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Influence of Rice Husk Ash Density on the Workability and Strength of Structural Concrete

John Kamau, Ash Ahmed, Fraser Hyndman, Paul Hirst and Joseph Kangwa

***Abstract*—Supplementary cementitious materials (SCMs) have been known to improve the properties of fresh and hardened concrete, and at the same time enhance the sustainability of concrete. Rice husk Ash (RHA), is one such material, but has neither been widely studied nor applied in practice. This work investigated the effect of the density of RHA on the workability and compressive strength of fresh and hardened RHA-replaced concrete respectively. Cement was replaced with RHA in concrete by weight (RHA-W) and by volume (RHA-V) at steps of 0%, 5%, 7.5%, 10%, 15%, 20%, 25% and 30%. The 0% replacement was used as the reference point from which performances were measured. Results showed that unlike the characteristic of other established pozzolans, RHA significantly reduced the workability of wet concrete and the rate of compressive strength gain over curing time due to a high water demand that is caused by the increased volume of replaced concrete, which results from its low density. Workability reduced with increased replacement for both RHA-W and RHA-V. Replacements of above 15% were not possible for the RHA-W due to the high water demand. However, replacements of up to 30% were achieved for the RHA-V. RHA-W specimens achieved lower compressive strengths and were observed to gain strength at a lower rate over the 28 to 91-days period of curing compared to RHA-V specimens. This behavior was attributed to the shortage of water that is necessary for the hydration of cement and subsequent pozzolanic reaction, which is the basis of the contribution that is made to the strength and performance of concrete by SCMs. However, the compressive strengths achieved were above the study's target concrete strength of class C32/40 at 91 days, which is among those classes that are listed as being durable and suitable for structural applications. A conclusion that RHA should supplement cements by volumetric replacement rather than simple substitution by weight was drawn.**

***Index Terms*—Compressive Strength; Density; Rice Husk Ash; Volume; Workability.**

I. INTRODUCTION

Cement is one of the notorious contributors to global anthropogenic CO_2 [1], [2]. The production of a tonne of cement emits approximately a corresponding tonne of CO_2, making it the most energy-intensive material produced after steel and aluminium [3], [4] .

The sustainability of cement can, however be improved by using materials that require less process heating and emit fewer levels of CO_2 to supplement cement in concrete [5], [6]. One such material, though only studied and used on a limited scale, is Rice Husk Ash (RHA) [6].

Rice is a cereal grain that is farmed for human consumption [6], [7]. Over 2 million tonnes of rice are produced every year all over the world, with Asia being the largest producer as is shown in Table I [8], [9]. Rice husk, the outer shell that covers the rice kernel, is a product of threshed paddy to separate rice grain and the husk [6],[10]. Over 600 million tonnes of paddy were produced in the year 2008 [6]. Paddy is of very low nutrition to even be suitable for animal feed, but of all plant residues, it contains the highest amount of silica [6]. RHA is obtained from either controlled or uncontrolled incineration of rice husks [6].

TABLE I: LARGEST RICE PRODUCING COUNTRIES IN THE WORLD [8]

Rank	Country	Rice produced (millions of hectares)
1	India	43.2
2	China	30.4
3	Indonesia	12.2
4	Bangladesh	12.0
5	Thailand	9.7
6	Vietnam	7.7
7	Burma	6.8
8	Philippines	4.5
9	Cambodia	2.9
10	Pakistan	2.9

A growing body of literature has claimed that besides leading to sustainable concrete and improving the durability of hardened concrete, the use of Supplementary Cementitious Materials (SCMs) such as Pulverised Fuel Ash (PFA), Ground Granulated Blast Furnace Slag (GGBS) and RHA improves the workability of fresh concrete and the strength and durability of hardened concrete [6], [11]. Givi, et al. [12] and [10] reported that RHA improved the workability of concrete studied, while [9], [13], [14], concluded that RHA significantly increased the water demand of fresh concrete. This paper calls into question this anomaly. Moreover, no work was found on the effect of the density of RHA on the workability and strength of RHA replaced concrete mixes. Also, even though the work of [15] recommended that RHA should supplement cement using volumetric replacement rather than simple substitution by weight, no work reporting the comparison between the two replacements was found.

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Research on the compressive strength of RHA replaced concrete has reported strengths above those achieved by control specimens [16], [10]. However, the increased volume of mixes as a result of RHA substitution could result in a shortage of water that is available for the hydration of cement to produce calcium hydroxide [$Ca(OH)_2$], which is necessary for the pozzolanic reaction to take place, and can lead to lower strengths, as this reaction is the basis of the contribution that is made to strength and the performance of concrete by SCMs [6], [17], [18].

This work investigated the effect of replacing cement in concrete mixes using RHA by weight (RHA-W) and by volume (RHA-V) on the workability of fresh concrete and compressive and tensile strengths of hardened concrete.

II. METHODS

RHA was sourced from Thailand through a stockist in the UK. Snowcrete cement type CEM 1 52.5 N to [19] was used, while the concrete mix proportions of cement, fine and coarse aggregates were 1: 2: 3 for a target strength of C32/40 which is listed by [20] among strength classes that are durable and suitable for structural applications.

Fine aggregates were well graded, washed concrete sand of between 0mm to 4.75mm, while coarse aggregates were crushed limestone graded between 4.75mm to 16mm, with a particle density of 2.62g/cm^3 and 2.63g/cm^3, and an absorption rate of 1.8% and 0.6% for sand and limestone respectively.

RHA was dried and sieved using a 45µm sieve to [21], to achieve a degree of fineness of not more than 63µm [22]. Apparent density, which is defined by [23] as the mass in grams of a powder which occupies a volume of one millilitre (ml) under standardized conditions, of RHA and cement was obtained conforming to [23].

The apparatus were a stainless steel lockable funnel, a 500ml receiver and a stand. The receiver was weighed before and after it was filled with RHA and cement respectively through the funnel. A total of two measurements were taken and the arithmetic mean of the two was used to calculate for the apparent density using (1) [24].

$$\frac{M_3 - M_0}{V} \qquad (1)$$

Where M_3 is the mass in grams (g) of the receiver with the powder, M_0 is the mass in grams of the empty receiver and V is the volume of the receiver in millilitres (ml).

Cement was replaced with RHA in concrete by weight and volume at steps of 0%, 5%, 7.5%, 10%, 15%, 20%, 25% and 30%. The 0% replacement, also referred to as the control was taken as the point of reference from which all performances were measured [5]. Table II and Fig. I show a comparison between the weights of RHA in both RHA-W and RHA-V replacements. The mixing of concrete conformed to [25].

TABLE II: COMPARISON OF THE WEIGHT OF RHA IN RHA-W AND RHA-V (KG)

Specimens	Weight of RHA at percentage replacement (kg)						
	5%	7.5%	10%	15%	20%	25%	30%
RHA-W	0.4	0.5	0.7	1.1	-	-	-
RHA-V	0.1	0.2	0.2	0.3	0.4	0.5	0.7

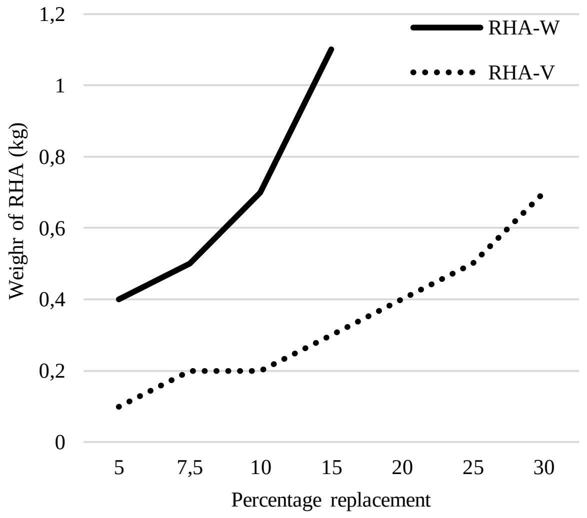

Fig. I. Weight of RHA in RHA-W and RHA-V used against percentage replacements (Kg)

Aggregates and cement were weighed and mixed using a concrete mixer for a total of eight minutes, with a three-minute rest in between the mixing. The top of the mixer was covered during the mixing to prevent evaporation.

A constant Water Cement Ratio (WCR) of 0.5 was used for all mixes in a bid to achieve a good balance of workability and strength in line with Abram's law which states that the strength of a concrete mix is determined by the WCR, with lower WCR spelling higher strengths and vice-versa [26].

Workability was measured using the slump test method, whose apparatus were a slump cone and a tamping rod conforming to [27]. The cone's top and bottom diameters measured 100mm and 200mm respectively, with a height of 300mm. The slump mould was filled in three layers and compacted using 25 uniform, vertical strokes of the tamping rod per layer, which were distributed evenly across the surface. The top of the mould was then levelled and the mould carefully removed. Slump was determined by measuring the difference between the top of the mould and the highest point of the slumped specimen as shown in Fig. II.

Cube moulds for compressive strength measured 100mm x 100mm x 100mm, whereas cylinder moulds for tensile strength testing were 150mm in diameter and 300mm in height, conforming to dimensional guidelines of [28].

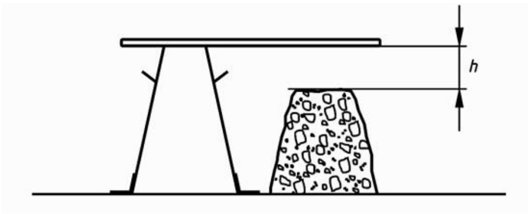

Fig. 2. Measurement of slump [27]

The method used to make cubes conformed to [29]. The insides of the moulds were sprayed with a thin film of non-reactive release material, filled with concrete and firmly secured on to a mechanical vibrating table. Full compaction was deemed to have been achieved when there was no further appearance of large bubbles on the surface of the concrete, and the surface became smooth with a glazed appearance.

For cylinders, three equal layers with 25 uniform, vertical strokes of the tamping rod distributed equally on the whole surface of each layer were used. The sides of the moulds were tapped with a mallet for each layer after compaction to remove air bubbles.

To ensure repeatability, three specimens were made for each test [30].

The specimens were left in the moulds for 24 hours, after which they were stripped, marked and submerged in a water tank at temperatures of 20^0C ±2 until their age of testing conforming to [29].

Specimens were cured for up to 91 days following the rationale that pozzolanic reactions require the hydration products of cement in the presence of water for the secondary hydration to take place, which leads to the formation of further calcium silicate and calcium aluminate compounds, that are strength giving [6, 29].

Compressive strength tests were conducted to [30]. The testing machine was wiped clean and the cubes were applied perpendicularly in the direction of the casting. A load of 0.2 N/mm^2.s (Newtons per square millimetres per second) was applied. After the application of an initial load of 0.6 ± 0.2 N/mm^2.s, which, according to [30] does not exceed 30% of the failure load, further constant load was applied at a rate of ±10% until no further load could be sustained.

Compressive tests were carried out at 7, 28, 56 and 91 days. Results were taken as an average of the three cubes per test, and expressed in N/mm^2. Tensile strengths were conducted to [31]. The testing machine conformed to [32] while packing strips conformed to [33].

The surfaces of the specimens, packing strips, loading pieces and platens were wiped to remove excess moisture and grit. The test specimens were then placed centrally in the machine and packing strips carefully positioned with the upper and lower platens parallel to each other. Initial load was applied at a constant rate of stress of 0.04 N/mm^2.s, which, according to [31] does not exceed 20% of the failure load. Further constant load was thereafter applied at a rate of ±10% until no further load could be sustained. The splitting tensile strength was calculated as in (2) conforming to [31].

$$f_{ct} = \frac{2 \times F}{\pi \times L \times d} \qquad (2)$$

Where f_{ct} is the splitting tensile strength (N/mm^2), F is the maximum load (N), L is the length of the line of contact of the specimen (mm) and d is the designated cross-sectional dimension (mm). The tensile strength tests were carried out at 91 days, and the results recorded in in N/mm^2.

III. RESULTS AND DISCUSSIONS

Table III shows the chemical composition of RHA obtained by X-ray diffraction (XRD). From these results, RHA contained a total of 88.6% the sum of Silicon dioxide (SiO_2), Aluminium oxide (Al_2O_3) and Iron oxide (Fe_2O_3), Sulphur trioxide (SO_3) of 0.1 and a loss on ignition (LOI) of 2.2, which satisfied the requirements of [34] for pozzolanic materials. Apparent density was calculated at 1093 kg/m^3 and 231.4 kg/m^3 for cement and RHA respectively.

TABLE III: CHEMICAL COMPOSITION OF RHA AND APPARENT DENSITY

	Percentage composition	
Chemical	Cement	RHA
Silicon dioxide (SiO_2)	21.9	87.8
Aluminium oxide (Al_2O_3)	4.0	0.4
Iron oxide (Fe_2O_3)	0.2	0.3
Calcium oxide (CaO)	66.5	0.7
Magnesium oxide (MgO)	1.4	0.6
Sodium oxide (Na_2O)	0.1	0.5
Potassium oxide (K_2O)	0.6	2.2
Loss on ignition (LOI)	-	2.2
Sulphur trioxide (SO_3)	2.6	0.1

A. *Density*

Table IV and Fig. 3 show the densities of RHA-W specimens in kg/m^3 over a 91-day curing period, while Table V and Fig. 4 show the same information for the RHA-V specimens. Fig. 5 shows the densities of RHA-W and RHA-V at 7 and 91 days. From the results, an addition of RHA significantly reduced the density of the resultant concrete, with further addition of RHA resulting in further reduction in density. The results were consistent with literature that the addition of RHA by weight results in an increased paste volume that ultimately reduces the density of concrete [10], [12].

For RHA-W, densities were observed to decrease with curing age, consistent with literature that like other SCMs, RHA acts as a filler in the early age because it has to wait for $Ca(OH)_2$ that is produced during the hydration of cement in the early age before the pozzolanic reaction can begin [6].

The reduction in density over time was explained as being a result of the consumption of $Ca(OH)_2$ during secondary hydration to form the strength giving calcium silicate hydrate (C-S-H), which is less dense than the cement components from which it is generated [6], [11], [35].

TABLE IV: DENSITIES OF RHA-W REPLACED SPECIMENS AT 28 TO 91 DAYS OF CURING (KG/M3)

CURING AGE (DAYS)	DENSITY AT PERCENTAGE REPLACEMENT				
	0%	5%	7.5%	10%	15%
7	2350	2275	2274	2260	2244
28	2350	2274	2272	2258	2225
56	2356	2269	2268	2255	2223
91	2366	2262	2260	2251	2219

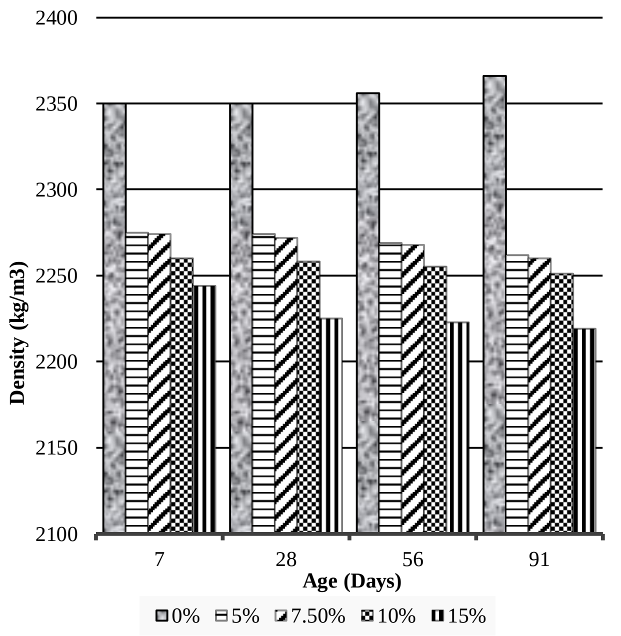

Fig. 3. Densities of RHA-W-replaced specimens against curing age (Kg/m^3)

TABLE V: DENSITIES OF RHA-V REPLACED SPECIMENS AT 28 TO 91 DAYS OF CURING (KG/M3)

Age	Density at percentage replacement							
(days)	0%	5%	7.5%	10%	15%	20%	25%	30%
7	2350	2305	2300	2299	2297	2297	2295	2288
28	2350	2310	2304	2307	2305	2296	2291	2283
56	2356	2313	2308	2306	2303	2298	2288	2279
91	2366	2322	2316	2318	2311	2305	2284	2276

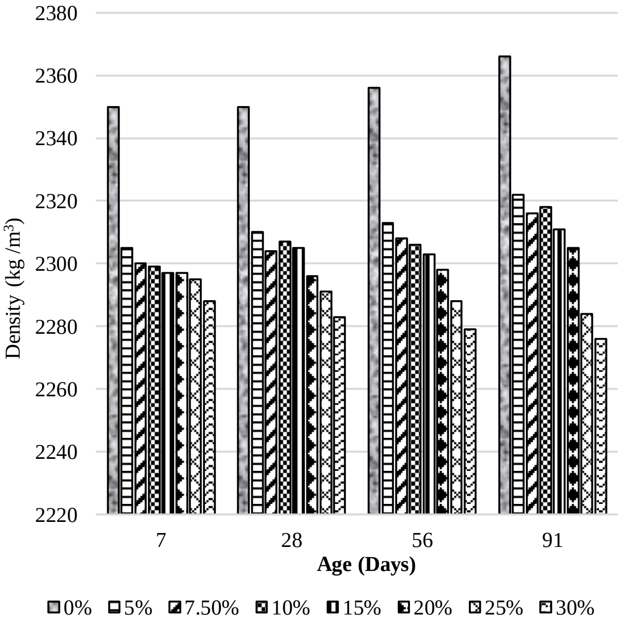

Fig. 4. Densities of RHA-V-replaced specimens against curing age (Kg/m^3)

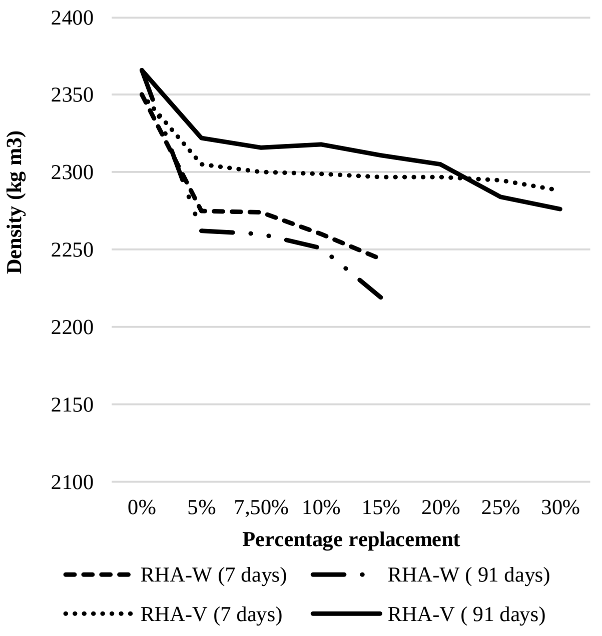

Fig. 5. RHA-W and RHA-V-replaced specimens' densities between 7 and 91 days (Kg/m^3)

For RHA-V, density was observed to increase with curing age up to the 20% replacement after which it decreased with tine for the 25% and 30% replacements. This could be the result of a higher ratio of cement to RHA at lower replacements that leaves some $Ca(OH)_2$ unreacted.

B. *Workability*

Table VI and Fig. 6 show the slumps that were obtained for RHA-W and RHA-V mixes. The slumps of RHA-V were of class S1 which is termed as *very low* by [36]. The workability of RHA-V reduced with further replacement up to the 10% replacement, after which no further slumps were recorded.

For RHA-W, no slumps were recorded for all replacements, with workability reducing significantly with further replacement. Due to a high water demand, replacements of above 15% by weight could not be achieved.

The low workability was attributed by literature to an increased ratio of the volume of RHA replaced mixes to WCR due to the very low density of RHA [6], [10]. As is shown in Tables IV and V and Figs. 3, 4 and 5 above, the densities of RHA replaced-specimens were much lower than those of 100% cement specimens. The apparent density was also found to be 4.7 times lower than that of cement, a factor which significantly increased the volume of mixes studied.

From Table II and Fig.1, a huge disparity between the weights of RHA-V and RHA-W was recorded, signifying the extent to which RHA-W could have increased the ratio of the volume of the mixes to that of WCR [10].

Replacements of above 30% could have been achieved for the RHA-V, even though with further reduced workability. However, even though workability was reduced, the compaction for both RHA-W and RHA-V mixes was good and no bleeding was observed.

TABLE VI: SLUMPS OF RHA-REPLACED MIXES (MM)

Specimens	0%	5%	7.5%	10%	15%	20%	25%	30%
RHA-W	30	0	0	0	0			
RHA-V	30	25	15	5	0	0	0	0

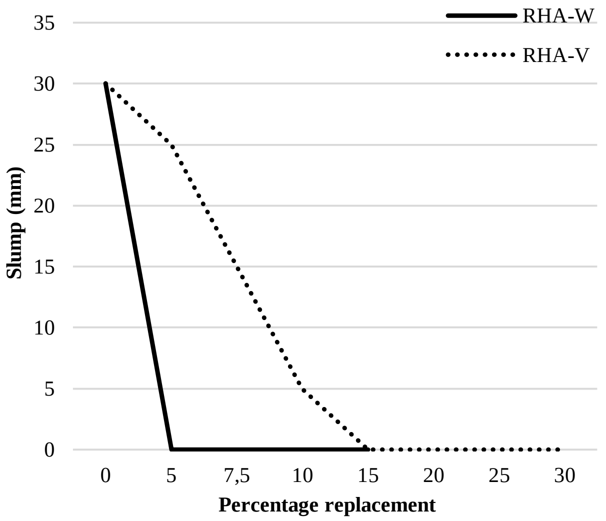

Fig. 6. Slumps of RHA-W and RHA-V-replaced mixes against percentage replacements (mm)

The results confirmed the findings of [9], [13], [14], [37], that RHA reduced the workability of concrete. From [6], [38], [39], it was also reported that a high water demand and coarseness is a major characteristic of RHA caused by its high pozzolanic activity and a high specific surface area, but can be mitigated by using RHA of between 4-8µm, with the addition of superplasticisers. As highlighted in the methods section, this study used a 45µm sieve and no plasticisers were introduced to the mixes. This could have been the reason for the low slumps observed. The results were however not consistent with [12], [10], who reported that a high cement replacement with RHA at a low WCR considerably increased the slump of mixes studied.

C. *Compressive Strength*

Table VII and Fig. 7, and Table VIII and Fig. 8 show the compressive strengths of RHA-W and RHA-V-replaced specimens respectively over a 91-day curing regime. The compressive strengths of RHA-V specimens were higher than those of RHA-W for all replacements. However, both RHA-W and RHA-V achieved compressive strengths that were well above the study's target strength of class C32/40 at 91 days, which is listed by [40] among strength classes that are durable and suitable for structural applications such as buildings and bridges.

The compressive strengths recorded are an indication that RHA could be used with up to 15% replacement by weight or 30% replacement by volume. Higher replacements might also have been achieved for both weight and volume had RHA with the right fineness been used together with superplasticisers [6], [11], [39].

RHA could therefore be used with an advantage to improve the sustainability and durability of concrete, as well as mitigate on the environmental nuisance that results from the throwing away of rice husks in landfill [6], [10], [11], [39].

Due to its high pozzolanic activity, RHA could be used to replace the more expensive silica fume in concrete [10].

TABLE VII: COMPRESSIVE STRENGTHS OF RHA-W-REPLACED SPECIMENS OVER 91 DAYS CURING (N/MM2)

AGE	0%	5%	7.50%	10%	15%
7	56.2	41.4	43.4	38.0	34.6
28	61.6	53.4	56.8	47.6	47.3
56	67.6	53.3	61.1	56.4	51.7
91	71.3	60.1	60.3	47.7	47.7

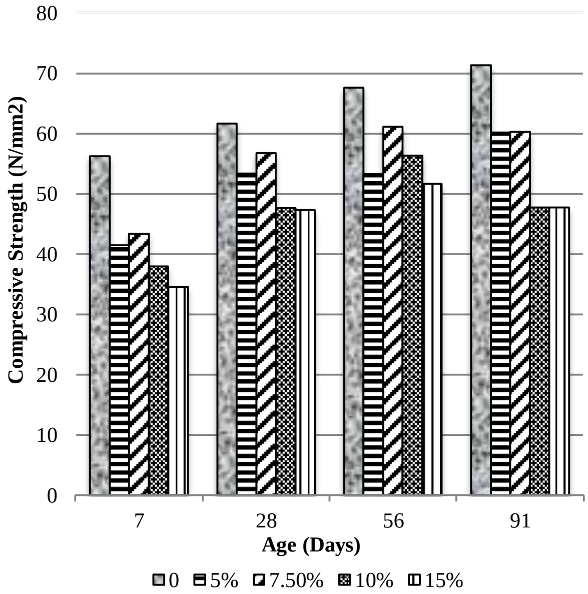

Fig. 7. Compressive strengths of RHA-W-replaced specimens against curing age (N/mm^2)

TABLE VIII: COMPRESSIVE STRENGTHS OF RHA-V-REPLACED SPECIMENS OVER 91 DAYS OF CURING (N/MM2)

Age	0%	5%	7.50%	10%	15%	20%	25%	30%
7	56.2	49.0	47.4	43.1	40.1	37.8	37.1	31.2
28	61.6	56.0	59.1	54.0	48.4	46.9	38.6	40.1
56	67.6	60.1	61.5	57.1	54.9	53.5	51.9	43.9
91	71.3	60.0	68.3	62.7	59.6	57.7	54.8	47.5

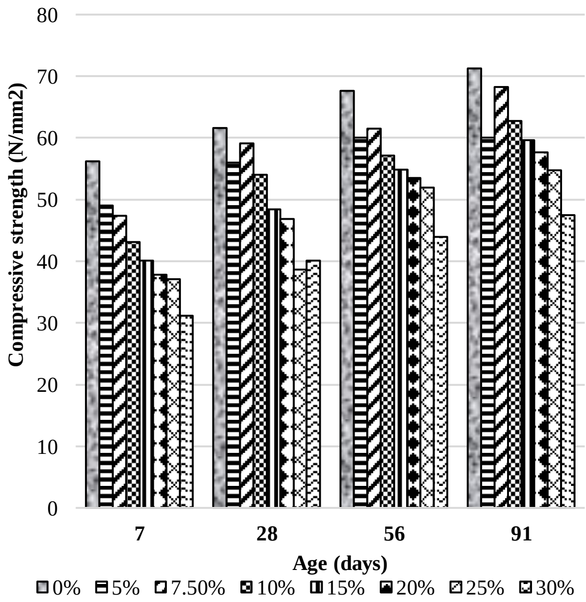

Fig 8. Compressive strengths of RHA-V-replaced specimens against curing age (N/mm^2)

D. Gain in Compressive Strengths between 28 and 91 Days

A gain in compressive strength above 100% cement specimens over time is a characteristic of SCM materials in concrete [6], [10], [41]. Table IX and Fig. 9 show the percentage increase in compressive strengths of RHA-W and RHA-V specimens between 28 and 91 days. The gain in compressive strengths between 28 and 91 days for the RHA-W specimens significantly decreased with further replacement. This could be a result of the increased volume of mixes with the addition of RHA, increasing the ratio of paste to the water available, which is necessary for the hydration of cement and consequent pozzolanic reaction, ending up in lower strengths [6].

For the maximum potential of RHA to be achieved, [6], [10], [41] claimed that replacement should be such that no silica is left unreacted, and that there should be some free lime after the completion of hydration. With the WCR used by this study, it is evident that the water available may not have been adequate for the completion of the hydration process and supporting of the subsequent use-up of silica in the pozzolanic reaction. As a result low levels of the strength giving C-S-H gel might have been formed, and this could be the reason for the slow gain in strength recorded with further replacement by weight. However, the compressive strengths of RHA-V-replaced specimens increased with time above those of the control.

Consistent with the characteristics of other SCMs, RHA further reacts with $Ca(OH)_2$ that is produced during the hydration of cement in the presence of water to form the strength giving C-S-H, which explains this increase in compressive strength over time [6], [7], [19].

At the 30% replacement level, the percentage increase in compressive strengths of RHA-V specimens regressed, an effect, which could also be attributed to an increase in the volume of concrete that results in a high water demand that subsequently leaves inadequate moisture for the hydration process [6]. The findings of this study were therefore consistent with [15]'s recommendation that RHA should supplement cement using volumetric replacement rather than simple substitution by weight.

TABLE IX: PERCENTAGE GAIN IN COMPRESSIVE STRENGTHS OF RHA-W AND RHA-V SPECIMENS BETWEEN 28 AND 91 DAYS.

Specimens	Percentage increase in compressive strength over several replacements							
	0%	5%	7.5%	10%	15%	20%	25%	30%
RHA-W	15.7	12.7	6.2	0.3	0.9	-	-	-
RHA-V	15.7	7.1	15.6	16.1	23.1	23.0	42.0	18.5

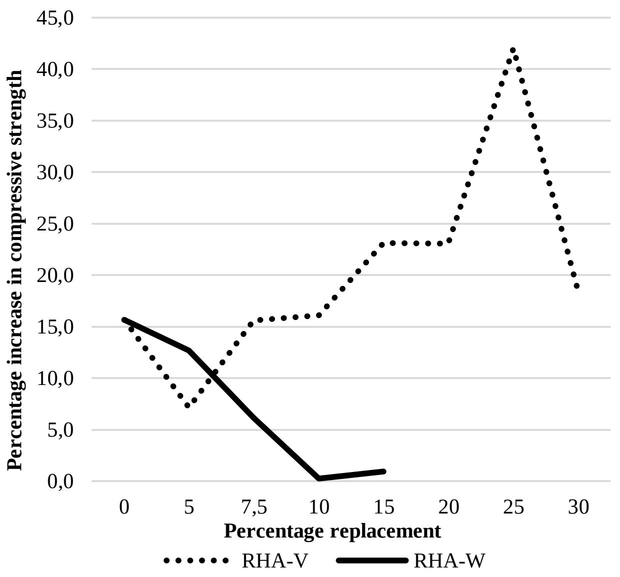

Fig. 9. Percentage increase in compressive strengths of RHA-W and RHA-V-replaced specimens against percentage replacements between 28 and 91 days

IV. TENSILE STRENGTH

Table X and Fig.10 show the tensile strengths of RHA-W and RHA-V-replaced specimens. Compared with RHA-V-replaced specimens, the tensile strengths of the RHA-W-replaced specimens decreased significantly with further replacement. This behaviour could equally be related to the shortage of water that is necessary for the hydration of cement that allows for the pozzolanic reaction to take place and form the strength giving C-S-H [6], [10]. The tensile strengths of both RHA-W and RHA-V could equally be improved by the use of finer RHA and superplastisisers [6].

TABLE X: TENSILE STRENGTHS OF RHA-W AND RHA-V-REPLACED SPECIMENS AT 91 DAYS (N/MM^2)

0	5	7.5	10	15	20	25	30
3.6	2.8	3.2	3.7	3.6	3.3	2.7	2.6
3.6	3.2	3.1	2.6	1.8			

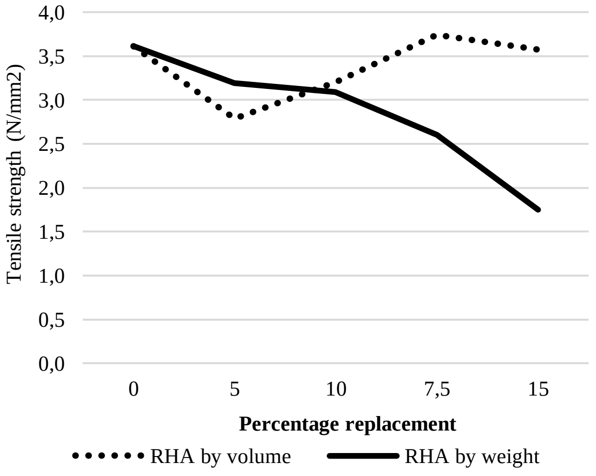

Fig. 10. Tensile strengths of RHA-W and RHA-V-replaced specimens at 91 days against percentage replacements (N/mm^2)

V. CONCLUSION

This study investigated the effect of density of RHA on the workability and strengths of RHA replaced concrete. It was concluded that the low density of RHA significantly increased the volume of mixes, increased the water demand, and consequently reduced the workability of the resultant concrete. The compressive strengths of both RHA-W specimens and RHA-V specimens were well above the targeted concrete class 32/40 at 91 days, which, is listed among strength classes that are suitable for structural applications, and showed that RHA could be used with an advantage to improve the sustainability and durability of concrete, as well as mitigate on the environmental nuisance that results from throwing away rice husks in landfill. The rate of strength gain of RHA-W specimens between 28 and 91 days was significantly lower than that of RHA-V specimens, and decreased with increased replacement. The lower strength gain of the RHA-W was attributed to the lack of sufficient free water that is necessary for the hydration of cement and subsequent pozzolanic reaction, which is the basis of the contribution that is made to the strength and performance of concrete by SCMs. Replacements of above 15% for the RHA-W could not be achieved due to the increased volume of concrete to WCR, while for the RHA-V, replacements of up to 30% were achieved. However, the compaction of both RHA-W and RHA-V concrete was found to be good and no bleeding was observed. Following these results, it can be concluded that RHA should supplement cement using volumetric replacement rather than simple substitution by weight.

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