Mechanical properties of fiber reinforced self-compacting concrete

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Self-compacting concrete (SCC) has been widely used in construction industry because of its economic and technical benefits. But SCC has intrinsic low ductility and poor toughness which restrict the fields of application of SCC. The disadvantage of SCC can be avoided by reinforcing with randomly distributed discontinuous fibers. This paper focuses on the experimental investigation carried out on fiber reinforced self-compacting concrete (FRSCC). The effect of type and content of fibers on the mechanical properties was experimentally investigated. The test results indicate that the addition of fibers can significantly improve the ductility and flexural toughness of FRSCC.

(Received June 15, 2010; accepted July 14, 2010)

Keywords: Polypropylene fiber, Steel fiber, Self-compacting concrete, Mechanical properties

1. Introduction

Self-compacting concrete (SCC) is considered a concrete that can be placed and compacted under its own weight without any vibration effort. The use of SCC in the construction industry can reduce the labor cost, eliminate the vibration noise pollution and ensure good structural performance. SCC has excellent applicability for elements with complicated shapes and congested reinforcement. SCC has been widely used in many countries since it was developed in Japan in the late 1980s [1].

Even though SCC has substantial economic and technical benefits, it is a relatively brittle material and has intrinsic low ductility and poor toughness. The disadvantage of SCC can be avoided by reinforcing with randomly distributed discontinuous fibers. Over the last decades, fibers have been widely used in concrete as a reinforced component. The randomly distributed fibers in concrete primarily control the propagation of cracks and limit the crack width [2]. The addition of fibers into SCC can significantly improve mechanical properties and extend the possible fields of application of SCC. Fiber reinforced self-compacting concrete (FRSCC) is viewed by many as promising materials because of its great significance for construction [3-6].

In this study, two different types of fibers including steel fiber and polypropylene (PP) fiber were used. Different contents of steel fiber and PP fiber were used. The effect of type and content of fibers on the mechanical properties (compressive strength, splitting tensile strength and flexural toughness) of FRSCC is experimentally investigated.

2. Experimental

2.1 Materials and mixture proportions

Ordinary Portland cement was used in this study. The coarse aggregate was crushed stone with a maximum size of 20 mm and the fine aggregate was natural sand with a maximum size of 5 mm. Fly ash was used as mineral addition.

The fibers used in the investigation were hooked end steel fiber and macro PP fiber. The properties of steel fiber and PP fiber are shown in Table 1. Different contents of steel fiber and PP fiber were used. Steel fiber content used was 15 kg/m^3, 25 kg/m^3 and 50 kg/m^3, and PP fiber content used was 3 kg/m^3, 6 kg/m^3 and 9 kg/m^3.

A polycarboxylic ether superplasticizer (SP) was used in all concrete mixtures. For different concrete mixtures, the dosage of SP was adjusted properly to obtain the required flowability and stability.

The details of the mixture proportions are shown in Table 2.

Table 1. Properties of steel fiber and PP fiber.

Property	Steel	PP
Length (mm)	25	24
Diameter (mm)	0.5	0.8
Aspect ratio (L/D)	50	30
Density (kg/m^3)	7.8	0.9
Tensile strength (MPa)	1000	450
Elastic modulus (GPa)	220	5.0

Table 2. Mixture proportions of concrete.

Mixture	Fiber (kg/m³)		Cement (kg/m³)	Water (kg/m³)	Coarse aggregate (kg/m³)	Fine aggregate (kg/m³)	Fly ash (kg/m³)	SP (kg/m³)
	Steel	PP						
C	-	-	425	184	860	680	146	26
SFRC 15	15	-	425	184	860	680	146	30
SFRC 25	25	-	425	184	860	680	146	37
SFRC 50	50	-	425	184	860	680	146	45
PFRC 3	-	3	425	184	860	680	146	29
PFRC 6	-	6	425	184	860	680	146	35
PFRC 9	-	9	425	184	860	680	146	42

2.2 Testing procedure

Slump flow test was used to evaluate the workability of fresh concrete mixtures. Cubes (100 × 100 × 100 mm) were used to evaluate the compressive strength and splitting tensile strength in accordance with Chinese Standard GB/T 50081-2002. The four-point loading flexural tests were carried out on the beams (100 × 100 × 400 mm) with a closed-loop arrangement in accordance with ASTM C1018. The loading was displacement control at a rate of 0.05 mm/min. Both the applied load and the specimen midspan deflection were recorded throughout the test. The flexural toughness of all the mixtures were evaluated by measuring the load-deflection curves in accordance with JSCE SF-4 standard [7].

In accordance with the JSCE method, the flexural toughness factor (σ_b) is defined as:

$$\sigma_b = \frac{\tau_b}{\delta_{tb}} \times \left(\frac{l}{b \times h^2} \right) \quad (1)$$

where l is beam span (300 mm in this study), b is beam width (100 mm in this study), h is beam depth (100 mm in this study), $\delta_{tb} = l/150$ (2 mm in this study), τ_b is the area under the load-deflection curve up to a midspan deflection of δ_{tb}.

3. Results and discussion

3.1 Fresh properties

The values of slump flow for all the mixtures achieved the minimum required value of slump flow [8]. Fresh FRSCC with considerable fiber inclusion can obtain desired workability by proper adjustment of SP dosage.

3.2 Compressive strength

The compressive strength values of all the mixtures are illustrated in Fig. 1 and Fig. 2. The test results show that compressive strength decreased with the increase of fiber content, no matter steel fiber or PP fiber. The decrease in compressive strength is due to the decrease of the coarse aggregate content and the increase of porosity caused by the incorporation of fibers.

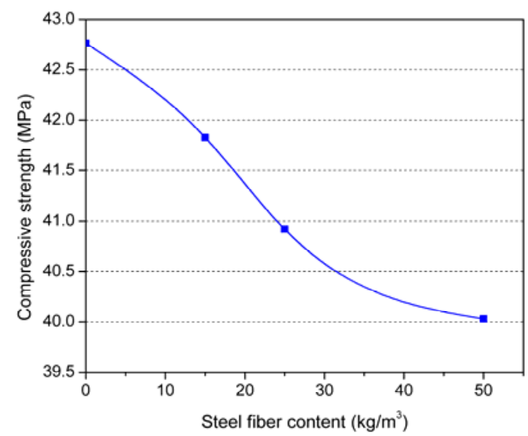

Fig. 1. Effect of steel fiber content on compressive strength.

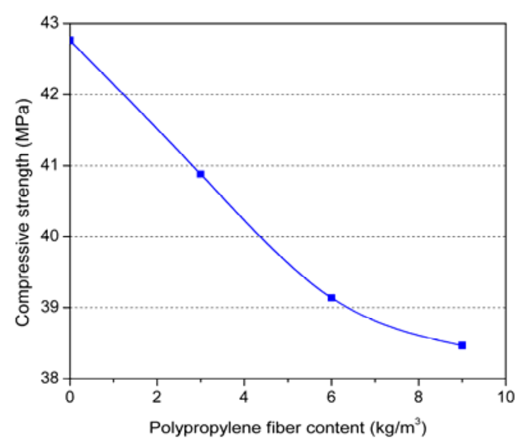

Fig. 2. Effect of PP fiber content on compressive strength.

3.3 Splitting tensile strength

The splitting tensile strength values of all the mixtures are shown in Fig. 3 and Fig. 4. The test results show that splitting tensile strength increased with the increase of fiber content.

Compared with control concrete without fiber, splitting tensile strength increased 9.6%, 13.0% and 18.4% for steel fiber content at 15 kg/m^3, 25 kg/m^3 and 50 kg/m^3, respectively.

Compared to control concrete without fiber, splitting tensile strength increased 11.1%, 23.5% and 32.5% for PP fiber content at 3 kg/m^3, 6 kg/m^3 and 9 kg/m^3, respectively.

At the stage of cracking, randomly oriented fibers bridge the cracks and limit crack propagation. Consequently, the splitting tensile strength values increased with the increase of fiber content.

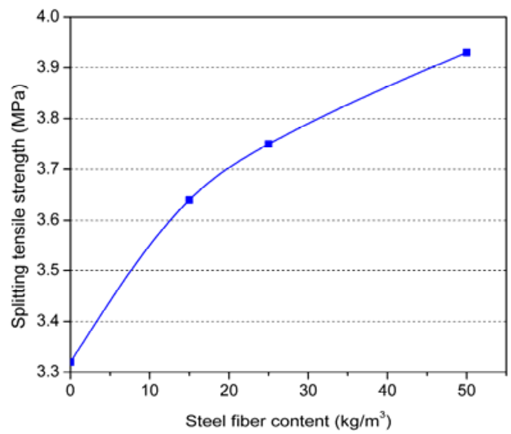

Fig. 3. Effect of steel fiber content on splitting tensile strength.

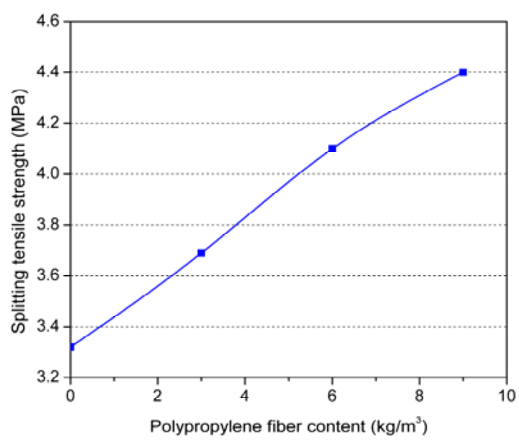

Fig. 4. Effect of PP fiber content on splitting tensile strength.

3.4 Flexural toughness

The flexural load-deflection curves of SFRC 15/25/50 (concrete with 15 kg/m^3, 25 kg/m^3 and 50 kg/m^3 steel fiber) and PFRC 3/6/9 (concrete with 3 kg/m^3, 6 kg/m^3 and 9 kg/m^3 PP fiber) are shown in Fig. 5 and Fig. 6, respectively.

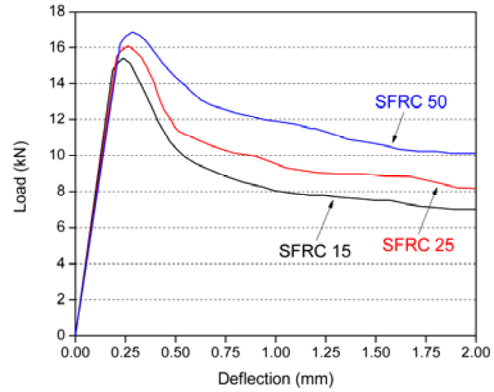

Fig. 5. Flexural load-deflection curves of FRSCC reinforced with steel fiber.

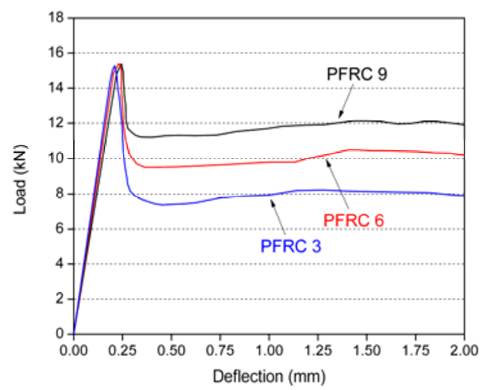

Fig. 6. Flexural load-deflection curves of FRSCC reinforced with PP fiber.

It can be observed that the type of fibers has significant effect on the flexural properties of FRSCC. The post-peak flexural response of FRSCC reinforced with steel fiber and PP fiber are obviously different. In beams reinforced with steel fibers, gradual decrease in load-carrying capacity and softening response were observed in the post-peak region, as seen in Fig. 5. The toughness improvement of FRSCC reinforced with steel fiber is mostly due to fiber pullout from concrete matrix. No fiber rupture was observed for steel fibers. The fiber-matrix adhesion is the important factor to determine the toughness performance of FRSCC reinforced with steel fibers.

On the other hand, for beams reinforced with PP fibers, sudden load drop was observed in the post-peak region. After the sudden load drop, the load-carrying capacity improved slowly. The sudden load drop is due to the rupture of individual fiber crossing the critical section. The subsequent increase in load-carrying capacity is due to that fibers bridged the initial crack by stretch elongation and fibres at the upper levels of the cracking plane activated.

Fiber content also has obvious effect on the flexural toughness. As shown in Fig. 5 and Fig. 6, the beams show better post-peak behaviour with the increase of fiber content when fiber type is kept the same.

The development of flexural toughness factor of FRSCC at various steel and PP fiber contents is shown in Fig. 7 and Fig. 8, respectively.

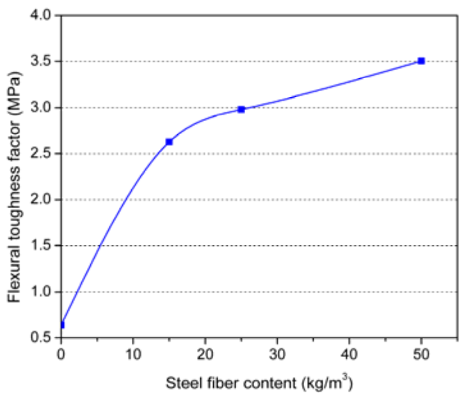

Fig. 7. Effect of steel fiber content on flexural toughness factor.

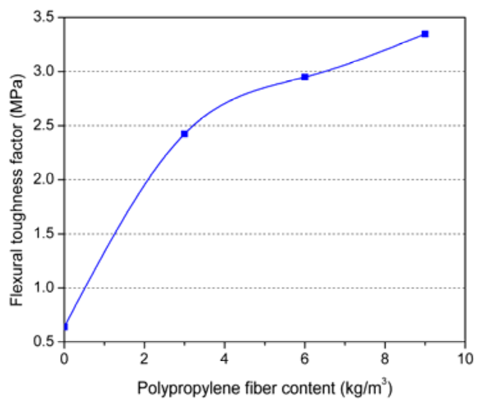

Fig. 8. Effect of PP fiber content on flexural toughness factor.

The results indicate that flexural toughness factor increased with the increase of fiber content. The mixture of SFRC 50 gave the highest flexural toughness factor.

4. Conclusions

This paper studies the effect of type and content of fibers on the mechanical properties of FRSCC. From the results obtained in this study, the following conclusions can be drawn:

Fresh FRSCC with considerable fiber inclusion can obtain desired workability by proper adjustment of superplasticizer dosage.

The compressive strength of FRSCC decreased with the increase of fiber content.

Compared with control concrete without fiber, splitting tensile strength increased 9.6%, 13.0% and 18.4% for steel fiber content at 15 kg/m^3, 25 kg/m^3 and 50 kg/m^3, respectively.

Compared to control concrete without fiber, splitting tensile strength increased 11.1%, 23.5% and 32.5% for PP fiber content at 3 kg/m^3, 6 kg/m^3 and 9 kg/m^3, respectively.

The type and content of fibers significantly affected the post-peak flexural softening response of FRSCC. The ductility and flexural toughness of FRSCC were significantly improved by the addition of fibers.

Acknowledgements

This work was financially supported by Department of Engineering Mechanics, Hohai University. The cooperation of Engineering Materials Experimental Center is greatly appreciated.

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