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Assessment of Compressive Strength of Sustainable Concrete Produced with Recycled Concrete Aggregate and Rice Husk Ash

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ABSTRACT

The research work aims to investigate the compressive strength of recycled aggregate concrete (RAC) produced with rice husk ash as a partial replacement of cement. In this research, recycled coarse aggregate was utilized as partial substitute of natural coarse aggregate (NCA) at constant percentage of 0% and 50% and cement was systematically replaced with rice husk ash (RHA) by 0%, 15, 20, and 25%. A grade 25 concrete was used and designed based on the IS 10262 (2009) method. The workability of the fresh concrete mixes was measured using slump test method and compressive strength of the hardened specimens was investigated at the end of 7, 14 and 28 days. The results of workability test obtained for the 0%, 15, 20, and 25% mixes were 100mm, 80mm, 50mm and 10mm, respectively. This indicates that the inclusion of the RHA affects the workability of the mixes. Furthermore, the compressive strength of the mixes at 28 days curing period were obtained as 34.4 N/mm^2, 32.3 N/mm^2, 28.4 N/mm^2, and 29.3 N/mm^2 for 0%, 15, 20, and 25% mixes, respectively. This implies that 15% RHA replacement proved to be the optimum percentage replacement. Therefore, the study concludes that 15% RHA can be used in the production of sustainable concrete with the recycled coarse aggregate. This will reduce over-dependent on the use of natural coarse aggregate in the construction industry.

Keywords: Cement, compressive strength, recycled coarse aggregate, rice husk ash, workability,

INTRODUCTION

Concrete is a composite material used in the construction industry which is made up of cement, coarse and fine aggregates, water, and admixtures. The massive amount of concrete is made by utilizing a huge amount of naturally existing materials such as natural coarse aggregates, fine aggregates. It has been discovered that an average of 40 billion tonnes of natural aggregates are used each year throughout the world. As a result of the incredible rate at which virgin aggregates are consumed, these resources are depleted, and natural aggregates are becoming increasingly scarce in various places throughout the world. The extraction of natural aggregates also has a significant influence on the emission of dust and noise, as well as the release of greenhouse gases, all of which have a detrimental effect on the environment. As a result, the necessity for the development of alternate sources of aggregates is a major source of concern for today's society (Tam *et al*., 2018, Mukharjee & Barai, 2014a, Mukharjee & Barai, 2014b).

Furthermore, the utilization of mineral admixtures has expanded dramatically in recent years. Because, Portland cement concrete manufacturing currently responsible for about 7% of yearly CO_2 emissions globally; thus, to reduce it is a global issue (Celik *et al.*, 2014). To address this issue, mineral admixtures are being used to replace ordinary Portland cement (OPC). Because some mineral admixtures are waste by-products from either agricultural waste or industries which can reduce the quantity of cement needed, resulting in more environmentally friendly concrete. Moreover, recycling and reusing of construction and demolition wastes as recycled aggregates to produce a recycled aggregate concrete (RAC) is a viable method of mitigating natural resource shortages, waste management, and environmental challenges (Zhou and Chen, 2014). However, several studies have found that substituting normal aggregates with recycled aggregates (RAs) has a negative effect on the mechanical and durability behaviour of concrete. Because, the bonding zone between old and new concrete that is too weak, along with a high porosity of RCA, may account for the poor strength and durability performance. For instance, Muduli and Mukharjee (2020) experimentally performed an investigation on durability performance of RAC in terms of resistance to acid and sulphate attack. In the experimental study, 100% recycled coarse aggregate was utilized to replace normal coarse aggregate. At 90 days of exposure to acid solution, they discovered that RAC showed a significant mass loss and strength loss of 3.12% and 12% respectively. But the unfavourable consequence of sulphate attack on RAC is significantly less severe than that of acid attack. Similarly, Ali *et al.* (2020) reported at the percentage substitution levels of 50 and 100% RCA, the water absorption of RAC increases by 7 and 21% compared to normal concrete. Also, the acid attack resistance of RAC decreased at the end of 120 days exposure by 15 and 20% for 50 and 100% RCA substitution levels, respectively.

However, the poor strength and durability characteristics of RAC can be improved by adding mineral admixtures as a partial replacement of cement in the production RAC, as previously stated (Limbachiya, 20212). In addition to creating calcium silica hydrate gel and improving the porous structures of RCA, mineral admixtures enhance the quality of recycled aggregates (Mohseni *et al.* 2017). It has been found that the utilization of mineral admixtures like silica fume, rice husk ash, bagasse ash and fly ash can improve the durability performance of RAC (Khodabakhshian *et al*. 2011 and Chang *et al.*, 2005). Additionally, Pedro *et al.* (2018) studied the water absorption, carbonation resistance, chloride permeability of recycled aggregate concrete. The authors found that water absorption due to use of 100% recycled aggregates was found to 16% higher than that of ordinary concrete; but adding silica fume water absorption was decreased to 12% and also carbonation resistance as well as chloride permeability reduced by 40 and 20% respectively compared to ordinary control.

Rice husk ash (RHA) is produced by burning rice husks, or the hard protective shell of rice grains, at temperatures far lower than 780 degrees Celsius. RHA has pozzolanic qualities and a high silica oxide content. RHA increased strength at later ages but had no influence on mechanical qualities at younger ages (Madandoust et al., 2021). However, very little information is available in the existing literature about the use of RHA to enhance the strength and durability characteristics of RAC. The mechanical and durability characteristics of RAC with 20% RHA were investigated by Koushkbaghi *et al.* (2019). They found that RHA-RAC outperformed RAC without RHA in terms of mechanical and durability performance at 28, 90, and 236 days. According to another study, RAC with 20–35% RHA demonstrated greater compressive strength than RAC without RHA (Tangchirapat *et al.*, 2021). Thus, the fundamental aim of this research work is to experimentally investigate the compressive strength of recycled aggregate concrete produced with rice husk ash as a partial substitute of cement. The cement was partially substituted with RHA at the percentage levels of 0, 15, 20 and 25%. The compressive strength was investigated at 7, 14 and 28 days. Furthermore, the coarse aggregate was partially replaced with recycled coarse aggregate (RCA) at 50%.

MATRIALS AND METHOD

Materials

The ordinary Portland cement of grade 43 was utilized in the experimental works. It was purchased from an accredited dealer at Birnin Kebbi, Kebbi State. The ordinary Portland cement (OPC) has satisfied the requirements of IS 269 (2015) and the percentage oxide compositions present in the cement are given in the Table 1. The RHA was produced by burning rice husk to a temperature of about 700ºC to obtain RHA with amorphous silica content of above 90% with particle size of lesser 25µm and specific surface area of 36.46 m^2/kg. The RHA has satisfied the requirements of pozzolanic materials as stipulated by ASTM C618 (2005). The oxide compositions are presented in Table 1. Furthermore, river sand that is free from impurities was used as a fine aggregate and it was obtained from Dukku river, Birnin Kebbi, Kebbi State. The natural coarse aggregate (NCA) used was crushed granite stone which contains maximum size of 20mm and minimum size of 10mm, while the recycled coarse aggregate (RCA) was obtained from demolished concrete structure at Birnin Kebbi Town; and was crushed and sieved to the size of 10- 20mm maximum size.

Table 1 Oxide compositions of ordinary Portland cement and rice husk ash

Oxide	OPC	RHA
SiO_2	21.2%	91.5%
Al_2O_3	5.3%	0.2%
CaO	65.5%	0.6%
Fe_2O_3	4.5%	0.4%
MgO	-	0.4%
SO_2	2.6%	0.2%
Alkalis	0.9%	2.5%
LOI	-	4.2%

Methods

Workability test

The test was carried out for each batch of fresh concrete produced with 0, 15, 20 and 25% replacement levels of OPC with RHA. This test is conducted with a mould, scoop, sampling tray, trowel, tamping rod, and measuring ruler as part of the equipment. After being cleaned and lubricated with lubricated oil, the inside surface of the mould was set on the sampling tray and securely held there. The mould was removed vertically upward after the fresh concrete was put into it in three levels, each about one-third of the mould's height. Each layer was tamped with 25 strokes. A slump value was calculated by measuring the difference between the height of the slump concrete and the mould. In compliance with B.S. EN 12350-2 (2009), this test was made.

Compression test

This test was undertaken at different ages of curing period of 7, 14 and 28 days and at each replacement levels of 0%, 15%, 20% and 25% of OPC with RHA. In compliance with B.S. EN 12390-3 (2000), the compression test was executed. After being taken out of the curing tank and allowed to dry on the outside, the concrete specimens (cubes) were weighed and put in the middle of a manual hydraulic compression machine to be crushed. By swinging the crushing machine's handle until the specimen was crushed, force was imparted to it. Next, the highest load at failure was noted. Equation 1.0 was used to get the compressive strength.

$$\text{Compressive strength} = \frac{\text{Maximum load (KN)} \times 1000}{\text{Cross- sectional Area (mm}^2\text{)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 1.0$$

RESULTS AND DISCUSSION

Workability

This characteristic of fresh concrete is demonstrated by the quantity of practical internal effort needed to completely compact the concrete without any bleeding or segregation in the final result. In the current study, the slump for each concrete mix is used to determine workability, and the results are shown in **Figure 1**. The slump test was conducted to assess the workability of the fresh concrete mixes produced with the 0%, 15%, 20% and 25% of OPC with RHA. It can be observed from the **Fig.1** that the slump of the various mixes generated with 50%RCA replacement decreased compared to the reference mix (control) at all levels of RHA replacement which concurs with the comparable findings by Mi *et al.* (2020). The higher porosity and water absorption (W.A.) of RCA relative to the NCA may be the cause of the decline in slump values when compared to the reference mix (control). The RCA employed in the experiment had a W.A. of 3.10%, whilst the NCA had 0.60%. The RCAs used a lot of mixing water because of the old cement paste that was still attached to their faces. Furthermore, it can be observed from the plot that, as the percentage replacement of the RHA increases the slump value decreased as well. This is attributable to the fact that rice husk ash has a larger surface area than cement, it may be the cause of these declines. In order to achieve the necessary workability, additional water is needed because the particles of rice husk ash have a large specific surface area (Masood *et al.*, 2019). The addition of RHA reduces the workability of the mixes, but the mixture is still very cohesive. To compensate for the decreased workability, a water-reducing additive was added to the mixture. The slump values were within the IS: 1199 (1959) medium degree of workability.

Consequently, Sadagopan *et al.* (2020) recommended pre-soaking RCA with only 50% of the water absorbed by RCA in 15 minutes in order to achieve workability in RAC comparable to that in ordinary concrete. The size of the RCA and the workability requirements determine the amount of compensation in the water compensation techniques. Because too much water can induce bleeding in concrete, the additional water injected during the mixing process should not be equal to the 100% water absorption capacity of RCA (Leite & Monteiro, 2016). Additionally, when concrete is mixed for a short period of time, RCA might not absorb this surplus water quickly (de Andrade *et al.*, 2020). Behera *et al.*, (2019) opines that care should be taken during the mixing to ensure that extra water is deposited around the interfacial transition zone, reducing the connection between aggregates and the surrounding paste matrix which weaken the concrete matrix.

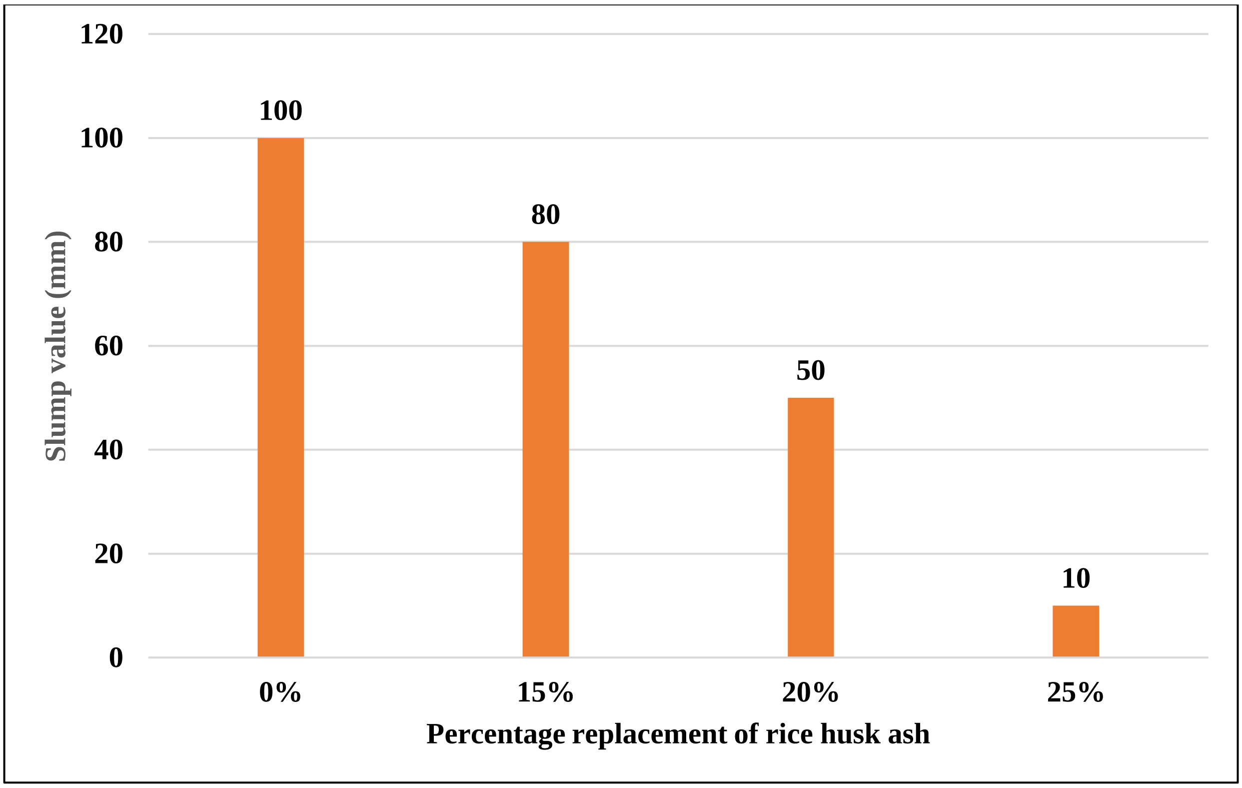

Fig. 1 Slump values of the various mixes with percentage replacement of rice husk ash

Compressive Strength

Fig. 2 presents the compressive strength of the various mixes with the 0, 15, 20 and 25% partial replacement of cement with RHA. As it can be seen in the plot, as the curing period increased the compressive strength increased as well in all the mixes. However, the mixes containing 20% and 25% RHA with 50% RCA replacements showed a significant decrease in compressive at all the ages of curing. For instance, 20% and 25% had compressive strength of 28.4 N/mm^2 and 29.3 N/mm^2 respectively at 28 days as against control mix with 34.4 N/mm^2. This phenomenon is caused by the greater porosity of the old cement paste and mortar that is linked to the recycled aggregate (Alhaji & Sharma, 2025, Poon *et al.,* 2004). Furthermore, the RCA had a high-water absorption rate (about 11 times higher than NCA), resulting in more mixing water in RAC than in normal aggregate concrete. Furthermore, the effect of weak old cement paste on RCA reduced aggregate strength, as evidenced by the increased crushing value of RCA compared to NCA. As a result, the RAC exhibited larger porosity and lower compressive strength than normal aggregate concrete, which is in line with earlier findings by (Katz, 2004).

Interestingly, the mix containing 15% RHA with 50% RCA replacements exhibited a significant improvement in strength at all ages of curing as compared to the mixes containing 20% and 25% RHA with 50% RCA replacements. The compressive strength recorded for the mix containing 15% RHA with 50% RCA replacements at 28 days was 32.3 N/mm^2 as against 34.4 N/mm^2 for the control mix. This implies that only 6.50% reduction in comparison with the control mix. Furthermore, the designed target strength of M25 (31.6 N/mm^2) is attained with 15% RHA with 50% RCA replacements. Therefore, 15% RHA replacement proved to be the optimum replacement. Thus, this improvement could be attributed to the fact that RHA lowers the concentration of calcium hydroxide and converts it to CSH-gel, the strength enhancement of RAC containing RHA may generally be the result of a pozzolanic interaction between RHA particles and free CH (Alhaji & Sharma, 2023). A greater net gain in compressive behaviour is the consequence of adding RHA to the binder, which fortifies the link between the aggregates and the binder matrix. Furthermore, the bonding strength of RCA with the binder matrix increases when RHA helps to create the addition C-S-H (Alhaji & Sharma, 2022).

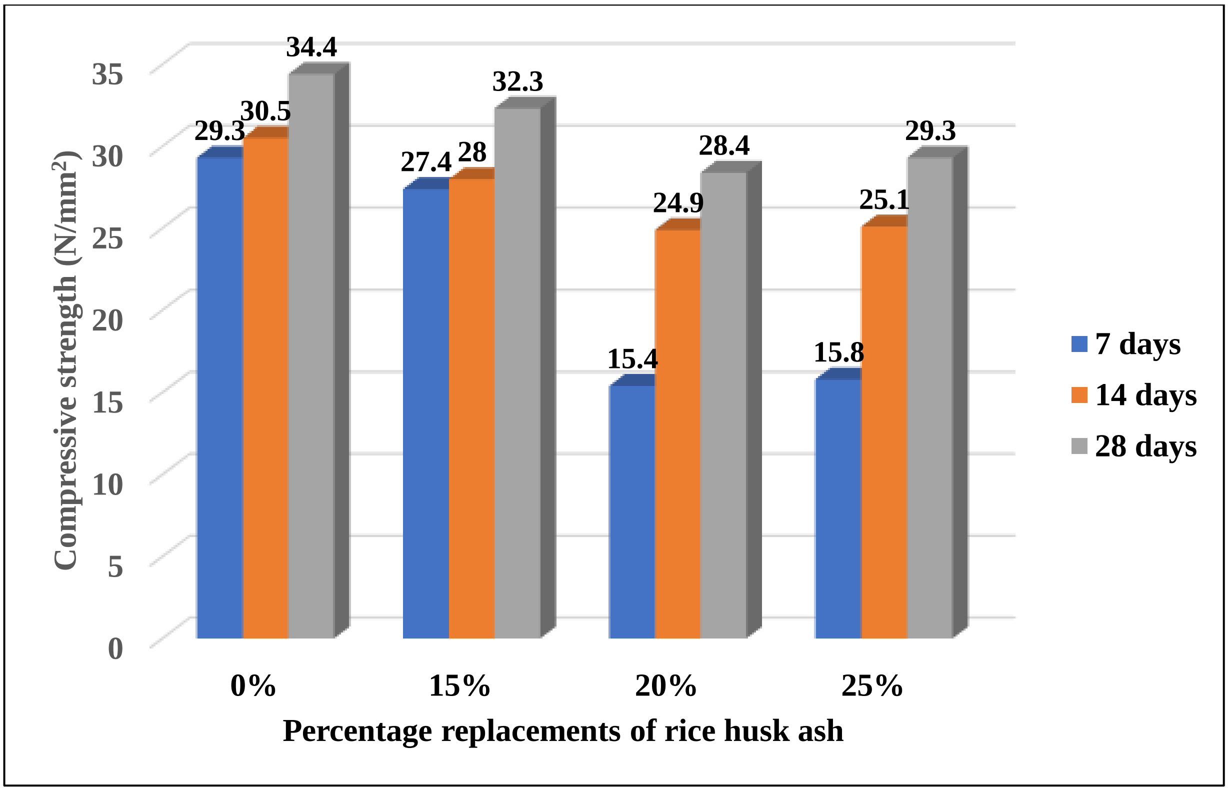

Figure 2 Compressive strength of various mixes with percentage replacement of rice husk ash

CONCLUSIONS

This study aimed at investigating the compressive strength of sustainable concrete produced with recycled concrete aggregate and rice husk ash as a partial replacement of cement. From the current investigation, the following important conclusions can be drawn:

- The rice husk ash used in this study has satisfied the ASTM C618-05 (2005) pozzolanic requirement.
- Workability (slump) of the fresh concrete mixes of 15%, 20% and 25% RHA replacements reduced as compared with the corresponding control which could ascribe to the high-water absorption of RCA. However, 15% replacement had 80mm slump values with control having 100mm. These values are within medium degree of workability.

- The compressive strength at 28 days indicates that 20% and 25% RHA replacements had significant reductions in strength when compared with the control. However, only mix containing 15% RHA gives an appreciable compressive strength values at 28 days with only 6.4% reduction in compressive in comparison with the control.
- To produce a sustainable concrete, 15% RHA + 50% RCA can be used as this value proved to be the optimum replacement.

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