Experimental Analysis of Polymeric Fiber-Reinforced Concrete at Low Fiber Content

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ABSTRACT: This paper investigates mechanical properties of concrete reinforced by polymeric fibers at relatively low volume fractions, by comparing them with those of concrete without fibers. Two fiber volume fractions were considered: 0.33% and 0.44% by weight of concrete. Tests to evaluate workability, compressive strength, splitting tensile strength, and flexural tensile strength were carried out. Experimental results show that flexural properties of the polymeric fiber-reinforced concrete permit secondary reinforcement to be reduced; and, in some cases, avoid,, even in the presence of low amount of fibers. Results show that fibers inside the concrete matrix were uniformly distributed.

1. INTRODUCTION

Fibers have gained popularity as secondary reinforcement for the control of shrinkage cracking in concrete. Synthetic fibers increase tensile strength and strain capacity of young concrete, beyond cracking: the fibers bridge across cracks and restrain their widening (Alhozaimy et al., Grzybowski et al., Zollo et al.). In addition, fibers presence at relatively low volume fractions does not produce any difficulty in handling and casting and, in hardening concrete, fibers distribution is uniform (Hsie et al.).
This study presents the results of an experimental program aimed at evaluating the behavior in terms of workability, compressive strength, splitting tensile strength and flexural tensile strength of concrete reinforced by short polymeric monofilament fibers at low volume fractions.

1 EXPERIMENTAL PROGRAM

1.1 Materials

Materials used for the mixture of the non fibrous control concrete consist of cement CEM 42.5 R II/A-L, gravel with maximum size of 300 mm, and sand with fineness modulus of 2.06. The mix proportion of cement, water, gravel and sand was 370, 200, 883 e 937 kg/m^3 respectively. Super plasticized at 1.2% was added. The employed synthetic fibers are made from a mix of polymer polyolefinic monofilament, with density of 0.91 kg/dm^3, length of 54 mm, equivalent diameter of 0.48 mm, and tensile strength of 650 MPa.
Two fiber reinforced concretes, type A (0.33% fiber volume fraction) and type B (0.44% fiber volume fraction), and a control concrete, type 0, were made. Concrete mixes and particle size distribution are reported in Table 1 and in Figure 1 respectively.

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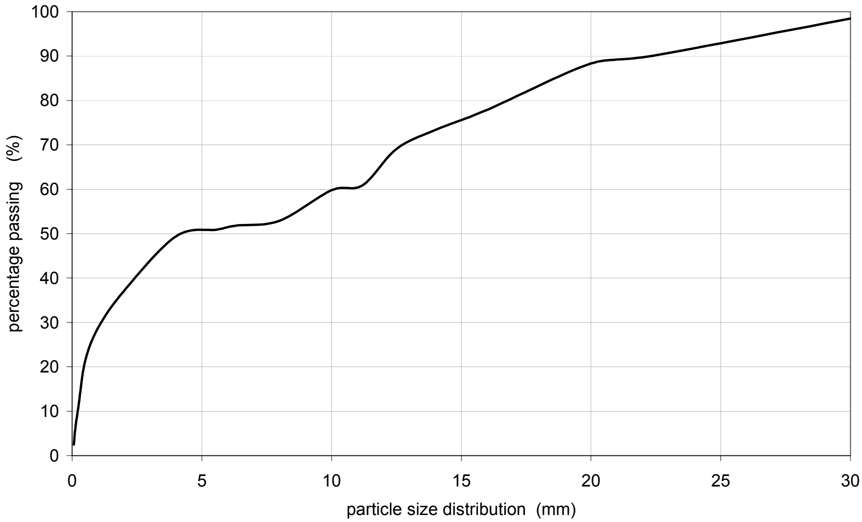

Figure 1 - Particle size distribution.

Table 1 - Concrete Mixes

Concrete Type	Cement (42.5R II/A-L) Dosage (kg)	Water (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)	Super-plasticizer (%)	Fiber volume fractions (% by mass of concrete)
0	370	200	883	937	1.2	0
A						0.33
B						0.44

1.2 Mixing and curing

The mixing process started with the dry mixing of coarse and fine aggregates, after which cement, water and super plasticized were added. The mixture has been mixed for 5 minutes. Finally the specified amount of fibers was added. The mixture has been mixed for 3 minutes to ensure that fibers can be dispersed evenly throughout the concrete.

Both cubic and prismatic molds were filled with fresh concrete, in order to carry compressive and splitting tensile strength tests and flexural tensile strength and residual tensile strength tests. Cubic and prismatic molds sizes were 150 mm and 150 mm x 150 mm x 600 mm respectively.

Molds have been removed after 24 h, and specimens have been put into a water cabinet at 24 °C. Tests have been performed after that samples had been cured for 28 days.

Each test result is the average of three replicate tests results.

1.3 Test methods

Tests have been carried out in compliance with the following standards:

- UNI EN 12390-3:2009 “Testing hardened concrete - Part 3: Compressive strength of test specimens”;
- UNI EN 12390-6:2010 “Testing hardened concrete - Part 6: Tensile splitting strength of test specimens”;
- UNI EN 14651:2007 “Test method for metallic fibre concrete - Measuring the

flexural tensile strength (limit of proportionality (LOP), residual)”. This test is carried out by using beam test under third-point loading, on notched specimens in middle span (the width of notch is 3 mm and high 25 mm).

2 RESULTS AND DISCUSSION

2.1 Slump

Table 2 shows fiber reinforced concrete slumps. The slump changes depending on the different fiber content. For plain concrete the slump is 17 cm. When adding polymer polyolefinic monofilament fibers at 0,33%, and 0,44% fiber volume fractions, slump is 16 cm and 19 cm respectively. Fiber presence has a little influence on concrete workability.

2.2 Compressive strength

Table 2 reports compressive strength, splitting tensile strength and LOP. Strength changes to different extents depending on the fiber content. Fig. 2 shows compressive strength variation of the synthetic fiber reinforced concrete in comparison to the plain concrete. Adding fibers at 0,33% can decrease strength of about 5%, while the improved percentage is 16% when adding fibers at 0,44%. Compressive strength variability is small and tends to come in the neighborhood of that of the plain concrete.

Table 2 - Concrete slump and strength.

Concrete Type	Slump (cm)	Compressive Strength		Splitting Tensile Strength		LOP		$f_{R,3}$
		Measured (N/mm^2)	Strength effectiveness, %	Measured (N/mm^2)	Strength effectiveness, %	Measured (N/mm^2)	Strength effectiveness, %	Measured (N/mm^2)
0	17	43,85	-	3,28	-	2,40	-	0
A	16	41,25	- 6	3,50	7	3,03	26	1,0
B	19	50,90	16	3,98	21	3,30	37	1,8

2.3 Splitting tensile strength

Fig. 2 shows the increase of splitting tensile strength of fiber reinforced concrete with respect to the plain concrete. When the tensile stress keeps in ruins the specimens, the stress is transferred to the fibers, so that macro cracks propagation can be arrested and splitting tensile strength is substantially improved. The increase is small, as it achieves 21% in concrete type B.

2.4 Flexural tensile strength

The tensile behavior of fiber reinforced concrete is evaluated in terms of residual flexural tensile strength values, determined from the load-crack mouth opening displacement curve, F-CMOD curve, obtained by applying a centre-point load on a simply supported notched prism (Fig. 3).

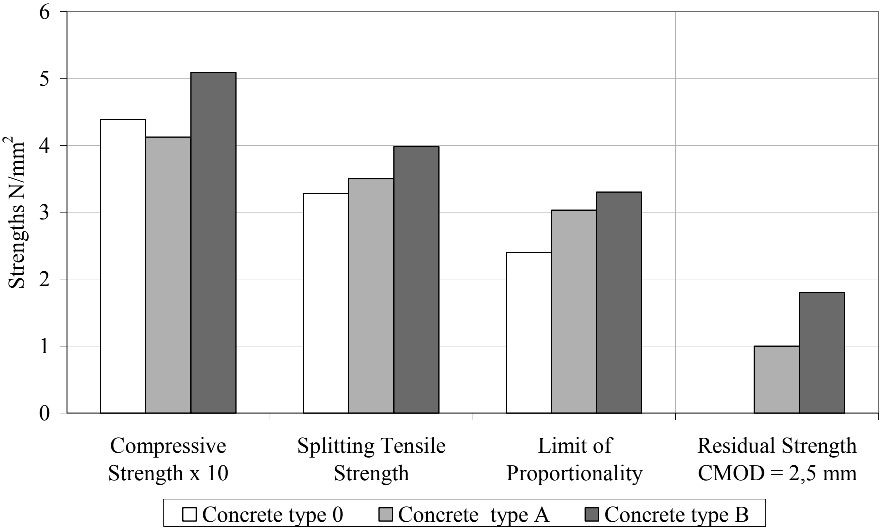

Figure 2 - Measured strengths of fiber reinforced and plain concrete.

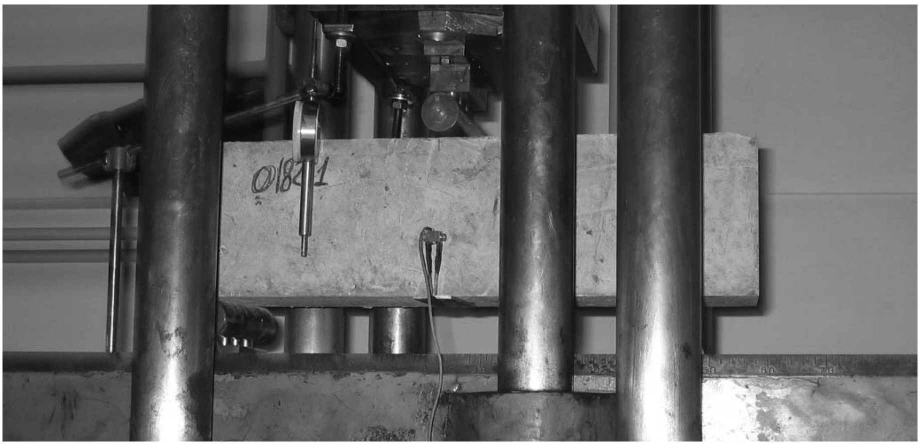

Figure 3 - Beam under third-point loading: test setup.

A displacement transducer has been mounted along the longitudinal axis at the mid-width of the test specimen, in order to evaluate the crack mouth opening displacement. Fig. 4 shows the F-CMOD curve of tested concretes. It can be noticed that ascending portions of F-CMOD diagrams are similar for both type A and B fiber reinforced concretes, while the residual force doubles when fiber volume changes from 0.33% to 0.44%.

3 THEORETICAL ANALYSIS

Stress-strain curve of fiber reinforced concrete can be obtained by F-CMOD curve, by assuming the following relationship for strain (ε) and stress (σ):

$\varepsilon = CMOD/h$

$\sigma = 3 \cdot F \cdot l/(2 \cdot b \cdot h_{sp}^2)$.

where h is the height of test specimen, h_{sp} is the distance between the tip of the notch and the top of the test specimen in the mid-span section, l is the length of span and b is the width of test specimen (in this case: h = 150 mm, l = 450 mm, b = 150 mm, h_{sp} = 125 mm).

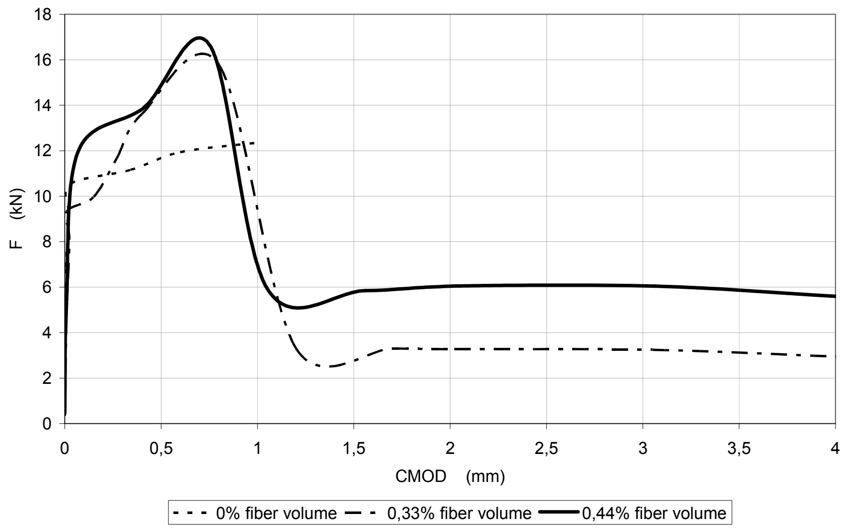

Figure 4 - F-CMOD curves of tested concretes.

Figure 5 reports both experimental and idealized theoretical tensile σ–ε diagrams for type A and B fiber reinforce concrete.

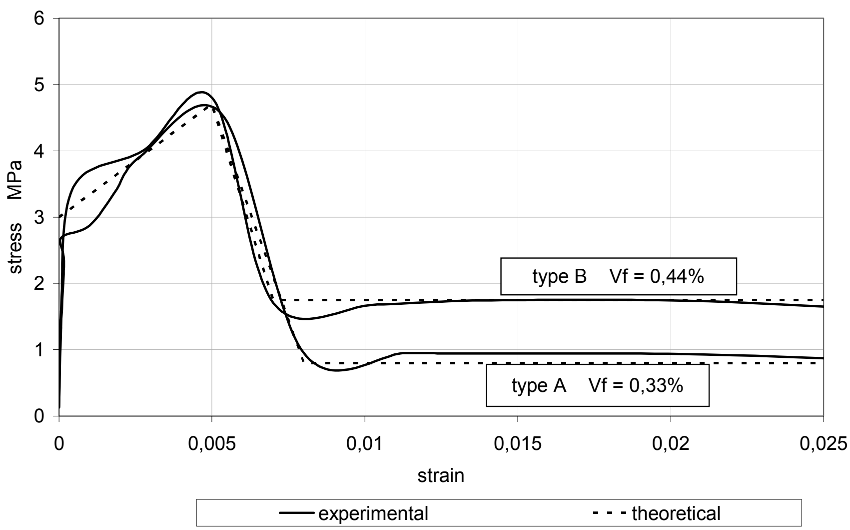

Figure 5 - Experimental and idealized theoretical tensile stress-strain curves of type A and B fiber reinforced concretes.

The internal resisting moment M_R of the notched prismatic specimen has been calculated when the tensile strain was 0.025 and the stress strain distribution of compression and tensile zone was the following:

- in compression zone:
  $\sigma_c = 0$ for $0 \leq \varepsilon_{cc} \leq 0.0007$
  $\sigma_c = f_c$ for $0.0007 \leq \varepsilon_{cc} \leq 0.0035$
- in tensile zone:
  $\sigma_c = 3$ for $\varepsilon_{ct} = 0$
  $\sigma_c = 3 + \varepsilon_c\,(4.7 - 3)/0.005$ for $0 < \varepsilon_{ct} \leq 0.005$
  $\sigma_c = 4.7 - (\varepsilon_c - 0.005)\,(4.7 - f_{residual})/0.003$ for $0.005 < \varepsilon_{ct} \leq 0.008$
  $\sigma_c = f_{residual}$ for $0.008 < \varepsilon_{ct} \leq 0.025$

where, for type A concrete f_c = 41 MPa and $f_{residual}$ = 0.8 MPa and for type B concrete f_c = 51 MPa and $f_{residual}$ = 1.7 MPa.

The internal resisting moments are 1.23 kNm and 2.15 kNm for type A and type B fiber reinforced concrete respectively.

When the beam is realized in ordinary concrete, the equivalent effect produced by the fibers is reached with a reinforcement equal to 0.4% of the concrete section for type A fiber reinforced concrete, and equal to 0.6% for type B fiber reinforced concrete.

4 CONCLUSIONS

This experimental study led to the following conclusions:

1. Presence of fibers had little influence on fiber-reinforced concrete workability: slump class was S4 for all concretes tested.
2. Compressive and tensile strengths and limit of proportionality of tested fiber-reinforced concrete came in at a similar magnitude of values as that of the plain concrete. The maximum increase was 20 % for fiber-reinforced concrete at 0.44% fiber volume fractions by mass/volume? of concrete.
3. Residual tensile strength doubled when fiber volume changed from 0.33% to 0.44%.
4. The presence of fibrous reinforcement produced a similar value of internal resisting moment given by the ordinary steel reinforcement equal to 0.4% and 0.6% by mass/volume of the concrete section for Type A and Type B fiber-reinforced concrete, respectively.

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