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

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Abstract

This work investigated the variation of strength of OPC-RHA-SDA cement composites with mix proportion. 168 concrete cubes of 150mm x 150mm x 150mmwere produced with OPC and RHA-SDAusing percentage OPC replacement with RHA-SDA of 0%, 10%, 15%, and 20%, and sevenwater: 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 soilcretecubes for each percentage OPC replacement with RHA-SDA 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-SDA 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-SDA at 50 days of curing rose from 20.60N/mm2 for 0.7:1:2.5:4 mix, to 21.20N/mm2 for 0.7:1:2.5:5, to 22.10N/mm2 for 0.7:1:3:5, and decreased to 21.60N/mm2 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-SDA cement composites for optimum compressive strength and cost effectiveness.

Keywords: Blended cement, cement composites, concrete, mix proportion, rice husk ash, sandcrete, saw dust ash, soilcrete.

Introduction

An increasing number of Nigerians in urban and sub-urban districts of the country cannot afford to pay for good accommodation. This ugly situation calls for an urgent search for suitable 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) and saw dust ash (SDA) as partial replacements for OPC in making cement composites. A number of researchers have already confirmed these otherwise agricultural wastes as pozzolanic materials capable of reacting with the lime produced as by-product of hydration of OPC to produce additional calcium silicate hydrate (C-S-H) thereby enhancing the compressive strength of blended cement composites (Mehta and Pirtz, 2000; Malhotra and Mehta, 2004; Cordeiro et al., 2009).

Rodríguez de Sensale (2006) 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 concrete. Dabai et al. (2009) found that suitable 28-day strengths could be obtained with RHA used as substitute for OPC at 10% and 20% replacement. Chik et al. (2011) 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%. Nagrale, Hajare, and Modak (2012) 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 (2012) also found that 90-day compressive strength of RHA concrete with 10% RHA was 7.07% greater than the control value with better resistance to acid and alkaline attacks. Karim et al. (2012) reviewed the influence of RHA on strength of mortar and concrete and concludedthat RHA could be used as supplementary cementing material up to about 20-30% replacement of OPC without sacrificing strength of concrete.Apataand Alhassan (2012) evaluated a number of locally available materials as partial replacement for OPC in concrete productionand concluded that partial replacement of these local materials with 10% OPC could be adopted forlow cost housing.Working on fracture behaviour of concrete with rice husk ashreplacement under uniaxial compressive loading, Akinwonmi and Seckley (2013) 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%.

Elinwa, Ejeh, and Mamuda (2008) have also investigated the suitability of sawdust ash as a pozzolanic material and found that it could be used in binary combination with OPC to improve the properties of cement composites. Mageswari and Vidivelli (2009) investigated the use of sawdust ash as fine aggregate replacement in concrete by replacing sand with 5 to 30% of SDA in making concrete cubes and cylinders and testing for compressive, tensile, and flexural strengths up to 180 days of curing. Their results indicated the similarity in properties of concrete with 100% sand as fine aggregate and those obtained by replacing sand with SDA at 10-20%. Further studies by Elinwa and Abdulkadir (2011) confirmed SDA as a pozzolanic material with optimum at 10% replacement and further established the material as reducing porosity as well as being effective in reducing corrosion of reinforcement in concrete. Marthong (2012a) investigated the strength of mortar cubes, concrete cubes, and beam specimen made with OPC-SDA blended cement and found that the inclusion of SDA caused a little expansion due to low calcium content but early strength development was about 50-60% of their 28-day strength. The study suggested the use of SDA as partial replacement of cement up to a maximum of 10% by volume in all grades of cement. Marthong (2012b) further investigated the size effect phenomenon of OPC-SDA cement concrete with 10% sawdust ash (SDA) as partial replacement of OPC using cylinders of different sizes. The results showed that OPC-SDA cement concrete had more size effect than 100% OPC concrete, the size effect being more pronounced at 28 days than at 90 days of hydration. Onwuka et al. (2013) optimized the compressive strength of OPC-SDA cement concrete and obtained 20.44N/mm^2 as the optimum 28-day compressive strength corresponding to 5% replacement of OPC with SDA.

Recent studies by Ettu et al. (2013a), Ettu et al. (2013b), Ettu et al. (2013c), and Ettu et al. (2013d) have confirmed the suitability of Nigerian RHA and SDA as pozzolanic materials for producing concrete, sandcrete, or soilcrete, either in binary combination with OPC or in ternary combination with OPC and one other agricultural by-product pozzolan. However, there is still need to examine appropriate mix proportions that would be most beneficial for production of OPC-RHA-SDA cement composites. The behavior of purely OPC cement concrete in this regard is reasonably 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 (Neville, 2008). 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 (Neville, 2008). 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 (Mehta and Monteiro, 2006).

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 (Mehta and Monteiro, 2006). 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 (Neville and Brooks, 2010). This work investigated the variation of strength of OPC-RHA-SDA concrete, sandcrete, and soilcrete with mix proportion. The results are expected to facilitate the production of better quality OPC-RHA-SDA cement composites for use in building and civil engineering works in South Eastern Nigeria and elsewhere.

Methodology

Rice husk was obtained from rice milling factories in Afikpo, Ebonyi State and Saw dust from wood mills in Owerri, Imo State, all in South Eastern Nigeria. These materials were burnt to ashes in a localfurnace at temperatures generally below 650^{o}C. The rice husk ash (RHA) and sawdust ash (SDA) were sieved and smaller particles passing the 600μm sieve were used for this work. The RHA had a specific gravity of 1.84, bulk density of 770 Kg/m^3, and fineness modulus of 1.48. The SDA had a specific gravity of 2.05, bulk density of 810 Kg/m^3, and fineness modulus of 1.89. Other materials used for the work are Ordinary Portland

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Cement (OPC) with a bulk density of 1650 Kg/m^3 and specific gravity of 3.13; crushed granite of 20 mm nominal size with a specific gravity of 2.96, bulk density of 1515 Kg/m^3, and fineness modulus of 3.62; river sand with a specific gravity of 2.68, bulk density of 1590 Kg/m^3, and fineness modulus of 2.82; laterite with a specific gravity of 2.30, bulk density of 1450 Kg/m3, and fineness modulus of 3.30; and potable water.

One hundred and sixty eight (168) concrete cubes of 150mm x 150mm x 150mmwere produced with OPC and RHA-SDAusing percentage OPC replacement with RHA-SDA of 0%, 10%, 15%, and 20%, and sevenwater: 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-SDA 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. RHA and SDA were first blended in equal proportions and subsequently blended with OPC at the required proportions.The homogenous OPC-RHA-SDA 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 soilcretecubes for each percentage OPC replacement with RHA-SDA and mix proportion were crushed to obtain their compressive strengths at 28 and 50 days of curing.

Results and Discussion

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

Table 1: Compressive strength of OPC-RHA-SDA cement concrete with different mix ratios

W/C Ratio	Mix Ratio	28-Day Compressive Strength (N/mm^2)				50-Day Compressive Strength (N/mm^2)			
		0% RHA/ SDA	10% RHA/ SDA	15% RHA/ SDA	20% RHA/ SDA	0% RHA/ SDA	10% RHA/ SDA	15% RHA/ SDA	20% RHA/ SDA
0.6	**1:1.5:3**	23.00	20.30	19.00	18.50	24.50	23.30	22.00	20.50
	1:2:3	23.60	21.00	20.40	19.10	25.10	24.00	23.20	22.10
	1:2:4	24.00	22.00	21.20	20.00	25.80	24.50	23.70	22.90
0.7	**1:2.5:4**	20.00	18.80	18.30	17.80	21.70	22.00	21.30	20.60
	1:2.5:5	20.30	19.90	19.00	18.50	22.30	22.30	21.70	21.20
	1:3:5	21.00	20.40	19.70	19.20	23.00	23.80	22.60	22.10
	1:3:6	20.60	20.10	19.50	18.80	22.70	23.00	22.30	21.60
Mix Ratio refers to the ratio of Blended Cement: Sand: Crushed Granite									

Table 2: Compressive strength of OPC-RHA-SDA cement sandcretewith different mix ratios

W/C Ratio	Mix Ratio	28-Day Compressive Strength (N/mm^2)				50-Day Compressive Strength (N/mm^2)			
		0% RHA/ SDA	10% RHA/ SDA	15% RHA/ SDA	20% RHA/ SDA	0% RHA/ SDA	10% RHA/ SDA	15% RHA/ SDA	20% RHA/ SDA
0.6	**1:4**	10.50	8.90	8.20	8.00	11.30	10.30	9.70	9.00
	1:5	10.80	9.20	9.00	8.70	11.60	10.50	10.20	9.90
	1:6	11.00	9.70	9.30	9.00	11.90	10.90	10.50	11.20
0.7	**1:7**	9.00	8.60	7.80	7.50	9.90	9.70	9.30	8.90
	1:8	9.20	9.10	8.30	8.00	10.20	9.90	9.60	9.20
	1:9	9.50	9.40	8.60	8.20	10.50	10.70	10.10	9.70
	1:10	9.30	9.20	8.40	8.00	10.40	10.30	9.80	9.40
Mix Ratio refers to the ratio of Blended Cement: Sand									

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Table 3: Compressive strength of OPC-RHA-SDA cement soilcretewith different mix ratios

W/C Ratio	Mix Ratio	28-Day Compressive Strength (N/mm^2)				50-Day Compressive Strength (N/mm^2)			
		0% RHA/ SDA	10% RHA/ SDA	15% RHA/ SDA	20% RHA/ SDA	0% RHA/ SDA	10% RHA/ SDA	15% RHA/ SDA	20% RHA/ SDA
0.6	**1:4**	9.50	7.90	7.20	6.80	10.20	9.20	8.70	7.90
	1:5	9.70	8.10	7.90	7.60	10.60	9.60	9.30	8.80
	1:6	10.00	8.60	8.30	7.90	10.90	10.00	9.60	9.40
0.7	**1:7**	8.10	7.70	6.90	6.50	8.80	8.70	8.30	7.80
	1:8	8.30	7.90	7.20	6.90	9.10	9.00	8.70	8.30
	1:9	8.60	8.30	7.70	7.30	9.50	9.60	9.20	8.70
	1:10	8.40	8.10	7.40	7.10	9.30	9.30	8.90	8.40
Mix Ratio refers to the ratio of Blended Cement: Laterite									

It can be seen in the Tables 1, 2, and 3 that the strength values of OPC-RHA-SDA composites vary with mix proportion in a similar way as those of normal OPC composites (with 0% RHA-SDA). For all percentage replacements of OPC with RHA-SDA 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-SDA). Concrete compressive strength values for 20% RHA-SDA at 50 days of curing rose from 20.60N/mm^2 for 0.7:1:2.5:4 mix, to 21.20N/mm^2 for 0.7:1:2.5:5, to 22.10N/mm^2 for 0.7:1:3:5, and decreased to 21.60N/mm^2 for 0.7:1:3:6.

Sandcrete strength values for 20% RHA-SDAat 50 days of curing rose from 8.90N/mm^2 for 0.7:1:7 mix, to 9.20N/mm^2 for 0.7:1:8, to 9.70N/mm^{2}for 0.7:1:9, and decreased to 9.40N/mm^2 for 0.7:1:10. Soilcrete strength values for 20% RHA-SDA at 50 days of curing similarly rose from 7.80N/mm^2 for 0.7:1:7 mix, to 8.30N/mm^2 for 0.7:1:8, to 8.70N/mm^2 for 0.7:1:9, and decreased to 8.40N/mm^2 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 terms of aggregates proportion, the results show that for a constant water/cement ratio at 0% to 20% replacement of OPC with RHA-SDA, the higher the ratio of total aggregate to OPC-RHA-SDA 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-SDA 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-SDA 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-SDA 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-SDA 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 at 10-20% OPC replacements with RHA-SDAthe 50-day strength values of OPC-RHA-SDA blended cement concrete, sandcrete, and soilcrete were respectively84-101%, 80-99%, and 77-101% of those for 100% OPC composites. This result is striking for all the mix proportions considered and further confirms the suitability of OPC-RHA-SDA blended cement for making concrete, sandcrete, and soilcrete.

Conclusions

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

(ii) The compressive strengths of OPC-RHA-SDA 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 effectiveness, a mix proportion of 0.7:1:3:5 would be ideal for OPC-RHA-SDA binary blended cement concrete. Similarly, a mix proportion of 0.7:1:9 would be ideal for OPC-RHA-SDA binary blended cement sandcrete and soilcrete.

(iv) The 50-day strength values of OPC-RHA-SDA blended cement concrete, sandcrete, and soilcrete arerespectively84-101%, 80-99%, and 77-101% of those for 100% OPC composites at 10-20% replacement of OPC with RHA-SDA.

(v) The results seem to suggest that the variation of OPC-RHA-SDA 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 this aspect and possibly determine the most suitable fine to coarse aggregate ratio for OPC-RHA-SDA blended cement concrete.

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