ELSEVIER

Cement and Concrete Composites 21 (1999) 73–81

Cement & Concrete Composites

Properties of high-strength steel fiber-reinforced concrete beams in bending

Qian Chunxiang,[a]* Indubhushan Patnaikuni,[b]

[a]Department of Materials Science and Engineering, Southeast University, Nanjing 210018, People's Republic of China
[b]Department of Civil and Geological Engineering, Royal Melbourne Institute of Technology, Melbourne, Victoria 3000, Australia

Received 15 October 1996; accepted 27 August 1998

Abstract

This paper presents research results of ten high-strength reinforced concrete beams and steel fiber-reinforced high strength concrete beams, with steel fiber content of 1% by volume. The enlarged ends of mild carbon steel fibers with three different dimensions were selected. This research shows that the flexural rigidity before yield stage and the displacement at 80% ultimate load in the descending curve are improved, and crack number and length at comparable loads is reduced after the addition of steel fibers. The descending part of the load–displacement curve of the concrete beams without steel fibers is much steeper than that with steel fibers, which shows that the addition of steel fibers makes the high strength concrete beams more ductile. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: High-strength-concrete; Steel fibre; Bending; crack

1. Indroduction

It is well known that steel fibers reduce the deflection of reinforced normal strength concrete beams as documented by other researchers [1–4]. But there is still no method to predict the deflection of steel fiber-reinforced concrete (SFRC) beams like the method for normal strength concrete beams without steel fibers, given in the ACI code and Australian Standard AS3600-1988, Section 8.5.3. [15]. For high-strength steel fiber-reinforced concrete (HSFRC) beams only limited research has been carried out. As shown in Refs. [5–11,16], the addition of steel fibers can also reduce the deflection of reinforced high strength concrete beams and improve post-cracking behaviour significantly.

This research used three types of enlarged-end steel fibers with different dimensions to study the effect of fiber on the deflection, cracking behaviour and ductility of reinforced concrete beams. The main purpose for the addition of the fiber is to control cracking caused by loading. Therefore, the fiber content belongs to the moderate range according to Zollo's classification [17]. The compressive strengths of concrete cylinders at 76 days were above 75 MPa. The purpose of this research is to provide more information about HSFRC beams in bending in order to establish a prediction model for deflection in the future.

2. Experimental program

2.1. Test specimens

In this research program, seven high-strength concrete beams reinforced with continuous bars [12–13] and with steel fibers were tested together with three reinforced concrete beams without steel fibers. All the beams were provided with shear reinforcement and had a constant cross-section of 120 × 150 mm and constant length of 2000 mm. The variables were types of steel fibers. Three types of steel fibers were used with a steel fiber content of 75 kg/m^3 which corresponds to a content of about 1% by volume. Three reinforced beams without steel fibers were used for comparison. Figure 1(a) represents the details of the test beams.

2.2. Materials

In this research, 16-mm Y16 deformed steel bars having about 400 MPa of yield strength were used as

---

*Corresponding author.

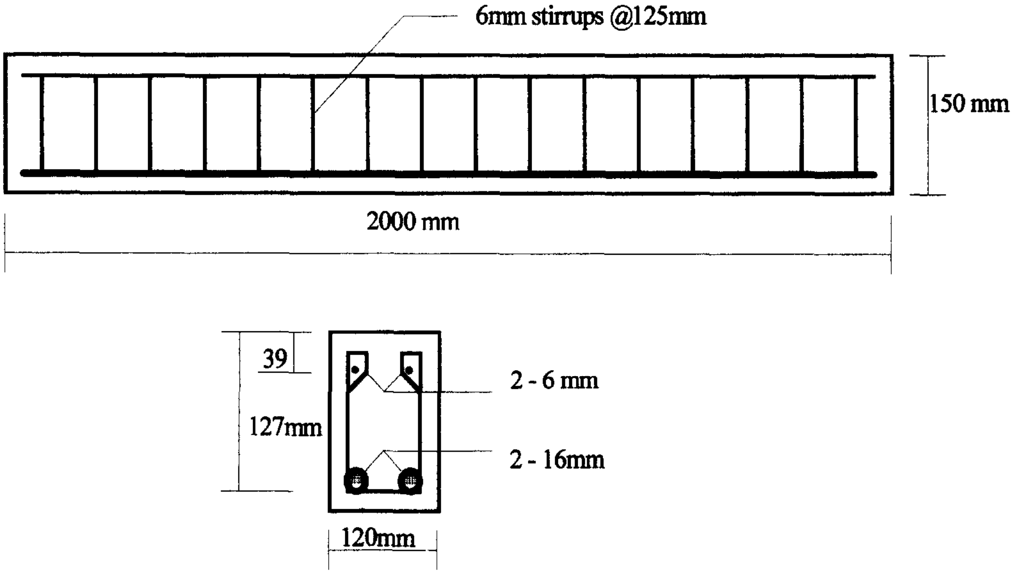
0958-9465/99/$ — see front matter © 1999 Elsevier Science Ltd. All rights reserved.
PII: S0958-9465(98)00040-7

longitudinal reinforcement. Three types of enlarged-end mild carbon steel fibers readily available in Australia were selected. Cross-sections of all three types of fibers were rectangular with sizes of 18 × 0.4 × 0.3 mm (Type I), 18 × 0.6 × 0.3 mm (Type II) and 25 × 0.6 × 0.4 mm (Type III). The length–nominal diameter (*L*/*d*) ratios were 46, 38 and 45, respectively.

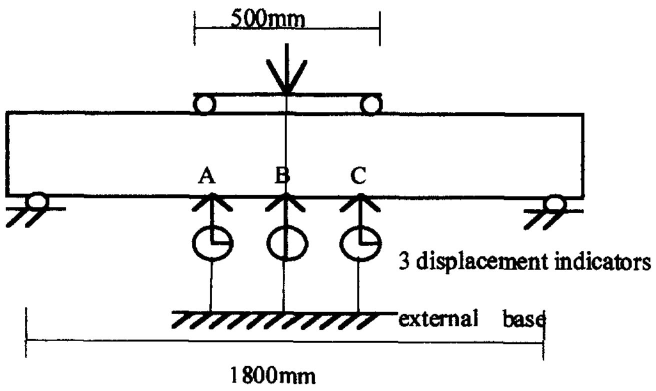
The basic mix proportion of concrete was 0.9:0.1:1.48:1.82 (cement:silica fume:sand:coarse aggregate). Ordinary Portland cement, basalt of 10 mm maximum size and superplasticizer of modified naphthalene polymers were used for the mix. The water binder (W/B) ratio, fiber content, dosage of superplasticizer (SP), compressive strength and workability of concrete are listed in Table 1. The compressive strength was obtained by testing concrete cylinders of size 75 × 150 mm. The loading rate was 20 MPa/min as specified by Australian standard AS1012.9-1986 (4) [14]. Rubber capping was used for testing cylinders. The workability of fresh concrete was measured by a slump test and the time of flow of the concrete through an inverted cone similar to that specified by ASTM C995. One mix was used to cast one beam and nine cylinders. As shown in Table 1, steel fibers I, II and III increased the compressive strength of concrete cylinders at 76 days to different extents. Steel fiber Type II can increase the compressive strength by about 24%.

2.3. Test procedure

The beams were tested after they were cured for 76 days at room temperature. Before testing, they were



(a) Details of Test Beams



(b) Test Setup

Fig. 1. Details of test beams and test set-up.

Table 1
Workability and compressive strength of concrete

Beam no.	Fiber type	W/B ratio	SP dosage (%)	Slump (mm)	Flow time (s)	Compressive strength (MPa)	
						28 days	76 days
IF	I	0.29	3.0	55	17	64.1	79.9
IT	I	0.29	3.0	150	9	66.1	81.0
IIF	II	0.305	2.5	35	30	79.9	95.7
IIS	II	0.305	2.5	15	28	82.6	91.9
IIT	II	0.305	2.5	60	23	77.9	92.2
IIIF	III	0.30	2.5	110	14	73.5	84.5
IIIS	III	0.30	2.5	45	35	78.1	81.0
CF	Without fiber	0.30	2.5	150	17	64.8	78.4
CS	Without fiber	0.30	2.5	150	8	68.1	74.3
CT	Without fiber	0.30	2.5	100	11	64.6	72.8

painted white and the longitudinal central line of the beam section was marked in order to investigate the crack propagation during testing. The beams were simply supported and were subjected to two-point loads, as shown in Fig. 1(b). The distance between the two-point loads was kept constant at 500 mm. The load was applied to the beam by means of a manual pump. The test was controlled by the displacement at the central point of the beam (Point B in Fig. 1(b)). At the end of each increment of 1 mm, the load, the central displacement and the displacements at points A and C, which correspond to two loading points, were recorded and are shown in Fig. 1(b). At various stages of cracking, the yield of tension of the steel bars and the ultimate load, the cracking patterns of the beam and the number of naked cracks were recorded.

3. Test results and discussion

3.1. Load–displacement behaviours

The measured displacement, as shown in Fig. 1, is relative to external base. It contains the deflection of the beam and the displacement of the supports. The latter can be assumed to be the same in all the beams in this research. Curves of the load–displacement relation at points A, B and C of each beam are shown in Fig. 2(a)–(j).

Figure 3(a)–(c) indicate the comparisons of concrete beams with steel fiber and plain concrete beams. With the addition of steel fibers, concrete beams show a steeper slope in the ascending part of the load–displacement curve, which means the beams possess higher flexural rigidity.

Figure 3(a)–(c) show that concrete beams with steel fibers possess higher ultimate load and larger displacement before their failure. The descending part of the load–displacement curve of concrete beams without steel fibers is steeper than that of concrete beams with steel fibers I, II or III, which means concrete beams with steel fibers possess better ductility.

From the aspect of flexural rigidity before steel yielding, ultimate load and ductility of concrete beams, fiber Types I and II are better than fiber Type III. Even though fiber Types I and III possess similar length–nominal diameter ratio, the former is smaller.

3.2. Characteristics of beams

The characteristics of each beam from the load–displacement curve shown in Fig. 2 are listed in Table 2. It shows the displacements at yield stage, at ultimate stage and at 80% ultimate load in the descending curve (0.8 × ultimate). (Load/disp.) at yield stage refers to load/average displacement at point B of the beam at yield stage. The bigger its value, the higher the ability of the concrete beam to resist deflection. It can be seen from Table 2 that the (Load/disp.) value of concrete beams with steel fibers I, II or III increased by about 21.6%, 30.0% and 5.8% compared to the reinforced concrete beam without steel fibers.

As shown in Table 2, with the addition of steel fibers I, II or III, the ultimate loads of concrete beams increase from 54.8 to 61.4, 62.9 and 56.7 kN, respectively, and the central displacements at 80% ultimate load in the descending curve increase 12.2, 35.1 and 12.2%.

3.3. Cracking pattern

Some information about the cracking process of each tested beam is listed in Table 3 and shown in Fig. 4. As shown in Table 3, the number of cracks of high

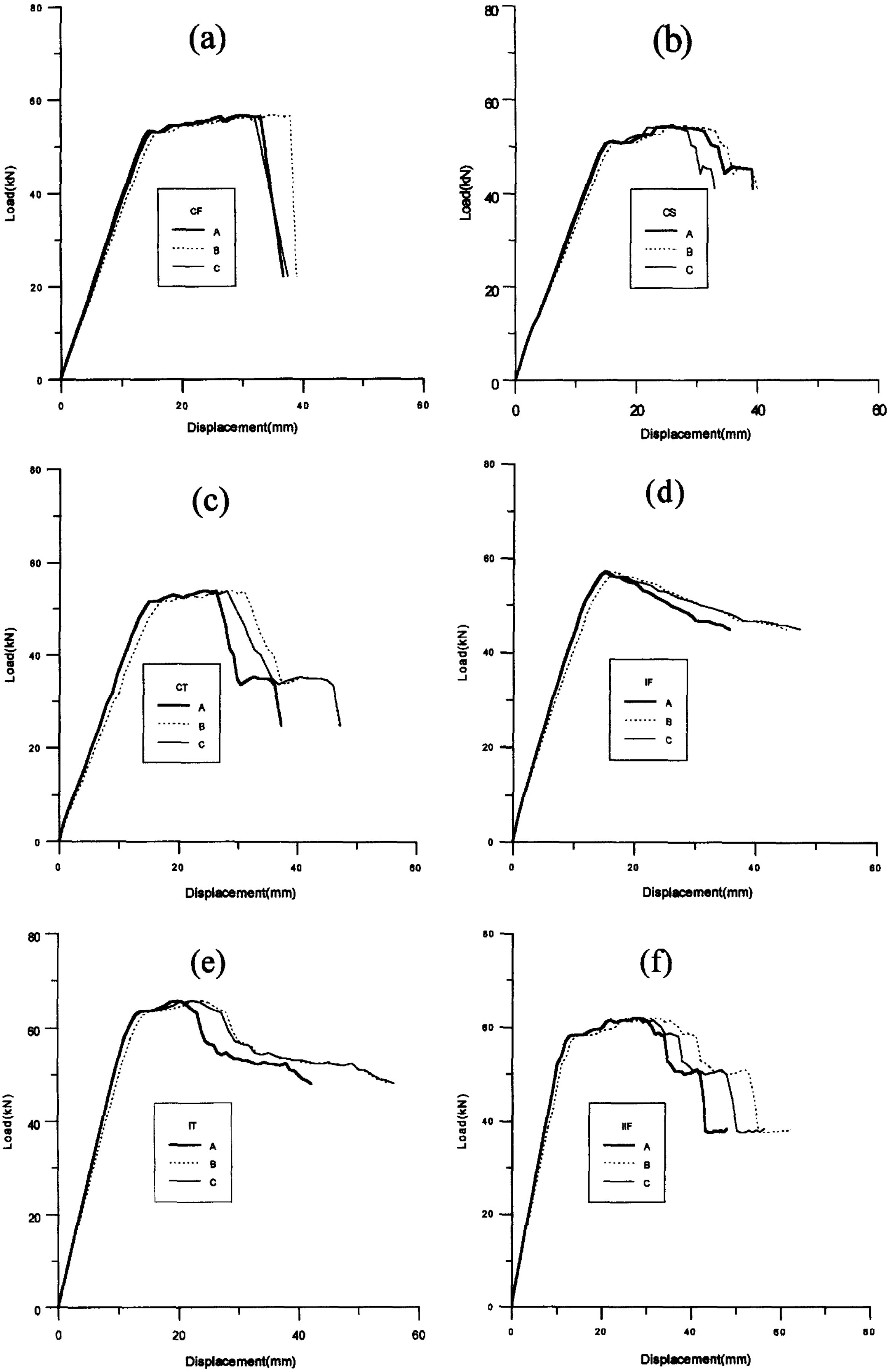


Fig. 2. Experimental load–displacement curves of beams.

strength concrete beams without steel fibers (CF, CS, CT) is more than that of HSSFRC beams at cracking stage, especially up to a load of 30 kN. This means that steel fibers increased the cracking moment of the beams and modified the properties of the beams near the service load.

Figure 4(a)–(c) illustrate the cracking pattern at cracking stage, yield stage and ultimate stage. At the same load level of cracking stage, the crack of high strength concrete beams without steel fibers is far longer than HSSFRC concrete beams (Fig. 4(a)). At yield stage more cracks in the concrete beams without steel fibers passed the beam central line (Fig. 4(b)). This shows that steel fibers arrested the crack propagation. The addition of steel fibers also reduces crack width of the concrete, as reported by Refs. [18, 19].

4. Conclusions

- Steel fiber can increase flexural rigidity of reinforced high strength concrete beams before yield stage. The

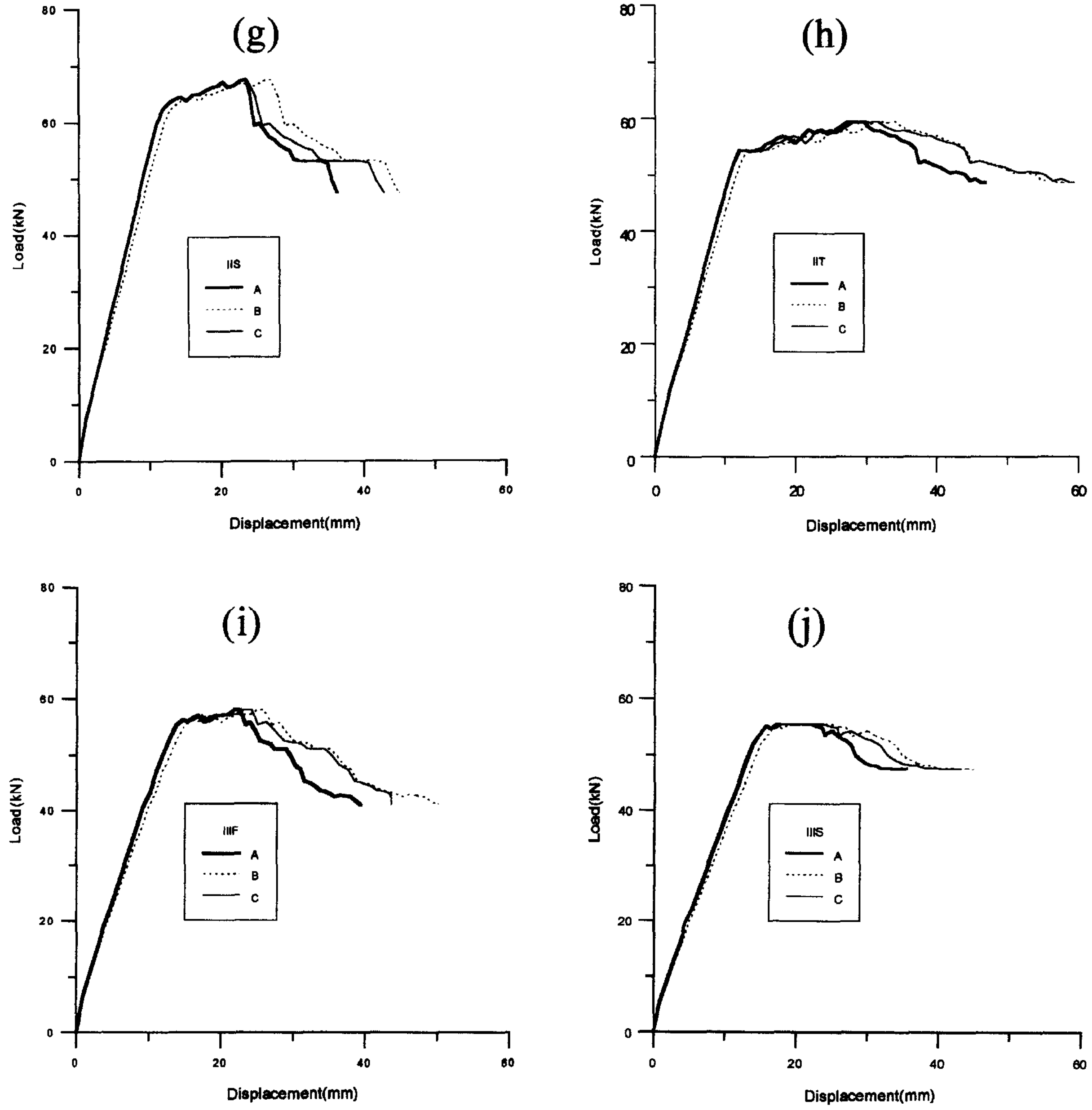


Fig. 2. *Continued*

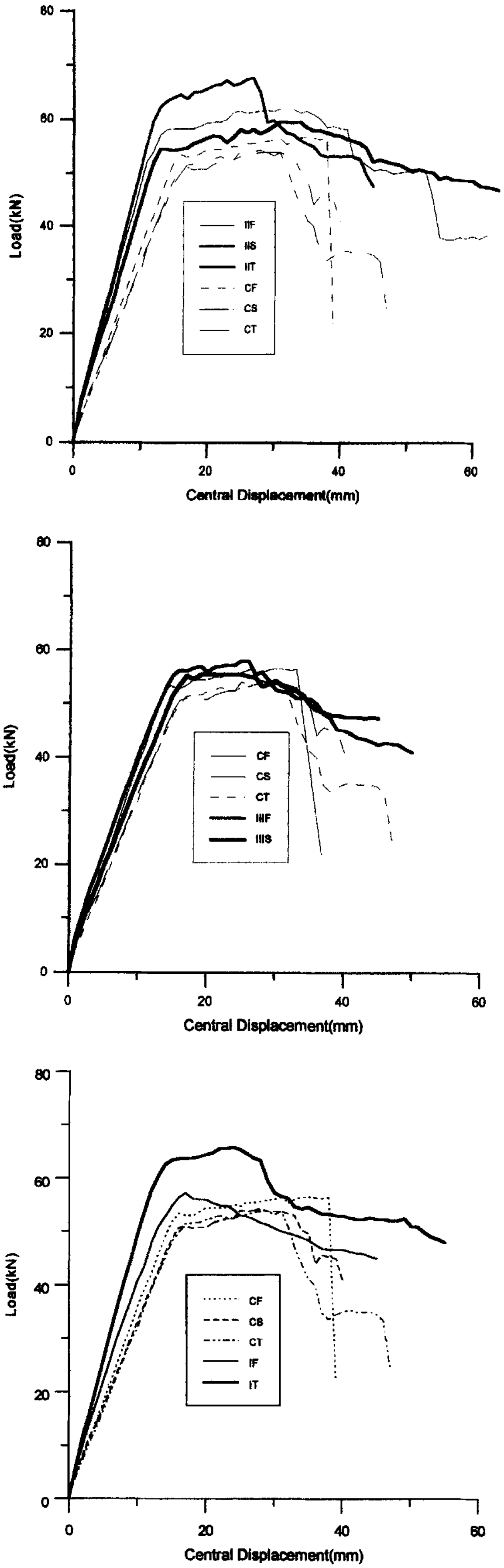
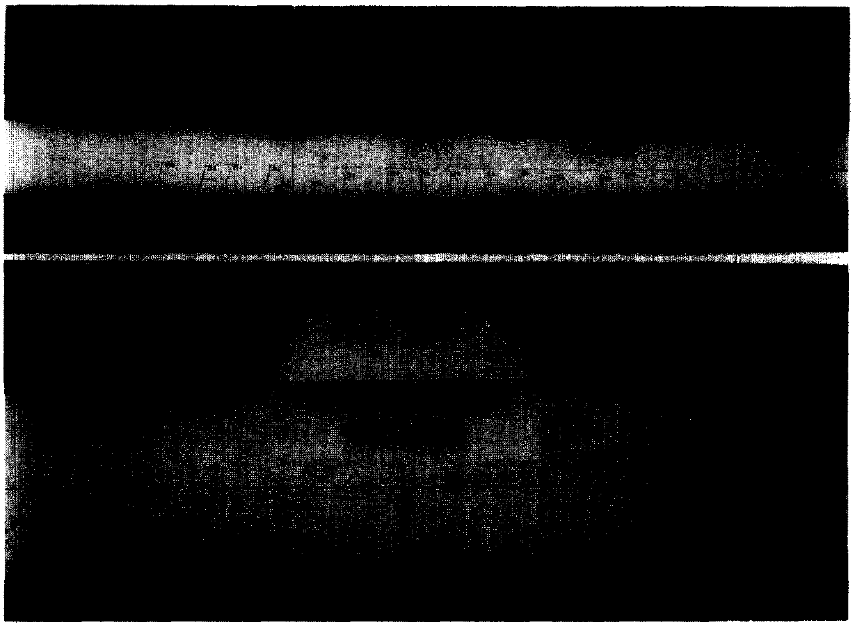
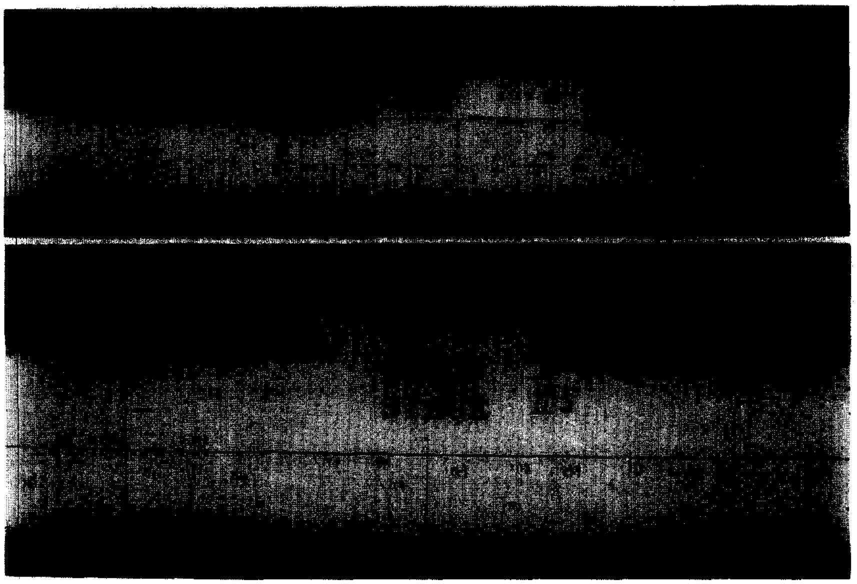


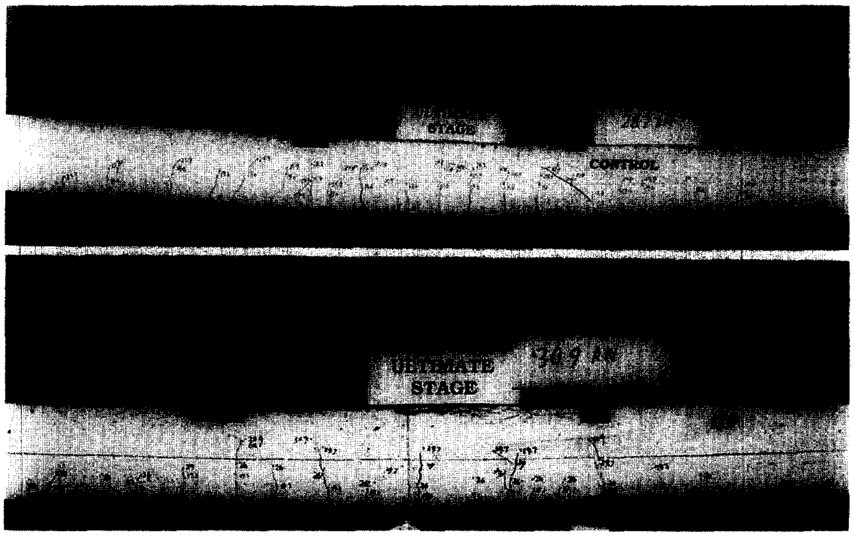
Fig. 3. Comparison of load–central displacement curves of concrete beams with and without steel fibers.



(a) At Cracking Stage (Load indicated is a half load.)



(b) At Yield Stage (Load indicated is a half load.)



(c) At Ultimate Stage (Load indicated is a half load.)

Fig. 4. Comparison of cracking pattern of HSSFRC beams and high strength concrete beam without steel fiber.

Table 2
Characteristics of concrete beam in load–displacement curve

Beam no.	Displacement (mm)									Load (kN)		Load/displacement at yield
	At yield			At ultimate			At (0.8 × ultimate)			Yield	Ultimate	
	A	B	C	A	B	C	A	B	C			
IF	15.239	17.000	15.704	15.239	17.000	15.704	34.305	42.000	44.880	57.2	57.2	
IT	13.455	15.000	13.813	18.728	22.000	20.209	32.168	41.000	41.824	63.4	65.6	3.77
Average	14.347	16.000	14.758	16.984	19.500	17.956	33.236	41.500	43.352	60.3	61.4	
IIF	13.274	15.000	13.663	26.910	31.000	27.348	41.940	53.000	47.896	58.2	61.8	
IIS	14.300	16.000	14.442	23.487	27.000	23.658	29.612	36.000	32.809	64.6	67.6	4.03
IIT	11.884	13.000	12.067	27.259	31.000	28.305	49.047	61.000	64.112	54.4	59.4	
Average	13.139	14.667	13.391	25.885	29.667	26.437	31.036	50.000	48.272	59.1	62.9	
IIIF	14.616	16.000	14.895	21.764	25.000	23.097	30.988	38.000	37.551	56.2	58	
IIIS	15.708	17.000	15.734	17.200	19.000	18.000	35.589	45.000	43.234	55.2	55.4	3.28
Average	15.162	16.500	15.314	19.482	22.000	20.548	33.288	41.500	40.392	54.1	56.7	
CF	14.556	16.000	15.156	26.416	31.000	25.756	33.044	38.000	31.805	53	56.4	
CS	15.000	16.000	14.648	25.879	28.000	24.417	38.009	39.000	32.311	50.6	54.2	3.10
CT	15.819	18.000	16.045	24.110	28.000	24.800	28.643	34.000	32.759	51.6	53.8	
Average	15.125	16.667	15.283	25.468	29.000	24.991	33.232	37.000	32.292	51.7	54.8	

load–central displacement ratio is improved by about 21.6, 30.0 and 5.8%, respectively, by the addition of 1% steel fibers I, II, or III.

- Steel fibers can increase the displacement of beams at failure. The central displacement at 80% ultimate load in the descending curve is increased by about 12.2, 35.1 and 12.2%, respectively, by the addition of fibers I, II and III. And after 80% ultimate load in descending, the load–displacement curve of concrete beams without steel fibers falls much faster with the increase in displacement, which means that the concrete beams with steel fibers possess better ductility.
- The smaller fibers are much better at improving the flexural rigidity.
- Steel fibers reduce the number of cracks and the size at comparable load levels.

Acknowledgements

The authors wish to acknowledge the financial support provided by the government of the People's Republic of China for the first author's flight to and stay in Australia to carry out this research. The authors

Table 3
Crack number at various load stages

Beams	$P< = 20$ kN No. of cracks (at load)	$P< = 30$ kN No. of cracks (at load)	$P< = 40$ kN No. of cracks (at load)	$P< = 50$ kN No. of cracks (at load)
IF		6 (30 kN)		11 (40.6 kN)
IT			5 (40 kN)	
IIF			16 (38.6 kN)	
IIS		7 (26.2 kN)	13 (35.8 kN)	
IIT		11 (18.8 kN)	13 (31.2 kN)	
IIIF		7 (22.2 kN)	10 (33.2 kN)	17 (47.2 kN)
IIIS	3 (19.6 kN)	9 (26 kN)	9 (39.2 kN)	17 (51.8 kN)
CF			19 (39.2 kN)	
CS	12 (14 kN)	17 (20.2 kN)	20-4p[a]-39 kN	
CT	10 (19.6 kN)		17-1p-39 kN	

[a] ‘p’: the crack passing the central line of beam section.

would also like to acknowledge the provision of the facilities by the Royal Melbourne Institute of Technology of Australia. The technical help provided by Mr Michael Ma, Mr Kar Keat Ch'ng and other technicians is gratefully acknowledged. The authors also wish to acknowledge the provision of steel fibers by BHP Steel, in particular the support given by Mr Kurt Sollner of BHP Steel.

References

[1] Swamy RN, Al-Ta'an A. Deformation and ultimate strength in flexure of reinforced concrete beams made with steel fiber concrete. ACI Journal 1981; Sept.-Oct.:395-405.

[2] Kormeling HA, Reinhardt HW, Shah SP. Static and fatigue properties of concrete beams reinforced with continous bars and with fibers. ACI Journal 1980; Jan.-Feb.:36-43.

[3] Byung H.O. Flexural analysis of reinforced concrete beams containing steel fibers. ASCE, Journal of Structural Engineering 1992;118(10):2821-2835.

[4] Dwarakanath HV, Nagaraj. Deformational behaviour of reinforced fiber reinforced concrete beams in bending. ASCE, Journal of Structural Engineering 1992; 118(10):2691-8.

[5] Tan K.H., Paramasivam P., Tan K.C. Instantaneous and long-term deflections of steel fiber reinforced concrete beams. ACI Structural Journal 1994;91(4):384-393.

[6] Lim TY, Paramasivam P, Lee SL. Bending behaviour of steel-fiber concrete beams. ACI Structural Journal 1987; Nov.-Dec.:524-36.

[7] Alsayed S.H. Flexural deflection of reinforced fibrous concrete beams. ACI Structural Journal 1993;90(1):72-76.

[8] Ashour S., Wafa F.F. Flexural behaviour of high-strength fiber reinforced concrete beams. ACI Structural Journal 1993; 90(3):279-287.

[9] Lim T.Y., Paramasivam P., Lee S.L. Behaviour of reinforced steel-fiber-concrete beams in flexure. ASCE, Journal of Structural Engineering 1987;113(12):2438-2458.

[10] Craig R.J., Decker J. et al. Inelastic behaviour of reinforced fibrous concrete. ASCE, Journal of Structural Engineering 1987;113(4):802-817.

[11] Hsu C.T.T., He R.L., Ezeldin A.S. Load-deformation behaviour of steel fiber reinforced concrete beams. ACI Structural Journal 1992;89(6):650-657.

[12] Griffel W. Beam formulas. New York: Frederick Ungar Publishing Co, 1970:45.

[13] Everard NJ. Schaum's outline of theory and problems of reinforced concrete design, 3rd ed. New York: McGraw-Hill, 1993:18-19, 65, 163, 169.

[14] AS 1012.9-1986. Methods of testing concrete, part 9 — method for the determination of the compressive strength of concrete specimens. Standards Association of Australia, Sydney, 1986.

[15] AS 3600-1988. Concrete structures. Standards Association of Australia, Sydney, 1988.

[16] Ashour S.A., Mahmood K., Wafa F.F. Influence of steel fibers and compression reinforcement on deflection of high-strength concrete beams. ACI Materials Journal 1997;94(6):611-624.

[17] Zollo R.F. Fiber-reinforced concrete: an overview after 30 years of development. Cement and Concrete Composites 1997; 19:107-122.

[18] Casanova P., Rossi P., Schaller I. Can steel fibers replace transverse reinforcements in reinforced concrete beams. ACI Materials Journal 1997;94(5):341-354.

[19] Furlan S. Jr., Bento de Hanai J. Shear behaviour of fiber reinforced concrete beams. Cement and Concrete Composites 1997;19(4):359-366.