THE EFFECTS OF DIFFERENT TYPES OF SHORT FIBERS ON THE BEHAVIOR AND STRENGTH OF REINFORCED CONCRETE BEAMS

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SUMMARY: The results of an experimental investigation of the effects of short fibers on the behavior and strength of simply supported reinforced concrete beams are presented. Three different types of fiber were used. They were made of steel, in two cases, and nylon. They had different shapes as well as lengths and cross-sections. Four series of reinforced concrete beams were cast and tested in the laboratory. In each series a different type of fiber and its proportion in the concrete mix were employed. The test results indicate expressively the better performance of the beams made with steel fibers. These beams exhibited smaller crack width and spacing and consequently more stiffness and load carrying capacity. The results also indicate an increase in the load capacity of the shear mechanisms of the concrete. In this study, the steel fibers employed had a better performance than the nylon ones.

KEYWORDS: reinforced concrete beams, short fibers, strength, behavior

INTRODUCTION

Reinforced concrete structures have been used successfully in many countries worldwide. The reason for this fact is due to the good compressive and tensile strength they exhibit, their durability and the freedom they provide architects and designers in terms of the different shapes they can be molded into. On the other hand, reinforced concrete elements, under certain conditions such as high shear stresses, present a brittle behavior, which in many instances have to be avoided.

Labor costs have increased worldwide in the last 10 years. For reinforced concrete structures keep its share of the constructional market, a reduction in the work necessary for bending the bars is mandatory. Some type of bars such as stirrups used for transverse reinforcement are labor intensive since four bents are necessary for each stirrup. If the number of stirrups in a beam can be reduced, significant savings can be achieved in the cost of the element.

The addition of short fibers randomly placed in the concrete mix is a promising way to overcome the above facts. These fibers may provide a more ductile behavior for the material and also in the case of beam elements reduce the amount of stirrups necessary to resist the applied shear forces.

The objective of this paper is to present the results of an experimental investigation of the effects of different types of short fibers on the behavior and strength of simply supported reinforced concrete beams [1,2]. The fibers differ not only in terms of the based material, steel or nylon, but also in terms of shapes and lengths. Beams fabricated with and without fibers were cast and tested in the laboratory for comparison. The compressive and tensile strength as well as the secant modulus of elasticity of the concrete employed in the beams were also investigated.

MATERIALS AND EXPERIMENTAL PROCEDURES

The beams were fabricated with a normal weight concrete having an expected compressive strength at 28 days of at least 40 MPa. Natural sand and limestone were used as fine and coarse aggregates respectively. ASTM Type III cement was employed in a content of 427 kg/m^3. The water /cement ratio was 0.49. For the necessary workability, a plasticizer RX 322 N, produced by REAX, was used in a percentage of 0.25 of the cement content.

Normal reinforcing steel bars were employed. The complete stress-strain relationships of each different bar diameter were determined. The longitudinal and transverse bars had a yield strength of 500 and 650 MPa respectively.

Two types of steel fibers and a nylon one were employed. The first steel fiber was DRAMIX, manufactured by Bekaert, with a length of 30 mm, diameter of 0.5 mm and consequently a aspect ratio of 60. They were also hooked-collated. The other steel fiber was XOREX, manufactured by Bombril, with a rectangular cross-section. It had a length of 25 mm, thickness of 0.4 mm and width of 2.25 mm. A view of these fibers is indicated in Fig. 1. The fiber of nylon was manufactured by Du Pont with a length of 21 mm and a diameter of 18 microns.

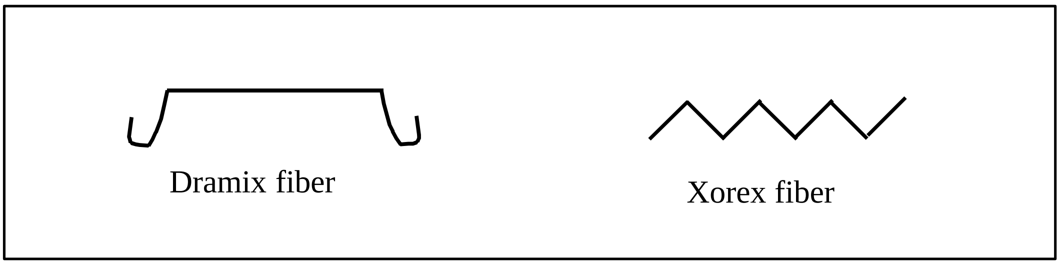

Fig. 1 – Details of the steel fibers

The details of the reinforced concrete beams cast and tested in the laboratory are shown in Fig. 2. The beams were divided in four series. In each series, composed of two beams, a different type of fiber and its proportion in the concrete mix were employed. The amount of fibers in the concrete mix was varied due the different workability found in a preliminary study. The first series contained no fibers. A fiber content of 0.8% in volume of concrete was used in the beams fabricated with steel fibers; for the beams with nylon fibers the percentage was reduced to 0.2%.

The mechanical properties of the concrete with and without fibers were also investigated. The axial compressive strength ($\mathbf{f_c}$), the secant modulus of elasticity ($\mathbf{E_c}$) as well as the modulus of rupture ($\mathbf{f_t}$) were evaluated at 7 and 28 days after casting the concrete as well as on the date the beams were tested. The compressive strength and the secant modulus of elasticity were also measured 3 days after casting. These test were conducted in accordance to Brazilian Standards [3,4,5].

The beams were tested in a simply supported condition with a two-point load set-up. This way each beam had a region of constant bending moment (between the applied loads) and a region of constant shear force along the shear span. The shear span – beam effective depth relation was 3.75 for all beams. Throughout the monotonic loading tests, midspan deflections and strains in the concrete as well as in the longitudinal and transverse reinforcement were measured.

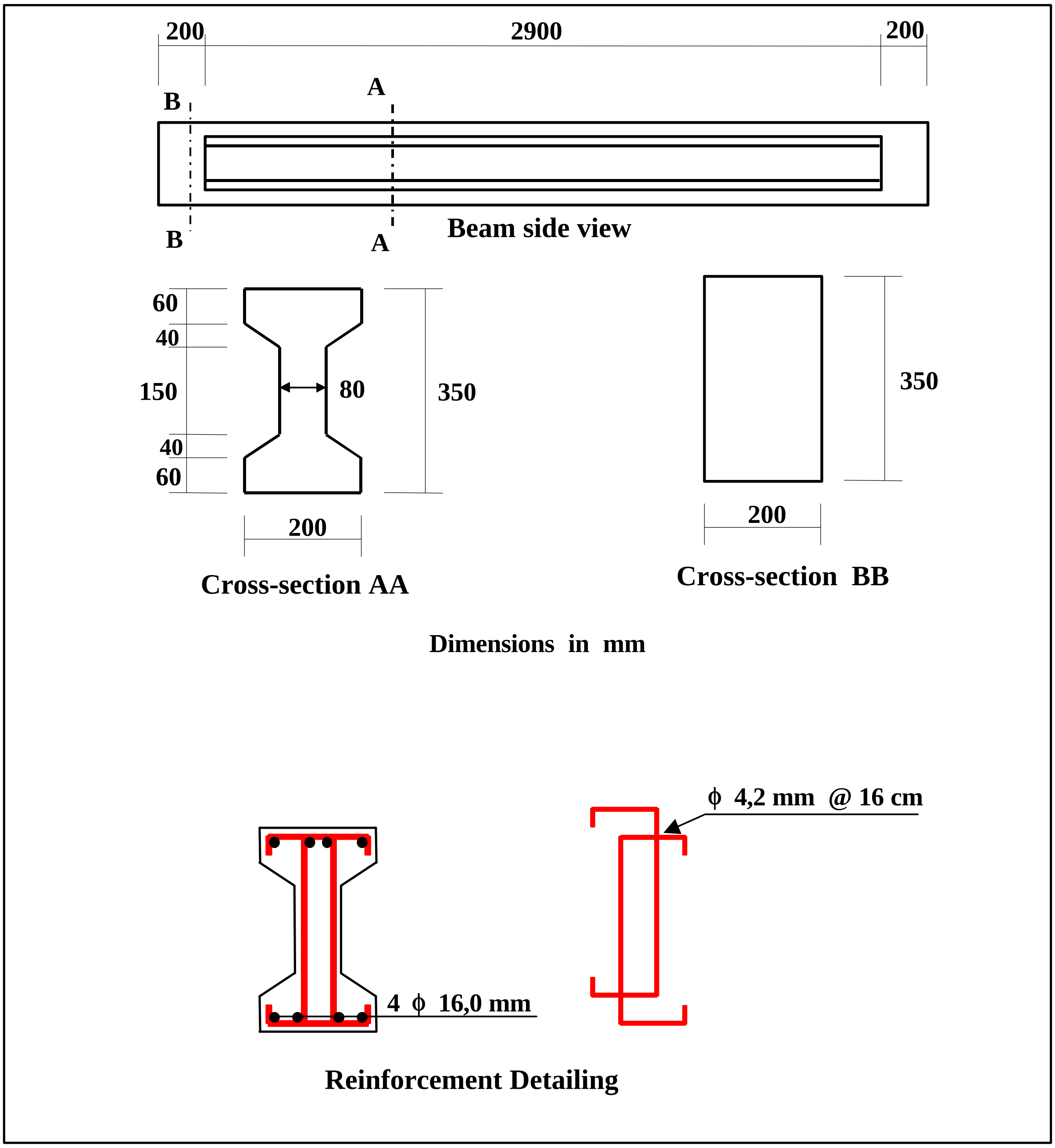

Fig. 2 – Reinforced concrete beams

TEST RESULTS AND ANALYSIS

Mechanical Properties of the Concrete

The results of the concrete properties are presented in Table 1. The last date shown for evaluating the mechanical properties corresponds to the age of the concrete in which the beams were tested to failure.

Table 1 – Concrete - Mechanical Properties

	Plain Concrete			**Concrete with steel fiber Dramix**		
"Slump"	100 mm			52 mm		
Age (days)	f_c (MPa)	E_c (MPa)	f_t (MPa)	f_c (MPa)	E_c (MPa)	f_t (MPa)
3	37.9	28798	-	36.4	26528	-
7	41.7	29962	4.0	42.2	30154	3.7
28	46.8	31763	5.2	44.0	31399	5.7
130	53.5	32046	5.3	-	-	-
189	-	-	-	48.7	31532	6.5

Table 1 – Concrete – Mechanical Properties (continuation)

	Concrete with steel fiber Xorex			**Concrete with nylon fiber**		
"Slump"	50 mm			32 mm		
Age (days)	f_c (MPa)	E_c (MPa)	f_t (MPa)	f_c (MPa)	E_c (MPa)	f_t (MPa)
3	33.8	25721	-	32.8	20204	-
7	38.0	29479	4.5	39.2	25159	4.2
28	43.5	33825	5.6	46.2	27565	5.4
290	52.9	36800	7.9	-	-	-
315	-	-	-	50.1	33892	5.9

The analysis of results indicates a substantial reduction in the value of the slump when fibers were added to the concrete mix. In the case of nylon fibers the reduction was much larger even for a smaller fiber content. This same fact has been found by other researchers [6,7].

The mechanical property test results reveal that the addition of fibers generates not only smaller values of the compressive strength and secant modulus of elasticity but also smaller rates of increase in these properties at ages below 28 days. After 28 days these differences were reduced.

As shown by other investigations [6,7] and corroborated by the present results, the addition of fibers increases the concrete tensile strength in flexure even before 28 days. The concrete with fibers has a 10 percent increase in the tensile strength with respect to the plain concrete. After 28 days the tensile strength in the concrete with steel fibers increases even more. The same rate of increase is not observed with the concrete made with nylon fibers.

With respect to the fibers employed, the mechanical property test results explicitly show a better performance of the steel fibers in relation to the nylon ones. Between the steel fibers, there is no significant difference. It is worth mentioning that the mode of rupture of the fiber concrete samples was always discrete with respect to the plain concrete which was brittle. This indicates an increase in ductility of the concrete promoted by the addition of fibers.

Beam Behavior

The overall beam behavior for each Series can be verified through the load versus midspan deflection relationship, as shown in Fig. 3.

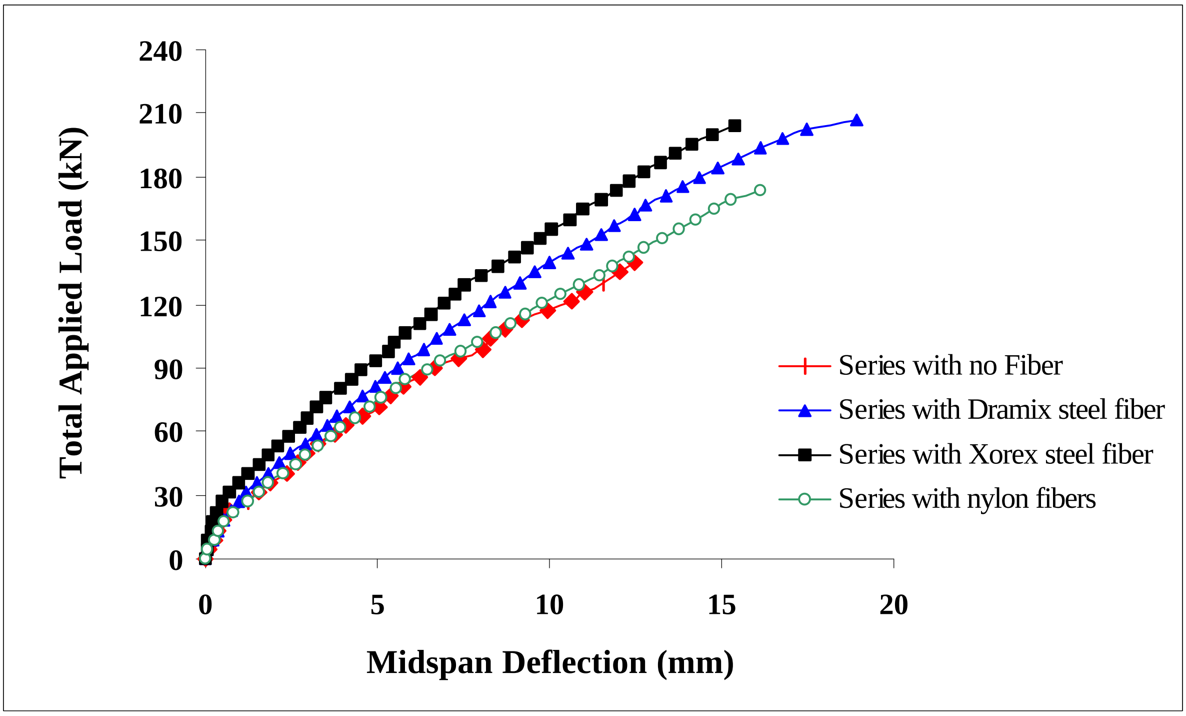

Fig. 3 – Load versus Midspan Deflection for all Series

Flexural Cracking Load

The analysis of the test results indicates that no significant difference in the flexural cracking load of the beams when fibers were added. This load corresponds to the first significant bent in the load-midspan deflection relationship.

Post Cracking Behavior

After cracking, the beams with steel fibers showed an increase in stiffness with respect to the beams with no fibers. This increase in the stiffness was due to a smaller crack width and spacing presented by the beams with steel fibers. On the other hand, the beams with nylon fibers exhibited the same stiffness as the beams with no fibers. The larger stiffness of the beams with steel fibers led to a larger load carrying capacity of these beams as well as a more ductile behavior when failure was imminent.

Stresses in the Transverse Reinforcement

The shear force versus the stresses in the stirrups for each series of beams is shown in Fig. 4. These stresses were calculated from the average strains measured on the stirrups of the beams. The stresses in the transverse reinforcement, predicted by the Mörsch truss analogy, are also presented in the figure.

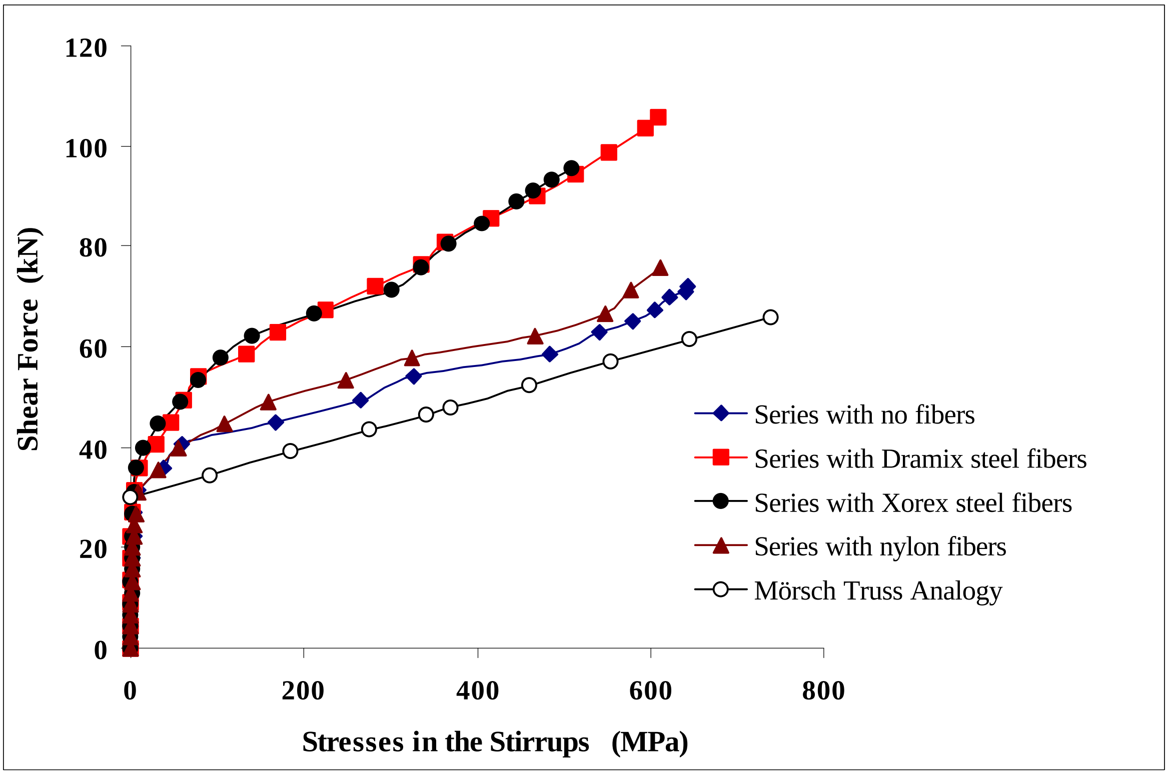

Figure 4 – Stresses in the Transverse Reinforcement

The analysis reveals that the load correspondent to the initial stressing of the stirrups is larger in the beams with steel fibers. The reduction in the opening of the inclined shear cracks by the steel fibers led to an increase of the load carrying capacity of the aggregate interlocking consequently retarding the initiation in the stressing of the stirrups. This means that these fibers improve the shear resisting mechanisms of the concrete represented by the aggregate interlocking and dowel action in the flexural reinforcement.

In the beams with nylon and no fibers, after the mobilization of the transverse reinforcement, the stirrup stresses increase proportionally to the increase of the external shear force following essentially the behavior predicted by the Mörsch truss analogy. For the beams with steel fibers, the increase in the stirrups stresses was much smaller, indicating that the fibers resist part of the increasing external shear forces. This way these fibers behave as an additional transverse reinforcement reducing the stresses in the stirrups. As the failure load is reached, the transverse reinforcement takes a larger share of the increasing shear force.

Strains in the Flexural Reinforcement

A plot of the total load versus the strains in the flexural reinforcement for each series is presented in Fig. 5. These results indicate that, up to the failure of the beams with no fibers, the addition of fibers did not affect the magnitude of the strains in the flexural reinforcement. It is important to mention that in the beams with no fibers and with nylon fibers, the longitudinal bars did not yield before failure. This way the flexural capacity of the beams of these two Series was never reached. On the other hand, the larger shear carrying capacity of the beams with steel fibers led to the yield of the flexural reinforcement which in turn made these beams reach their corresponding flexural capacity and a more ductile failure mode.

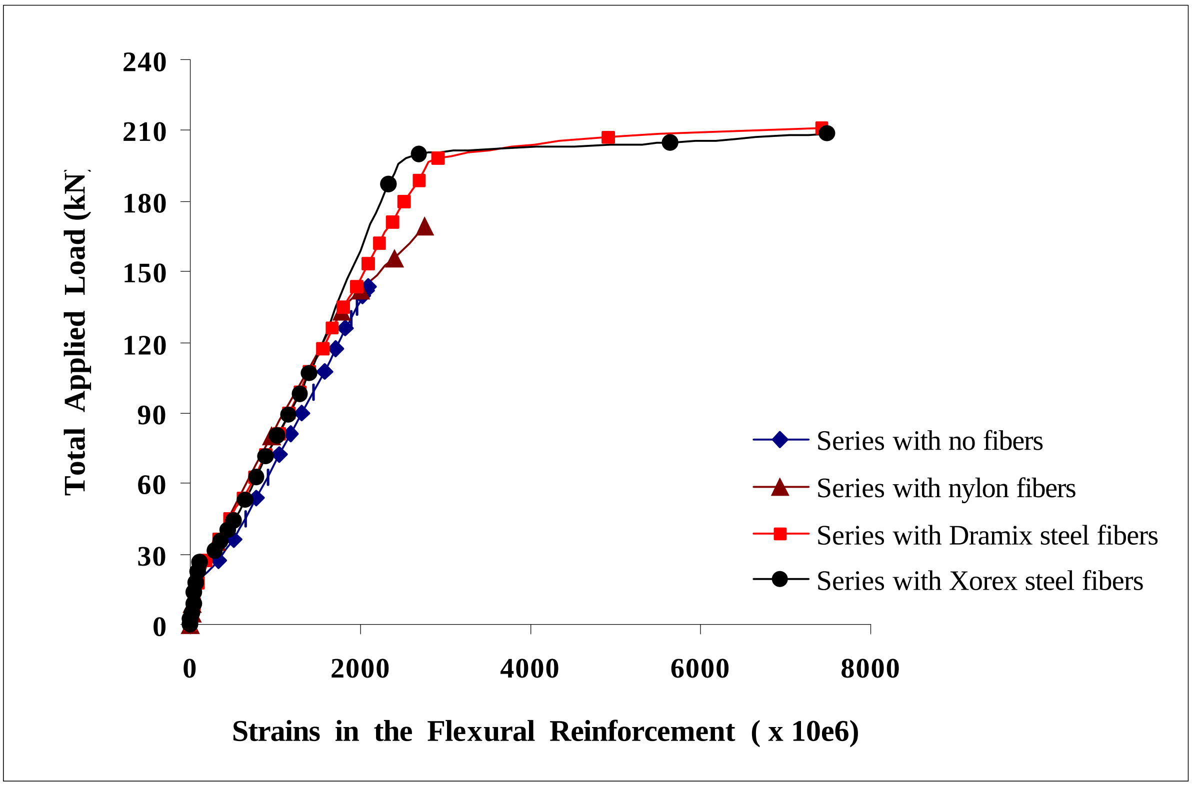

Figure 5 – Strains in the Flexural Reinforcement

Ultimate Strength

The failure load and its corresponding mode for each beam of each Series are shown in Table 2. The analysis of the failure loads reveals that the addition of fibers increase the ultimate strength of the beams. With nylon fibers the increase was of approximately 10% while with steel fibers jumped to 28%.

Table 2 – Failure Loads and Modes for each Beam

Series	Beam Number	Failure Load (kN)	Failure Mode
Beams with no fibers	V1	179.9	Shear – diagonal tension
	V2	157.4	Shear – diagonal tension
Beams with Du Pont nylon fibers	V3	186.8	Shear – diagonal tension
	V4	182.4	Shear – diagonal tension
Beams with Dramix steel fibers	V5	220.4	Flexure – crushing of the concrete
	V6	214.1	Flexure – crushing of the concrete
Beams with Xorex steel fibers	V7	216.2	Flexure – crushing of the concrete
	V8	217.1	Flexure – crushing of the concrete

The addition of steel fibers changed the beam failure mode. In these beams, the flexural capacity was reached with yield of the flexural reinforcement. This corresponds to a much more ductile failure in contrast to the shear brittle failure which occurred in the beams with no fibers and with nylon fibers. These brittle failures showed no warning before they took place and should be avoided in many instances.

CONCLUDING REMARKS

The overall analysis of the test results indicate expressively the better performance of the beams made with steel fibers. These beams exhibited smaller crack width and spacing and consequently more stiffness and load carrying capacity. For these beams, the results also show that the steel fibers behave as an additional transverse reinforcement consequently reducing the stresses in the stirrups. This fact may push a code revision lowering the amount of shear reinforcement in concrete beams fabricated with steel fibers. This in turn will certainly diminish the labor costs in the fabrication of these beams. The addition of steel fibers also led to a flexural failure mode of the beams. This corresponds to a more ductile behavior in contrast to the brittle behavior shown by the beams without fibers and with nylon fibers. In this study, the steel fibers employed had a better performance than the nylon ones.

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