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# Variation of OPC-Rice Husk Ash Composites Strength with Mix Proportion

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**Abstract**— This work investigated the variation of strength of OPC-RHA cement composites with mix proportion. 168 concrete cubes of 150mm x 150mm x 150mm were produced with OPC and RHA using percentage OPC replacement with RHA of 0%, 10%, 15%, and 20%, and seven water: blended cement: sand: granite mix proportions of 0.6:1:1.5:3, 0.6:1:2:3, 0.6:1:2:4, 0.7:1:2.5:4, 0.7:1:2.5:5, 0.7:1:3:5, and 0.7:1:3:6. 168 sandcrete cubes and 168 soilcrete cubes were also produced using the same percentage replacements and water: blended cement: sand (or laterite for soilcrete) mix proportions 0.6:1:4, 0.6:1:5, 0.6:1:6, 0.7:1:7, 0.7:1:8, 0.7:1:9, and 0.7:1:10. Three concrete, sandcrete, and soilcrete cubes for each percentage OPC replacement with RHA and mix proportion were crushed to obtain their compressive strengths at 28 and 50 days of curing. It was found that for all percentage replacements of OPC with RHA at 28 and 50 days of curing, at a given water/cement ratio, the compressive strengths increased with leanness of mix up to some level of leanness after which the strength reduced. Concrete compressive strength values for 20% RHA at 50 days of curing rose from 21.00N/mm$^2$ for 0.7:1:2.5:4 mix, to 21.50N/mm$^2$ for 0.7:1:2.5:5, to 22.60N/mm$^2$ for 0.7:1:3:5, and decreased to 22.00N/mm$^2$ for 0.7:1:3:6. These results suggest that the leanest mix proportions that would still allow for good compaction should be used in making OPC-RHA cement composites for optimum compressive strength and cost.

**Index Terms**— Blended cement, cement composites, concrete, mix proportion, rice husk ash, sandcrete, soilcrete.

## 1 INTRODUCTION

The critical housing condition in most urban and sub-urban districts in Nigeria and all over Africa necessitates urgent search for alternatives to Ordinary Portland Cement (OPC) in order to reduce the cost of building projects. The primary focus in this regard is currently on the prospects of commercializing the use of suitable agricultural waste products such as rice husk ash (RHA) as partial replacement for OPC in making cement composites. A number of researchers have already confirmed RHA as a pozzolanic material capable of reacting with the lime produced as by-product of hydration of OPC to produce addition calcium silicate hydrate (C-S-H), thereby enhancing the compressive strength of OPC-RHA cement composites [1], [2], [3], [4].

Zhang and Malhotra [5] found that RHA is highly pozzolanic and can be used as a supplementary cementing material to produce high-performance concrete. Their work showed that RHA concrete had higher compressive strengths at various ages up to 730 days compared with that of the control concrete, but a lower value than that of silica fume concrete. The flexural and splitting tensile strengths, modulus of elasticity, and drying shrinkage of RHA concrete were comparable to those of the control concrete. Zhang, Lastra, and Malhotra [6] also studied the effects of the incorporation of rice-husk ash (RHA) in cement paste and concrete on the hydration and the microstructure of the interfacial zone between the aggregate and paste. The incorporation of the RHA in concrete reduced its porosity and the $Ca(OH)_2$ amount in the interfacial zone as well as the width of the interfacial zone between the paste and the aggregate, which the authors proffered as probable explanation for the higher compressive strength of the RHA concrete compared with that of the control. Oyetola and Abdullahi [7] investigated the use of RHA in low-cost sandcrete block production and found that an optimum level of 20% replacement of OPC with RHA is suitable for sandcrete block production.

Rodríguez de Sensale [8] found that both residual RHA from a rice paddy milling industry and RHA produced by controlled incineration were effective in improving the compressive strength, splitting tensile strength, and air permeability of the concrete. Dabai et al. [9] studied the effect of RHA as cement admixture by testing the compressive strength of mortar cubes produced using different percentages of OPC replacement with RHA. Their results showed that suitable 28-day strengths could be obtained with RHA used as substitute for OPC at 10% and 20% replacement. Chik et al. [10] investigated the properties of OPC-RHA cement concrete blocks and concluded that high performance masonry blocks could be produced using RHA as cement replacement material at an optimum replacement level of 15%. Nagrale1, Hajare, and Modak [11] investigated the effect of concrete properties when OPC is replaced with varying percentages of RHA and found that concrete strength increased with addition of RHA and the use of RHA considerably reduced the water absorption of concrete at 15-25% replacement of OPC with RHA.

Ramasamy [12] studied the compressive strength and durability properties of RHA concrete using percentage OPC

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replacement with RHA of 5%, 10%, 15% and 20%. They found that 90-day compressive strength of RHA concrete with 10% RHA was 7.07% greater than the control value. The porosity of RHA concrete also decreased from 4.70% to 3.45% when the replacement level increased from 5% to 20%. RHA concrete also had better resistance to acid and alkaline attacks. Karim et al. [13] reviewed the influence of RHA on strength of mortar and concrete and concluded that RHA could be used as supplementary cementing material up to about 20-30% replacement of OPC without sacrificing strength of concrete. Apata and Alhassan [14] evaluated a number of locally available materials as partial replacement for OPC in concrete production, including rice husk ash, calcined clay, and lime, and concluded that partial replacement of these local materials termed pozzolana with 10% OPC could be adopted for low cost housing. Working on fracture behaviour of concrete with rice husk ash replacement under uniaxial compressive loading, Akinwonmi and Seckley [15] partially replaced OPC with RHA at percentage replacement of 10%, 15%, 20%, 25% and 30% and found that the 28-day compressive strength of the resultant OPC-RHA cement concrete increased with percentage replacement up to 30%.

Recent studies by Ettu et al. [16], Ettu et al. [17], Ettu et al. [18], and Ettu et al. [19] have further confirmed that Nigerian RHA is a suitable pozzolanic material for producing cement composites. However, there is still need to examine appropriate mix proportions that would be most beneficial for production of OPC-RHA cement composites. The behavior of purely OPC cement concrete in this regard is reasonable well known. For example, the mechanical interlocking of the coarse aggregate contributes to the strength of concrete in compression and this explains the higher compressive strength of concrete than mortar [20]. In general, the strength of concrete depends on the strength of the mortar (the matrix), the bond between the mortar and the coarse aggregate (the interfacial transition zone), and the strength of the coarse aggregate particles [20]. However, aggregate strength is usually not a factor in normal strength concrete because the aggregate particle is several times stronger than the matrix and the interfacial transition zone, both of which determine concrete failure [21].

It is also known that a change in the aggregate grading without any change in the maximum size of coarse aggregate, and with water-cement ratio held constant, can influence the concrete strength when this change causes a corresponding change in the consistency and bleeding characteristics of the concrete mixture [21]. Moreover, for a given curing age and temperature, water/cement ratio and degree of compaction are the two primary factors that determine the strength of concrete. For a constant water/cement ratio, a leaner mix leads to a higher strength provided good compaction can be achieved. This is so because the cement paste represents a smaller proportion of the volume of concrete in a leaner mix; therefore the total porosity of the cement paste (and hence of the concrete) is lower and the strength higher [22]. This work investigated the variation of strength of OPC-RHA concrete, sandcrete, and soilcrete with mix proportion. The results are expected to facilitate the production of better quality OPC-RHA cement composites for use in building and civil engineering works in South Eastern Nigeria and elsewhere.

## 2 METHODOLOGY

Rice husk was obtained from rice milling factories in Afikpo, Ebonyi State in South Eastern Nigeria. The material was burnt to ashes in a local furnace at temperatures below 650$^{o}$C. The rice husk ash (RHA) was sieved and smaller particles passing the 600μm sieve were used for this work. The RHA had a specific gravity of 1.85, bulk density of 780 Kg/m$^3$, and fineness modulus of 1.48. Other materials used for this work are Ordinary Portland Cement (OPC) with a specific gravity of 3.13 and bulk density of 1650 Kg/m$^3$; 20 mm crushed granite with specific gravity of 2.96, bulk density of 1515 Kg/m$^3$, and fineness modulus of 3.62; river sand with specific gravity of 2.68, bulk density of 1590 Kg/m$^3$, and fineness modulus of 2.82; laterite with specific gravity of 2.30, bulk density of 1450 Kg/m$^3$, and fineness modulus of 3.30; and potable water. The chemical analysis of the ash showed it satisfied the ASTM requirement that the sum of $SiO_2$, $Al_2O_3$, and $Fe_2O_3$ should be not less than 70% for pozzolans.

One hundred and sixty eight (168) concrete cubes of 150mm x 150mm x 150mm were produced with OPC and RHA using percentage OPC replacement with RHA of 0%, 10%, 15%, and 20%, and seven water: blended cement: sand: granite mix proportions of 0.6:1:1.5:3, 0.6:1:2:3, 0.6:1:2:4, 0.7:1:2.5:4, 0.7:1:2.5:5, 0.7:1:3:5, and 0.7:1:3:6. One hundred and sixty eight (168) sandcrete cubes and one hundred and sixty eight (168) soilcrete cubes were also produced using the same percentage OPC replacements with RHA and water: blended cement: sand (or laterite for soilcrete) mix proportions 0.6:1:4, 0.6:1:5, 0.6:1:6, 0.7:1:7, 0.7:1:8, 0.7:1:9, and 0.7:1:10. Batching was by weight and mixing was done manually on a smooth concrete pavement. The ash was first thoroughly blended with OPC at the required proportion and the homogenous blend was then mixed with the fine aggregate-coarse aggregate mix (or fine aggregate only for sandcrete and soilcrete), also at the required proportions. Water was then added gradually and the entire concrete, sandcrete, or soilcrete heap was mixed thoroughly to ensure homogeneity. All the concrete cubes were cured by immersion while the sandcrete and soilcrete cubes were cured by water sprinkling twice a day in a shed. Three concrete, sandcrete, and soilcrete cubes for each percentage OPC replacement with RHA and mix proportion were crushed to obtain their compressive strengths at 28 and 50 days of curing.

## 3 RESULTS AND DISCUSSION

The variation of the compressive strengths of the OPC-RHA cement composites with mix proportion is shown in Tables 1, 2, and 3 for concrete, sandcrete, and soilcrete respectively.

TABLE 1
COMPRESSIVE STRENGTH OF OPC-RHA CEMENT CONCRETE WITH DIFFERENT MIX RATIOS

| W/C Ratio | Mix Ratio | 28-Day Compressive Strength (N/mm²) | | | |
|---|---|---|---|---|---|
| | | 0% RHA | 10% RHA | 15% RHA | 20% RHA |
| 0.6 | 1:1.5:3 | 23.00 | 20.80 | 19.50 | 19.00 |
| | 1:2:3 | 23.60 | 21.40 | 20.90 | 19.70 |
| | 1:2:4 | 24.00 | 22.50 | 21.80 | 20.50 |
| 0.7 | 1:2.5:4 | 20.00 | 19.10 | 18.70 | 18.20 |
| | 1:2.5:5 | 20.30 | 20.40 | 19.50 | 19.00 |
| | 1:3:5 | 21.00 | 20.80 | 20.10 | 19.50 |
| | 1:3:6 | 20.60 | 20.50 | 20.00 | 19.20 |
| W/C Ratio | Mix Ratio | 50-Day Compressive Strength (N/mm²) | | | |
| | | 0% RHA | 10% RHA | 15% RHA | 20% RHA |
| 0.6 | 1:1.5:3 | 24.50 | 23.80 | 22.50 | 21.00 |
| | 1:2:3 | 25.10 | 24.40 | 23.60 | 22.70 |
| | 1:2:4 | 25.80 | 25.00 | 24.20 | 23.50 |
| 0.7 | 1:2.5:4 | 21.70 | 22.40 | 21.70 | 21.00 |
| | 1:2.5:5 | 22.30 | 22.70 | 22.20 | 21.50 |
| | 1:3:5 | 23.00 | 24.30 | 23.10 | 22.60 |
| | 1:3:6 | 22.70 | 23.50 | 22.70 | 22.00 |
| Mix ratio refers to Blended Cement: Sand: Granite | | | | | |

It can be seen in the Tables 1, 2, and 3 that the strength values of OPC-RHA composites vary with mix proportion in a similar way as those of normal OPC composites (with 0% RHA). For all percentage replacements of OPC with RHA at 28 and 50 days of curing, at a given water/cement ratio, the compressive strengths increased with leanness of mix up to some level of leanness after which the strength reduced. This result agrees with previous findings by researchers for normal OPC concrete (with 0% RHA). Concrete compressive strength values for 20% RHA at 50 days of curing rose from 21.00N/mm² for 0.7:1:2.5:4 mix, to 21.50N/mm² for 0.7:1:2.5:5, to 22.60N/mm² for 0.7:1:3:5, and decreased to 22.00N/mm² for 0.7:1:3:6.

Sandcrete strength values for 20% RHA at 50 days of curing rose from 9.50N/mm² for 0.7:1:7 mix, to 9.80N/mm² for 0.7:1:8, to 10.30N/mm² for 0.7:1:9, and decreased to 10.00N/mm² for 0.7:1:10.

TABLE 2
COMPRESSIVE STRENGTH OF OPC-RHA CEMENT SANDCRETE WITH DIFFERENT MIX RATIOS

| W/C Ratio | Mix Ratio | 28-Day Compressive Strength (N/mm²) | | | |
|---|---|---|---|---|---|
| | | 0% RHA | 10% RHA | 15% RHA | 20% RHA |
| 0.6 | 1:4 | 10.50 | 9.40 | 8.80 | 8.50 |
| | 1:5 | 10.80 | 9.70 | 9.50 | 9.90 |
| | 1:6 | 11.00 | 10.30 | 9.90 | 9.30 |
| 0.7 | 1:7 | 9.00 | 9.60 | 8.40 | 8.10 |
| | 1:8 | 9.20 | 9.20 | 8.80 | 8.50 |
| | 1:9 | 9.50 | 9.40 | 9.10 | 8.80 |
| | 1:10 | 9.30 | 9.30 | 9.00 | 8.60 |
| W/C Ratio | Mix Ratio | 50-Day Compressive Strength (N/mm²) | | | |
| | | 0% RHA | 10% RHA | 15% RHA | 20% RHA |
| 0.6 | 1:4 | 11.30 | 10.90 | 10.30 | 9.50 |
| | 1:5 | 11.60 | 11.20 | 10.80 | 10.40 |
| | 1:6 | 11.90 | 11.50 | 11.10 | 11.80 |
| 0.7 | 1:7 | 9.90 | 10.20 | 9.90 | 9.50 |
| | 1:8 | 10.20 | 10.40 | 10.10 | 9.80 |
| | 1:9 | 10.50 | 11.20 | 10.60 | 10.30 |
| | 1:10 | 10.40 | 10.80 | 10.40 | 10.00 |
| Mix ratio refers to Blended Cement: Sand | | | | | |

TABLE 3
COMPRESSIVE STRENGTH OF OPC-RHA CEMENT SOILCRETE WITH DIFFERENT MIX RATIOS

| W/C Ratio | Mix Ratio | 28-Day Compressive Strength (N/mm²) | | | |
|---|---|---|---|---|---|
| | | 0% RHA | 10% RHA | 15% RHA | 20% RHA |
| 0.6 | 1:4 | 9.50 | 8.40 | 7.80 | 7.40 |
| | 1:5 | 9.70 | 8.60 | 8.40 | 8.70 |
| | 1:6 | 10.00 | 9.20 | 8.80 | 8.30 |
| 0.7 | 1:7 | 8.10 | 8.60 | 7.40 | 7.10 |
| | 1:8 | 8.30 | 8.10 | 7.70 | 7.50 |
| | 1:9 | 8.60 | 8.50 | 8.20 | 7.90 |
| | 1:10 | 8.40 | 8.30 | 8.00 | 7.70 |
| W/C Ratio | Mix Ratio | 50-Day Compressive Strength (N/mm²) | | | |
| | | 0% RHA | 10% RHA | 15% RHA | 20% RHA |
| 0.6 | 1:4 | 10.20 | 9.80 | 9.30 | 8.50 |
| | 1:5 | 10.60 | 10.20 | 9.80 | 9.40 |
| | 1:6 | 10.90 | 10.60 | 10.10 | 10.70 |
| 0.7 | 1:7 | 8.80 | 9.30 | 8.90 | 8.40 |
| | 1:8 | 9.10 | 9.50 | 9.20 | 8.80 |
| | 1:9 | 9.50 | 10.20 | 9.60 | 9.20 |

| | | | | | |
|---|---|---|---|---|---|
| | **1:10** | 9.30 | 9.90 | 9.40 | 9.00 |

Soilcrete strength values for 20% RHA at 50 days of curing similarly rose from 8.40N/mm² for 0.7:1:7 mix, to 8.80N/mm² for 0.7:1:8, to 9.20N/mm² for 0.7:1:9, and decreased to 9.00N/mm² for 0.7:1:10. The increase in strength with leanness of mix at constant water/cement ratio could be due to reduced voids within the composite as much of the water is used up by the composite. The strength begins to decrease when the mix becomes so lean that adequate compaction is no longer achieved.

In other words, the results show that for a constant water/cement ratio at 0% to 20% replacement of OPC with RHA, the higher the ratio of total aggregate to OPC-RHA blended cement the greater the composite compressive strength, provided a high degree of compaction is still achievable. It also appears from the results that the variation of OPC-RHA cement concrete strength with mix proportion does not depend so much on the ratio of fine aggregate to coarse aggregate as on the proportion of total aggregate.

These results suggest that the leanest mix proportions that would still allow for good compaction should be used in making OPC-RHA cement composites for optimum compressive strength and cost. Thus, water: blended cement: sand: granite mix proportion of 0.7:1:3:5 would be ideal for OPC-RHA binary blended cement concrete from the stand point of both cost and compressive strength. Similarly, water: blended cement: sand (or laterite for soilcrete) mix proportion of 0.7:1:9 would be ideal for OPC-RHA binary blended cement sandcrete and soilcrete since these mix proportions give strength values suitable for general works in cement composites.

It is also interesting for engineering purposes to note that the 50-day strength values of OPC-RHA blended composites are comparable to those of 100% OPC composites at OPC replacements with RHA up to 20%. This result is striking for all the mix proportions considered and further confirms the suitability of OPC-RHA blended cement for making concrete, sandcrete, and soilcrete.

## 4 CONCLUSIONS

(i) OPC-RHA composites vary with mix proportion in a similar way as those of normal OPC composites (with 0% RHA).

(ii) The compressive strengths of OPC-RHA cement composites increased with leanness of mix up to some level of leanness after which the strength reduced.

(iii) On the basis of compressive strength and obvious cost implications, mix proportion of 0.7:1:3:5 would be ideal for OPC-RHA binary blended cement concrete. Similarly, mix proportion of 0.7:1:9 would be ideal for OPC-RHA binary blended cement sandcrete and soilcrete.

(iv) The 50-day strength values of OPC-RHA blended composites are comparable to those of 100% OPC composites at OPC replacements with RHA up to 20%.

(v) The results seem to suggest that the variation of OPC-RHA cement concrete strength with mix proportion does not depend so much on the ratio of fine aggregate to coarse aggregate as on the proportion of total aggregate. Further studies would be required to determine the most suitable fine to coarse aggregate ratio for OPC-RHA blended cement concrete.

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