZnO	–	0.00
Cr_2O_3	0.038	0.00
Na_2O	–	3.20

3.5 Flexural strength of revibrated and non-revibrated beams

The average flexural strength for revibrated and non-vibrated beams at each RHA replacement concrete mix are summarized in Table 8. The average strength output of revibrated concrete after loading the beams to failure at 28 days curing, shows that only spacemen *B* with 5% RHA attained the highest flexural strength of 9.71 N/mm^2 from the initial control value obtained as 9.13 N/mm^2. Further

Table 6

Slump and compacting factor (w/c = 0.5)

Serial number	Specimens	Percentage of RHA (%)	Slump value (mm)	Compacting Factor
1	A	0%RHA+100%OPC	20	0.978
2	B	5%RHA+95%OPC	20	0.976
3	C	10%RHA+90%OPC	20	0.966
4	D	15%RHA+85%OPC	15	0.885
5	E	20%RHA+80%OPC	15	0.878

Table 7

Flexural strength of beam specimen for 28 days curing

Percentage of RHA	Revibrated beams				Non-revibrated Beams		
	Specimens	Re-vibration time interval (minutes)	Weight (kg)	Flexural strength (N/mm²)	Specimens	Weight (kg)	Flexural strength (N/mm²)
0	A_0 (Control)	0	33.50	9	A_0 (Control)	33.50	9.0
	A_1	10	35.65	10	A_1	35.65	8.8
	A_2	20	35.80	10.5			
	A_3	30	33.50	9			
	A_4	40	33.65	8.8	A_2	33.1	8.5
	A_5	50	33.10	8.5			
	A_6	60	33.90	8.1			
5	Bo (Control)	0	35.65	9.2	Bo (Control)	33.65	7.0
	B_1	10	33.05	10.4	B_1	33.10	6.8
	B_2	20	33.29	10.7			
	B_3	30	33.00	10.3			
	B_4	40	34.50	9.6	B_2	34.05	7.4
	B_5	50	35.05	9.0			
	B_6	60	34.50	8.8			
10	C_0 (Control)	0	33.80	7.0	C_0 (Control)	32.50	6.50
	C_1	10	34.54	7.03	C_1	33.60	5.90
	C_2	20	33.50	7.05			
	C_3	30	34.54	7.0			
	C_4	40	33.05	7.0	C_2	33.30	6.20
	C_5	50	33.15	7.0			
	C_6	60	35.05	7.0			
15	D_0 (Control)	0	33.20	6.80	D_0 (Control)	33.20	6.30
	D_1	10	33.50	6.83	D_1	33.15	6.10
	D_2	20	33.60	7.0			
	D_3	30	32.54	6.89			
	D_4	40	34.05	6.80	D_2	33.10	6.20
	D_5	50	33.70	6.80			
	D_6	60	33.80	6.80			
20	E_0 (Control)	0	34.00	5.0	E_0 (Control)	33.05	5.95
	E_1	10	33.00	6.1	E_1	33.00	6.00
	E_2	20	32.80	6.2			
	E_3	30	32.35	5.8			
	E_4	40	33.00	5.1	E_2	32.65	6.00
	E_5	50	33.00	5.0			
	E_6	60	33.05	5.1			

Table 8

Compressive strength (N/mm²)

% RHA – % OPC	Specimen	Non-revibrated beam at 28 days		Re-vibrated beam at 28 days	
		No. of beams	Average strength	No. of beams	Average strength
0%RHA + 100%OPC (Control)	A	3	8.8	7	9.13
5%RHA + 95%OPC	B	3	7.07	7	9.71
10%RHA + 90%OPC	C	3	6.53	7	7.01
15%RHA + 85%OPC	D	3	6.2	7	6.8
20%RHA + 80%OPC	E	3	5.98	7	5.47

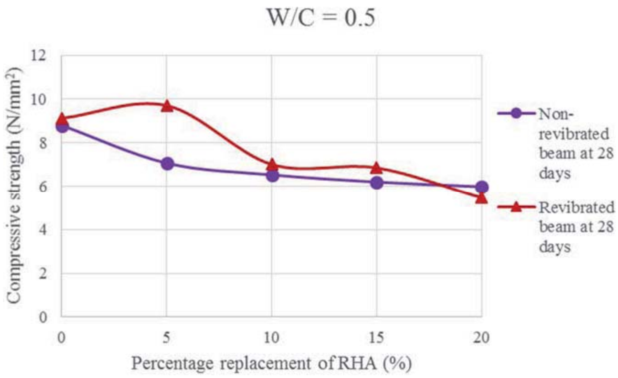

Fig. 5. Flexural strength of revibrated and vibrated beams at 28 days curing

incremental addition of RHA quantities above 5% shows that the control sample strength becomes higher than the one of re-vibrated samples after 28 days of curing. For non-revibrated beams, increasing the RHA gradually decreases flexure strength. The results obtained are in agreement with studies undertaken by [31], which indicated that revibration of concrete improves the flexural strength of concrete.

4 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

From the study carried out, the following conclusions can be made:

Optimum flexural strength is observed at 5% RHA replacement of OPC in concrete in both revibrated and non-revibrated concrete.

Increasing RHA concentration beyond 5% decreases the flexural strength for both revibrated and non-revibrated concrete. Hence, it can be recommended that replacement of RHA for cement should not be done beyond 5% for w/c ratio of 0.5.

4.2 Recommendations

Based on the experimental works the following recommendations can be made:

RHA can be utilized in concrete for low-cost construction and low strength elements like plaster, low-cost sandcrete block and mortar. The replacement may aid in the reduction of cost and equally in waste disposal. Up to 5% of RHA is recommended for use as a replacement for cement.

The study was based on 1:2:4 concrete mix ratio and a constant water/cement ratio of 0.5. Further study should be carried out on different mix designs and water / cement ratio.

References

1. Sridhar M. K. C, Hammed T. B. Turning Waste to Wealth in Nigeria. An Overview. *Journal on Human Ecology,* 2014, no. 46(2), pp. 195–203.

2. Oyekan G. L., Kamiyo, O. M. Effect of Nigerian Rice Husk Ash on some engineering properties of concrete and sandcrete blocks. *Proceedings of the 32nd Conference on Our World in Concrete & Structures***.** Singapore, 2007, pp. 28–29. Available at: http://www.cipremier.com/100032045.

3. Thandavamoorthy T. S, Ramasamy V. (2013). Experimental testing of Rice Husk Ash concrete beam. *Research in Civil Engineering and Environmental Engineering*, 2013, no. 1(1), pp. 139–148.

4. Akeke G. A., Ephraim M. E., Akobo I. Z. S., Ukpata J. O. Structural properties of Rice Husk Ash concrete. *International Journal of Engineering and Applied Sciences*. 2012, no. 3(3), pp. 57–62, ISSN 2305-8269. Available at: www.eaas-journal.org

5. Ogunbode E., Hassan I. O., Isa R. B. Evaluation of Compressive Strength of Concrete made with Rice Husk Ash obtained by open air burning. *Environmental Technology and Science Journal,* ETSJ. 2011, no. 4(1), pp. 137–147. Available at: www.academia.edu

6. Dewi S. J, Ramadhansyah P. J., Norhidayah A. H., Maniruzzaman A. A. M., Hainin M. R., Wan I. M. H. Effect of Rice Husk Ash fineness on the properties of

concrete. *Applied Mechanics and Materials*, 2014, p. 554, pp. 203–207. Available at: www.scientific.net

7. Monika N. C., Kiranbala, T. D. Contribution of Rice Husk Ash to the properties of cement mortar and concrete. *International Journal of Engineering Research & Technology (IJERT),* 2013, no. 2(2), ISSN: 2278-0181. Available at: www.ijert.org

8. Opeyemi D. A., Makinde O. O. The suitability of partial replacement of cement with Rice Husk Ash and bone powder in concrete structures. *International Journal of Emerging Technology and Advanced Engineering,* 2012, no. 2(9), ISSN 2250-2459.

9. Marthong C. Effect of Rice Husk Ash (RHA) as partial replacement of cement on concrete properties. *International Journal of Engineering Research & Technology (IJERT),* 2012, no. 1(6), ISSN 2278-0181.

10. Habeeb A. G., Mahmud B. H. Study on properties of Rice Husk Ash and its use as cement replacement material. *Journal of Material Research*, 2010, no. 13 (2), pp. 185–190, doi.org/10.1590/S1516-14392010000200011

11. Godwin A. A., Maurice E. E., Akobo I. Z. S., Joseph O. U. Structural properties of rice husk ash concrete. *International Journal of Engineering and Applied Sciences*, 2013, no. 3(1), pp. 57–62.

12. Oyekan G. L., Kamiyo O. M. Effect of Nigerian Rice Husk Ash on some engineering properties of concrete and sandcrete blocks. *Proceedings of 32nd Conference on Our World in Concrete & Structures.* Singapore, 2007.

13. Sampaio J., Coutinho S. J., Sampaio M. N. Portuguese rice husk ash as a partial cement replacement. *Proceedings of 1st Inter-American Conference on Non-Conventional Materials and Technologies on the Eco-construction and Infrastructure*. Joao Pessoa, Brazil, 2003.

14. British Standards Institution. BS 1881: Part 111. *Testing concrete. Methods for testing cement in a reference concrete.* BSI, London, UK, 1998.

15. British Standards Institution. BS EN 1008. *Mixing water for concrete. Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete.* BSI, London, UK, 2002.

16. British Standards Institution BS 812: Part 109 *Methods for determination of moisture content.* BSI, London, UK, 1990.

17. British Standards Institution. BS 882: Part 2. *Specification for aggregates from natural sources for concrete.* BSI, London, UK, 1992.

18. BS EN 772-1: *Methods of test for masonry units. Determination of compressive strength*. British Standard Institution, London, UK, 2000.

19. British Standards Institution. BS 1008: Part 116. *Mixing water for concrete.* BSI, London, UK, 2002.

20. British Standards Institution. BS 1377-2: *Methods of test for soils for civil engineering purposes. Classification tests*. BSI, London, UK, 1990.

21. British Standards Institution. BS 812: Part 103.1. *Methods for determination of particle size distribution – sieve test*. BSI, London, UK, 1985.

22. British Standards Institution. 812: Part 107. *Methods for determination of particle density and water absorption*. BSI, London, UK, 1995.

23. British Standards Institution. BS 812: Part 2. *Methods for determination of bulk densities of aggregate*. BSI, London, UK, 1995.

24. British Standards Institution. BS EN 12350-2. *Testing fresh concrete: slump test.* BSI, London, UK, 2000.

25. British Standards Institution. BS 1881: Part 111. *Method for normal curing of concrete.* BSI, London, UK, 1983.

26. British Standards Institution. BS 1881: Part 116. *Method for determination of Compressive Strength of Concrete Cubes.* British Standards Institution, London, UK, 1983.

27. ASTM C618. *Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete*. ASTM International, West Conshohocken, PA, 2012.

28. Ettu L. O., Osadebe N. N., Mbajiorgu M. S. W. Suitability of Nigerian agricultural by-products as cement replacement for concrete. *International Journal of Modern Engineering Research (IJMER)*, 2013, no. 3(2), pp. 1180-11085. ISSN: 2249-6645. Available at: www.ijmer.com

29. Appa R. G. Role of water binder ratio on the strength development in mortars incorporated with silica fumes. *Cem Concrete Res*., 2001, no. 31(3), pp. 443–447.

30. Ergul Y., Erdogan Y., Kilic A. Effect of limestone aggregate type and water cement ratio on concrete strength. *Mater Lett*., 2003, no. 58(5).

31. Auta S. M., Abanda M. A., Tsado T. Y. Experimental study on the flexural strength of reinforced and re-vibrated RHA concrete beam. *1st International Conference on Green Engineering for Sustainable Development, IC-GESD, Kano*, 2015, pp. 54–58.