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Experimental Investigation on the Effect of Rice Husk Ash as a Partial Replacement of Ordinary Portland Cement in Cement Mortar

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Abstract: The growing demand for cement-based construction materials and the environmental burden associated with cement production have encouraged the use of supplementary cementitious materials derived from agricultural residues. Rice husk ash (RHA), a silica-rich by-product of rice-husk combustion, is a potential partial substitute for Ordinary Portland Cement (OPC). This paper investigates the influence of RHA on the compressive strength development of cement mortar. Mortar of 1:3 proportion (binder to sand) was prepared with OPC replaced by RHA at 0%, 5%, 10%, 15% and 20% by mass, and 70.6 mm cube specimens were tested for compressive strength at 7, 28 and 90 days of water curing. The 7- and 28-day strengths decreased with increasing RHA content, whereas the 90-day strength increased up to 15% replacement. The maximum 90-day strength of 43.0 MPa was obtained at 15% RHA, about 5.7% higher than the 40.7 MPa of the control mortar, while the strength declined to 39.9 MPa at 20% replacement. The results indicate that moderate RHA contents can improve the later-age strength of cement mortar, and that 15% replacement gives the best performance among the levels tested.
Keywords: Rice Husk Ash, Cement Mortar, Partial Cement Replacement, Compressive Strength, Pozzolanic Material, Sustainable Construction.

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I. INTRODUCTION

Cement mortar is widely used in masonry, plastering and other construction applications. Portland cement is the essential binder in mortar, but its manufacture is energy intensive and contributes significantly to carbon dioxide emissions. At the same time, agricultural processing generates large quantities of residues that require appropriate management. Converting rice husk into ash and using suitable ash as a partial replacement of cement provides a route to reduce cement demand while creating value from an agricultural by-product.

Rice husk ash (RHA) is produced by the combustion of rice husk. Its properties depend strongly on the combustion temperature and duration, the degree of grinding and the resulting structure of the silica. Controlled burning in the range of about 600–700 °C is favourable for producing ash with high pozzolanic potential, and the ash used in this study had a silica-rich composition. Fine, reactive RHA can contribute to the strength of cementitious materials through particle packing and through pozzolanic reaction with the calcium hydroxide released during cement hydration [1], [5].

Although RHA has been investigated extensively in concrete [7]–[9], comparatively less information is available on its effects in cement mortar. This paper therefore investigates the compressive strength of cement mortar in which OPC is partially replaced by RHA at levels of 0–20%.

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II. LITERATURE REVIEW

Previous studies describe RHA as a supplementary cementitious material whose performance depends on the characteristics of the ash and the replacement proportion. Shaheen [1] examined the durability of mortars incorporating several pozzolanic materials, including RHA. Akasaki et al. [2] compared amorphous and crystalline RHA in mortar, highlighting the importance of the structure of the ash. Oyetola and Abdullahi [3] used RHA in sandcrete blocks and discussed the variation of strength with replacement level. Chindaprasirt and Rukzon [4] studied ternary blended mortar containing OPC, RHA and fly ash and reported improvements in strength, porosity and corrosion resistance.

Givi et al. [5] reviewed the contribution of RHA to the properties of mortar and concrete, while Abu Bakar et al. [6] discussed the use of Malaysian RHA for improving the durability and corrosion resistance of concrete. Nair et al. [7] investigated the mechanical properties of high-strength concrete containing RHA, and Ephraim et al. [8] and Kulkarni et al. [9] reported the compressive strength of concrete with RHA as a partial replacement of OPC. These studies indicate that RHA may improve later-age performance when it is sufficiently fine and reactive, but that excessive replacement can reduce strength because the dilution of cement and the increased water demand may outweigh the benefits of pozzolanic reaction and particle packing. This balance supports the evaluation of several replacement levels rather than the assumption of a single universal optimum.

III. RESEARCH GAP AND OBJECTIVES

Comparatively limited information is available on the effect of RHA in cement mortar relative to concrete. The present study therefore evaluates the compressive-strength response of 1:3 cement mortar at different RHA replacement levels. The objectives are: (i) to compare the compressive strength of RHA mortar at 7, 28 and 90 days; (ii) to identify the replacement level giving the highest 90-day strength; and (iii) to discuss the implications and limitations of using RHA in cement mortar.

IV. MATERIALS AND METHODOLOGY

A. Materials

The materials used were Ordinary Portland Cement, rice husk ash, natural fine aggregate and potable water for mixing and curing. The RHA was grey in colour and very fine, with a particle size below 45 μm. The fine aggregate was natural sand conforming to Zone III. The properties of the RHA and the fine aggregate are given in Table 1.

Table 1: Properties of rice husk ash and fine aggregate

Property	Value
RHA colour	Grey
RHA particle size	< 45 μm
RHA specific gravity	2.3
RHA silicon dioxide (SiO_2)	≈ 86.94%
Fine aggregate grading zone	Zone III
Fine aggregate specific gravity	2.7
Fine aggregate fineness modulus	2.71

B. Mix Proportions

The mortar proportion was 1:3 by mass (binder to sand). RHA replaced OPC at 0%, 5%, 10%, 15% and 20% by mass. Each batch for the compressive-strength specimens consisted of 200 g of total binder and 600 g of sand, with RHA substituted for part of the cement, as given in Table 2.

Table 2: Mix proportions of RHA mortar

RHA replacement	OPC (g)	RHA (g)	Sand (g)
0%	200	0	600
5%	190	10	600
10%	180	20	600
15%	170	30	600
20%	160	40	600

C. Specimen Preparation and Testing

The cement, RHA and sand were mixed in dry condition, the required water was added, and the mortar was placed in 70.6 mm cube moulds and compacted. The specimens were demoulded after about 24 hours and immersed in clean water until the age of testing. The compressive strength was determined using a compression-testing machine at 7, 28 and 90 days, and the result at each age was taken as the average of three specimens. The compressive strength was calculated as:

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$$f_c = \frac{P}{A}$$

where f_c is the compressive strength (MPa), P is the maximum applied load (N) and A is the loaded cross-sectional area of the cube (mm^2).

V. RESULTS AND DISCUSSION

A. Compressive Strength

The compressive strengths of the RHA mortar at different curing ages are given in Table 3 and shown in Figure 1. The change in strength relative to the control mortar is shown in Figure 2.

Table 3: Compressive strength of RHA mortar at different curing ages

RHA (%)	7 days (MPa)	28 days (MPa)	90 days (MPa)
0	27.0	38.0	40.7
5	26.3	37.5	41.0
10	26.0	37.0	42.1
15	25.1	36.2	43.0
20	23.6	35.1	39.9

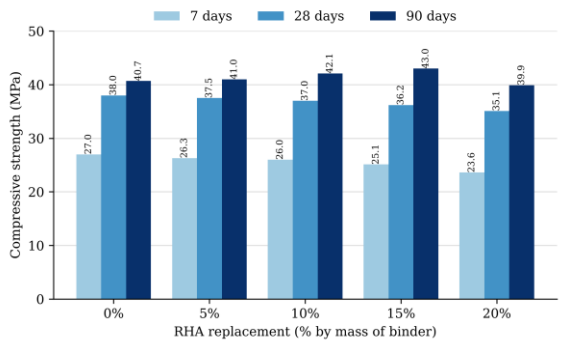


Figure 1: Compressive strength of RHA mortar at 7, 28 and 90 days

B. Early-Age Strength Response

At 7 days, the compressive strength decreased from 27.0 MPa for the control mortar to 23.6 MPa at 20% RHA, a reduction of 12.6%. A similar trend was observed at 28 days, when the strength decreased from 38.0 MPa to 35.1 MPa (7.6%). The reduction in early-age strength is attributed to the replacement of cement, which reduces the quantity of clinker available for early hydration, since the pozzolanic reaction of RHA proceeds more slowly than the hydration of cement.

C. Later-Age Strength Response

The 90-day results show a different pattern. The strength increased from 40.7 MPa for the control mortar to 41.0 MPa, 42.1 MPa and 43.0 MPa at 5%, 10% and 15% RHA, respectively. The 15% mix was about 5.7% stronger than the control. At 20% RHA, the strength decreased to 39.9 MPa, 2.0% below the control value. These results show that moderate replacement supported later-age strength development, whereas the highest replacement level tested did not.

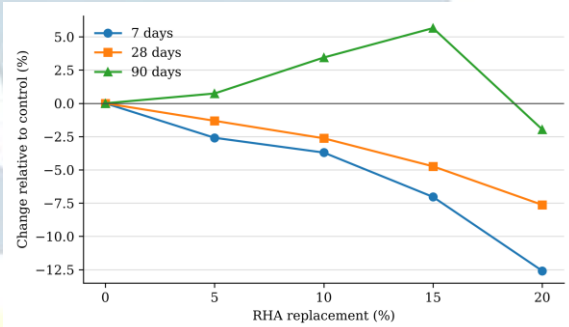


Figure 2: Change in compressive strength of RHA mortar relative to the control mortar

D. Interpretation and Practical Implications

The age-dependent behaviour is consistent with the role generally attributed to reactive, finely divided RHA: it acts as a micro-filler and participates in pozzolanic reactions that form additional cementitious products over time [4], [5]. At early ages the dilution effect dominates, while at later ages the pozzolanic contribution compensates for and eventually exceeds the loss of cement, up to a replacement level of about 15%. Beyond this level, the reduction in cement content and the higher water demand of the fine ash outweigh the pozzolanic benefit.

The 15% replacement level gave the highest 90-day compressive strength among the mixes tested. It should not, however, be treated as a universal optimum, since the conditions of ash production, its fineness, the water-to-binder ratio, the curing regime and the properties of the local materials can change the outcome.

VI. CONCLUSIONS

RHA was investigated as a partial replacement of OPC in 1:3 cement mortar at replacement levels of 0%, 5%,

10%, 15% and 20%. The following conclusions are drawn:

(1) The compressive strength decreased with increasing RHA content at 7 and 28 days, by up to 12.6% and 7.6%, respectively, at 20% RHA.

(2) At 90 days, the strength increased up to 15% RHA, reaching 43.0 MPa compared with 40.7 MPa for the control mortar.

(3) The 20% RHA mix recorded a 90-day strength of 39.9 MPa, showing that replacement beyond the moderate range did not improve strength further.

(4) 15% RHA is the best-performing replacement level among those tested for 90-day compressive strength; validation with further batches and durability and workability tests is recommended before field application.

VII. LIMITATIONS AND FUTURE SCOPE

The present study was limited to the compressive strength of mortar at three curing ages. Future work should report individual specimen results and standard deviations; characterise the fineness, loss on ignition and amorphous silica content of the RHA; investigate water demand and workability; and assess durability indicators such as water absorption, sorptivity and chemical resistance. Further replacement levels between 10% and 20% could also be evaluated to refine the optimum.

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