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BEHAVIOR AND STRENGTH OF REINFORCED CONCRETE BEAMS WITH THE ADDITION OF SHORT STEEL FIBERS

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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. Two types of steel fiber with different shapes, lengths and cross sections were used. The uniaxial compressive strength, the secant static elastic modulus and the modulus of rupture of the concrete employed in the beams were also investigated. Six series of reinforced concrete beams were cast and tested in the laboratory. Each series had a different ratio of transverse reinforcement as well as the addition or not of steel fibers in the concrete mix. Analysis of the mechanical properties of the concrete shows that the addition of fibers generates not only smaller values of compressive strength and secant modulus of elasticity but also smaller rates of increase in these properties at ages below 28 days. For the modulus of rupture, the inverse was observed. The beam test results indicate expressively the better performance of the beams made with 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.*

Keywords: *Reinforced concrete beams, Short steel fibers, Strength, Behavior*

1. 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 their 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 required 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, executed by Vidal Filho (1999) and Gonçalvez (1999), on the behavior and strength of simply supported reinforced concrete beams with the addition of short steel fibers. The fibers differed in terms of shapes, cross-sections and lengths. Six series of reinforced concrete beams were cast and tested in the laboratory. Each series had a different ratio of transverse reinforcement as well as the addition or not of steel fibers in the concrete mix. The compressive and tensile strength as well as the secant modulus of elasticity of the concrete employed in the beams were also investigated.

2. 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 (maximum size = 25 mm) were used as fine and coarse aggregates respectively. Brazilian CP V type 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 bar diameter were determined. The longitudinal and transverse bars had a yield strength of 500 and 650 MPa respectively.

Two types of steel fibers 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”.

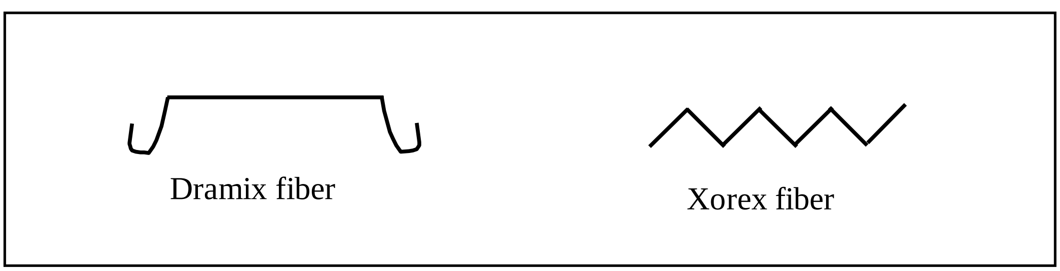

Figure 1 – Details of the steel fibers

The details of the reinforced concrete beams cast and tested in the laboratory are shown in “Fig. 2”. The beams were divided in six series, each one with two beams. All beams had the same flexural reinforcement. In series 1, the transverse reinforcement consisted of 3,4 mm diameter bars spaced every 16 centimeters. This reinforcement corresponds to the minimum amount required by the Brazilian Standard NBR 6118 (1980). The beams of Series 2 had 4,2 mm diameter bars as stirrups spaced at 16 centimeters. A fiber content of 0,8% in volume of concrete was used in the beams fabricated with steel fibers. Table 1 presents the main characteristics of the tested beams.

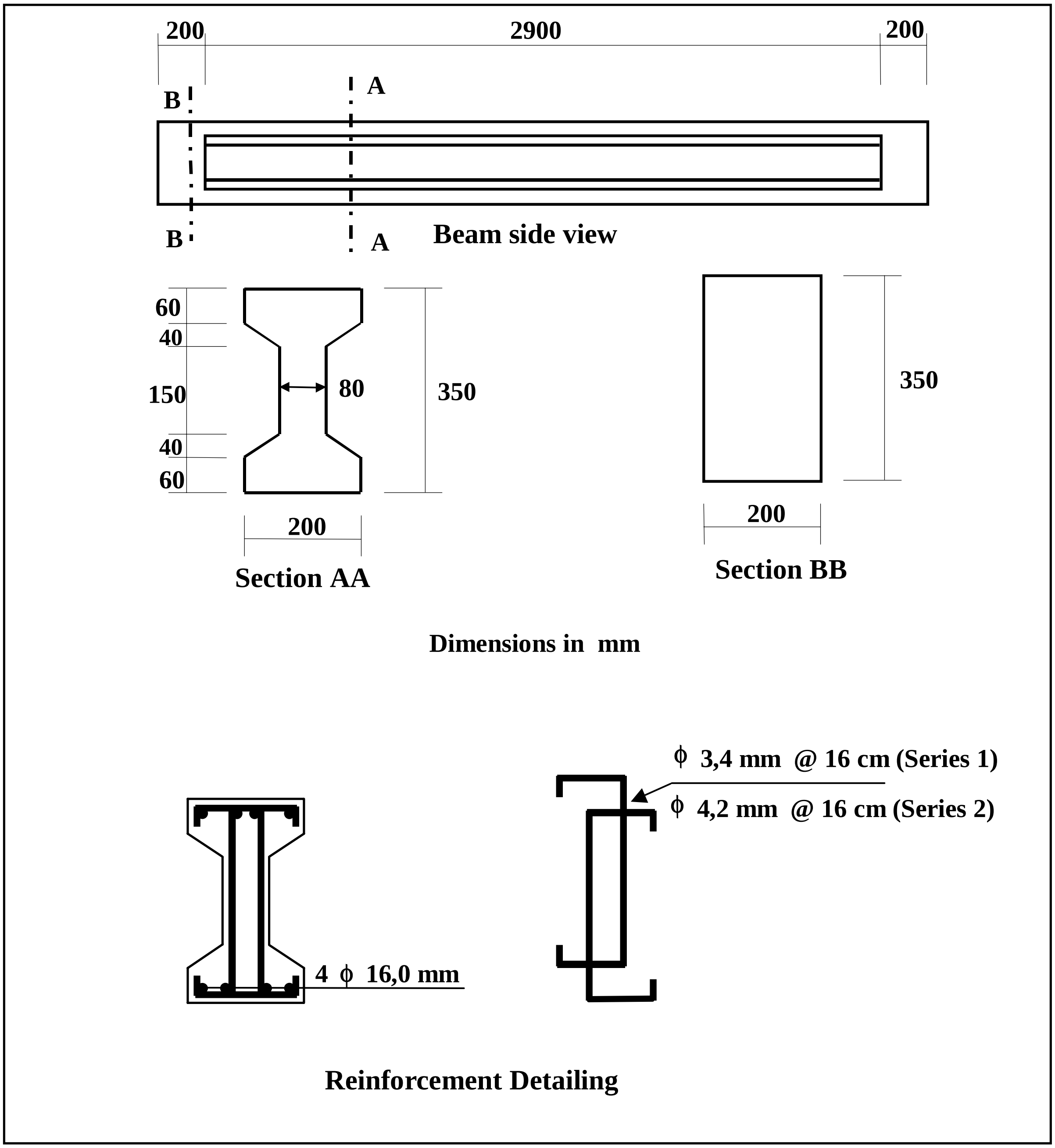

Figure 2 – Detailing of the beams

The mechanical properties of the concrete with and without fibers were also investigated. The axial compressive strength (**f_c**), the secant modulus of elasticity (**E_c**) as well as the modulus of rupture (**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 NBR 5739 (1980), NBR 12142 (1991) and NBR 8522 (1984).

Table 1 – Characteristics of the tested beams

Series	Beam	Fiber content (1)	Fiber type	Stirrup diameter	Stirrup spacing
1	1	-	-	3,4 mm	16 cm
	2	-	-	3,4 mm	16 cm
1 Dramix	3	0,8 %	Dramix	3,4 mm	16 cm
	4	0,8 %	Dramix	3,4 mm	16 cm
1 Xorex	5	0,8 %	Xorex	3,4 mm	16 cm
	6	0,8 %	Xorex	3,4 mm	16 cm
2	7	-	-	3,4 mm	16 cm
	8	-	-	3,4 mm	16 cm
2 Dramix	9	0,8 %	Dramix	3,4 mm	16 cm
	10	0,8 %	Dramix	3,4 mm	16 cm
2 Xorex	11	0,8 %	Xorex	3,4 mm	16 cm
	12	0,8 %	Xorex	3,4 mm	16 cm

(1) – Content with respect to concrete volume

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.

3. TEST RESULTS AND ANALYSIS

3.1 Mechanical properties of the concrete

The results of the concrete properties are presented in “Table 1”. The values obtained for the slump test are also shown.

Table 2 – Concrete – Mechanical Properties

	Plain Concrete			**Concrete with Dramix steel fibers**			**Concrete with Xorex steel fibers**		
Slump	100 mm			52 mm			50 mm		
Age (days)	**f_c** (MPa)	**E_c** (MPa)	**f_t** (MPa)	**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	-	33,8	25721	-
7	41,7	29962	4,0	42,2	30154	3,7	38,0	29479	4,5
28	46,8	31763	5,2	44,0	31399	5,7	43,5	33825	5,6

The analysis of results indicates a substantial reduction in the value of the slump when steel fibers were added to the concrete mix. This same fact has been found by Shah & Rangan (1971) and Soroushian & Bayasi (1981).

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. With respect to the concrete with fibers, the results indicate a better performance of the Dramix fiber in relation to the Xorex.

As shown by Shah & Rangan (1971) and Soroushian & Bayasi (1981) and corroborated by the present results, the addition of fibers increases the concrete tensile strength in flexure even before 28 days. At 28 days the concrete with fibers has a 10 percent increase in the tensile strength with respect to the plain concrete. Similar strength was achieved with both Dramix and Xorex fibers.

It is worth mentioning that the mode of rupture of the fiber concrete specimens 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.

3.2 Beam behavior

The overall beam behavior for each Series can be verified through the load versus midspan deflection relationship, as shown in “Figures 3 and 4” respectively.

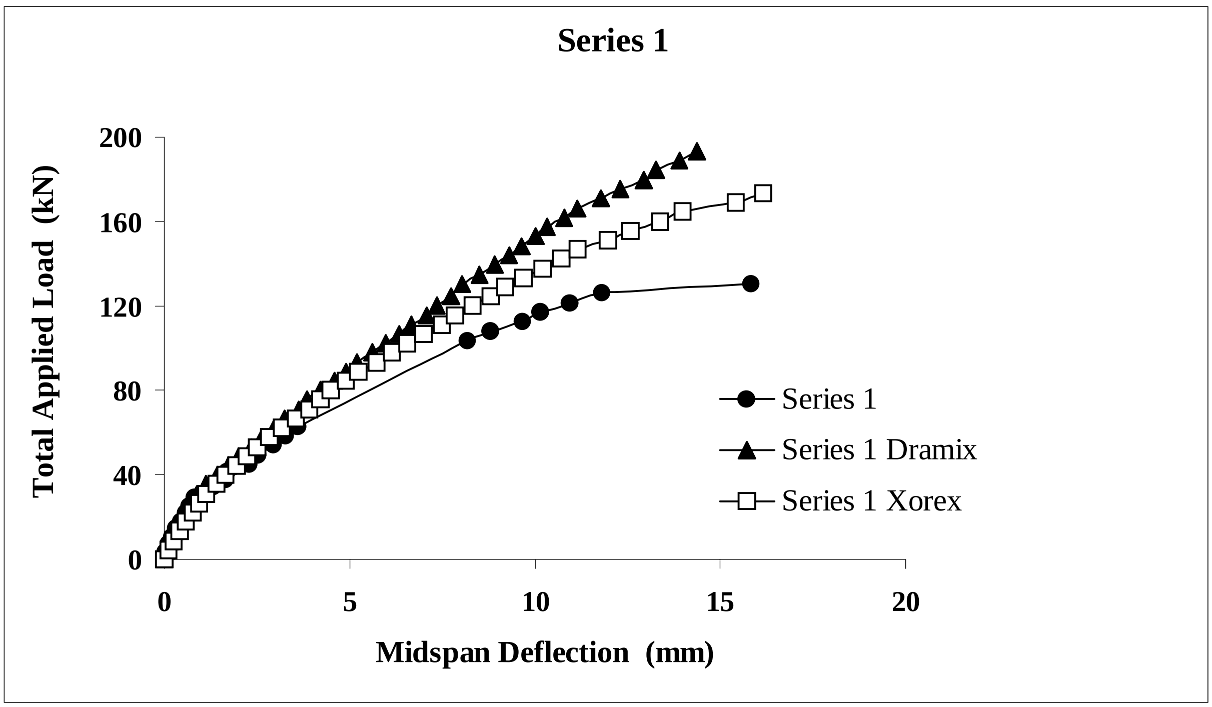

Figure 3 – Load versus Midspan Deflection for Series 1

Flexural Cracking Load. The analysis of the test results indicates that no significant difference in the flexural cracking load of the beams when steel 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. These beams also had a larger load carrying capacity as well as a more ductile behavior when failure was imminent.

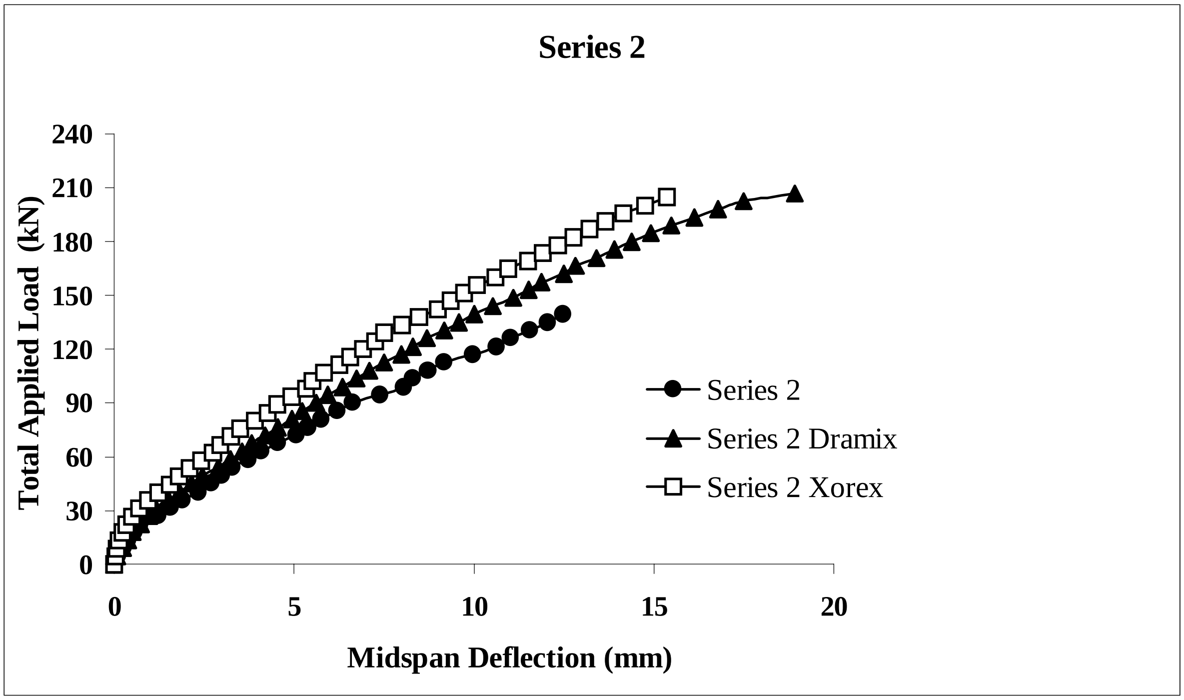

Figure 4 – Load versus Midspan Deflection for Series 2

Stresses in the Transverse Reinforcement. The shear force versus the stresses in the stirrups for Series 2 is shown in “Fig. 5”. 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.

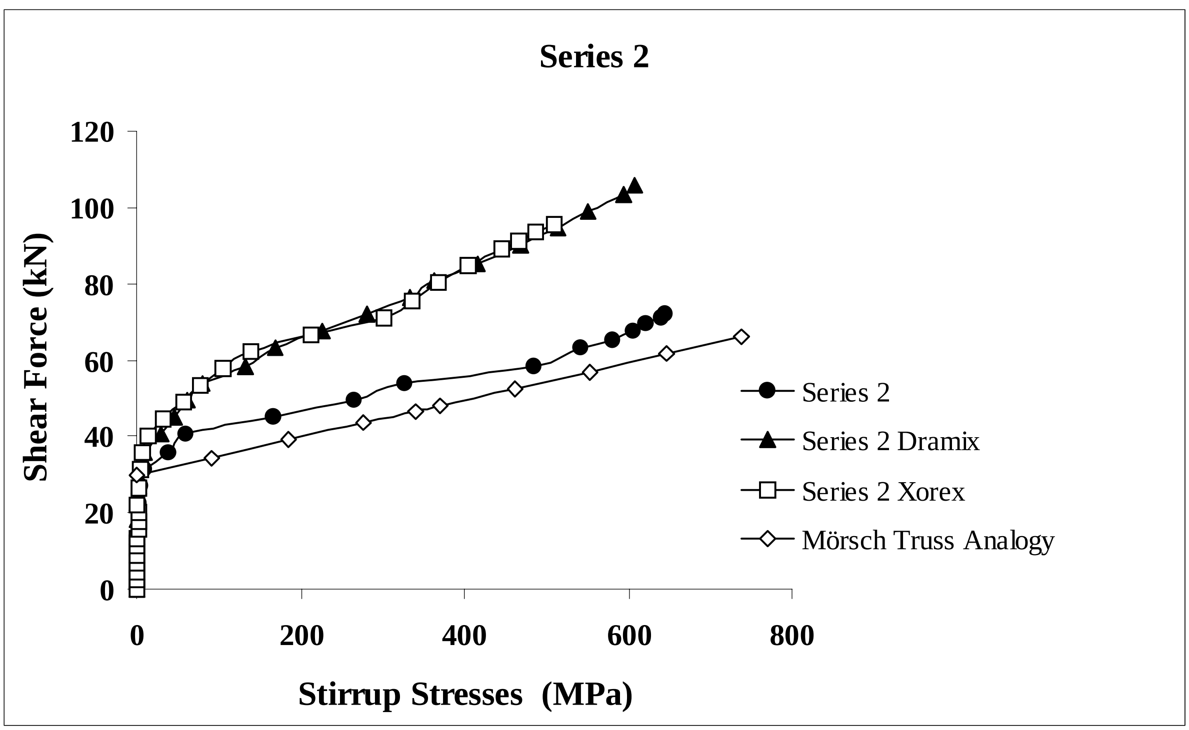

Figure 5 – Series 2 - Stresses in the Transverse Reinforcement

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 without fibers, after the mobilization of the transverse reinforcement, the stirrup stresses increase rapidly following essentially the behavior predicted by the Mörsch truss analogy. For the beams with steel fibers, the increase in the stirrups stresses was more gradual, 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 beams of Series 2 is presented in "Fig. 6". These results indicate that, up to the failure of the beams without fibers, the addition of fibers did not affect the magnitude of the strains in the flexural reinforcement. It is worth mentioning that the flexural reinforcement in these beams did not yield before failure. 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.

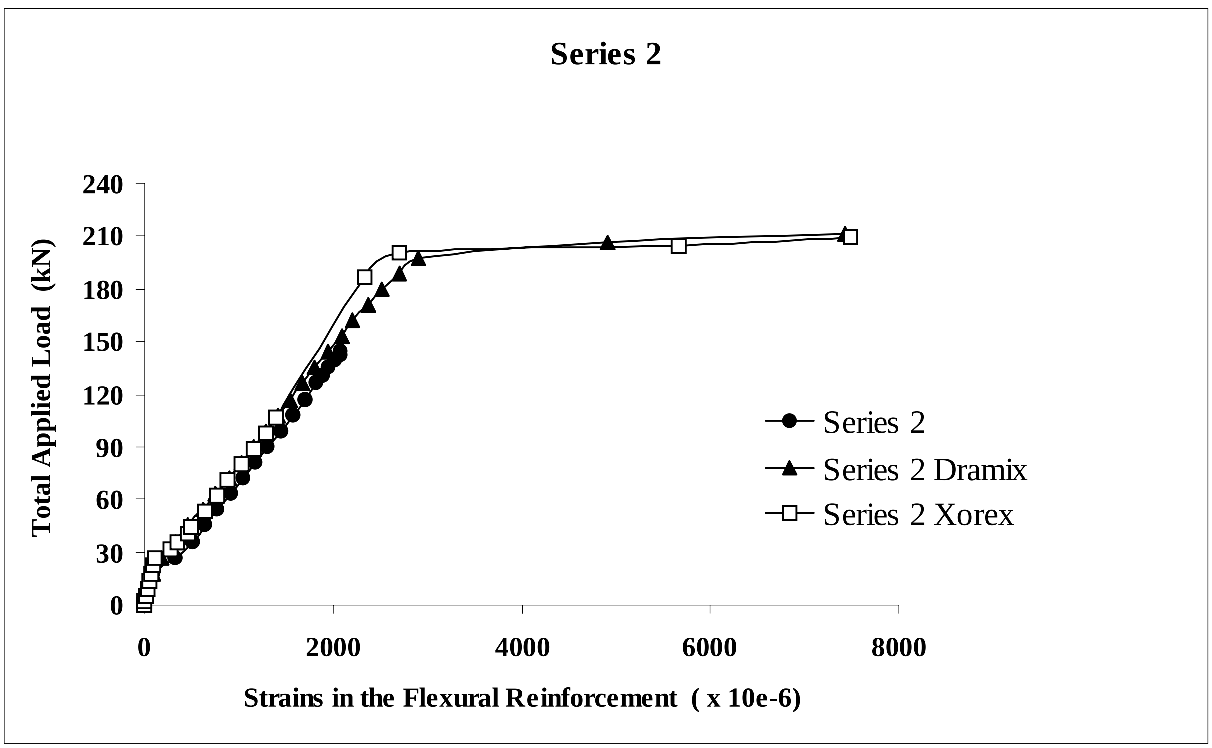

Figure 6 – Series 2 - Strains in the Flexural Reinforcement

Ultimate Strength. The failure load and its corresponding mode for each beam of each Series are shown in "Table 3". The analysis of the failure loads reveals that the addition of steel fibers increased the ultimate strength of the beams. This increase was of at least 50% for Series 1 and of 28 % in the case of Series 2. The results also indicate that with Dramix fibers the beams' failure loads were approximately the same independently of the amount of transverse reinforcement.

Table 3 – Failure load and modes for each beam

Series	Beam	Fiber type	Failure load (kN)	Failure mode
1	2	-	130,4	Shear – diagonal tension
1 Dramix	3	Dramix	211,4	Shear – diagonal tension
	4	Dramix	223,1	Flexure – crushing of the concrete
1 Xorex	5	Xorex	188,6	Shear – diagonal tension
	6	Xorex	177,9	Shear – diagonal tension
2	7	-	179,9	Shear – diagonal tension
	8	-	157,4	Shear – diagonal tension
2 Dramix	9	Dramix	220,4	Flexure – crushing of the concrete
	10	Dramix	214,1	Flexure – crushing of the concrete
2 Xorex	11	Xorex	216,2	Flexure – crushing of the concrete
	12	Xorex	217,1	Flexure – crushing of the concrete

In the beams with larger area of transverse reinforcement (Series 2), the addition of steel fibers changed the 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. These brittle failures showed no warning before they took place and should be avoided in many instances.

4. FINAL 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 test results also indicate a better performance of the Dramix fiber with respect to Xorex.

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REFERENCES

ABNT, Standard NBR 5739, 1980, Ensaio de Compressão de Cilindros de Concreto.

ABNT, Standard NBR 8522, 1984, Concreto - Determinação do Módulo de Deformação Estática e Diagrama Tensão-Deformação.

ABNT, Standard NBR 12142, 1991, Concreto – Determinação da Resistência à Tração na Flexão em Corpos-de-Prova Prismáticos.

Gonçalvez, C. M., 1999, Influência da Adição de Fibras Curtas de Diferentes Materiais no Comportamento e Resistência de Vigas de Concreto Armado, Master's Dissertation, Universidade Federal de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil.

Shah, S. P; and Rangan, B. V., 1971, Fiber Reinforced Concrete Properties, American Concrete Institute Journal, vol. 78, n. 2, pp. 126-135.

Soroushian, P., and Bayasi, Z., 1981, Fiber-Type Effects on the Performance of Steel Fiber Reinforced Concrete, American Concrete Institute Structural Journal, vol. 88, n. 2, pp. 129-134.

Vidal Filho, L. S., 1999, Influência da Adição de Fibras Curtas de Aço no Comportamento e Resistência ao Esforço Cortante em Vigas de Concreto Armado, Master's Dissertation, Universidade Federal de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil.