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## EFFECT OF RICE-HUSK ASH (RHA) ON THE STRENGTH PROPERTIES OF CONCRETE

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### Abstract

*This paper is an investigation into the effect of Rice-Husk Ash (RHA) on the strength properties of concrete. RHAs were produced by Open-Air Burning method which was marked RHA-1 and by Closed-Air Burning method which was marked RHA-2. RHA-concrete of mix proportion of 0.35:0.65:2:4 (RHA:Cement:Sand:Stone) by volume and conventional concrete of mix proportion of 1:2:4 (Cement:Sand:Stone) by volume were produced and their strength properties were determined. The results of the study show that the maximum strength properties attained in terms of compression, tension and bonding were  $6.75\text{N/mm}^2$ ;  $4.32\text{N/mm}^2$ ;  $1.37\text{N/mm}^2$ ; and  $7.42\text{N/mm}^2$ ;  $4.75\text{N/mm}^2$ ;  $1.70\text{N/mm}^2$  for RHA-1 and RHA-2 concrete respectively. This is an indication that RHA-2 concrete produced from Closed Air method is more reliable in strength than from Open Air method.*

**Keywords:** Effects, Rice-Husk Ash, Concrete, Strength Properties

### Introduction

Rice husk ash (RHA) is produced by burning rice husk (which is a by-product of rice paddy obtained by milling) into ashes. The method of burning varies from individual to individual and place to place. But, generally, there are two major methods of burning: Open-Air-Burning and Closed-Air-Burning. There are a number of variations in the Open-Air-Burning method. One involves igniting a heap of the husk in open field and allowing it to burn for several days. Another method is to burn the husk in an open container for several days depending on the volume of the husk. The other method is to burn the husk in an incinerator which can be a metal sheet or ferro-cement chamber with or without a chimney and a space for adequate air circulation to assist the burning. All the above methods of burning subjected to natural conditions only. That is, after igniting the husk, it is allowed to burn on its own without external source of heat. The closed-Air-Burning method of producing RHA uses artificial aids to achieve the burning process. Furnaces are usually employed in this method. They are closed chambers

with insulating lining fitted with burners or electric coils capable of reaching high temperatures. Various furnaces are available depending on the capacity, temperature ranges and the source of heat supply in the chamber. RHA can be produced by this method by feeding the furnace with the husk and adjusting the temperature until a complete combustion at a specified temperature is ensured. According to Okereke and Obeng (1985) when rice husks are burnt in open field, the temperature of burning ranges from 200 – 300°C, (depending on the depth of the heaped husks). They found that the resulting ash has an average degree of fineness of 8,000 $\text{cm}^2/\text{g}$  with low degree of pozzolanic activity due to the presence of considerable amount of carbon. According to them (Okereke and Obeng, 1985) when burnt in open container at greater depth, the temperature ranges from 400 – 500°C, producing ash of an average degree of fineness of 10,000 to 12,000  $\text{cm}^2/\text{g}$  with greater pozzolanic activity.

Rahman (1986) produced RHA by Open-Air-Burning with the help of an open container (drum) of size 600mm in

diameter and 800mm in height and used it for lateritic soil stabilization for construction purpose. Loo *et al* (1984) also produced RHA by Open-Air Burning with the help of an incinerator which is basically a ferro-cement drum with a diameter of 750mm and a height of 1250mm and used it to produce RHA concrete. The maximum temperature recorded during the burning process was 760°C. Mehta (1977) produced RHA by Closed-Air-Burning method with the help of an industrial furnace and found that the ash consists of 80 – 95% SiO<sub>2</sub>, 1 – 2% K<sub>2</sub>O, and the rest essentially unburnt carbon. X-ray diffraction analysis of the ash showed that the silica was present in amorphous state. The ash has a degree of fineness of 500,000 to 600,000 cm<sup>2</sup>/g by gas absorption. Habeeb and Mahmud (2010) produced RHA by Closed-Air-Burning method by burning the husk in the laboratory using a ferro-cement furnace. The investigation they carried out on RHA concrete shows that incorporation of RHA in concrete increased water demand and RHA concrete gave excellent improvement in strength for 10% replacement (30.8% increment compared to the control mix), and up to 20% of cement could be valuably replaced with RHA without adversely affecting the strength. They further found that increasing RHA fineness enhanced the strength of blended concrete compared to coarser RHA and control OPC mixtures. Dabai *et al* (2009) produced RHA by Closed-Air-Burning by burning the husk in a muffle furnace for two hours at 1100°C to obtain a finely divided ash. Chemical analysis of the ash revealed high amount of silica (68.12%), alumina (1.01%) and oxides such as calcium oxide (1.01%) and iron oxide (0.78%) responsible for strength, soundness and setting of the concrete. It also contained high amount of magnesia (1.31%) which is responsible for the unsoundness. This result, therefore, indicated that RHA can be used as cement substitute at 10% and 20% replacement

and 14 and 28 day curing age. Abalaka (2012) produced RHA by Closed-Air-Burning method by burning the husk in a charcoal fired incinerator. The results of the tests carried out on RHA concrete show that RHA could be used to replace 25% of Ordinary Portland Cement (OPC) in normal strength concrete at water/binder ratio of 0.55 without compressive strength loss. The results also show increased tensile strength for the mix containing RHA over the control. Each of the researchers mentioned above produced the RHA either by using the Open-Air Burning or the Closed-Air Burning methods. No direct correlation between the reactivity of the various ashes used is possible as the researchers considered different parameters under different conditions in their investigations. In the research conducted by Ramasamy (2012) investigation was conducted on Rice Husk Ash (RHA) concrete to evaluate the compressive strength and to study its durability properties. In the preparation of rice husk concrete, cement was replaced at various percentage levels such as 5%, 10%, 15% and 20%. Besides control concrete was also prepared for comparison purpose. Two grades of concrete, namely M30 and M60, were prepared. Test results show that the addition of RHA as cement replacement material improves the strength and durability properties of concrete to considerable extent. In the research by Onojah *et al* (2013) rice husks were burnt in an open environment and the resulting black ash heated in a carbolite furnace at a controlled temperature of 6500C. The initial impurities of the resulting milky white RHA were determined by XRF technique. The RHA were subsequently mixed with binders and sintered at a temperature range of 1000 to 14000C. X-ray diffraction (XRD) Spectroscopy was carried out to determine the major crystallographic phases. Two crystalline silica phases, tridymite and cristobalite were dominant. Crystallite size of the insulators at this range of temperature

varies from 6mm to 10.02mm depending on the dominant phase. Khassaf, Jasim and Mahdi (2014) conducted a research to find out the effect of rice husk ash (RHA) on Fresh and Hardened Properties of concrete which used to reduction the seepage in the canal lining. The Rice Husks Ash (RHA) used in this investigation was burnt in a furnace with control in order to establish the optimum burning temperature and burning time. The combustion temperature was about 550°C and duration time was 2 hours. To establish the suitable proportion of RHA for the partial replacement of cement, concrete specimens were molded with 10%, 20%, and 30% of (RHA) replacing the cement, and the properties measured were workability, compressive strength, splitting tensile strength and dryings shrinkage. The results were compared with the concrete mix that does not contain RHA. The obtained results indicated that it was a significant reduction of workability in fresh concrete with the increase amount of RHA content in concrete, and it was an increase in the compressive strength and splitting tensile strength by increased of RHA% until 20%. The maximum increment was around 10.5% and 11% for the compressive strength and splitting tensile strength respectively then it were decrease with the increase of RHA to 30%, the decrease was around 17 % and 10.5% for compressive strength and tensile splitting strength respectively. The test of drying shrinkage indicated that it was decreased with increased of RHA%, the maximum decreased given by 30% RHA it was about 28% of normal concrete shrinkage after 90 days age. This research, therefore is aimed at producing RHA by an Open-Air Burning method and a Closed-Air Burning method and determine the physical properties of the respective RHAs and find their effect on the strength characteristics of concrete with the view to finding out the method that more reliable in terms of the strengths of concrete produced by partial substitution of cement with each RHA.

The physical properties of the respective RHAs considered were specific gravity, loose bulk density and fineness. The tests carried out on the RHA concrete were compressive strength, tensile strength and bond strength. Similar tests were also carried out on conventional concrete (concrete with 100% ordinary Portland cement) for comparison.

## Material and Methods

### Rice-Husk Ash (RHA):

The RHA used in this research were produced from the two conventional methods of burning - the Open-Air burning method and the Closed-Air burning method. The RHA produced by the Open-Air Burning method was marked "RHA-1". It was produced by burning the rice husks in an aluminum dust-bin. The dust-bin is closed at the bottom and opened at top with an internal diameter of 500mm, height of 600mm and thickness of 3mm. It was filled with the rice husks and the burning was started with a little amount of kerosene, after which, it was allowed to burn until the combustion was finished. The maximum temperature recorded was 560°C. At the end of the combustion, it was observed that the ash at the centre of the dust-bin was completely white in colour, signifying full combustion, but the colour varies from grey to black towards the walls of the dust-bin. The ash obtained from the dust-bin was whitish grey in colour. It was also noticed that the husks close to the walls of the dust-bin were only partially burnt and was sieved out. This resulted in wastage of rice husks.

The ash was sieved through the 300mm B.S. sieve (which was found more appropriate) and stored in polythene bags. The RHA produced by the Closed-Air burning method was identified as "RHA-2". It was produced using an electric industrial furnace. The furnace is a rectangular steel chamber with brick lining fitted with electric coils and having one steel door with brick lining on the inner

face. The rice husks were filled in clay bowls and kept in the furnace until they were completely burnt into ashes. The maximum temperature recorded was 870°C. The resulting ash after sieving through the 300µm B.S. sieve was dark grey in colour. There was no wastage of rice husks since they were completely burnt into ashes.

**Cement:** The cement used was the Ashaka brand of Ordinary Portland cement type obtained in 50Kg bag. Cement is the binding medium in a concrete mix when mixed with water and subsequently sets and hardens with time.

**Aggregates:**

Aggregate passing 5mm sieve are referred to as fine aggregate or sand while those retained on 5mm sieve are coarse aggregates or stones. The fine aggregate used was natural sand obtained from the "in Kano and was sieved remove all particles retained on 5mm sieve. The coarse aggregate used was the crushed

$$\frac{(W2-W1)}{(W4-W1)-(W3-W2)}$$

Where: W1 = Weight of empty jar plus cover

W2 = Weight of jar plus cover plus RHA sample

W3 = Weight of jar plus cover plus RHA sample plus water

W4 = Weight of jar plus cover plus water

Summaries of the specific gravities and loose bulk densities are given in Table 1.

**Table 1. Summary of the Results of Specific Gravity:**

Sample No	Specific Gravity of	
	RHA-1	RHA-2
1	2.14	2.13
2	2.13	2.14
Average	2.14	2.14

**Loose Bulk Density:** The loose bulk densities of RHA-1 and RHA-2 were determined in accordance with B. S. 812

granite stone of 30mm maximum size and was sieved to remove dust and other constituents which can react harmfully with cement.

**Water:**

Water is the constituent material that initiates the chemical reactions in the concrete mix. The water used for the mixes was taken from tap water and assumed to be free of materials that can significantly affect the hardening or strength and durability of concrete.

**Specific Gravity, Loose Bulk Density and Fineness of RHA:**

**Specific Gravity:** The specific gravities of RHA-1 and RHA-2 were determined in accordance with B. S. 812 (1975): the test was carried out on two samples for RHA-1 and RHA-2 and the specific gravity, G<sub>s</sub> was calculated from the relationship given below:

(1975): the test was carried out with the aid of a galvanized steel mould of volume  $4.0269 \times 10^{-3} \text{m}^3$ . Each sample of the

respective RHA was loosely poured into the mould to the brim and leveled neatly with a strip of metal. The weight of the empty mould and the weight of mould plus sample were recorded for each sample. The loose bulk density was calculated from the relationship:-

$$\text{Bulk Density} = \frac{w_2 - w_1}{v}$$

Where:  $w_1$  = Weight of empty mould

$w_2$  = Weight of mould plus sample

$v$  = Volume of mould

A summary of the results is presented in Table 2.

**Table 2. Summary of the Results of Loose Bulk Density**

Sample No	Loose Bulk Density (kg/m <sup>3</sup> )	
	RHA-1	RHA-2
1	297.00	349.89
2	302.61	354.80
Average	299.81	352.35

**Fineness:** The fineness of RHA-1 and RHA-2 was determined as the percentage of the respective RHA passing B.S. 63mm sieve when wet-sieved (Loo *et al.*, 1984). Each sample of the respective RHA (200 grammes) was soaked in water for 5 minutes and then wet-sieved for about 20 minutes when the water coming out of the sieve became clear of any particles of RHA. The ash retained on the B. S. 63 sieve was poured into a pan and kept in an oven at a constant temperature of 105°C for 24 hours after which it was removed

and weighed. The fineness was calculated from the relationship:-

$$\text{Fineness} = \frac{W_1 - W_2}{W_1}$$

Where:  $W_1$  = Weight of sample (200 grammes)

$W_2$  = Weight of sample retained on B. S. 63 sieve

A summary of the results of fineness is given in Table 3.

**Table 3. Summary of the Results of Fineness:**

Sample No	Fineness (%)	
	RHA-1	RHA-2
1	70	53
2	69	52
Average	69.50	52.50

**Concrete Mix Design:**

**Trial Mix:** The concrete was designed using the Absolute Volume method of mix

design and a constant mix proportion of 1:2:4 (cement: sand: coarse aggregate). Cement was replaced by 35% of RHA in

order to have full effect of RHA on the concrete. The mix design was based on the specific gravities and bulk densities given in Table 4. Trial mixes were first

prepared so as to determine the optimum W/(C+RHA) ratio which was used in the design of the main test. Details of the trial mixes are given in Table 5.

**Table 4: Specific Gravities and Bulk Densities of Cement, Sand, Stone and Water**

Materials	Specific Gravity	Bulk Density (Kg/m <sup>3</sup> )
Cement	3.15	1440
Sand	2.65	1660
Stone	2.65	1550
Water	1.00	1000

**Table 5: Details of the Trial Mixes**

Mix	% of OPC	% of RHA-1	% of RHA-2	W/(C+RHA) Ratios
A1	65	35	-	0.63
A2	65	-	35	0.63
B1	65	35	-	0.72
B2	65	-	35	0.72
C1	65	35	-	0.81
C2	65	-	35	0.81
D1	65	35	-	0.90
D2	65	-	35	0.90
E1	65	35	-	0.99
E2	65	-	35	0.99

The quantities of materials required for the trial mixes are given in Table 6.

**Table 6: Quantities of Materials required for the Trial Mix**

Mix	W/(C+RHA) Ratios	No. of cubes	Total Amount of Materials Required (Kg)				
			Cement	RHA	Sand	Stone	Water
A1	0.63	3	2.10	1.13	7.46	13.92	2.04
A2	0.63	3	2.10	1.13	7.46	13.92	2.04
B1	0.72	3	2.10	1.13	7.46	13.92	2.04
B2	0.72	3	2.10	1.13	7.46	13.92	2.04
C1	0.81	3	2.10	1.13	7.46	13.92	2.04
C2	0.81	3	2.10	1.13	7.46	13.92	2.04
D1	0.90	3	2.10	1.13	7.46	13.92	2.04
D2	0.90	3	2.10	1.13	7.46	13.92	2.04
E1	0.99	3	2.10	1.13	7.46	13.92	2.04
E2	0.99	3	2.10	1.13	7.46	13.92	2.04

**Main Mix:** Four mixes were designed for the main tests for compressive, tensile and bond strengths. Details of the main

mixes and the quantities of materials required are given in Table 7 and Table 8 respectively.

**Table 7: Details of the Main Mix**

Mix	% of OPC	% of RHA-1	% of RHA-2	W/(C+RHA) Ratios
A0-1	100	-	-	0.63
A0-2	100	-	-	0.86
A1-1	65	35	-	0.86
A2-2	65	-	35	0.86

**Table 8: Quantities of Materials Required for the Main Mix**

Mix	W/C or W/(C+RHA) Ratios	No. & Types of Specimens	Total Amount of Materials Required (Kg)					
			cement	RHA-1	RHA-2	Sand	Stone	Water
A0-1	0.63	12 Cubes, 3 Cylinders	18.14	-	-	41.87	78.13	11.41
A0-2	0.86	"	17.00	-	-	39.27	73.27	14.62
A1-1	0.86	"	11.05	5.95	-	39.27	73.27	14.62
A2-2	0.86	"	11.05	-	5.95	39.27	73.27	14.62

**Tests for Concrete Strengths:****Compressive Strength:**

The test for compressive strength was carried out in accordance with B.S. 1881 (1970). The samples were cast in steel moulds of 150mm cubes. A total of 78 cubes were prepared and cured in water by

immersion, out of which 30 were crushed at the age of 7 days for the trial tests and 48 were crushed at the ages of 7, 14, 21 and 28 days. The crushing was carried out in a universal testing machine of 600KN capacity. The results for the trial tests and the main tests are presented in Table 9 and Table 10 respectively.

**Table 9: Average Compressive Strength for the Trial Test**

Mix	W/(C+RHA) Ratios	Average Compressive Strength (N/mm <sup>2</sup> )
A1	0.63	3.74
B1	0.72	4.71
C1	0.81	5.80
D1	0.90	5.70
E1	0.99	4.61
A2	0.63	4.11
B2	0.72	5.17
C2	0.81	5.78
D2	0.90	5.87
E2	0.99	5.43

**Table 10. Average Compressive Strength**

Age (Days)	Tensile Strength for a given mix (N/mm <sup>2</sup> )			
	A0-1	A0-2	A1-1	A2-2
7	7.85	4.18	3.25	3.37
14	9.28	5.55	3.81	4.13
21	10.68	5.81	4.16	4.58
28	12.12	6.44	4.32	4.75

**Splitting Tensile Strength:**

The test for splitting tensile strength was carried out in accordance with B.S. 1881 (1970). The cube method of indirect tensile test was used to determine the tensile strength using the following equation:  $Tensile\ Strength = \frac{0.64f_{cu}}{a^2}$

Where:  $f_{cu}$  = Failure Load;  $a$  = Length of sides of the cube

A total of 48 cubes were cured in water by immersion and crushed at the ages of 7, 14, 21 and 28 days. The crushing was carried out in a universal testing machine of 600KN capacity. The result for the test is presented in Table 11.

**Table 11: Average Tensile Strength for the Main Test**

Age (Days)	Tensile Strength for a Given Mix (N/mm <sup>2</sup> )			
	A0-1	A0-2	A1-1	A2-2
7	7.85	4.18	3.25	3.37
14	9.28	5.55	3.81	4.13
21	10.68	5.81	4.16	4.58
28	12.12	6.44	4.32	4.75

**Bond Strength:** The bond strength test was conducted on 150mm diameter by 300mm long concrete cylinders in accordance with CP114 Part 2 (1969) using 10mm diameter plain bars. A total of 12 concrete cylinders were prepared for the four mixes, cured in water by

immersion for 28 days and tested for bond strength. The 28 day average bond strength was determined for each of the four mixes. The universal testing machine of 600KN capacity was used for the bond strength. The result for the test is presented in Table 12.

**Table 12: 28-Day Average Bond Strength**

Mix	A0-1	A0-2	A1-1	A2-2
Bond Strength (N/mm <sup>2</sup> )	2.45	1.80	1.37	1.70

## Results and Discussions

### Specific Gravity:

The results of the specific gravity tests presented in Table 1 show that the RHA produced by Open-Air Burning method (RHA-1) and that produced by Closed-Air Burning method (RHA-2) have the same specific gravity, 2.14. This result indicates that the method of producing RHA does not affect its specific gravity.

### Loose Bulk Density:

The loose bulk density test results presented in Table 2 show that the average loose bulk density of RHA-1 was  $299.81\text{kg/m}^3$  while that of RHA-2 was  $352.35\text{kg/m}^3$ . These values show that the RHA produced by Closed-Air Burning method has a greater loose bulk density than that produced by Open-Air Burning method. In other words, RHA-2 weighs

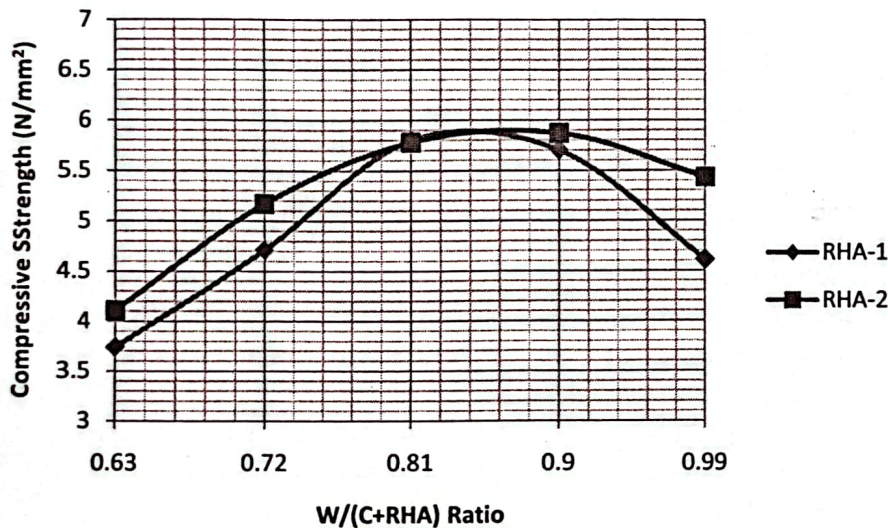
more and occupies less volume than RHA-1. This is probably because RHA-2 contain more fine particle compared to RHA-1 despite all of them were sieved through the same 300um B.S. sieve.

### Fineness:

The results of the fineness test presented in Table 3 show that the fineness of RHA-1 and RHA-2 were 69.5% and 52.5% (passing B.S. 63um sieve) respectively. Thus, RHA-1 is finer than RHA-2. The reason is that RHA-2 contains more coarse particles resulting, probably, from unburnt carbon compared to RHA-1.

### Compressive Strength

The variation of the compressive strength of the two RHA concretes with W/(C+RHA) ratios for trial tests is illustrated in Figure 1.

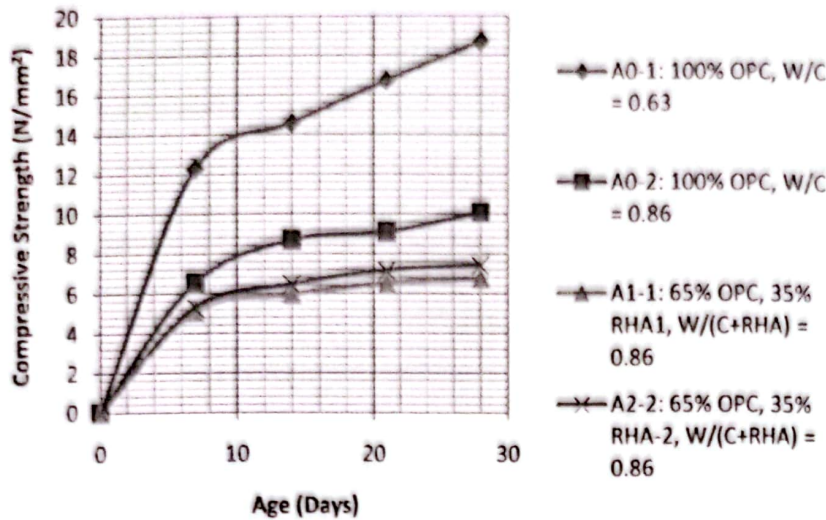


**Figure 1 Variation of Compressive Strength of Concrete with Age for the Trial Test**

The compressive strength of RHA-1 concrete increases from  $3.7\text{N/mm}^2$  at a W/(C+RHA) ratio of 0.63 to a maximum of  $5.90\text{N/mm}^2$  at an optimum W/(C+RHA) ratio of 0.85 and then decreases to  $4.61\text{N/mm}^2$  while that of RHA-2 concrete increases from  $4.11\text{N/mm}^2$  at a W/(C+RHA) ratio of 0.63 to a maximum of  $5.95\text{N/mm}^2$  at an optimum W/(C+RHA) ratio of 0.87 and the

decreases to  $5.43\text{N/mm}^2$ . These results show that RHA-2 concrete has slightly higher compressive strength compared to RHA-1 concrete but at slightly higher W/(C+RHA) ratio. From the results of these trial tests, an average W/(C+RHA) of 0.86 [that is  $(0.85+0.87)/2$ ] was adopted for the main tests. The variation of compressive strength of RHA-1 and RHA-

2 concretes with age for the main tests is



as illustrated in Figure 2.

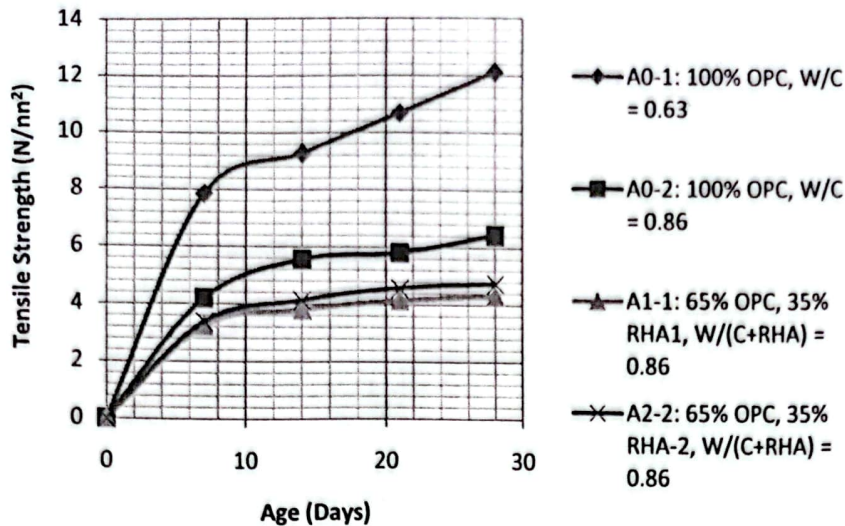
**Figure 2 Variation of Compressive Strength of Concrete with Age for the Main Test**

The compressive strength of RHA-1 concrete increases gradually with age as represented by curve A1-1 while those of RHA-2 concrete also increases gradually (but at higher values) with age, as represented by curve A2-2 of the same figure. The compressive strength of conventional concrete of w/c ratio equal to 0.63 increases more rapidly with age and at higher values (see curve A0-1 of figure 1) when compared with the trend of changes for the RHA concretes. However, the compressive strength of conventional concrete of w/c ratio of 0.86 increases gradually with age (although at higher values) just like in the case of the RHA concretes. The results of the compressive strength test, generally, indicate that the compressive strengths of RHA-2 concrete are slightly greater than those of RHA-1 concrete. Although, RHA-1 being finer than RHA-2, is expected to produce a concrete of greater strength (Loo *et al.*

1984; Habeeb and Mahmud 2010), but the fact that RHA-2 concrete has greater strengths suggests that RHA-2 probably contains more reactive silica than that of RHA-1. (Note: amorphous silica is more reactive than crystalline silica). Hence the closed-air burning method produced a more reactive RHA than the open-air burning method. The compressive strengths of conventional concrete are only slightly greater than those of the RHA concretes if a W/(C+RHA) ratio of 0.86 is used. However, the strengths are greater if a lower W/C ratio of say (0.63) is used.

### Tensile Strength

The variation of tensile strengths with age for the RHA concretes and the conventional concretes, as illustrated in Figure 3, follows similar pattern as for compressive strengths with age except that the tensile strengths are about 35% less than the compressive strengths in all the cases.



**Figure 3 Variation of Tensile Strength of Concrete with Age for the Main Test**

Curves A0-1, A0-2, A1-1 and A2-2 of Figure 3 represent the variation of tensile strength with age for conventional concrete of W/C ratio of 0.63; conventional concrete of W/C ratio of 0.86; RHA-1 concrete and RHA-2 concrete of W/(C+RHA) ratio of 0.86 respectively. As expected, the tensile strengths of RHA-2 concrete are slightly greater than those of RHA-1 concrete. The tensile strengths of conventional concrete is also slightly greater than those of the RHA concretes if a W/(C+RHA) ratio of 0.86 is used but the strengths are greater if a lower W/C ratio (0.63) is used.

#### **Bond Strength**

Table 12 gives the 28-Day average bond strength for the respective mixes. The average 28-day bond strength of conventional concrete of a W/C ratio of 0.63 was  $2.45\text{N/mm}^2$  while that of the same concrete of W/C ratio of 0.86 was  $1.8\text{N/mm}^2$ . For RHA-1 concrete of W/(C+RHA) ratio of 0.86, the average 28 day bond strength was  $1.39\text{N/mm}^2$  while for RHA-2 concrete of the same W/(C+RHA) ratio; the bond strength was  $1.70\text{N/mm}^2$ . The above results show that RHA-2 concrete has a greater bond strength (about 18.24% more) than RHA-1 concrete which is again indicative of

RHA-2 being more reactive than RHA-1. A comparison of the bond strengths of conventional concrete with those of the RHA concretes shows that, for the same W/C or W/(C+RHA) ratio, there is no significant difference between the bond strengths especially with the bond strength of RHA-2 concrete. However, at a lower W/C ratio (0.63), the bond strength of conventional concrete is about 30.61% greater than that of RHA-2 concrete.

#### **Conclusions and Recommendations**

After a critical analysis and discussions on the various tests performed on the rice husk ashes, the RHA concretes and conventional concrete, the following conclusions were drawn:

- It was found that the method of producing RHA does not have any significant effect on the specific gravity of RHA. A value of 2.135 was obtained for both RHA-1 and RHA-2 which is about 32% less than that of cement (3.15).
- The closed-air-burning method produced an RHA which has a greater loose bulk density ( $352.35\text{kg/m}^3$ ) than the open-air-burning method with a loose bulk density of  $299.81\text{kg/m}^3$ .
- The RHA produced by open-air-burning method was found to be finer

(with fineness of 69.5% passing B.S. 63um sieve) than that produced by closed-air-burning method (with fineness of 52.5% passing B.S. 63um sieve).

- The RHA produced by closed-air-burning method increases the strength properties (compressive, tensile and bond strengths) of RHA concrete and therefore more reactive than that produced by open-air-burning method. Comparison of the various properties of the two RHA concretes with those of conventional concrete shows that the values of the latter is only slightly higher than those of the former if the same W/C or W/CRHA ratio is used throughout but considerably higher if a lower W/C is used for the conventional concrete.

- In the final analysis it is worth concluding that the open-air-burning method of producing RHA yields RHA which has a smaller loose bulk density, finer but less reactive (in terms of the compressive, tensile and bond strengths of the concrete made with it) compare to that produced by closed-air-burning method.

Haven considered the above conclusion; it is hereby recommended that, the Closed-Air Burning method for the production of RHA be used. This is evident from the literature review where it is seen that most of recent researches on RHA used the Closed-Air Burning method in preference to the Open-Air-Burning method which was mostly used in the olden days.

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