EFFECT OF RICE HUSK ASH INCORPORATION IN STEEL FIBER REINFORCED CONCRETES

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Abstract

Steel fiber reinforcement aims to improve composites properties regarding to crack propagation. It is known that concrete has high compressive strength and durability, but its toughness is low, being considered a fragile material. The role of the fibers as a toughening strategy depends on several factors, including bond strength between the fiber and matrix. RHA has a high content of amorphous silica, which gives it high pozzolanic activity. This RHA characteristic may lead to the formation of new hydration products, especially C-S-H, giving a higher density to the cement matrix; thus, enhancing the bonding between fibers and the cementitious matrix. This research aims to evaluate if a highly reactive RHA incorporated as mineral admixture in steel fiber reinforced concrete improves its toughness. Concrete samples were produced with fiber volume fractions of 0.5, 0.75 and 1.0%. To investigate the RHA effect, the same reinforcement rates were used in concretes in which cement was partially replaced by 15% RHA. Four points bending tests were carried out in a servo controlled universal testing machine, with being controlled by the displacement transducer. The results indicate that RHA composites presented slightly higher values of toughness and residual stress than those without the mineral admixture. Therefore, RHA can be considered as viable approach to enhance fiber-matrix interactions and making the reinforcement more effective when in considering the whole composite behaviour.

Keywords: Rice Husk Ash; Flexural test, Steel Fiber

1. INTRODUCTION

The main approach to improve concrete performance regarding toughness is the incorporation of fibers to the matrix, which act as a stress bridge, promoting higher resistance to crack propagation. The fiber acts by transmitting the stresses from one side of fissure to the other, avoiding stress concentration and early material failure [1]; [2].

Steel fiber reinforced concretes can be produced using the same procedure adopted to make conventional concrete, with adaptations to promote homogeneity. Particular attention should be given to the uniform dispersion of the fiber along the concrete mix in order to achieve performance improvements in concrete mechanical properties, also considering the workability required for a suitable mix, release and finishing of this composite. Even with the use of superplasticizers, this percentage of incorporation remains around 2% when adopting conventional concrete mixing practices [3]. To Johnston [4], this percentage is between 0.25 and 1.0% by volume.

Many factors influence the properties of fiber-reinforced concrete, mainly: the type and size of the fiber; their constituent material and aspect ratio; incorporated fiber volume and the quality of the cementitious matrix (characterized by interfacial transition zone between composite phases). All these variables influence the fiber / matrix adhesion stress, which is the property that will promote toughness to fiber reinforced concrete [3]; [5].

The interaction between the concrete matrix and fibers is one of the main challenges for reinforced concrete research. The region known as Interfacial Transition Zone (ITZ) is responsible for the adhesion between the materials. As this region becomes denser, the interaction becomes better and consequently increases composite strength [6].

Pozzolanic activity of materials consisting of large amounts of silica, such as rice husk ash (RHA), is of great importance to promote a more complete cement hydration, making the matrix denser and less subject to degradation by external agents. In the case of steel fiber reinforced concrete, it increases the adhesion strength between the materials [7]. In addition, because they have particles smaller than cement, they allow a better compaction of the cement paste [8].

The research objective was to evaluate the effect of cement substitution by RHA, aiming to densify the cement matrix to the point where the adhesion stress with the steel fiber was higher than in the conventional mixture. For this, control specimens and specimens with 15% of cement replaced by RHA were produced. In addition, steel fiber incorporation was evaluated in percentages of 0.5, 0.75 and 1.0% by volume. Using the four-point flexural test, it was possible to measure the toughness of each formulation. The results indicate an increase in toughness in comparisons with and without the addition of RHA, besides a gain of load capacity in the post-cracking phase.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this research were cement, sand, gravel # 0, steel fiber, water, superplasticizer and rice husk ash. The cement used was the Portland High Initial Strength Cement (CPV-ARI) from Holcim. Because it is a purer cement, it is ideal to evaluate the efficiency of RHA incorporation and its pozzolanic activity in the composite. The sand used was average river sand, with fineness modulus of 1.65 and maximum characteristic size of 1.2mm. Coarse aggregate was grade # 0 of gneiss with 12.5mm for maximum dimension and 1.11 fineness modulus. Industrialized highly reactive RHA presenting 92% of amorphous silica, average diameter of 7.7 µm, density and its specific surface area (S_{BET}) of, respectively, 2161 Kg/m^3 and 21150 m^2/Kg. As superplasticizer, Fluxer RMX 7000 from ERCA was used.

The steel fibers adopted in this research were DRAMIX type 80/60BG fibers manufactured by Belgo Bekaert in accordance with ASTM [9]. It is a smooth fiber with hooks. The fiber characterization is described in Table 1.

Table 1 – Steel fiber characterization

Steel fiber Dramix 80/60BG - Belgo Bekaert	
Type of fiber	SF01
Diameter (mm)	0,75
Length (mm)	60
Tensile strength (N/mm²)	1.100
Max. load (N)	485
Aspect ratio (l/d)	80

Source: Belgo Bekaert

2.2 Methods

Table 2 shows the proposed formulations. In all formulations, the amounts of the following materials were maintained: water/binder factor, sand, gravel and superplasticizer. The percentages of 0.5, 0.75 and 1.0% by volume of concrete were adopted as variables for the incorporated fiber volume. The formulations were also adopted without the addition of RHA and with the replacement of 15% of cement by RHA.

Table 2 – Quantitative materials for each formulation

Materials for 1m³ of concrete	Formulations						
	CPFL_00_0	CPFL_00_0.5	CPFL_00_0.75	CPFL_00_1.0	CPFL_15_0.5	CPFL_15_0.75	CPFL_15_1.0
Cement (Kg)	409,84	409,84	409,84	409,84	348,36	348,36	348,36
RHA (Kg)	0	0	0	0	61,48	61,48	61,48
Sand (Kg)	568,85	568,85	568,85	568,85	568,85	568,85	568,85
Grain #0 (Kg)	1292,62	1292,62	1292,62	1292,62	1292,62	1292,62	1292,62
Water (Kg)	179,51	179,51	179,51	179,51	179,51	179,51	179,51
Water / Cement factor	0,44	0,44	0,44	0,44	0,44	0,44	0,44
Steel fiber (Kg)	0	39,25	58,88	78,50	39,25	58,88	78,50
Superplasticizer (Kg)	2,61	2,61	2,61	2,61	2,61	2,61	2,61

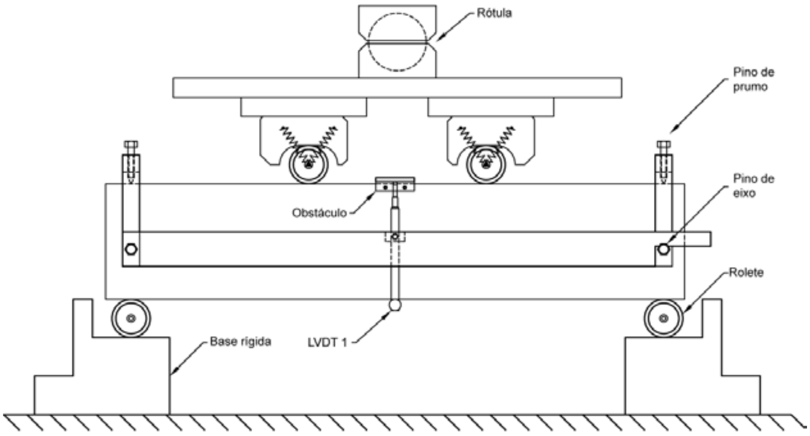
Samples

Three prismatic specimens were produced for each proposed formulation, with 21 samples in total. Samples were produced in the dimensions of 100x100x350mm, according to the American standard ASTM [10] for flexural tests.

A conventional 200 litres mixer was used for the concrete production. The total mixing time was 10 minutes. The moulds were filled in two layers that were compacted using a metal rod with 75 strokes. Samples were removed from the moulds after 48hs and the curing method was by immersion in water saturated with calcium hydroxide for a minimum 28 days in order to protect the steel fiber from corrosion. After the curing period, the specimens were tested for flexural strength

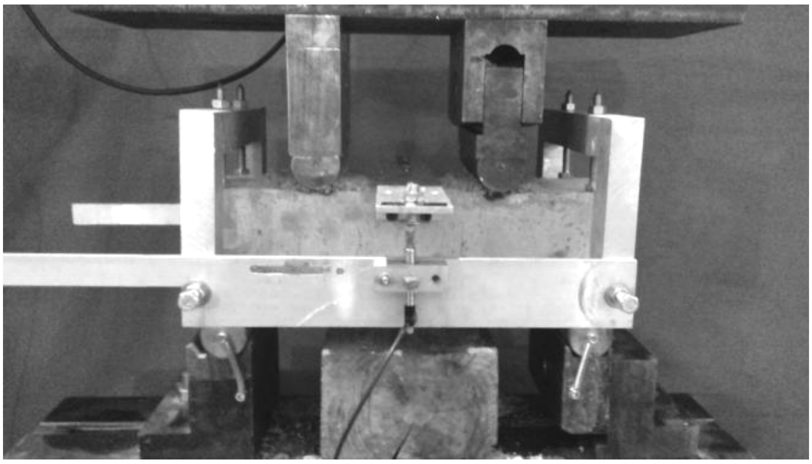
Four-point flexural test

Four-point flexural tests followed the requirements of ASTM [10]. According to the norm mentioned, the toughness value obtained in the four point bending test is given by the area under the load X deflection curve up to limit of L/150. L corresponds to the span length (300mm). The test machine used has a MTS servo-hydraulic actuator with load capacity equal to 100KN, mounted under a rigid gantry with a vertical displacement controller monitored by an LVDT device with a measuring capacity of 4mm. The LVDT device HBM 20mm was attached to each sample using a Yoke type apparatus, shown in Picture1.



Picture 1 – Mounting detail for four-point flexural test [11]

The test parameter used an actuator displacement rate of 0.1mm/min, with data acquisition frequency of 5Hz. The deflection measured by the LVDT was used as the control of the test, being limited to 2mm (equivalent to L/150, as prescribed by the reference standard). The base of the gantry was aligned, followed by the positioning of the support rollers and the adjustment of the wheelbase. Support rollers were 300mm apart and 25mm from the ends of the samples. Load application rollers, in turn, were 100mm apart, placed in the middle third of the samples. In order to measure deflection during the test, a Yoke support device and the obstacle plate for data acquisition via LVDT were installed in each sample. Finally, the LVDT was connected to the QuantumX MX440B HBM data acquisition device (Picture 2).



Picture 2 – Sample detail prepared for testing with LVDT device and Yoke support

3. RESULTS

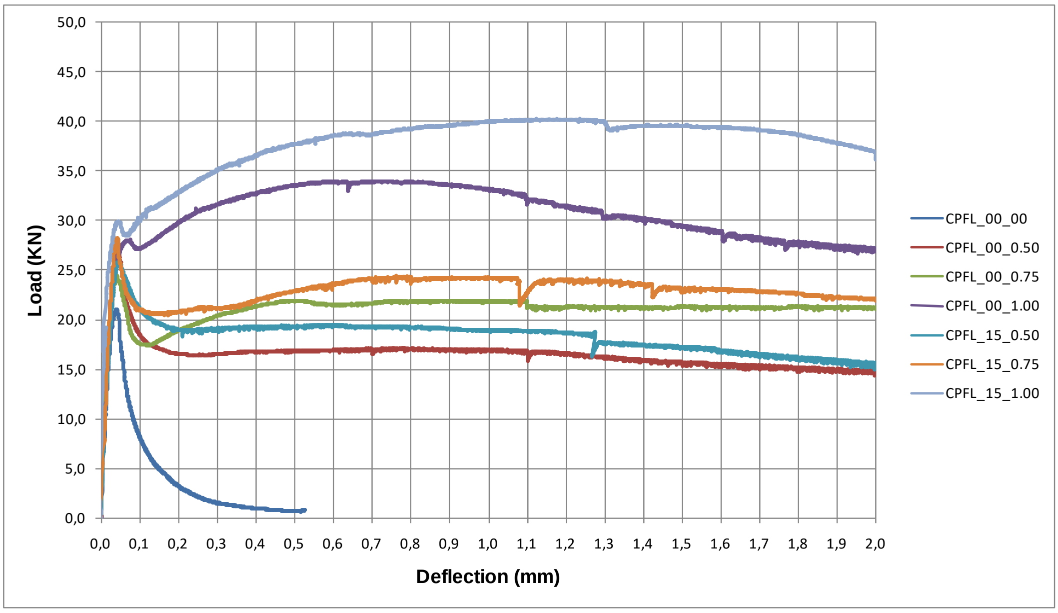
The average results obtained in each of the seven series tested under flexion are in Table 3.

Table 3 – Flexural test results

Four-point flexural test results											
Formulations	cure (days)	δp1 (mm)	Cp1 (KN)	*f*p1 (MPa)	δL/600 (mm)	CL/600 (KN)	*f*L/600 (MPa)	δL/150 (mm)	CL/150 (KN)	*fL/150* (MPa)	T (KN.mm)	dev. T (KN.mm)
CPFL_00_0	65	0,040	21,03	6,31	0,50	0,69	0,21	2,00	-	-	2,32	0,36
CPFL_00_0.5	36	0,043	26,92	8,08	0,50	16,86	5,06	2,00	14,73	4,42	33,05	3,88
CPFL_00_0.75	42	0,042	24,47	7,34	0,50	21,90	6,57	2,00	21,08	6,32	32,52	12,18
CPFL_00_1.0	44	0,067	28,02	8,41	0,50	33,56	10,07	2,00	27,02	8,11	60,53	3,28
CPFL_15_0.5	63	0,047	25,81	7,74	0,50	19,21	5,76	2,00	15,62	4,69	36,70	13,30
CPFL_15_0.75	50	0,042	28,26	8,48	0,50	22,91	6,87	2,00	22,08	6,62	45,82	7,32
CPFL_15_1.0	61	0,044	29,58	8,87	0,50	35,14	10,54	2,00	34,71	10,41	75,13	10,94

Where,

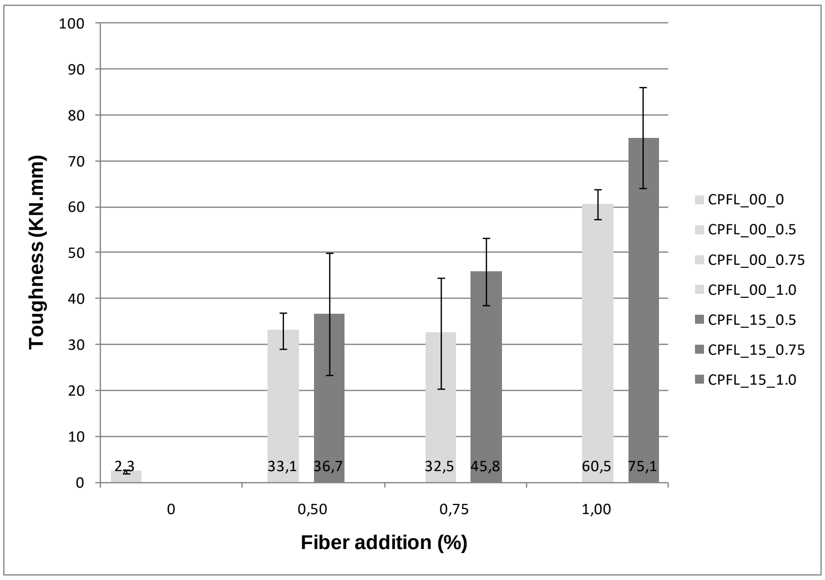
δp1 = deflection at peak load, or first cracking;
Cp1 = peak at the point of first cracking;
fp1 = tension in first crack;
δL/600 = deflection at point L/600 (0,5mm);
CL/600 = load at point L/600 (0.5mm);
fL/600 = tension at point L/600 (0.5mm);
δL/150 = deflection at point L/150 (2.0mm);
CL/150 = load at point L/150 (2.0mm);
fL/150 = tension at point L/150 (2.0mm);
T = toughness (by area under load X deflection curve);
dev. T = standard deviation for toughness calculation.



Picture 3 – Load X deflections graph

Regarding the post-cracking residual strength (Picture 3), the graph shows the strain-hardening behaviour for 1.0% fiber formulations. In formulations with 0.5 and 0.75% of fiber, the analysed behaviour is strain-softening.

According to Picture 4, formulations with 0.50% addition of steel fibers presented a toughness gain of 11%, comparing the propositions with and without RHA. In formulations with 0.75% addition, the gain was of 41%, and for the additions of 1.00%, an increase of 24.1% was observed.



Picture 4 – Comparison of toughness between formulations

4. CONCLUSIONS

- For formulations with 0.5 and 0.75% of fibers, the post-cracking behaviour was strain-softening, which means there was little contribution of the residual strength for the load capacity.
- In composites with 1.0% of fibers, the profile of strain-hardening was observed with load peaks in the residual phase being higher than the first peaks. In flexure tests, it was also possible to verify that cracks always appeared in the intermediate region of the samples, which is a pure flexion zone;
- With regard to composites toughness, the increase in this characteristic becomes evident as the percentage of the addition rises. With the propositions studied, it was not possible to establish the limit of fiber addition that corresponds to maximum gain of toughness. Therefore, there is a need for complementary studies;
- The use of RHA in partial replacement of cement as a measure of densification of ITZ and consequently improvement of adhesion between materials showed promising results. Four-point flexural strength tests showed significant increases in toughness (in order of 24% for 1.0% fiber formulations). Therefore, it is correct to assert that, in general, RHA contributes for the increase in steel fiber reinforced concrete properties;

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REFERENCES

[1] BRAZ, M. C. A.; NASCIMENTO, F. B. C. Concreto reforçado com fibras de aço. Ciências exatas e tecnológicas, v. 3, n. 1, p. 43-56, 2014. ISSN 2357-9919.

[2] BREITENBUCHER, R.; MESCHKE, G.; SONG, F.; ZHAN, Y. Experimental, analytical and numerical analysis of the pullout behaviour of steel fibres considering different fibre types, inclinations and concrete strengths. Structural Concrete, v. 15, n. 2, p. 126-135, 2014. DOI 10.1002/suco.201300058.

[3] BENTUR, A.; MINDESS, S. Fibre reinforced cementitious composites. 2. New York: Taylor & Francis Group, 2007. ISBN 978-0-415-25048-1.

[4] JOHNSTON, C. D. Fiber-reinforced cements and concretes. New York: Taylor & Francis Group, 2001. ISBN 90-5699-694-0.

[5] RANA, A. Some Studies on Steel Fiber Reinforced Concrete. International Journal of Emerging Technology and Advanced Engineering, v. 3, n. 1, p. 120-127, 2013. ISSN 2250-2459.

[6] LIAO, K. Y.; CHANG, P. K.; PENG, Y. N.; YANG, C. C. A study on characteristics of interfacial transition zone in concrete. Cement and Concrete Research, v. 34, p. 977-989, 2004. ISSN 0008-8846/$.

[7] KULKARNI, M. S.; MIRGAL, P. G.; BODHALE, P. P., TANDE, S. N. Effect of rice husk ash on properties of concrete. Journal of Civil Engineering and Environmental Technology, v. 1, n. 1, p. 26-29, 2014. ISSN 2349-8404.

[8] KAIKEA, A.; ACHOURA, D.; DUPLAN, F.; RIZZUTI, L. Effect of mineral admixtures and steel fiber volume contents on the behaviour of high performance fiber reinforced concrete. Materials and Design, v. 63, p. 493-499, 2014. ISSN 0261-3069.

[9] ASTM-A820. Standard Specification for Steel Fibers for Fiber-Reinforced Concrete. United States of America: American Society for testing and materials: 4 p. 2016.

[10] ASTM-C1609. Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading). United States of America: American Society for testing and materials: 9 p. 2012.

[11] PEREIRA, E. V. Influência de Fibras de Aço no Comportamento Mecânico e nos Mecanismos de Fissuração de Concretos Autoadensáveis. Dissertação de Mestrado. Departamento de Engenharia Civil, PUC-Rio, Brasil. 2017.