EFFECT OF STEEL FIBERS ON THE FLEXURAL BEHAVIOR OF HIGH-STRENGTH CONCRETE BEAMS WITH LOW FLEXURAL REINFORCEMENT

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ABSTRACT The effect of inclusion of steel fibers on the flexural behavior of high-strength concrete beams is investigated in this study. Twelve fiber reinforced concrete (FRC) beams were tested by a two-point loading. The beam dimension was kept constant for all beams. Hooked end steel fibers and micro-silica were used to enhance the concrete properties. The variable were the concrete compressive strengths (52, 63 and 85 MPa), the fiber contents (0.0 and 1.0 %) and the flexural reinforcement ratio (0.0 and 0.56 %). The influence of the fibers addition on the crack propagation, cracking moments and ultimate moments were investigated. The nonlinear interactions among concrete, longitudinal reinforcement and steel fibers were monitored and analyzed for the tested beams. Test results showed that the cracking and ultimate flexural strengths increased with the increase of the concrete compressive strength and with the addition of the steel fibers.

1. INTRODUCTION

The term high-strength concrete generally is used for concrete with compressive strength higher than 41 MPa (6000 psi). Its use in the construction industry has increased steadily in recent years because it results in reduced dead loads, which lead to longer spans and taller structure. The maximum potentiality of high-strength concrete cannot be realized fully in structures due to the brittleness of the material and the serviceability problems associated with the resulting reduced cross-sectional dimension. High-strength concrete is considered to be a relatively brittle material because the post-peak portion of its stress-strain diagram descends deeply or almost vanishes as compressive strength increase. This inverse relationship between strength and ductility is a serious drawback in using the material [1-3]. A compromise between strength and ductility can be obtained by using discontinuous fibers. The concept of using fibers to improve the characteristics of construction materials is very old. Adding fibers to concrete makes it a homogeneous and isotropic material and converts its brittle characteristic to a ductile one. When concrete cracks, the randomly oriented fibers function to arrest microcracking, thus improving strength and ductility. Adding fibers influences the ascending portion of the stress-strain curve only slightly but leads to a noticeable increase in the peak strain (strain at peak stress) and a significant increase in ductility [4-7]. The addition of steel fibers also enhance the flexural strengths of plain and reinforced concrete beams [5-12]. However, the contribution of fibers on the enhancement of strength of the reinforced concrete beam relative to the plain concrete beam is not investigated.

2. EXPERIMENTAL PROGRAM

2.1 Test specimens

A total of 12 beams were tested in this investigation. Concrete strength of 52, 63 and 85 MPa were used. For each concrete strength, four beams were tested. This includes a plain concrete beam, a longitudinately reinforced beam with no fibers, a fibrous concrete beam with no longitudinal reinforcement, and a beam with longitudinal reinforcement and steel fibers. The shear-span/depth (a/d) ratio was 6 and the beam cross-section was 125x250 mm (8x10 in.)

and both kept constant. For the longitudinally reinforced beam, adequate shear reinforcements were provided except in the constant moment zone.

Table 1 and Fig. 1 present details of the testing program. Each beam is designated by a group of letters and a number. The first is the letter B to denote beam. The second is a letter that indicates the reinforcement condition, R for beam with low flexural reinforcement (0.56 %) and P for plain concrete beam. The third is a number to indicate the steel fiber volume content. The fourth is a letter to indicate the concrete strength, N for normal-strength (52 MPa), M for medium strength (63 MPa) and H for high-strength (85 MPa). Thus, the beam BR-1-H is a beam with longitudinal reinforcement ratio of 0.56 %, with steel fiber volume content of 1.0 %, and made with concrete compressive strength of 85 MPa.

Table 1. Concrete mix design

Variable / Concrete strength (1)	Mix design (2)	W/C (3)	Silica fume (%) (4)	Super-plasti-cizers (%) (5)	f_c' (MPa) (6)
Normal	1.0 : 1.8 : 1.2	0.41	0.0	1.0	52.0
Medium	1.0 : 1.2 : 1.8	0.26	0.0	6.0	63.0
High	1.0 : 1.0 : 2.0	0.23	20.0	6.0	85.0

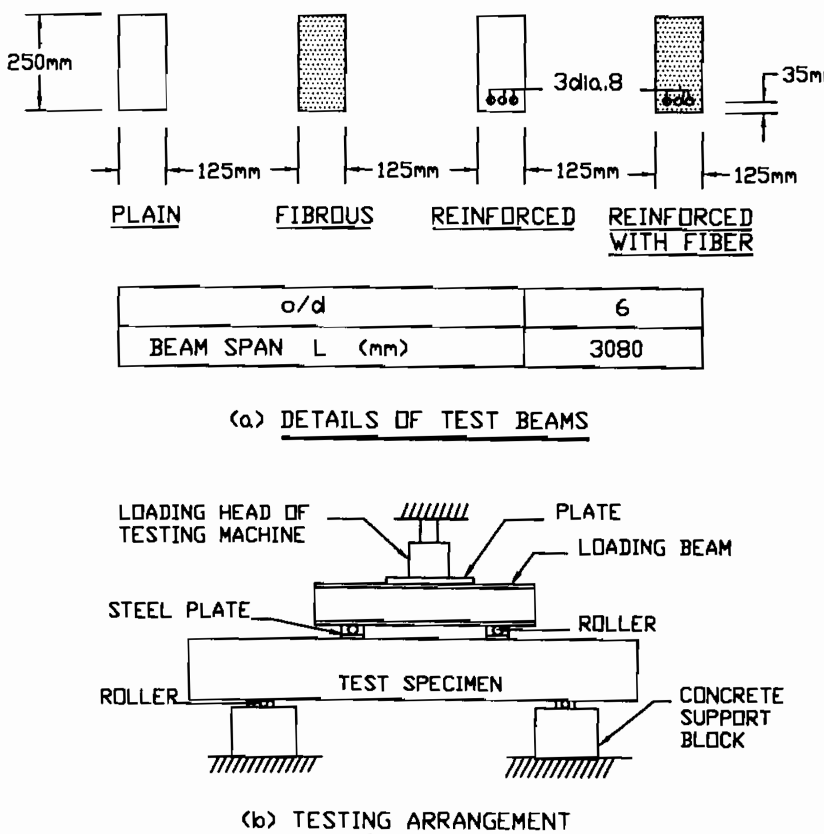

Figure 1 : Details of test beams and testing arrangement.

2.2 Materials

In the testing program, 20-mm Grade 60 deformed steel bars having 437 MPa (63,400 psi) yield strength were used as flexural reinforcement. The concrete mix proportions used are shown in Table 1. Ordinary portland cement(Type I), desert sand with a fineness modulus of 3.1, and coarse aggregate (crushed basalt) of 9.5 mm(3/8 in.) maximum size were used. Light gray density field microsilica (20 percent by weight of cement) with a specific gravity of 2.2, a bulk density of 6.0 kN/m^3(37.4 lb/ft^3), and a specific surface of 23 m^2/g was used in the high-strength concrete mix. Hooked-ends mild carbon steel fibers with average length of 60 mm (2.36 in.), nominal diameter of 0.8 mm (0.03 in.), aspect ratio of 75, and yield strength of 1100 MPa(159,500 psi) were used. A super-plasticizer was used (Table 1) and enough mixing time was allowed to produce uniform mixing of concrete without any segregation.

The measured concrete strengths were based on an average value of three specimens. For each tested beams, six 150 x 300-mm (6 x 12-in.) cylinders were cast to determine the concrete compressive strength and splitting tensile strength. Additionally, three 150 x 150 x 530-mm (6x6x21-in.) beams were tested to find the modulus of rupture of the concrete used. The concrete was placed in three layers and was vibrated internally and externally immediately afterward. All beams and control specimens were cast and cured under similar conditions. The specimens were kept covered with polyethylene sheets until 24 hour before testing (28 days) to prevent the loss of moisture.

2.3 Test Procedure

The beams were simply supported and subjected to a two-point load as shown in Fig. 1(b). The distance between the two-point loads was kept constant at 500 mm (20 in.). Special bearing assemblies (roller, guide plates, etc.) were designed to facilitate applying loads to the test specimens.

The beam vertical deflection and the strains at the top and bottom faces of the beam at midspan were measured. External strain gages were glued to the top surface of the concrete to measure the compressive strain. Strains were also measured by strain gages glued on the beam side at the level of the steel reinforcement or 35 mm (1.4 in.) from the bottom tension fiber in the constant moment region of the beam. End rotation was measured by two transducers.

The two-point loads were applied to the beams by a 400-kN hydraulic testing machine in 15 to 25 increments up to failure. At the end of each load increment, midspan deflection, rotation, strain-gage readings, curvature, and crack development and propagation on the beam surfaces were recorded.

3. EXPERIMENTAL RESULTS

A total of 12 high-strength plain and reinforced concrete beams were tested. Table 2 and Figs. 2 to 6 present the experimental results of the test beams.

3.1 Flexural Behavior

Fig. 2 shows the moment-deflection behavior of the tested beams. For the plain concrete beams (Fig. 2a) the relationship is almost linear, and the beams showed small ductility and failed suddenly. The addition of 1% steel fibers to the plain concrete beams enhanced both the strength and ductility (Fig. 2b). The tested beams with longitudinal reinforcement showed a great enhancement in both strength and ductility when compared with the plain concrete (Fig. 2c), however, these enhancements were increased with the addition of fibers to the reinforced concrete beams (Fig. 2d). Fig. 3 shows difference in flexural strength between longitudinally reinforced beam and plain beam for both cases, without fibers (BR0-BP0) and with fibers (BR1-BP1). It can be seen that the presence of fibers increases the efficiency of the longitudinal reinforcement.

3.2 Effect of the Concrete Strength

Three concrete compressive strength of 52, 63 and 85 MPa were used. Fig. 4 and Table 2 show the variation of the flexural cracking stress, ultimate strength and the ratio of ultimate to cracking strengths as a function of the concrete compressive strength. The figure shows that the cracking and ultimate moment generally increases as the compressive strength increases. Increasing the concrete compressive strength from 52 to 86 MPa increased the cracking

Table 2. Material properties of tested beams

Beam (1)	f_c' (MPa) (2)	f_r (MPa) (3)	V_f (%) (4)	r (%) (5)	M_{cr} (kN.m) (6)	M_u (kN.m) (7)
BP-0-N	51.60	4.45	0.0	0.0	2.69	2.69
BP-1-N	51.80	8.14	1.0	0.0	3.46	4.74
BR-0-N	51.60	4.45	0.0	0.56	3.29	15.26
BR-1-N	51.80	8.14	1.0	0.56	4.11	19.60
BP-0-M	63.10	5.94	0.0	0.0	3.95	3.95
BP-1-M	63.30	10.56	1.0	0.0	4.58	6.09
BR-0-M	63.10	5.94	0.0	0.56	4.51	15.65
BR-1-M	63.30	10.56	1.0	0.56	5.53	21.50
BP-0-H	85.86	9.49	0.0	0.0	4.74	4.74
BP-1-H	85.35	12.39	1.0	0.0	5.61	7.83
BR-0-H	85.86	9.49	0.0	0.56	4.90	15.81
BR-1-H	85.35	12.39	1.0	0.56	5.69	21.34

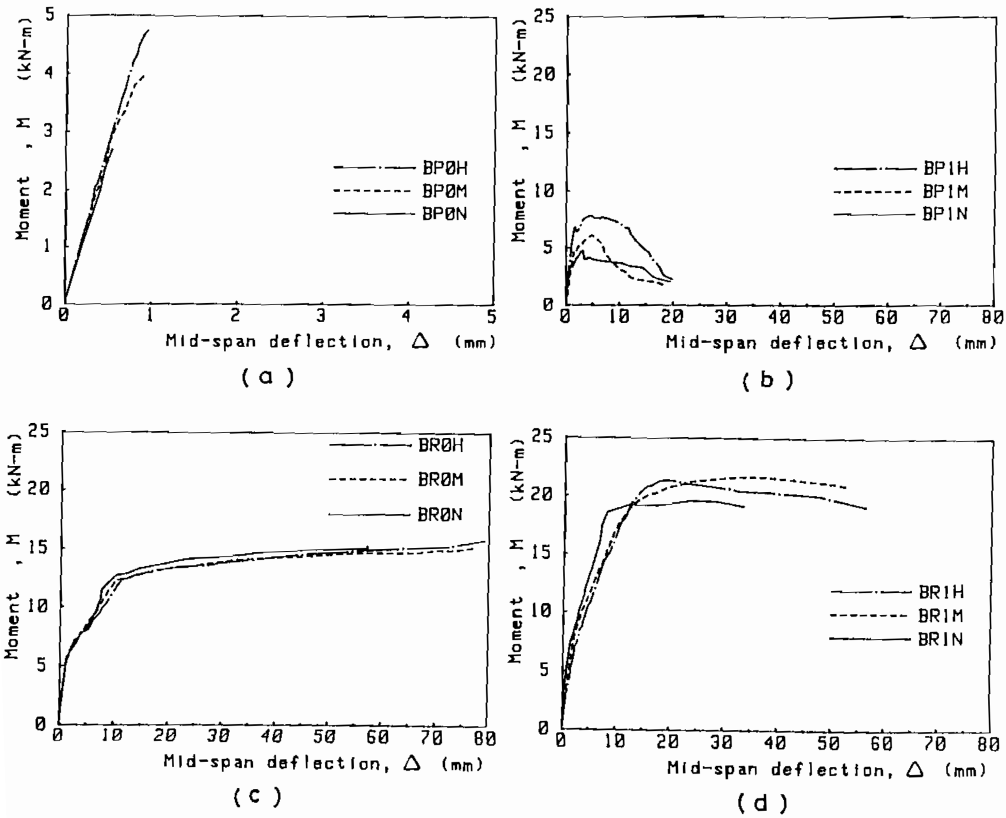

Figure 2 : Moment versus mid-span deflection relationships

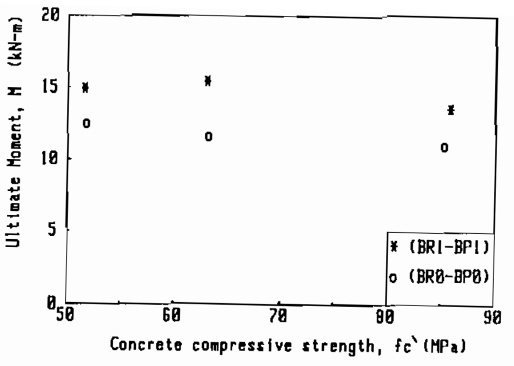

Figure 3 : Effect of the longitudinal flexural reinforcement on the flexural strength of the tested beams.

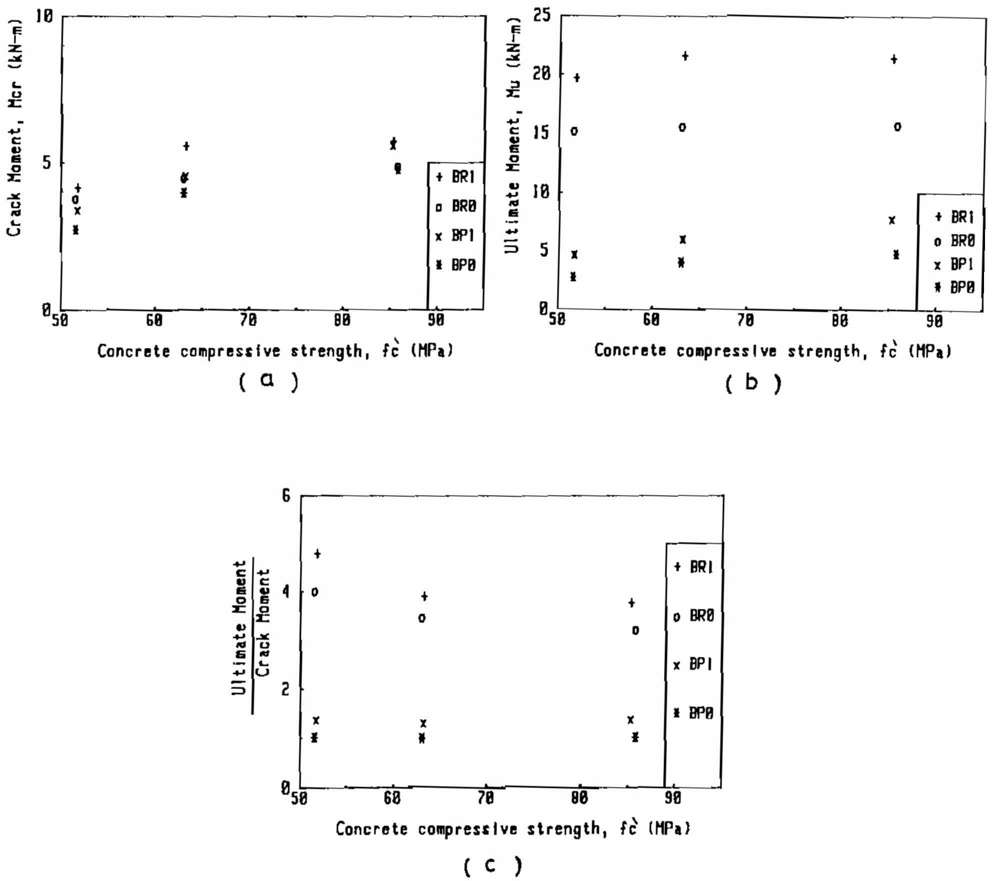

Figure 4 : *Effect of the concrete compressive strength on a) the cracking stress, b) flexural strength and c) flexural strength to cracking stress ratio*

flexural stress by 73, 68, 49 and 38 % and the flexural strength by 73, 65, 3 and 9 % for the plain concrete beams, the FRC beams, the reinforced concrete beams, and the reinforced FRC beams, respectively. Although that the relative increase in the flexural strengths of the plain concrete beams (73 and 65 %) are more than that of the reinforced concrete beams (3 and 9 %), the net increases are almost the same for all cases.

3.3 Effect of Steel Fibers

Fig. 5 shows the effect of the fiber presence on the flexural behavior of the tested lightly reinforced concrete beams. A comparison of the test beams with longitudinal reinforcement showed that the presence of steel fibers reduced the crack width, enhanced the flexural rigidity and resulting in better deflection control. The addition of steel fibers increased the flexural strength and reduced the total deflection. The net increase in the flexural strength due to

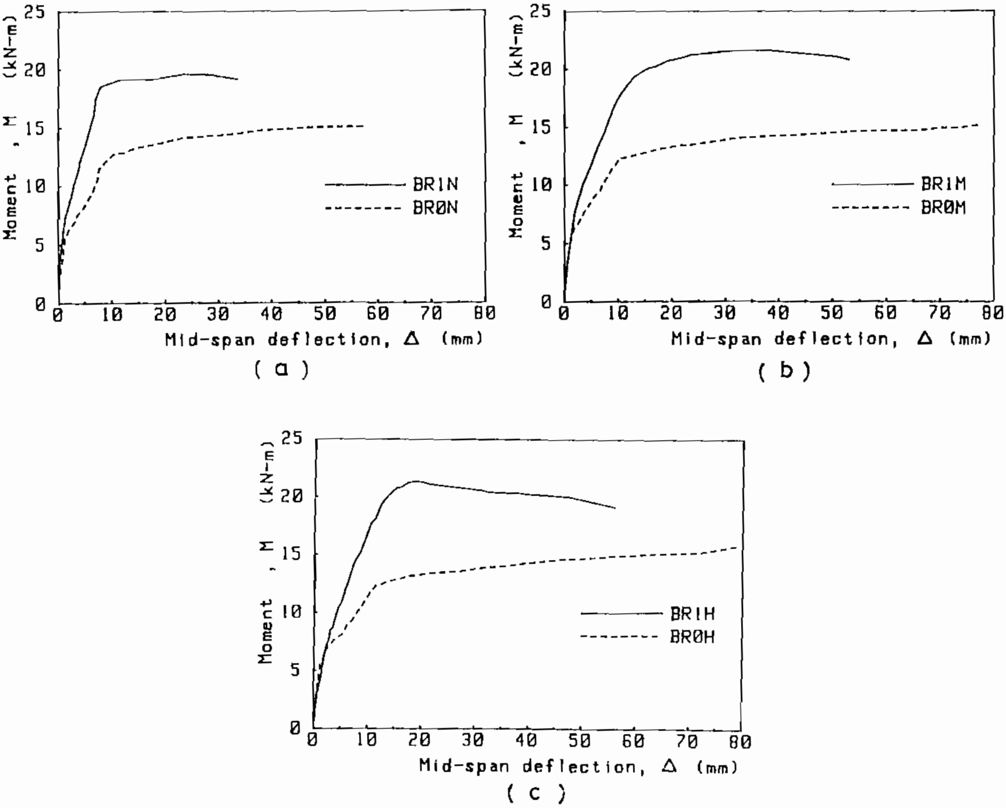

Figure 5 : Effect of steel fibers on the flexural behavior of beams with a) normal, b) medium, and c) high-strength concrete beams.

the fibers addition were higher for the reinforced concrete beams than for the plain concrete beams as shown in Fig. 6. The net increase in flexural strengths were 2.05, 2.14 and 3.09 kN-m for the normal, medium and high-strength concrete beams, respectively. This increase was higher for the reinforced concrete beams and was equal to 4.34, 5.85 and 5.53 kN-m for the normal, medium and high-strength concrete beams, respectively. The presence of 1% steel fibers caused a relative increase of the flexural strength of the plain concrete beams by 76, 54 and 65 % for the normal, medium and high-strength concrete, respectively. However, this increases were less for the reinforced concrete beams and were equal to 28, 37 and 35 % for the normal, medium and high-strength concrete beams, respectively.

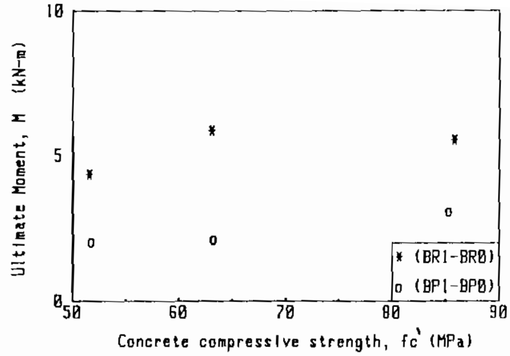

Figure 6 : Effect of steel fibers on the flexural strength of the tested beams.

4. CONCLUSIONS

Based on the test results of twelve high-strength concrete beams, the following conclusions are drawn:

1. The tested plain concrete beams failed suddenly and showed no ductility.
2. The increase of the concrete compressive strength increased both the cracking stress and the flexural strength.
3. The presence of steel fibers reduced the crack propagation in the test beams and enhanced the flexural rigidity, resulting in better deflection control, and better ductility before and during failure
4. Addition of steel fibers improved the flexural cracking stress, the flexural strength and the ductility.
5. The presence of steel fibers increases the efficiency of longitudinal reinforcement in terms of member strength.

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