Performance Evaluation of Steel Fibres in Rice Husk Ash Substituted Concretes

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Abstract. The potential use of supplementary cementitious materials in plain cement concrete for improving concrete properties has been a growing concern in recent years. In addition, the effective strengthening of the matrix by fibre reinforcements to avoid brittle failure is another requirement for plain concrete. This provided the motivation for exploring the benefits of rice husk ash (RHA) as a cement replacement material and the addition of steel fibres for reducing brittleness in concrete. The rice husk ash used in this study was the residue of burnt raw rice husk sintered in a muffle furnace at 800°C. The fine particle size of the rice husk ash provided an early pozzolanic reaction upon cement hydration and thus resulted in high cementing efficiency. This paper reports a systematic evaluation of the mechanical properties of rice husk ash substituted concrete mixtures containing RHA as a partial cement substitute at replacement levels of 10% and 20% by weight of cement, with different dosages of steel fibres. Our experimental results demonstrated that 10% RHA substitution led to improved compressive properties compared to plain concrete. The highest increase of split tensile and flexural strength was reported in the case of RHA substituted concrete with steel fibre added.

Keywords: *rice husk ash; setting properties; superplasticizer; strength; ultrasonic pulse velocity.*

1 Introduction

It is understood that worldwide approximately 630 million tons of rice husk ash are produced each year. Because of the demand for rice this figure shows a tremendous increase along with the increase of the world population. The milling of rice produces rice husk as a waste material. It is calculated that the generation of rice husk on average adds upto approximately 30% of the total weight of rice that is processed. Most of the husk is burnt or dumped, not being used advantageously in civil engineering works. In recent years significant work has been undertaken to investigate rice husk ash as a beneficial addition to concrete, either as a partial replacement for cement or as an additive. The present rapid increase of the use of rice husk ash can be attributed to its positive effects on the mechanical properties of cementitious composites. Though added strength and low permeability are the two main reasons to add rice husk ash to

Received February 28th, 2013, Revised July 15th, 2013, Accepted for publication August 14th, 2013.
 ISSN: 2337-5779, DOI: 10.5614/j.eng.technol.sci.2013.45.3.4

concrete, there are other properties that it can improve, such as the modulus of elasticity, strength at later ages and durability properties.

It is well-documented that the use of rice husk ash as a partial replacement for cement in combination with superplasticizer provides a significant increase in the strength of the concrete. Durability properties are also improved, as a result of an enhanced microstructure. Della, *et al.* [1] 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. Isaia, *et al.* [2] have demonstrated that residual RHA is produced with a lower quality because of its high carbon content, which leads 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. Rodrigues de Sensale [3] has suggested that upto 20% of ground RHA can be advantageously blended with cement without adversely affecting the strength and durability properties of the concrete. They also revealed that the electrical resistance of all RHA concrete exhibited a higher value than the control mix after 91 days of curing. The strength efficiency of the ground RHA concrete was also found to be higher than that of the control concrete. Chao-Lung Hwang, *et al.* [4] and Raoul Jauberthie, *et al.* [5] have investigated the effect of rice husk ash content as partial replacement of cement on compressive strength and volume stability for different mixes. The test results showed that upto 40% replacement by rice husk could be made without affecting the compressive strength when compared to the control concrete. Incorporation of RHA upto a 30% replacement level reduces chloride penetration, decreases permeability and improves strength and corrosion resistance properties. Muhammad Shoaib Ismail, *et al.* [6] and Moayad, *et al.* [7] demonstrated in their studies that the rate of hydration is slow in concrete made with partial replacement of cement by RHA compared to the control mix. Even though the deceleration in strength gain is more dominant during the initial three days of curing and at later ages (beyond day 45), the concrete did show improvement in strength properties. Saraswathy, *et al.* [8] have suggested that a higher proportion of cement replacement by RHA – up to 30% – resulted in enhanced strength and corrosion resistance. It also caused a reduction of chloride penetration and permeability. Alireza Naji Givi, *et al.* [9] demonstrated that the addition of ultra fine RHA with average particle size of 5 microns provided better mechanical and durability properties of concrete. The partial replacement of RHA at 10% exhibited higher compressive properties and also showed an appreciable reduction in water permeability of hardened concrete.

The research studies summarized above provide useful information about the mechanical properties of concrete altered by the addition of rice husk ash. It can be noted from the earlier studies that the reactive silica present in rice husk ash can be beneficial for improving the pozzolanic reactivity with cement hydration products. However, very limited studies have been carried out to investigate the addition of rich husk ash to cement concrete because of workability problems and delayed reactivity. Also, the importance of burning the rice husk ash at a higher temperature for improving the pozzolanic reactivity was not given due concern in most studies. Furthermore, a systematic evaluation of the setting properties of the cementitious system using the ultrasonic pulse velocity (UPV) test needs to be conducted for assessing the integrity of the concrete. The limitations of these earlier studies have been addressed in the present study and a systematic evaluation of the mechanical properties of various rice husk ash substituted concretes was conducted. The reinforcing effect of discrete steel fibres in rice husk ash concretes was also investigated in order to assess flexural performance. This provided a prospective scope for the present study to investigate the strength gain properties and the reinforcing efficiency of steel fibres in rice husk substituted concretes.

The present study explored the importance of rice husk ash substitution for the improvement of the mechanical properties of cement concrete with steel fibre added. We also looked at the increased performance levels of the rice husk ash achieved by the addition of high-range water reducers that can suitably improve the workability in order to obtain maximum strength properties. A systematic study was carried out to evaluate the effects of cement substitution by rice husk ash and steel fibre addition on the flexural strength properties of concrete for different concrete mixtures. Ultrasonic pulse velocity tests were conducted to evaluate the qualitative properties of the various concrete mixes used in this study.

2 Materials Used and Experimental Testing Methodology

2.1 Cement

A 53 grade ordinary Portland cement satisfying the requirements of IS 12269–1987 [10] was used in the present study. The specific gravity of the cement was found to be 3.16, with a Blaine's fineness value of 325 m^2/kg.

2.2 Fine Aggregates

River sand obtained from a locally available source passing through 4.75 mm Indian standard sieve conforming to grading zone II of IS 383–1970 [11] was used, with a fineness modulus of 2.57, specific gravity of 2.71 and water absorption of 0.67% at 24 hours.

2.3 Coarse Aggregates

Machine-crushed, well-graded angular blue granite stone with 12.5 mm maximum size conforming to IS 383–1970 [11] was used. The specific gravity of the aggregates was found to be 2.75, with a fineness modulus of 7.20 and water absorption of 0.62%.

2.4 Rice Husk Ash

Rice husk obtained from a nearby rice milling plant was burnt at two different temperatures (200°C and 800°C) to determine the efficiency of burning in terms of carbon content. The burning of the rice husk was carried out in a muffle furnace, shown in Figure 1. The ash particles obtained at the higher burning temperature (800°C) showed complete burning (grey ash colored particles) and resulted in low carbon content (less than 5%). Conversely, in the case of the lower burning temperature (200°C) the ash particles were not completely burnt (black colored particles), as can be seen in Figure 2. In the present study, the rice husk ash obtained at the higher sintering temperature was selected for further studies, as it contained less carbon. The physical and chemical properties of the rice husk ash obtained at the higher temperature are given in Table 1.

Figure 1 Rice husk ash sintered at 800°C in Muffle furnace.

Figure 2 Rice husk ash used in the study.

Table 1 Physical and chemical properties of RHA.

Physical Properties (values)								
Fineness % passing (sieve size)							45 μm	
Specific gravity							2.05	
Pozzolanic index at 28 days (%)							94.5	
Chemical composition (% by mass)								
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI
90.5	0.4	0.4	0.4	0.5	0.19	2.1	0.2	4.8

2.5 Chemical Admixture

The workability properties of fresh concrete mixtures were improved by the addition of superplasticizer. In this study, a special type of acrylic-based superplasticizer known as high range water reducer (HRWR) was used. The specific gravity of the HRWR was around 1.18 with a solids content of 40% by total weight.

2.6 Glued Steel Fibres

Steel fibres imported from Korea were used, whose properties are given in Table 2. A snapshot of the fibres is shown in Figure 3. The steel fibres were glued together with water-soluble glue. When added with water, the glue dissolved and allowed for easy dispersion without fibre balling. This ensures uniform mixing in a concrete with a high degree of homogeneity. The steel fibres had hooked ends to improve the bond strength and pullout resistance of the fibres in the concrete.

Table 2 Properties of glued steel fibres (GSF) used in the study.

Material	Relative density (KN/m^3)	Length (mm)	l/d ratio	Diameter (mm)	Tensile strength (MPa)	Failure strain (%)
Glued steel fibres	7.65	35	70	0.5	1700	3 to 5

Figure 3 Snapshot of glued steel fibres (GSF) used in this study.

2.7 Concrete Mix Design

A total of nine different concrete mixture proportions were taken for the experiment. A plain concrete mix with target strength of 40 MPa without rice husk ash was designed, based on Indian standard codal provision 10262–2009 [12]. The remaining concrete mixes consisted of rice husk ash substitution at 10% and 20% by weight of cement respectively, and steel fibre replacement levels of 0.5 and 1.0% volume fraction (V_f) respectively. Details of the compositions of the various concrete mixtures are presented in Table 3.

Table 3 Mixture proportions of concretes used in this study.

Mix Id	w/b ratio	F/c ratio	Cement	RHA	Fine aggregate	Coarse aggregate	Water	Steel fibres (%) V_f
			(kg/m^3)					
V	0.3	0.6	400	0	672	1113	120	0
V1	0.3	0.6	400	0	672	1113	120	0.5
V2	0.3	0.6	400	0	672	1113	120	1
M	0.3	0.6	360	40	672	1113	120	0
M1	0.3	0.6	360	40	672	1113	120	0.5
M2	0.3	0.6	360	40	672	1113	120	1
S	0.3	0.6	320	80	672	1113	120	0
S1	0.3	0.6	320	80	672	1113	120	0.5
S2	0.3	0.6	320	80	672	1113	120	1

Note: w/b – water to binder ratio; F/c – fine to coarse aggregate ratio; V_f – volume fraction of fibres in terms of concrete volume. Superplasticizer was added at a dosage of 1.50% by weight of binder to all mixes.

2.8 Casting and Curing of Fresh Concrete Specimens

The concrete ingredients were mixed in a pan type concrete mixer with a capacity of 40 kg, for a period of 5 minutes. First, the required amount of superplasticizer was mixed thoroughly with the calculated mixing water and then added to the dry ingredients in the mixer, followed by the addition of the steel fibres. The fresh concrete was then casted in a standard cube mould of size 100 x 100 x 100 mm for compressive strength evaluation. Similarly, cylindrical moulds of size 100 x 200 mm and 150 x 300 mm were casted for testing split tensile and elastic modulus properties respectively. After one day the specimens were remoulded and kept in the required amount of water for curing and taken for testing at different ages.

2.8.1 Evaluation of Compressive and Split Tensile Strength

The compressive and split tensile strength of the concrete specimens were determined using a digital compression testing machine, as shown in Figure 4, with a capacity of 200 kN and loading rate of 2 kN/sec as per IS 516-1959 [13].

2.8.2 Determination of Modulus of Elasticity

The elastic modulus of the concrete was determined from the cylindrical specimens with a 150 mm diameter and 300 mm height. First, the specimens were capped at the ends and a compressometer was attached, as shown in Figure 4. The specimen was then placed in the digital compressive testing machine and a maximum load of up to 40% of ultimate load was applied. During the loading process the compressometer dial gauge readings were noted for every 10 kN load increment and the results were plotted graphically between stress and strain. In the graph, a straight line was drawn through the various points and the slope of the line was measured to obtain the elastic modulus of the concrete specimen.

Figure 4 Test setup for Young's Modulus of concrete.

2.8.3 Flexural Strength Test

A flexural testing machine with a capacity of 100 kN operated at a rate of 1.5 mm/min was used to study the flexural tensile properties of the hardened concrete using a third-point loading arrangement, as shown in Figure 5. The different concrete specimens of size 100 x 100 x 500 mm were tested to study the effect of the steel fibre reinforcements on the resistance to cracking during bending. The experimental results of the evaluation of flexural stress were then calculated using Eq. (1):

$$f_{cr}=PL/bd^2 \quad (1)$$

where

f_{cr} : flexural tensile stress (N/mm^2)
P : load (kN)
L : length of concrete specimen (mm)
b : width of concrete specimen (mm)
d : depth of specimen (mm)

Figure 5 Test setup for flexural testing.

2.9 Ultrasonic Pulse Velocity Test (UPV)

The quality of the concrete and the rate of strength improvement were measured indirectly using the ultrasonic pulse velocity method, which involves measurement of the travel time of an ultrasonic pulse passing through the concrete. The pulse generator circuit consists of an electronic circuit for generating pulses and a transducer for transforming the electronic pulses into mechanical energy with a vibration frequency of 50 kHz. The path length divided by the travel time gives the average velocity of wave propagation. The test results were verified as per IS 13311-1992 part 1 [14].

3 Experimental Test Results and Discussion

3.1 Fresh Concrete Properties

The workability of the various fresh concrete mixtures containing rice husk ash and steel fibres was measured using a slump cone test. It can be noted from Figure 6 that the slump value of the steel fibre concretes (0.5% V_f) without rice husk ash showed a high degree of workability. However, with the addition of rice husk ash and an increased dosage of steel fibres, the slump values were found to be reduced. The reduction in workability noticeable with the addition of rice husk ash compared to the addition of steel fibres was caused by the increased paste volume and the increased fineness of the binder particles. This results in an increase of the specific surface area of the particles and thereby increases the water demand. It can be noted that the addition of high range water reducers (1.5% by weight of binder) showed a reasonable improvement of the workability properties. This could be noticed from the mixes containing rice husk ash and steel fibres at optimum content (10% and 1.0% respectively). However, a higher percentage of rice husk ash added to the concrete led to a drastic reduction in workability caused by a loss in consistency. The addition of hyperplasticizing admixtures provided a targeted slump value above 75 mm for all the concrete mixtures, which is essential for obtaining a reasonable degree of compaction.

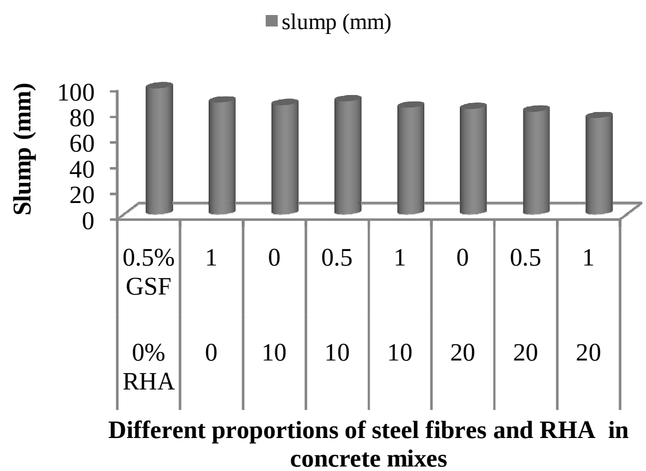

Figure 6 Slump test for various mixtures of fresh concrete.

3.2 Compressive Strength of Concrete

The compressive strength results of the various concrete mixtures with and without rice husk ash are summarized in Table 4. In the case of plain concrete mixes, the addition of steel fibres showed a marginal increase of the compressive properties, as can be seen in Figure 7. A marginal increase in compressive properties was caused by the effect of the fine to coarse aggregate ratio. It can be noted from Figure 8 that the effect of rice husk ash addition (10%) was better realized, with a maximum strength gain of up to 44.30 MPa. This increase was appreciable when compared to the plain concretes. However, an increase of the level of rice husk ash substitution to 20% showed a gradual reduction in strength, as can be seen in Figure 9. It can be also noted that the

Table 4 Compressive strength of concrete for different mixture proportions.

Mix Id	Rice husk ash % (by weight of cement)	Steel fibres (%) V_f	Compressive strength (MPa)			Split tensile strength (MPa) 28 days	Flexural strength (MPa)		Young's Modulus (GPa) 28 days
			3 days	7 days	28 days		7 days	28 days	
V	0	0	32.10	36.00	40.10	3.70	4.40	5.10	37.26
V1	0	0.5	29.80	36.70	39.50	3.30	4.20	5.00	36.70
V2	0	1	31.20	37.40	39.30	3.50	4.10	5.30	35.37
M	10	0	30.90	35.20	39.00	3.20	3.95	4.90	36.09
M1	10	0.5	31.60	38.10	41.50	3.60	4.32	5.45	36.63
M2	10	1	34.30	41.40	44.30	4.10	4.60	5.90	38.10
S	20	0	27.90	31.509	35.30	3.10	3.60	3.98	33.69
S1	20	0.5	28.30	32.40	36.10	3.40	3.82	3.98	34.08
S2	20	1	28.90	33.40	35.90	3.50	3.60	3.99	34.94

Note: The test results indicate an average of six concrete specimens

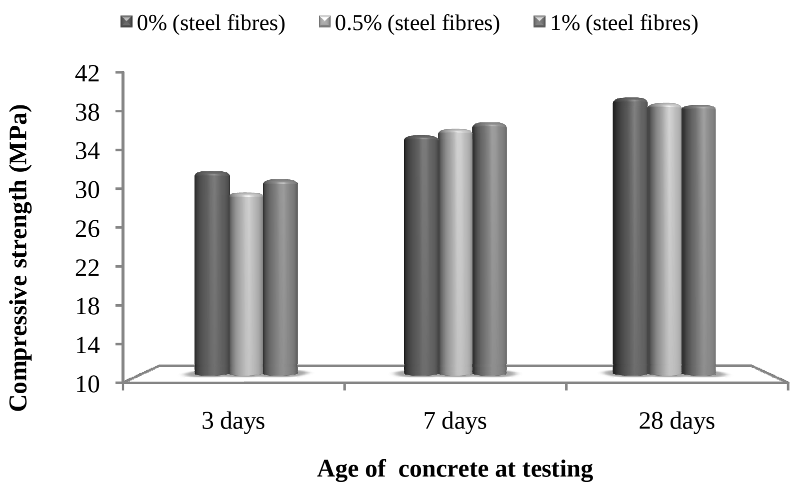

Figure 7 Variation of compressive strength of plain concrete without RHA.

increased addition of steel fibres in rice husk ash substituted concretes exhibited a small increase or decrease in compressive strength value. The improvement of the rate of strength gain in rice husk ash substituted concretes was notably higher. Also, the optimum rice husk ash substituted concrete mixtures (10%) showed a relatively higher rate of strength gain compared to the 20% rice husk ash concrete mixes. 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 1% V_f provides remarkable improvement of compressive strength.

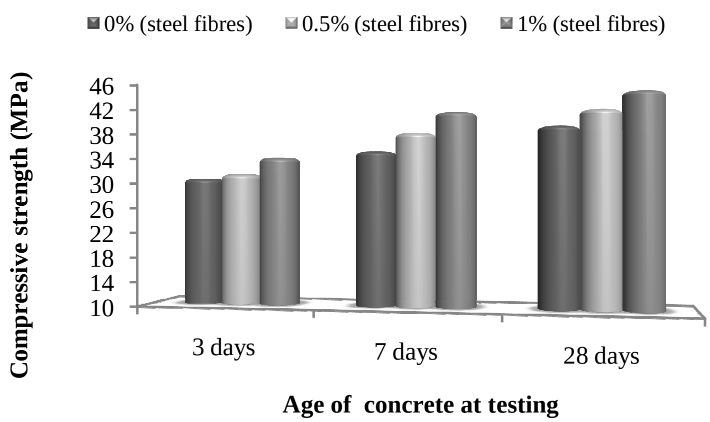

Figure 8 Variation of compressive strength of plain concrete with 10% RHA.

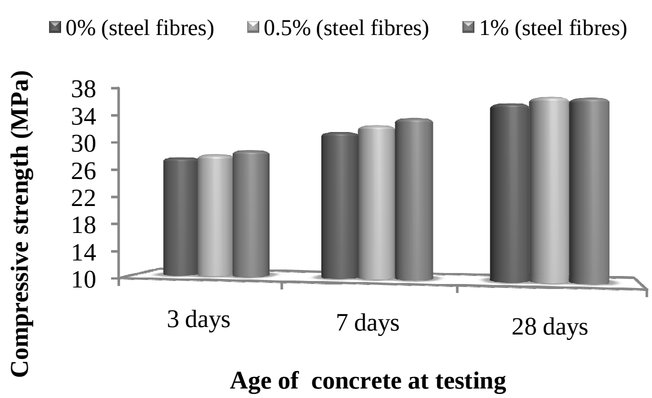

Figure 9 Variation of compressive strength of concrete with 20% RHA.

3.3 Indirect Tensile Strength Properties

The split tensile values of the various concrete mixtures are presented in Table 4. It can be noted that the maximum value (4.10 MPa) of split tensile strength was observed in the case of 10% rice husk ash substituted concrete with 1% (V_f) of steel fibres. The results demonstrate 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.

3.4 Flexural Strength Properties

The flexural strength properties evaluated for the various concrete mixtures are given in Table 4. It can be observed from the experimental trends shown in Figure 10 that in the case of plain concrete the improvement in flexural strength was noticeable at later ages, primarily as a result of steel fibre addition. In the case of 10% rice husk ash substituted concretes containing a steel fibre dosage of 1% (V_f), the highest flexural strength recorded was 5.90 MPa (after 28 days), as shown in Figure 11. This resulted in an increase of flexural strength of 15.68% compared to plain concrete; however, there was no further increase with 20% rice husk ash substitution, even with the addition of steel fibres, as shown in Figure 12. The test results show clearly that steel fibre addition gives

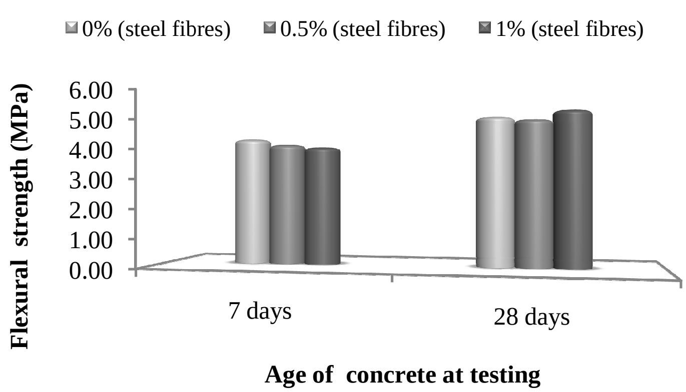

Figure 10 Variation of flexural strength of concrete without RHA.

better enhancement of flexural properties compared to rice husk ash substitution. In addition, the test results clearly demonstrate that the presence of steel fibres provided the tensile carrying capacity required of brittle matrices. Also, the effective crack bridging and crack opening controlled by the steel fibres, as shown in Figure 13, occurred even after failure of the concrete beam, which exhibited a significant enhancement of post-peak characteristics. In general, steel fibre addition had a synergistic effect together with the pozzolanic reaction of rice husk ash substituted cement (10%) and showed improved flexural strength compared to the plain concrete mixes.

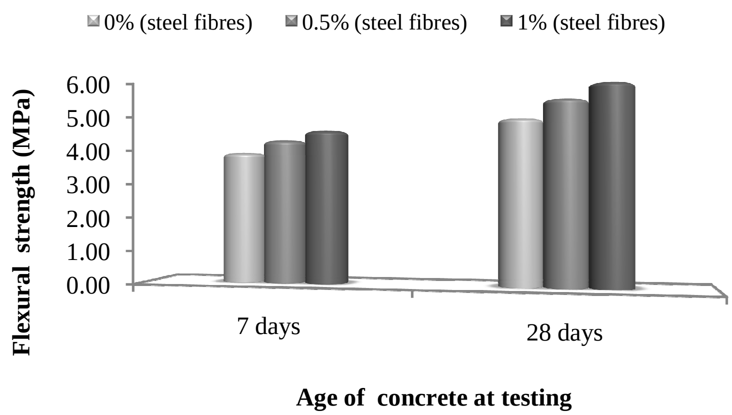

Figure 11 Variation of flexural strength of concrete with 10% RHA.

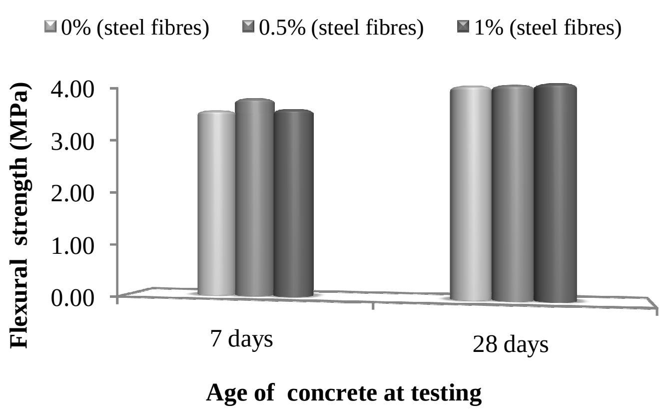

Figure 12 Variation of flexural strength of concrete with 20% RHA.

Figure 13 Effective fibre bridging showing pullout resistance

3.5 Young's Modulus of Concrete

The elastic modulus values of the various concrete specimens are provided in Table 4. The elastic modulus of the concrete was found to be dependent on the improvement of the matrix properties. It is evident from Figure 14 that the RHA concretes with steel fibre addition exhibited higher elastic modulus values compared to the plain concretes without RHA. It can be noted that the main contribution in the improvement of the elastic modulus of RHA concretes came from steel fibre addition, since the higher RHA substitution level showed a

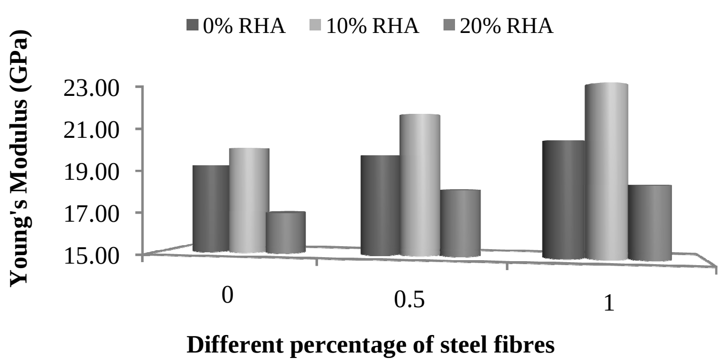

Figure 14 Variation of Young's modulus of concrete for different mixture proportions.

reduction in elastic modulus value. Furthermore, it can be concluded from the test results that the improvement of the composite elastic modulus is a function of matrix strengthening that is primarily caused by the addition of discrete reinforcements and refined matrix properties as a result of the pore filling effect of RHA. This shows that the optimum addition of RHA (10%) with 1% steel fibres has a maximum elastic modulus value of around 38.10 GPa.

3.6 Rate of Hardening – using UPV Test

The pulse velocity technique is an important assessment tool for predicting the quality of concrete for different mixture proportions. The ultrasonic pulse velocity values for the various rice husk ash based concretes containing steel fibres are given for different curing ages in Table 5 and depicted in Figure 15. The results show that good hardening properties were noticeable in all mixtures. However, the concrete mix with optimum rice husk ash substitution (10%) performed better than all other concretes. The ultrasonic pulse velocity values showed an increasing trend for different concrete mixes, with pulse velocity values in the range of 4000 to 4220 m/sec. However, the highest UPV value (4220 m/sec) was recorded for the 10% rice husk ash substitution containing 1% V_f of steel fibres. All concrete mixes were found to exhibit a UPV value conforming to good quality (values above 3500 m/sec) as per IS 13311–1992 part 1 [14], which denotes a stable improvement of the microstructural properties and rate of hardening at different ages.

Table 5 Ultrasonic pulse velocity test values for various mixture proportions (m/sec).

Mix Id	1 day	7 day	28 day
V	3520	3870	4120
V1	3690	3820	4100
V2	3700	3910	4090
M	3790	4030	4210
M1	3730	4100	4220
M2	3680	3930	4130
S	3740	3810	4000
S1	3790	3950	4010
S2	3750	3940	4020

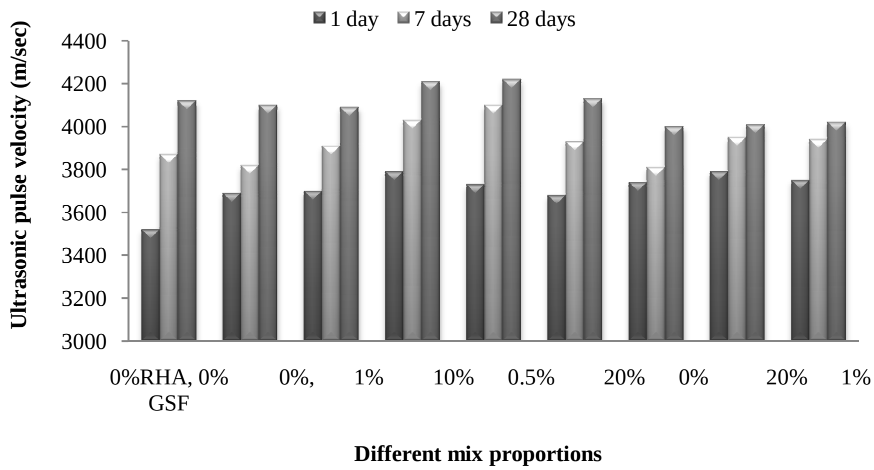

Figure 15 Ultrasonic pulse velocity test values for different mixture proportions of concrete.

4 Conclusions

The experimental investigation conducted in this study has shown a strength enhancement for rice husk ash substituted concretes at the optimum substitution level (10%), while the increase was insignificant at a higher substitution level (20%) because of decreased reactivity. The rate of strength gain 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. Careful dosage of the different ingredients, e.g. controlling the water-to-binder ratio (0.3) and the fine-to-coarse aggregate ratio (0.6), had a significant effect on the microstructural alterations of the concrete, which resulted in improvements of the matrix properties.

Compressive properties were improved with 10% rice husk ash substitution, while the addition of steel fibres was not found to have an appreciable influence, the fibres not being part of the stress transfer mechanism. Split tensile strength was higher in the case of rice husk ash concretes reinforced with steel fibres. However, steel fibres at higher addition levels were found to be favorable for increasing the indirect tensile strength developed during loading. The elastic modulus of the concrete was found to be dependent on the rice husk substitution as well as on the steel fibre addition because of which an improved matrix strengthening and resistance towards deformation under loading were observed. Furthermore, the quality of the various concrete mixes, established using the ultrasonic pulse velocity method, conformed to the standard requirements for a good quality concrete.

It can be summarized that strength of plain RHA substituted concrete can be enhanced by a low water to cement ratio, optimum RHA addition, selection of the right fine to coarse aggregate ratio, addition of hyperplasticizer, and higher steel fibre content. Concrete mixes with 10% rice husk ash substitution can be beneficial for producing high-strength concrete, while higher replacement levels are not recommended because of loss in consistency of concrete and requires the addition of high range water reducers. Steel fibres addition to high strength concrete is an essential requirement to improve the toughness properties and to eliminate explosive brittle failure.

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