ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE, March, 2019. Vol. 15(1):163-173
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

MECHANICAL PROPERTIES OF RICE HUSK ASH CEMENT MASS CONCRETE MIXED WITH DISCRETE STEEL FIBRES

Y.O. Abiodun[1]* and O.O. Sijuwola[2]

[1]Department of Civil and Environmental Engineering, University of Lagos, Nigeria
[2]Department of Civil Engineering, University of Ilorin, Nigeria
**Corresponding Author: yabiodun@unilag.edu.ng*

ARTICLE INFORMATION

Submitted 28 March, 2018
Revised 15 December, 2018
Accepted 19 December, 2018

Keywords:
Rice Husk Ash
Discrete Steel Fibre
Compressive Strength
Flexural Strength
Tensile Strength

ABSTRACT
The potential use of supplementary cementitious materials in concrete for improving concrete properties has been a growing concern in recent years. This is due to the environmental and health hazards associated with the increase in the use of cement in concrete as a result of infrastructural development all over the world. The effective strengthening of the concrete matrix by reinforcements helps to prevent brittleness that occurs in plain concrete. This study investigated the mechanical properties of randomly distributed discrete steel fibers in Rice Husk Ash-cement matrix and its effect on the strength and performance of concrete. Rice husk was burnt at a controlled temperature of 600°C for 4 hours in an electric furnace to get the rice husk ash. Prescribed mix ratio of 1:2:4 and water-cement ratio of 0.5 were used in all the mixes of rice husk ash cement mass concrete mixed with discrete steel fibres. The parameters varied were Rice Husk Ash content at 0%, 10%, 15%, 20%, and 25% and discrete steel fiber dosage of 0.5kg and 1kg.The mechanical properties of the rice husk ash cement mass concrete mixed with discrete steel fibres were studied through Compressive strength test, Split Tensile test and Flexural test. Results obtained show that the RHA-cement mass concrete mixed with discrete steel fibres reached maximum compressive strength at an optimum value of 10% RHA and 1kg of discrete steel fibres. The highest values for split tensile and flexural strengths were obtained at 10% RHA replacement.

1.0 Introduction

Concrete is well known as a heterogeneous mix of cement, water, fine and coarse aggregates. Globally, it is the backbone for the development of infrastructure, including buildings, industrial structures, bridges and highways. The contribution of portland cement production worldwide to greenhouse gas emission is estimated to be about 1.35 billion tonne annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere. To reduce the greenhouse effect, some mineral admixtures have been studied as partial replacements for cement in plain and reinforced concrete (Malhotra, 2002).

In recent years, Rice Husk ash (RHA) has been used as ordinary portland cement replacement material in concrete industries. RHA is the ash produced from husk fibre of rice burning. It is found to have high Pozzolans material and it can not only be used as a partial cement replacement but also can increase the compressive strength and durability of concrete (Fernandez, 2007).

Fibre reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It may also be defined as a composite material mixed with Portland cement, aggregate, and incorporating discrete discontinuous fibre. Without the fibre, the concrete has is relatively strong in compression but weak in tension and brittle. The weakness in tension can be overcome by the use of conventional steel reinforcement and to some extent by the inclusion of a sufficient volume of certain fibres (Lofgren, 2005). The reason for adding such fibres to concrete is that plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capacity. The role of randomly distributed discontinuous fibres is to bridge across the cracks that develop and provide some post-cracking “ductility”. If the fibres are sufficiently strong and sufficiently bonded to material, this permit the FRC to carry significant stresses over a relatively large strain capacity in the post cracking stage (Zhang et al, 2005).

Della, et al. (2002) have shown that RHA burnt under controlled conditions produces high levels of reactive silica particles in amorphous state (up to 95%). The increased reactivity of RHA is mainly caused by the high content of non-crystalline silica and in general reactivity is also favoured by the increased fineness of RHA. Isaiah, et al. (2003) have demonstrated that residual RHA is produced with a lower quality because of its high carbon content, which led to an increase in water demand and produces a darker color of mortar and concrete. However, residual RHA has a better filling effect compared to pozzolanic material. Chao-Lung, et al. (2011) and Raoul, et al. (2003) investigated the effect of rice husk ash content as partial replacement of cement on compressive strength and volume stability for different mixes and test results showed that up to 40% replacement by rice husk could be made without affecting the compressive strength when compared to the control concrete.

The aim of this study was to investigate the mechanical properties of rice husk ash – cement mass concrete, mixed with discrete steel fibres using an indigenous species of rice; Olomo-nla/ Oryza glaberrima from Kaduna state, Nigeria. Specifically, this involves the:

Determination of chemical composition of the rice husk ash obtained from the study specie

Determination of mechanical properties of the rice husk ash cement mass concrete mixed with discrete steel fibres through compressive strength test, flexural test and split tensile test

Determination of the optimum percentage replacement of rice husk ash in the rice husk ash cement mass concrete mixed with discrete steel fibres

Investigation of effect of discrete steel fibres in the rice husk ash – cement mass concrete

2.0 Materials and Methodology

2.1 Materials

The Rice husk used in this study was sampled from Katsina state, Nigeria and the local name of the specie is olomo nla/soro. 100kg of rice husk was burnt at a controlled temperature of 600°C/4 hours in an electric furnace at Federal Institute of Industrial Research Oshodi (FIIRO), Lagos, Nigeria. About 25kg of rice husk ash was generated after burning.

Hooked end steel fibres of diameter 0.9 mm and length 30 mm was used for this study. The fibre was imported from China. From the manufacturer's data, the range of ultimate tensile strength on tension test is above 1100 N/mm2 for diameters ranging from 0.45 - 1mm. The density of steel fibre is 7850 kg/m^3.

Granite of sizes between 12mm and 19mm was used in this study and it was sourced from BM mining and quarrying limited located along Abiola way, Abeokuta, Ogun state, Nigeria. River sand from Olorunsogo Village, Ifo Local Government Area, Ogun State, Nigeria was used. The particles passed through a 9.5mm sieve.

Dangote portland cement was used in this study. The quality of the portland composite cement was approved by SIRIM (certified to MS 522-1:2007) and BS EN 197-1:2000, CEM II/B-L 32.5N/42.5R. The cement was stored away from air moisture in the workshop to ensure the material was in good condition during the experimental period.

Master Rheobuild 850 admixture produced by Master Builders, Inc., was used. According to manufacturer's data and specifications, it is a high range; water-reducing super plasticizer. It is normally dispensed depending on the desired plasticizing or water reducing effect at a rate of 0.2-2.0ltr/100kg of cement or 0.23–2.34% cwt. In this study, 0.03% of the weight of water was replaced with Rheobuild850.

2.2 Methodology

2.2.1 Sieve analysis on aggregates

A sieve analysis (or gradation test) was used to assess the particle size distribution of both the granite (coarse aggregate) and sand (fine aggregate). Column of sieves with wire mesh cloth (screen) were arranged and a representative weighed sample of each aggregate was poured into the top sieve which has the largest screen openings. Each lower sieve in the column has smaller openings than the one above. At the base is a round pan, called the receiver. The column of sieves was placed in mechanical shaker for about 10mins. The material on each sieve was weighed and the weight was divided by the total weight to give percentage retained on each sieve.

2.2.2 Experimental design

Rice husk ash was used to partially replace cement at 0%, 10%, 15%, 20% and 25% by weight of binder content and steel fibre replacement levels of 0.5 and 1.0% volume fraction. Mix ratio 1:2:4 and water-cement ratio of 0.5 were adopted all through the study.

Nine mixes were prepared and fifty- four (54) beams of size of 150 mm x 150 mm x 550 mm were cast in accordance to BS EN 12390-5:2000 (methods for making test beams from fresh concrete). These beams were tested, using the flexural testing machine with a capacity of 100 KN operating at a rate of 1.5 mm/min to study the flexural tensile properties of the hardened concrete using a third-point loading arrangement. Specimens were water-cured for 28 and 56 days. Figures 1 and 2 show the cast beam specimens and the set-up of the specimen for flexural strength test

Figure 1: Cast beam specimens

Figure 2: Set-up for flexural strength test

The split tensile test was carried out in accordance to BS EN 12390-6:2000 on a digital compression testing machine with a capacity of 200 KN and loading rate of 2 KN/sec. The load was applied by the machine platens through two plywood strips (25 mm wide, 3.2 mm thick). The cured cylinders were tested as shown in Figure 3 with their horizontal axes between the platens until failure occurred. The strips allowed even load distribution by conforming to small irregularities on the specimen surface. The splitting tensile strength is given by:

$$\sigma = \frac{2P}{\pi LD} \quad (1)$$

Where P is the maximum load, D is the cylinder diameter, and L is the cylinder length.

Fifty-four (54) cylinders of size 150mm × 300mm were cast. Specimens were water-cured for 28 and 56 days.

Figure 3: Testing of specimen for split tensile strength

Figure 4: Compressive strength test set-up

For the compressive strength test was carried out in accordance to BS EN 12390-3:2002. Eighty-one (81) cubes of size 150mm × 150mm ×150mm were cast. The specimens were de-moulded after 24 hours and cured under water in a curing tank for 3, 14 and 28 days. The cured specimens were taken to the electronic testing machine as shown in Figure 4 where load was applied and increased until failure. The machine automatically stops when failure occurs, and then displays the load and the compressive strength was evaluated. The compressive strength of each sample was determined as follows;

Compressive strength (N/mm^2) = Crushing Load / Area of cube

Three cubes at each percentage RHA replacement and fibre content were tested to determine the compressive strength.

3.0 Results and Discussions

3.1 Results of Sieve analysis

Tables 1-4 show the sieve analysis of coarse aggregate, Fine aggregate and Rice husk ash while Figure 5 shows the graphical representation of the sieve analysis data from tables 1 and 2.

Table 1: Sieve analysis for coarse aggregate

Test Sieves	Weight Retained (g)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Percentage Passing (%)
25 µ	–	-	-	-
19 µ	726.2	13.30	13.30	86.70
14 µ	1,544.8	28.29	41.59	58.41
12.7 µ	458.4	8.39	49.98	50.02
10 mm	1,242.8	22.76	72.74	27.26
5 mm	1,268.1	23.22	95.96	4.04
2.36 mm	73.8	1.35	97.30	2.70
Dust	147.2	2.70	100.00	0.00

Table 2: Sieve analysis for Fine aggregate

Test Sieves	Weight Retained (g)	Percentage Retained (%)	Cumulative Passing Retained (%)	Percentage Passing (%)
10mm	8.6	0.25	0.25	99.75
5mm	20.1	0.58	0.83	99.17
2.36mm	91.7	2.64	3.47	96.53
1.18mm	538.4	15.52	18.99	81.01
600µ	1,249.1	36.00	54.99	45.01
300µ	1,173.6	33.82	88.81	11.19
150µ	307.5	8.86	97.67	2.33
75µ	1.1	0.03	97.70	2.30
Dust	79.7	2.30	100	0

Table 3: Aggregates Coefficients

	Sand	Granite
D_{10}	0.279	6.749
D_{30}	0.461	10.325
D_{60}	0.775	14.211
Cu	2.78	2.11
Cc	0.98	1.11

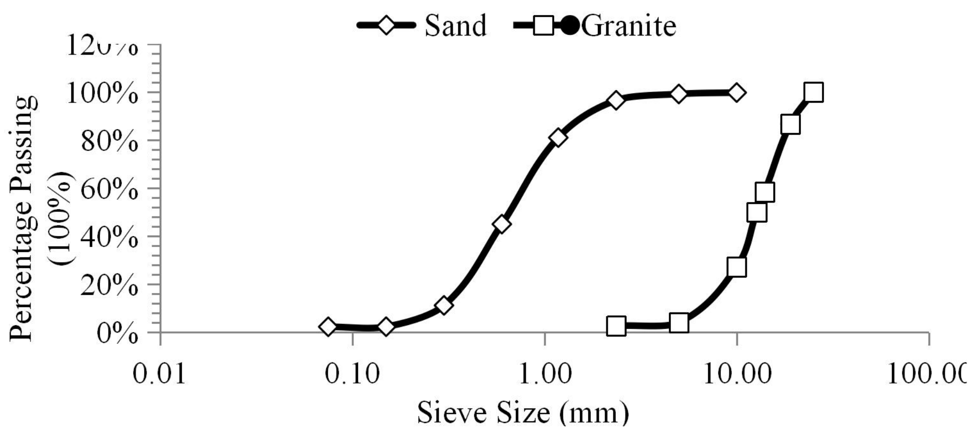

Figure 5: Particle Size Distribution Curves for Sand and Granite

Using the equations below, the coefficient of uniformity (Cu) and the coefficient of curvature (Cc) were obtained from Figure 2 and the results shown in table 3.

$$Cu = \frac{D60}{D10} \quad (2)$$

$$Cc = \frac{D30*D30}{D10*D60} \quad (3)$$

The fine and coarse aggregates had uniformity coefficients (Cu) of 2.78 and 2.11 respectively while they had a coefficient of curvature (Cc) of 0.98 and 1.11 respectively. According to Unified Soil Classification, the fine aggregates could be classified as well graded medium to coarse sand while the coarse aggregates could be classified as well graded fine to medium granite.

3.2 Chemical composition of RHA

Table 4: Comparison between the Chemical Composition (%) of Ordinary Portland cement (OPC) and Rice Husk Ash (RHA)

S/N	Name Of Compounds	Ordinary Portland Cement (%)	Rice Husk Ash (%)
1	Silica, (SiO_2)	18.34	59.5
2	Sodium oxide (Na2O)	0.55	3.0
3	Potassium oxide (K2O)	0.48	12.6
4	Calcium oxide (CaO)	63.97	7.3
5	Magnesium oxide (MgO)	2.16	2.2
6	Aluminium oxide (Al_2O_3)	4.73	2.1
7	Ferric oxide (Fe_2O_3)	3.58	8.8
8	Sulphate (SO_3^{2-})	1.67	-
9	Manganese oxide (MnO)	-	2.0
10	Insoluble residue (IR)	20.02	2.5
11	Loss on ignition (L.O.I)	1.11	-
12	Fibres	0.002	-

It was observed that cumulative percentage of SiO_2, Al_2O_3 and Fe_2O_3 in composition of rice husk ash is 70.4%. This value falls within the range recommended for class N pozzolan and it is an indication of high reactivity of the RHA sample tested for in this study (ASTM C618-92a 1994). The percentage of CaO present in cement was higher than that of RHA. This portrays the cementing power of cement over RHA which is a pozzolan; a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Malhotra and Mehta, 1996)

3.3 Effect of RHA-Steel Fibre Matrix on the Setting Times of Cement

Table 5: Setting Time Values (mins) with Percentage Replacement of Rice Husk Ash

Percentage Replacement	Initial Setting Time (Mins)	Final Setting Time (Mins)
Control	166	268
10	176	279
15	182	283
20	188	290
25	196	297

The results indicated that the addition of steel fibres considerably increases the initial and final setting time of cement based pastes. The rice husk ash particles in the pastes act as agents to suppress nucleation and prompt decelerated hydration mechanism. The deceleration of the setting time of cement pastes could have been caused by the decreasing volume of hydration compounds as well as the reduction of distances between individual particles as a result of the presence of steel fibres in the matric. The relationship between the setting time and percentage of replacement of RHA-steel fibre matrix is shown in Figure 6

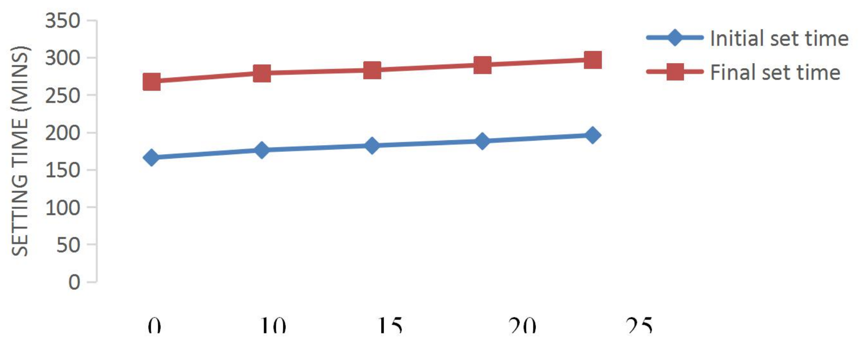

Figure 6: Effect of RHA-steel fibre On Setting Times (initial and final) Of Cement Paste

3.4 Workability test

Table 6: Slump Values and Degree of Workability

% Percentage Replacement	Slump Value (mm)
Control (0% RHA)	33
10% RHA+Fibre	58
15% RHA+Fibre	70
20% RHA+Fibre	79
25% RHA+Fibre	85

The workability of the fresh concrete, as determined by the slump test in accordance with BS EN 12350-2:2009 for all the mix proportions with constant percentages of cement replaced with rice husk ash is presented in Table 6. It was observed that the workability reduced at 10% cement replacement with rice husk ash. This indicates a dehydrating effect of rice husk ash.

3.5 Compressive Strength Test

Table 7: Average Compressive Strength (N/mm2)

curing ages	3 days		14 days		28 days	
Steel fibres (kg)	0.5	1.0	0.5	1.0	0.5	1.0
0% (control)	14.96		20.81		23.25	
10%	23.9	25.5	27.9	29.8	32.2	34.7
15%	17.8	19.1	18.5	20.2	23.3	23.9
20%	16.5	16.7	17.3	18.9	19.3	19.9
25%	14.5	15.0	15.3	16.5	17.3	18.0

In the case of plain concrete mixes, the addition of steel fibres showed a marginal increase of the compressive properties. A marginal increase in compressive properties was caused by the effect of the fine to coarse aggregate ratio. It can also be noted that the maximum strength gain of the rice husk ash-cement matrix was achieved at the 10% replacement with RHA, at 28 days. Further increase after 10% replacement showed a gradual reduction in strength of 27.64% and 31.12% at 15% replacement for 0.5kg and 1.0kg of steel fibres respectively. It can be also noted that the increased addition of steel fibres in rice husk ash substituted concretes exhibited a slight increase in compressive strength value. The effect of steel fibre addition on the compressive properties is known to be a marginal improvement because compressive failure of concrete involves fracture in which case the tensile failure of the fibres is not realized. It can be deduced from the experimental results that a homogeneous presence of fibres in the matrix does not actively contribute to stress redistribution in compressive failure mode and thereby neither the matrix nor the aggregate failure is delayed. The results suggest that the addition of rice husk ash at a level of 10% and steel fibres of up to 1kg at 28 days curing age gave remarkable improvement of compressive strength as shown in Figure 7.

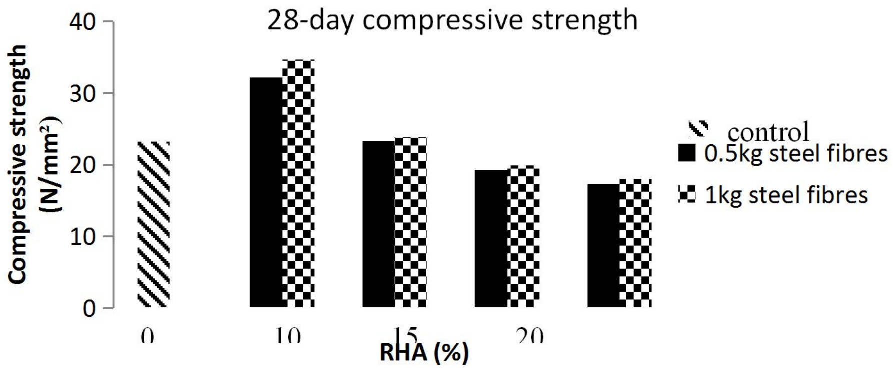

Figure 7: 28-day average compressive strength at percentage replacement levels

3.6 Flexural Strength Test

Table 8: Average Flexural Strength (N/mm^2)

curing ages	28 days		56 days	
Steel fibres (kg)	0.5	1.0	0.5	1.0
0% (control)	12.30		13.6	
10%	12.52	13.31	13.81	14.0
15%	8.92	10.59	9.34	11.3
20%	7.15	9.25	8.75	10.2
25%	6.78	8.72	7.82	9.56

A comparison of the flexural strength properties evaluated for the various concrete mixtures is given in Table 8 above. It can be observed from the experimental trends shown in the results that, in the case of plain concrete the improvement in flexural strength were noticeable at later ages. In the case of 10% rice husk ash substituted concretes containing a steel fibre dosage of 1kg (Vf), the highest flexural strength was recorded at 56 days. This resulted in an increase of flexural strength compared to plain concrete. Also, an increase in RHA percentage beyond 10% yielded no further increase in flexural strength, even with the addition of steel fibres as shown in Figure 8.

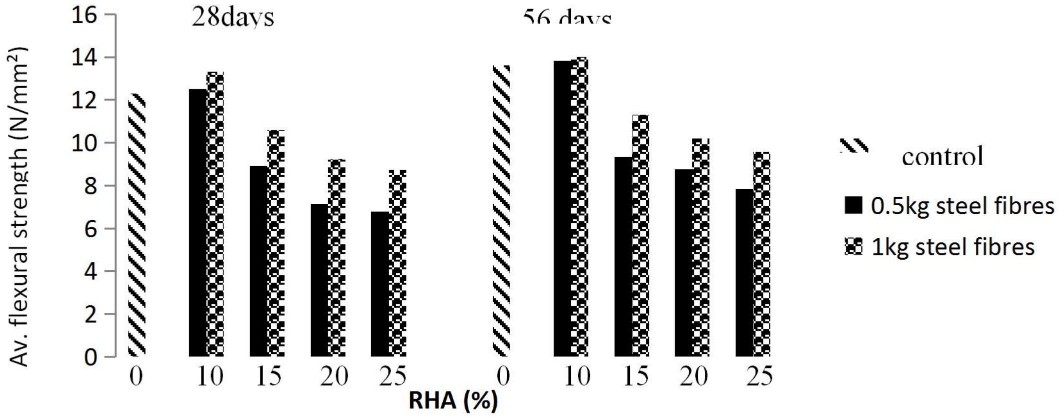

Figure 8: Flexural strength at various replacement levels

This result is similar to what was obtained by Sandesh et al. (2004), where the inclusion of Steel fibers showed more significant effects on flexural tensile strength at 0.25% to 1.0% volume fractions and an increase in fibre content resulted in an increase in flexural strength. The test results show clearly that steel fibre addition gives better enhancement of flexural properties up to 10% RHA and randomly distributed discrete steel fibres helps to control cracks.

3.7 Split tensile test

Table 9: Average Split tensile strength (N/mm^2)

curing ages	28 days		56 days	
Steel fibres (kg)	0.5	1.0	0.5	1.0
0% (control)	1.78		1.92	
10%	1.88	1.98	1.96	2.05
15%	1.61	1.70	1.64	1.75
20%	1.57	1.64	1.61	1.71
25%	1.48	1.56	1.50	1.65

The split tensile values of the various concrete mixtures are compared in Figure 8 above. It can be noted that the maximum value of split tensile strength for rice husk ash substituted concrete was observed at 10% replacement, with 1kg (Vf) of steel fibres as shown in Figure 9. As the percentage replacement increases, there was a gradual reduction in split tensile value; however, increase of the steel fibre dosage suitably improved the strength properties. The increased addition of steel fibres showed reasonable improvement of the split tensile strength because of the bridging action of the fibres realized under tension. On the other hand, increased percentage replacement of rice husk ash did not show an appreciable increase in strength, because of probable reduction of the microstructural densification. The results shows that the effect of steel fibre addition is better realized when bridging stress developed during indirect tension.

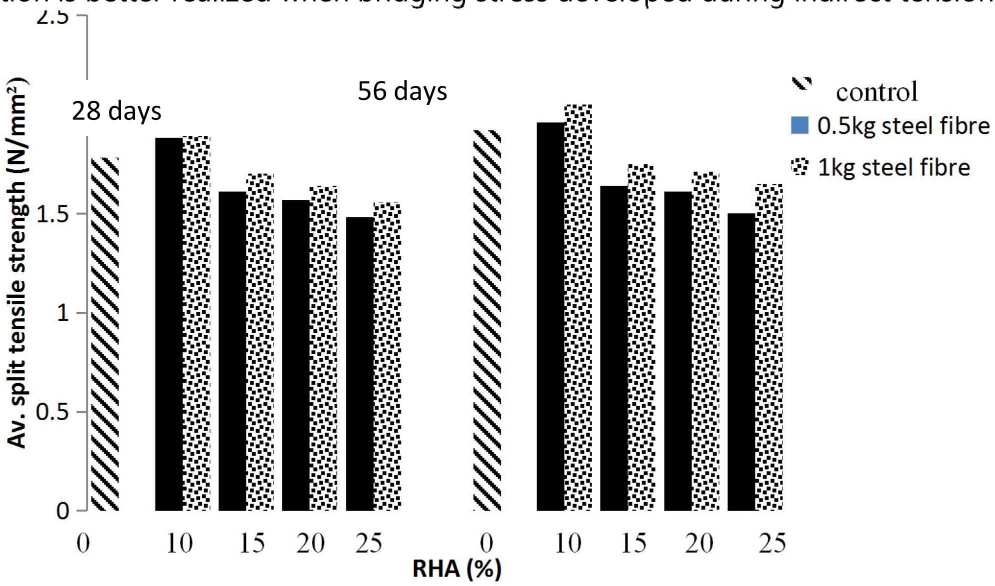

Figure 9: Average split tensile strength at various replacement levels

This result is also in accordance with Sandesh et al. (2004) where for 12.5% RHA and 0.25% steel fibres, the split tensile strength was 2.76N/mm^2 and for 12.5% RHA and 0.5% steel fibres, the split tensile strength was 2.83 N/mm^2. Steel fibers in the concrete increase the splitting tensile strength and the highest volume fraction of fibers gives the maximum increase of strength.

4.0 Conclusions

Concrete mix with 10% replacement level of RHA gave maximum compressive strength, flexural strength and split tensile strength. The increase was insignificant at a higher substitution level (15%) because of decreased reactivity. The rate of strength gains in rice husk ash substituted concretes was appreciable for various curing ages because of the more effective pozzolanic reaction, the pore filling effect and the fineness of the rice husk ash particles. The results demonstrated that a higher substitution of rice husk ash showed a gradual reduction in split tensile value; however, increase of the steel fibre dosage suitably improved the strength properties. The increased addition of steel fibres showed reasonable improvement of the split tensile strength because of the bridging action of the fibres realized under tension. On the other hand, increased rice husk ash substitution did not show an appreciable increase in strength, because of probable reduction of the microstructural densification. The test results demonstrate that the effect of steel fibre addition is better realized when bridging stress developed during indirect tension.

References

American Society for Testing Materials (ASTM), ASTM C618-92a, Standard specification for Fly ash and raw calcined natural pozzolan for use as mineral admixture in portland cement concrete. ASTM Designation C618-92a-1994. West Conshohocken, PA: ASTM, 1994

British Standard Code of Practice 2009. Bs 12350 part 2. Testing fresh concrete Sampling. British Standards Institution. London, UK

British Standard Code of Practice 2000. Bs 12390 part 5. Testing hardened concrete: Flexural strength of test specimens. British Standards Institution. London, UK

British Standard Code of Practice 2000. Bs 12390 part 6..Testing hardened concrete: Tensile splitting strength of test specimens. British Standards Institution. London, UK

British Standard Code of Practice 2009. Bs 12390 part 3. Testing hardened concrete: Compressive strength of test specimens. British Standards Institution, London.UK

Chao-Lung, H., Anh-Tuan, BL. and Chun-Tsun, C. 2011. Effect of Rice Husk Ash on the Strength and Durability Characteristics of Concrete. Construction and Building Materials, 25(3): 3768-3772

Della, VP., Kuhn, I. and Hotza, D. 2002. Rice Husk Ash as an Alternate Source for Active Silica Production. Mater Lett, 57(4): 818-821

Fernandez, H. 2007. Partial replacement of sand with Fly ash. International Conference on Fly ash utilization and disposal in India by CBIP. January 20-22, 2007. 45-54

Isaiah, GC., Gastaldini, ALG. and Moraes, R. 2003. Physical and Pozzolanic Action of Mineral Additions on the Mechanical Strength of High Performance Concrete. Cement Concrete Composite, 25(1): 69-76

Malhotra, VM. and Mehta, PK. 1996. Pozzolanic and Cementitious Materials. Gordon and Breach Publishers, Philadelphia

Malhotra, VM. 2000. Role of Supplementary Cementing Materials in Reducing Greenhouse Gas Emissions, in Concrete Technology for a Sustainable Development in the 21st Century, O.E. Gjorv and K. Sakai, eds., E&FN Spon, London

Raoul, J., Rendell, F., Tamba, S. and Cisse, IK. 2003. Properties of Cement Rice Husk Mixture, Construction and Building Materials 17, 239-243

Löfgren, I. 2005. Fibre-reinforced Concrete for Industrial Construction – a fracture mechanics approach to material testing and structural analysis. Ph.D. thesis, Department of Civil and Environmental Engineering, Chalmers University of Technology, Göteborg, pp. 1-162

Sandesh, DD., Pravin, VD., Satish, DK. and Deotale, RS. 2004. Experimental study on strength of concrete by artificial fibres with rice husk ash. International Journal of Engineering Research and Applications, 1(3): 571-581

Zhang, L. and Mindess, S. 2005. The compressive toughness of high strength fibre reinforced concrete. Construction Materials Symposium, Vancouver, Columbia, Canada, August 22-24, 2005. CDROM. Vancouver, Canada: University of British Columbia