コンクリート工学年次論文報告集, Vol.15, No. 1, 1993

論 文

[1211] Flexural Behavior of Steel Fiber Reinforced Concrete under Low Temperatures

Petia STANEVA*1, Koji SAKAI*1, Takashi HORIGUCHI*2 and
Nemkumar BANTHIA*3

1. INTRODUCTION

The advantages of fiber reinforced concrete are well known and extensive research has been carried out for a long time in order to find a wider range of its economical application. The basic benefit of adding steel fibers into the concrete matrix is that steel fiber reinforced concrete (SFRC) holds higher ductility, crack opening resistance and, depending on type and amount of fibers, its strength is higher than that of the concrete matrix.

Under low temperatures, the concrete matrix shows a more brittle character but some improvement in the strength. Rostasy and Sprenger [1] found a greater improvement in the strength of SFRC than of plain concrete (PC) at low temperatures. Banthia's study [2] showed that a reduction of 2 to 20% in the flexural toughness indexes (I_5,I_{10},I_{30}) occurred at temperature below zero compared with the conditions of normal temperature. The data related to the flexural behavior of SFRC are restricted to the constant amount and type of fibers and one level of temperature below zero.

The objective of the present study is to obtain more data about the flexural behavior of SFRC at normal and low temperatures.

2. EXPERIMENTAL PROGRAM

2.1 MATERIALS

2.1.1 Steel fibers

Two fibers, a type NN and a type EN, with a specific gravity of 7.8, used by Kohno et al.[3], were applied. Their characteristics are presented in Table 1.

Table 1. Characteristics of fibers

Type	Size in cross section, mm	Length mm	Surface area, mm^2	Aspect ratio
NN	0.2x1.3	30	90.52	52
EN	0.5x0.5	30	60.50	53

---

*1.Materials Section, Civil Engineering Research Institute, Sapporo
*2.Department of Civil Engineering, Hokkaido Institute of Technology
*3.Department of Civil Engineering, University of British Columbia

2.1.2 Cement, aggregates and admixtures

Ordinary portland cement with a specific gravity of 3.15 and a specific surface area of 3240 cm^2/g was used. A coarse aggregate, river stone with the maximum size of 10 mm, and a fine aggregate, river sand, were used. The main properties of the aggregates are presented in Table 2. An aminosulfonate type superplasticizer (SP) and a rosin-based air-entraining admixture (AEA) were used.

Table 2. Properties of aggregates

Materials	Properties
Fine aggregate(S)	Specific gravity 2.72, absorption 1.37%, fineness modulus 2.78
Coarse aggregate(G)	Specific gravity 2.74, absorption 1.13%, fineness modulus 6.32

2.2 MIXTURE PROPORTIONS

The mixture proportions are shown in Table 3. The targets of slump and air content were 8±2 cm and 5±1 %, respectively. The constant water-cement ratio (w/c) of 50% and sand-aggregate ratio (s/a) of 63% were chosen. The steel fiber content by volume was 1 and 2 percent. The air-entraining admixture was applied in 0.6 percent to the weight of cement in all cases. The amount of superplasticizer (the percentage of cement amount by weight) was determined with consideration of the requirements for a proper slump.

Table 3. Mixture proportions and compressive strength

Type of mixture	Quantities (kg/cub.m)							Density (kg/cub.m)	Concrete compr.str 28d-(MPa)
	C	W	S	G	SF	SP	AEA		
Plain PC	394	197	1086	642	-	-	2.36	2319	29.6
EN1.0 (SF=1%)	394	197	1069	632	78	0.90	2.36	2388	31.8
EN2.0 (SF=2%)	394	197	1052	622	156	2.96	2.36	2450	33.3
NN1.0 (SF=1%)	394	197	1069	632	78	2.96	2.36	2396	30.7
NN2.0 (SF=2%)	394	197	1052	622	156	5.52	2.36	2442	32.8

2.3 TEST SPECIMENS

The concrete mixture was prepared in three batches using Omni mixer with 30-liter capacity. The mixing procedure was as follows: (1) fine aggregate, cement, water and admixtures were mixed for 30 seconds; (2) coarse aggregate was added and the mixing was continued for 60 seconds; (3) steel fibers were added at slow speed of the mixer using a sieve for 120 seconds; (4) the mixing was continued for 60 seconds.

The fresh concrete properties (slump, air content, inverted cone time and concrete temperature) were measured. The concrete was placed into 3 beam molds of size 10x10x42 cm and 3 cylinder molds of size 10x20 cm, compacted by a vibrating table and demolded within 24 and 48 hours after mixing. The test specimens were cured under water at 20±2°C until the day of testing.

2.4 TEST

2.4.1 Compressive strength tests

The 28 day compressive strength was determined according to JIS A1108 and at normal temperature (20 °C).

2.4.2 Flexural strength tests

Flexure tests were performed in accordance with JCI-SF4 [4] on beams 100x100x420 mm over a span of 300 mm. A stainless steel bar supported by bolts attached to the specimen at points of support was used to measure the displacements. The net deflection of the beam-top middle point was measured using Cantilever Displacement Transducer (CDT).The hydraulic type, load control machine equipped with load cell was used. The data from the load cell and the CDT were recorded by an acquisition system. The flexure tests were carried out at normal temperature,+20°C and two low temperatures, -20°C; -50°C. A nitrogen was used to decrease the temperature in a chamber from normal to -20 (or -50)°C with a speed of 1°C/min. At the time of cooling and loading the maximum temperature differences between the surface and center of specimen were less than 10°C and 0.5°C, respectively. The details of the test setup are shown in Figure 1.

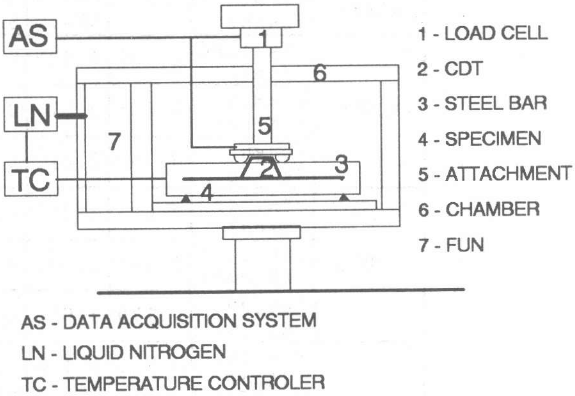


Figure 1. Test setup

2.4.3 Flexural toughness

The flexural toughness is the ability of the material to absorb energy in the fracture process. It is expressed by the area below the load-deflection curve until the deflection at the beam-top middle point becomes 1/150 of the span (2 mm in case of 300 mm span) [4]. The area below the load-deflection curve was measured with a digital planimeter.

3. RESULTS AND DISCUSSION

3.1 COMPRESSIVE STRENGTH

The test results of the compressive strength are shown in Table 3. They indicate a small increase in the strength with an increase of fiber volume. The strength of SFRC with EN-fiber is insignificantly higher than the strength of SFRC with NN-fiber (which is reported also by Kohno et al.[3]). The data obtained agree with the previous results about the relatively small effect of fiber type and its volume (up to 2%) on the compressive strength of SFRC.

3.2 FLEXURAL STRENGTH, LOAD-DEFLECTION CURVE AND FLEXURAL TOUGHNESS

The average maximum load, the flexural strength calculated according to JCI-SF4 [4], and the flexural toughness determined, are presented in Table 4. The load-deflection curves for the different temperatures and volume of fibers are shown in Figures 2.a,b,c and Figures 3.a,b,c, respectively.

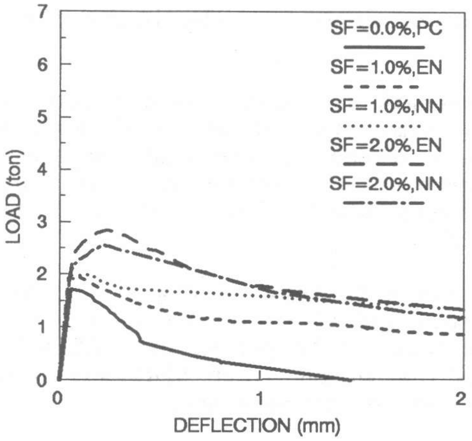
Table 4. Maximum load, flexural strength and flexural toughness

Temper-ature	Max.load Flex.str Toughn.	Type of mixture				
		PC	EN1.0 SF=1%	EN2.0 SF=2%	NN1.0 SF=1%	NN2.0 SF=2%
+20° C	Max.load (ton)	1.697	1.939	2.727	1.969	2.455
	Flex.str (kN/cm2)	0.525	0.574	0.842	0.581	0.786
	Toughn. (kN.cm)	0.793	2.311	3.716	3.093	3.444
-20° C	Max.load (ton)	3.636	3.939	4.424	4.182	4.515
	Flex.str (kN/cm2)	1.104	1.234	1.313	1.225	1.334
	Toughn. (kN.cm)	0.170	3.025	4.984	4.123	6.389
-50° C	Max.load (ton)	4.818	5.152	5.813	5.121	6.000
	Flex.str (kN/cm2)	1.415	1.613	1.732	1.562	1.711
	Toughn. (kN.cm)	0.293	4.044	6.015	4.407	7.069

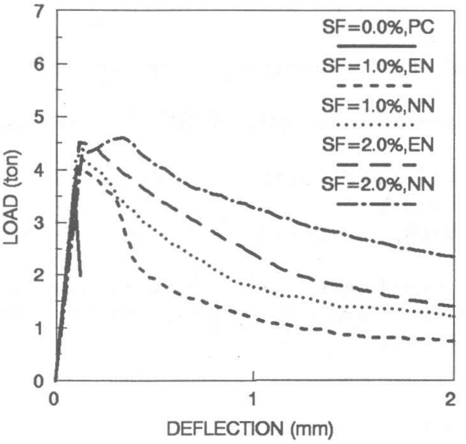
The data presented in Table 4 show that the maximum load increased with a decrease of temperature at constant fiber volume as well as with an increase of fiber amount at constant temperature. The same table and the Figures 3.b,c show that the increase of maximum load was influenced more by the temperature than by the fiber volume.

A clear nonlinear behavior can be seen in the ascending part of the load-deflection curve for SFRC with 1% and 2% fibers at normal temperature (Figure 2a). The same figure shows the positive influence of fiber volume on the load-deflection relationship. Because of the brittleness of the concrete matrix at low temperatures the first crack load coincided with the maximum load and then the behavior showed a gradual softening character (Figure 2.b,c). An exception was SFRC with 2% NN fiber at low temperatures where a distinction was found between the first crack load and the maximum load, probably because of the larger amount of fibers and their shape. As shown in Figure 2, the post-peak behavior at low temperatures was less tough than at normal temperature.

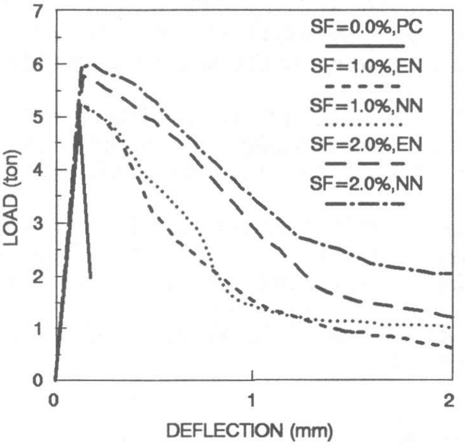
The plain concrete was extremely brittle at low temperatures



(a) +20deg

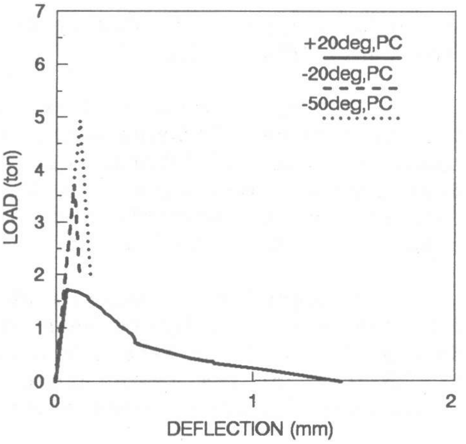


(b) -20deg

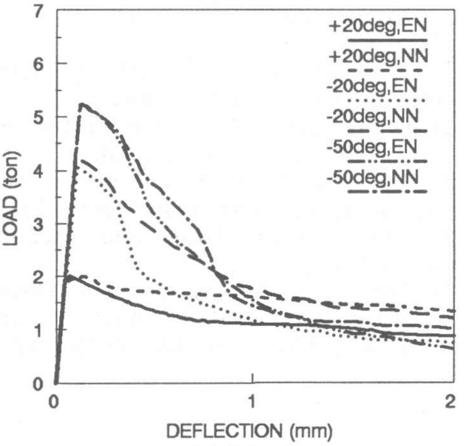


(c) -50deg

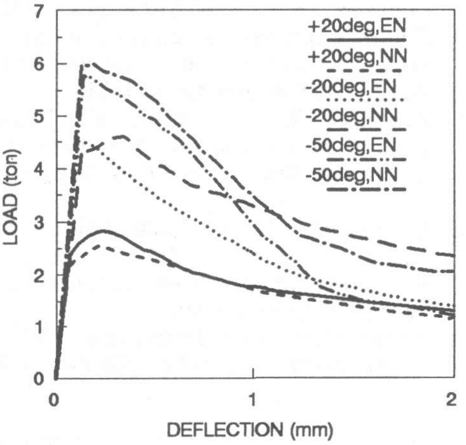
Figure 2. Load–deflection curves at the different temperatures



(a) SF=0%



(b) SF=1%



(c) SF=2%

Figure 3. Load–deflection curves at the different fiber volumes

and data was not recorded in the descending part of the load-deflection curve (Figure 3.a).

The improvement of flexural strength was found as a result of the decreasing of temperature from normal to -20 and -50°C with a constant volume of fibers. From Table 4, it can be seen that the flexural strength increased with the increase of fiber volume while the temperature is constant. There was very small effect of the fiber shape on flexural strength of the SFRCs.

A significant improvement in flexural toughness was noticed with the adding of fibers both at normal and at low temperatures. The data in Table 4 indicate the highest flexural toughness of SFRC with 2%, NN-fiber at low temperatures. The low volume fiber SFRC was less tough than the high volume fiber SFRC at low temperatures.

4. CONCLUSIONS

Based on the test results and their analysis, the following conclusions can be drawn:

(1) A negligible increase in the compressive strength of SFRC compared to that of PC was found;

(2) The effect of temperature on the flexural strength was found to be greater than the effect of fiber volume;

(3) The flexural toughness increases with an increase of the volume of fibers;

(4) The improvement in the flexural toughness with a decrease of temperature and a constant volume of fibers is influenced by the maximum load and the shape of the fibers.

REFERENCES

1. Rostasy, F.S. and Sprenger, K.H., "Strength and deformation of steel fiber reinforced concrete at very low temperature", The International Journal of Cement Composites and Lightweight Concrete, Vol.6,N°1,Feb.,1984,pp.47-51.
2. Banthia, N. and Mani, M., "Toughness indices of steel fiber reinforced concrete at low temperatures", Proceedings of Second Canada/Japan Workshop "Low temperature Effects on Concrete",1991,pp.269-279
3. Kohno, K. et al., "Comparison of fundamental properties of concrete using new-and old-type steel fiber", Proceedings of the Fourth RILEM International Symposium "Fiber Reinforced Cement and Concrete",1992,pp.51-60.
4. Japan Concrete Institute, "JCI Standards for Test Methods of Fiber Reinforced Concrete",JCI,Feb.,1984,pp.45-51.

ACKNOWLEDGMENTS

The authors would like to thank to Mr.S.Sasaki and the other colleagues from the Materials Section, Civil Engineering Research Institute for their comments and help to this work.