TOUGHNESS ANALYSIS OF STEEL FIBER REINFORCED CONCRETE BY PULLOUT TEST

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Abstract

Use of steel fibers in cement-based composites has become popular due to possibility of using that material as total or partial replacement of conventional reinforcement, as in floor slabs or tunnel cover. This reinforcement aims at improving composites properties with regard, mainly, to cracks propagation. It's known that concrete has high compressive strength and durability, but its toughness is low, being considered a fragile material. The performance of the fiber as stress bridge depends on several factors, among them bond strength between fiber and matrix. Interfacial Transition Zone (ITZ) is one in which first cracks that lead to material failure appear. Some researches with mineral additives, such as rice husk ash (RHA), are aimed at ITZ densification. RHA has a high content of amorphous silica, which gives it high potential for its pozzolanic activity. That RHA characteristic is able to potentiate new hydration products formation, especially C-S-H, giving a higher density to cement matrix and pores and voids reduction. Research's objective was to evaluate the effect of cement substitution by RHA, aiming to densify cement matrix to point where the adhesion tension with steel fiber was higher than in conventional mixture. For this, control specimens were produced and 15% of the cement replaced by RHA. Through the single fiber pullout test it was possible to measure the adhesion tension between steel fiber and cement matrix. Results indicate an increase in the adhesion strength with a long curing time, indicating that the RHA hydration occurs late in relation to cement.

Keywords: Rice Husk Ash; Bond Strength, Steel Fiber

1. INTRODUCTION

In order to improve the concrete performance, with respect to toughness, studies have been developed through incorporation of fibers to the matrix, which act as a bridge of stress, promoting to the composite a better fissure response. The fiber acts by transmitting tensions from one side to other of fissure, avoiding the stress concentration, which avoids the early material failure [1]; [2].

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

Although the increase in fiber-reinforced concrete properties is known, it is not yet possible to quantify this gain, since fibers are randomly distributed in the matrix. Other factors influencing this relationship are type and size fiber, their constituent material, 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 property that will promote toughness to fiber reinforced concrete [3]; [5].

The interaction of concrete matrix and fibers is one of main challenges of reinforced concrete research. This region known as Interfacial Transition Zone (ITZ) is responsible for the adhesion between that materials and as this region becomes denser, the interaction will be 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 more dense and less subject to degradation by external agents and, in case of steel fiber reinforced concrete reinforced, increase 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].

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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 A820 [10]. 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 with proposed formulations is presented in Table 2. For the formulations water / binder factor, sand, gravel and superplasticizer were maintained. As variables were adopted formulations without RHA and with replacement of 15% of cement by RHA.

Table 2 – Quantitative materials for each formulation

Materials for 1m³ of concrete	Control	15% RHA
Cement (Kg)	409,84	348,36
RHA (Kg)	0,00	61,48
Sand (Kg)	568,85	568,85
Gravel (Kg)*	1292,62	1292,62
Water (Kg)	179,51	179,51
Water / binder factor	0,44	0,44
Superplasticizer (Kg)	2,61	2,61
* removal after mixing in concrete mixer		

Samples

Five cylindrical specimens of ø50mm per 100mm height were produced for each proposed formulation. It was adopted as a mixing procedure of the materials the launch in conventional concrete mixer of 200 litres, first of half of the water, followed by aggregates. Mixture was blended for one minute for humidification of these components. Afterwards, the remainder of water, binders and superplasticizer were added. For 5 minutes these materials were homogenized. Total mixing time was 10 minutes. After homogenization, the material was sieved in a # 4.8mm mesh to remove the gravel, leaving only the paste and small aggregate. Moulds were filled in four layers and each one was compacted with a metal socket with 30 strokes. In each proof body (PB) a ø6.3mm steel bar 90mm long was introduced in the lower face, with half of this bar being kept external to the specimen. In the upper face was introduced a single steel fiber, which had the hooks subtracted, with anchorage length fixed at 20mm. Hooks were subtracted in order to measure only the adhesion strength between matrix and fiber, without mechanical action generated by hooks. A device adapted to vibrate the mixture was used. Figure 1 shows details of the mould produced in acrylic, according to

Abbas and Khan [9]. The PB's were demoulded with 24hs and curing method was by immersion in water saturated with calcium hydroxide in order to protect steel fiber against corrosion during minimum period of 28 days. After the curing period, the specimens were submitted to pullout test.

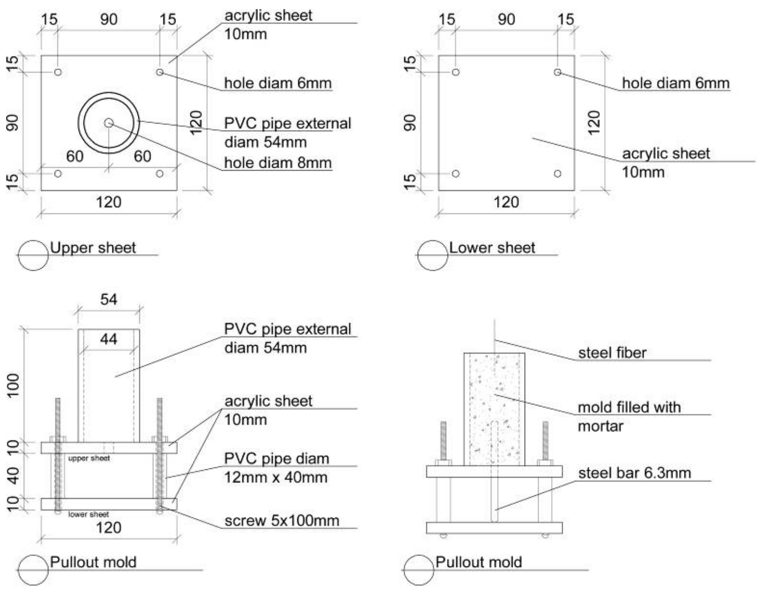


Figure 1 – Detail of acrylic mould for pullout testing [9]

Pullout test

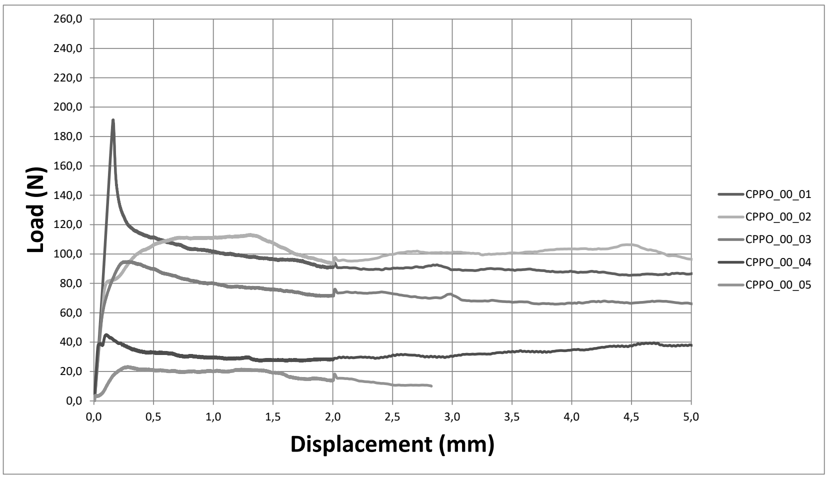
Pullout tests were carried out using a universal EMIC / Instron 23-300 test machine, in which the appropriate claws for traction tests were installed. Lower clamp was used to fix the ø6.3mm rod, while upper clamp fixed steel fiber, as shown in Figure 2. Actuator displacement rate was defined as 0.2 mm/min and the cell load factor was 20KN. The software used to capture data was Bluehill 3, from Instron.

Figure 2 – Pullout test

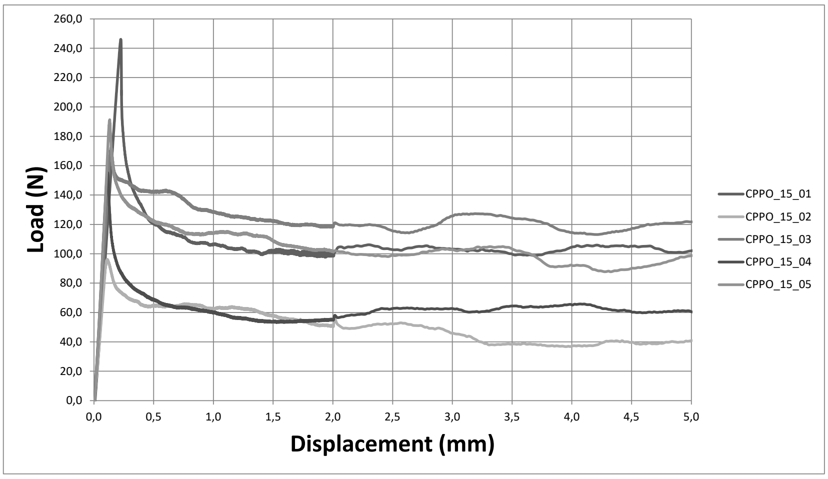
3. RESULTS

In the analyses, first load peak (1), which configures adhesion tension zone and displacement limit point (2), was considered as key points, which for that research was 5mm. This point is located in frictional tension area, which extends from peak of load until complete pulling of fiber (in case of fibers without hook).

For the formulations with RHA, the linear phase is observed until the peak of load (adhesion tension) and then phase of frictional tension. For PB's without RHA results are dispersed and it is not possible to identify in some with clarity phase changes throughout the test, according to graphs shown in Figures 3a and 3b. It is also possible to notice a less diverse behaviour among PB's during trials, with lower variability of results and a more uniform pattern of results in those using RHA.



(a)



(b)

Figure 3a and 3b – Pullout results

Table 3 summarizes test results.

Table 3 – Pullout results

Pullout results									
Formulations	curing (days)	δp1 (mm)	Cp1 (N)	*f*p1 (MPa)	δp2 (mm)	Cp2 (N)	*f*p2 (MPa)	T (N.mm)	dev. T (N.mm)
CPPO_00_01	90	0,161	191,37	4,06	5,00	86,67	1,84	472,3	
CPPO_00_02	90	1,300	113,26	2,40	5,00	96,38	2,05	505,1	
CPPO_00_03	90	0,288	94,93	2,01	5,00	66,06	1,40	364,5	
CPPO_00_04	90	0,103	45,10	0,96	5,00	37,77	0,80	162,1	
CPPO_00_05	90	0,283	23,41	0,50	5,00	-	-	47,0	
Average_00			**93,6**	**1,987**		**71,7**	**1,522**	**310,2**	**199,0**
CPPO_15_01	90	0,224	245,99	5,22	5,00	102,13	2,17	534,3	
CPPO_15_02	90	0,113	96,20	2,04	5,00	40,87	0,87	252,6	
CPPO_15_03	90	0,145	172,56	3,66	5,00	121,73	2,58	615,2	
CPPO_15_04	90	0,116	155,11	3,29	5,00	60,36	1,28	314,6	
CPPO_15_05	90	0,132	191,31	4,06	5,00	98,81	2,10	521,4	
Average_15			**172,2**	**3,655**		**84,8**	**1,799**	**447,6**	**155,5**

Regarding post-crack friction strength, it was verified that mean tension at 5mm displacement point is of order of 18% higher in RHA formulations. It is also possible to note that the average peak load in formulations with RHA is 84% higher. Regarding the composites toughness, a gain of 44% was verified in formulations with RHA.

Standard deviation of composite toughness without RHA addition is significantly higher than in RHA formulations, suggesting that matrix is more heterogeneous with regions of different strengths in its composition.

Bond stiffness obtained for each pull-out curve is reported in Table 4. Results obtained for formulations with RHA are on the order of 36% higher than those without that mineral addition. In addition, the variation in results is lower (60%) for RHA formulations.

Table 4 – Bond stiffness

Bond stiffness		
Formulations	E (MPa)	dev. E (MPa)
Average_00%	408,1	172,0
Average_15%	554,3	104,5

4. CONCLUSIONS

- In pullout tests dispersed results were obtained, which did not follow a pattern of behaviour. This variability is due to the fact that cement matrix and, especially, the ITZ have regions of different resistances in its interior, besides the position, geometry and surface of constituent aggregates, as reported by ISLA et al. [11];
- With regard to bond stiffness, RHA had a good contribution in increasing modulus of elasticity, increasing the values obtained, as well as reducing variability of that results. This suggests a densification and homogenization of the ITZ, which contributes to improved performance of fiber reinforced composites;
- The strength gains at the initial load peak (84%), residual strength (18%) and toughness (44%) were also relevant. Therefore, it is correct to state, even with the great variability in the results, that in general, RHA contributes to the increase of steel fiber reinforced concrete properties, especially, toughness;
- It should be emphasized that a greater sampling is necessary to increase representativeness of results and dispersions. Pullout tests typically have a number of discarded specimens.

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