A

Seminar report

On

POLYMER MODIFIED STEEL FIBRE REINFORCED CONCRETE

Submitted in partial fulfillment of the requirement for the award of degree
Of Civil

SUBMITTED TO: **SUBMITTED BY:**

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Preface

I have made this report file on the topic **POLYMER MODIFIED STEEL FIBRE REINFORCED CONCRETE ;** I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to …………..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

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INTRODUCTION

Steel fibre reinforced concretes are structural materials that are gaining importance quite rapidly due to the increasing demand of superior structural properties. These composites exhibit attractive tensile and compressive strengths, low drying shrinkage, high toughness, high energy absorption and durability. This is due to the tendency of propagating micro-cracks in cementitious matrices to be arrested or deflected by fibres, which is guaranteed by the local bond between fibres and matrix. Studies show that fibre-matrix interfacial bond is provided by a combination of adhesion, friction and mechanical interlocking (Li, 2007). Thus fibre reinforced concrete has superior resistance to cracks and crack propagation. The net result of all these is to impart to the fibre composite pronounced post- cracking ductility which is unheard of in ordinary concrete (Nguyen Van,2006). These properties of SFC can be enhanced by the addition of a suitable polymer into it. The properties of which has been overlooked based on the studies conducted by Gengying Li and Xiaohua Zhao, Dept. of civil engg, Shantou university, China.

Polymer cement concretes have high tensile strength, good ductile behavior and high impact resistance capability due to the formation of a three dimensional polymer network through the hardened cementitious matrices. Because of the void-filling effect of this network and its bridging across cracks, the porosity decreases and pore radius are refined. Furthermore, the transition zone may be improved due to the adhesion of a polymer. A styrene butadiene rubber emulsion is incorporated to improve the ductile behavior and flexural strength of steel fibre reinforced cement concretes (SFC). Silica fume and fly ash are also used to enhance the densification of cementitious matrix. The mechanical properties, microstructure, porosity and pore size distribution of polymer modified steel fibre reinforced concrete are studied.

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STEEL FIBRE REINFORCED CONCRETE

GENERAL

Plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capacity. Steel fibre reinforcement is widely used as the main and unique reinforcing for industrial concrete floor slabs, shotcrete and prefabricated concrete products. It is also considered for structural purposes in the reinforcement of slabs on piles, tunnel segments, concrete cellars, foundation slabs and shear reinforcement in prestressed elements. In tension, SFC fails only after the steel fibre breaks or is pulled out of the cement matrix. The role of randomly distributed discontinuous fibres is to bridge across the cracks that develops and provide some post- cracking ductility. The real contribution of the fibres is to increase the toughness of the concrete under any type of loading. When the fibre reinforcement is in the form of short discrete fibres, they act effectively as rigid inclusions in the concrete matrix.

MIX DESIGN OF SFC

As with any other type of concrete, the mix proportions for SFC depend upon the requirements for a particular job, in terms of strength, workability, and so on. Several procedures for proportioning SFC mixes are available, which emphasize the workability of the resulting mix. However, there are some considerations that are particular to SFC. In general, SFC mixes contain higher cement contents and higher ratios of fine to coarse aggregate than do ordinary concretes, and so the mix design procedures the apply to conventional concrete may not be entirely applicable to SFC. Commonly, to reduce the quantity of cement, up to 35% of the cement may be replaced with fly ash (Nguyen Van, 2006). In addition, to improve the workability of higher fibre volume mixes, water reducing admixtures and, in particular, superplasticizers are often used, in conjunction with air entrainment. The range of proportions for normal weight SFC is shown in Table 2.1.

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Property	Mortar	9.5mm Maximum aggregate size	19 mm Maximum aggregate size
Cement (kg/m^3)	415-710	355-590	300-535
w/c ratio	0.3-0.45	0.35-0.45	0.4-0.5
Fine/coarse	100	45-60	45-55
aggregate(%)	7-10	4-7	4-6
Entrained air (%)	1-2	0.9-1.8	0.8-1.6
Fibre content (%) by volume	0.5-1.0	0.4-0.9	0.3-0.8
smooth steel			
deformed steel			

Table 2.1 Range of proportions for normal weight fibre reinforced concrete (steel fibre reinforced concrete, Nguyen Van).

PROPERTIES OF SFC

Compressive strength

Fibres do little to enhance the static compressive strength of concrete, with increases in strength ranging from essentially nil to perhaps 25%. Even in members which contain conventional reinforcement in addition to the steel fibres, the fibres have little effect on compressive strength. However, the fibres do substantially increase the post-cracking ductility, or energy absorption of the material.

Tensile strength

Fibres aligned in the direction of the tensile stress may bring about very large increases in direct tensile strength, as high as 133% for 5% of smooth, straight steel fibres. However, for more or less randomly distributed fibres, the increase in strength is much smaller, ranging from as little as no increase in some instances to perhaps 60%, with many investigations indicating intermediate values, as shown in Fig. 2.1. Splitting-tension test of SFRC show similar result. Thus, adding fibres merely to increase the direct tensile strength is probably not worthwhile. However, as in compression, steel fibres do lead to major increases in the post-cracking behaviour or toughness of the composites.

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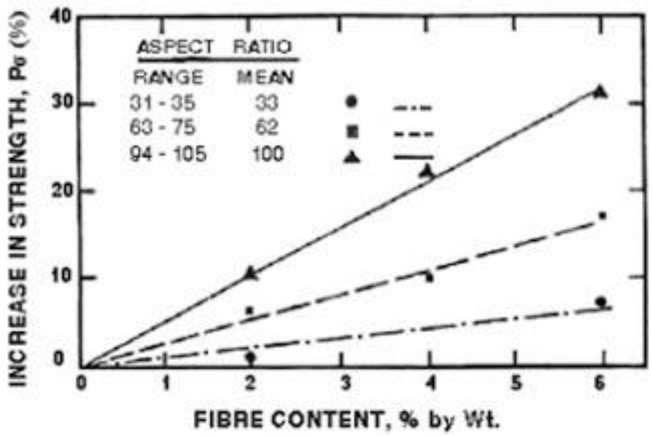

Fig. 2.1. Influence of fibre content on tensile strength (steel fibre reinforced concrete, Nguyen Van)

Flexural strength

Steel fibres are generally found to have aggregate much greater effect on the flexural strength of SFC than on either the compressive or tensile strength, with increases of more than 100% having been reported. The increase in flexural strength is particularly sensitive, not only to the fibre volume, but also to the aspect ratio of the fibres, with higher aspect ratio leading to larger strength increases. Fig. 2.2 describes the fibre effect in terms of the combined parameter W*l/d*, where *l/d* is the aspect ratio and W is the weight percent of fibres. It should be noted that for W*l/d* > 600, the mix characteristics tended to be quite unsatisfactory. Deformed fibres show the same types of increases at lower volumes, because of their improved bond characteristics.

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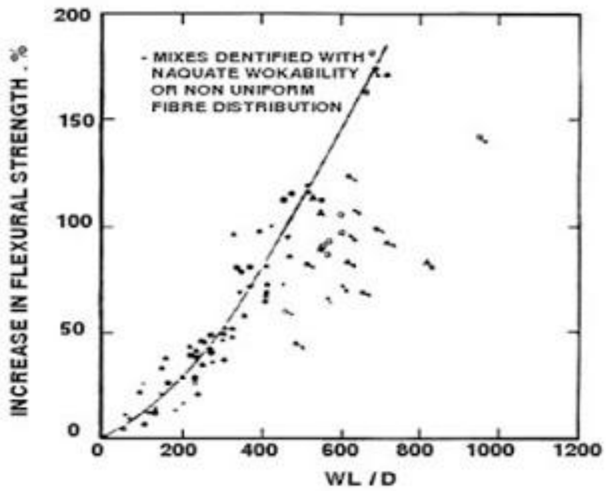

Fig.2.2. The effect of Wl/d on the flexural strength of mortar and concrete (steel fibre reinforced concrete, Nguyen Van)

APPLICATIONS OF SFC

The uses of SFC over the past thirty years have been so varied and so widespread, that it is difficult to categorize them. The most common applications are pavements, tunnel linings, pavements and slabs, shotcrete and now shotcrete also containing silica fume, airport pavements, bridge deck slab repairs, and so on. There has also been some recent experimental work on roller-compacted concrete (RCC) reinforced with steel fibres. The fibres themselves are, unfortunately, relatively expensive; a 1% steel fibre addition will approximately double the material costs of the concrete, and this has tended to limit the use of SFC to special applications.

To improve the properties of SFC a suitable polymer is added and the resulting changes in properties are closely examined.

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POLYMER MODIFIED SFC

To the steel fibre reinforced concrete a styrene butadiene rubber emulsion was added and the properties of such polymer modified steel fibre reinforced concrete (PSFC) are studied.

Experimental program

Materials

The cementitious material used in the test was ordinary Portland cement. Fly ash and silica fume. The coarse aggregate was crushed limestone with a maximum size of 12 mm. The fine aggregate was river sand with a fineness modulus of 2.35. Hooked-end straight steel fibers were added in concrete mixes at different volumetric fractions. Fiber shapes are shown in Fig. 3.1, and specifications are listed in Table 3.1. The superplasticizer (SP) is a liquor of phenolic aldehyde, with a solid content of 31% and the density 1.1 g/cm3. The polymer used is a styrene butadiene rubber emulsion (SBR), which is a fluid milk-white solution, with a solid content of 48% and the density 1.09 g/cm3.

Fig.3.1 Shape of steel fibres (properties of PSFC, Li, Zhao).

Table 3.1 Specifications of hook-end steel fibres (properties of PSFC, Li, Zhao)

Tensile strength (MPa)	Specific gravity (g/cm^3)	Fibre length (mm)	Fibre diameter (mm)
550-900	7.9	16	0.4

Specimen preparation and test methods

The concrete mixes are presented in Table 3.2. In the test, both silica fume and fly ash remained unchanged. However, the amount of steel fibers and polymer varied. Firstly, steel

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fibers, cement, stone, sand, silica fume and fly ash were added and mixed for about 5 min. Then, water, SBR latex, and superplasticizer were added. The mixture was mixed until a uniform concrete was obtained. Three specimens (with a size of 100 x 100 x 300 mm^3) were prepared for each mix. The specimens were demoulded after 2 days, and then cured for 5 days in water with a temperatureof 20 ^{0}C, and for another 21 days in room conditions.

Table 3.2 Mix proportions of concrete (kg/m^3) (properties of PSFC, Li, Zhao).

Mixes	Cement	Water	Sand	Stone	Silica fume	Fly ash	Steel fibre	Polymer	SP(wt%)	W/B	P/B[a] (wt)%	F dosage[b]
SFCI	490	141.6	650	1062	50	50	78	-	1	0.240	0	1
SFCII	490	141.6	650	1036	50	50	156	-	1.1	0.240	0	2
SFCIII	490	141.6	650	1010	50	50	234	-	1.1	0.240	0	3
PSCIa	490	135.7	650	1062	50	50	78	17.7	1.5	0.230	3	1
PSCIb	490	126.9	650	1062	50	50	78	24.5	1.5	0.215	5	1
PSCIc	490	109.2	650	1062	50	50	78	59	1.2	0.185	10	1
PSCIIa	490	135.7	650	1036	50	50	156	17.7	1.5	0.230	3	2
PSCIIb	490	126.9	650	1036	50	50	156	24.5	1.5	0.215	5	2
PSCIIc	490	109.2	650	1036	50	50	156	59	1.3	0.185	10	2
PSCIIIa	490	135.7	650	1010	50	50	234	17.7	1.5	0.230	3	3
PSCIIIb	490	126.9	650	1010	50	50	234	24.5	1.5	0.215	5	3
PSCIIIc	490	109.2	650	1010	50	50	234	59	1.3	0.185	10	3

[a] P/B: polymer given as the total binder content by mass

[b] F: steel fibres given as percent of volume

The microstructure of concrete containing 1 vol.% steel fibers was analyzed by using Scanning electron microscope (SEM). Three samples with a size of 1 x 1 x 1 cm were collected for each mix after steel fibers being pulled out to observe the interface change between steel fibers and cement matrix. Another six samples for each mix were collected at random after compressive testing. Three of them were dried in an oven at 50 ± 2 _C, while the other three were etched with 3% hydrochloric acid (HCl) solution for 10 min. Thereafter, the three samples were washed with water and dried in an oven too. All samples were kept in alcohol until testing, and gold-coated before examination. The effects of SBR content on concrete porosity and pore size distribution were determined by using Mercury Intrusion Porosimetry (MIP). After strengths were tested, samples were collected randomly from four mixes of concrete, which are SFCI, PSCIa, PSCIb, and PSCIc (as shown in Table 3.2). An AUTOSCA-10 Mercury Intrusion Porosimetry, able to determine the distribution of pores from 2 to 5000 nm, was used for the measurement. The maximum pressure provided by the machine was 600 MPa. The contact angle and mercury surface tension used were 140 and 480.0 erg/cm^2, respectively.

RESULTS

Table 4.1. Mechanical properties of specimens after 28 days curing (properties of PSFC, Li, Zhao).

Mixes	Compressive Strength (MPa)	Flexural strength (MPa)	Cost (¥ per m³ concrete)		
			SF	SBR	Total
SFCI	70+-3.1	9.60±3.8	390	0	640
SFCII	79.9±2.9	12.60±4.0	780	0	1030
SFCIII	82.8±3.4	15.60±3.7	1170	0	1420
PSCIa	74.2±2.8	12.75±3.2	390	230.1	870.1
PSCIb	73.5±3.4	13.05±2.5	390	318.5	958.5
PSCIc	62.0±3.3	11.10±3.3	390	767	1407
PSCIIa	79.2±2.8	12.70±3.2	780	230.1	1260.1
PSCIIb	77.0±2.9	14.60±3.5	780	318.5	1348.5
PSCIIc	69.2±3.0	13.71±3.7	780	767	1797
PSCIIIa	83.3±3.9	17.30±3.9	1170	230.1	1650.1
PSCIIIb	78.1±3.6	18.55±4.1	1170	318.5	1738.5
PSCIIIc	69.5±4.3	14.80±4.0	1170	767	2187

Mechanical properties and cost feasibility

As shown in Table 4.1, the compressive strengths of concretes (SFC) reinforced with 1, 2, 3 vol.% SFs are 70.0, 79.9, 82.8 MPa, and the flexural strengths are 9.6, 12.6, 15.6 MPa, respectively. With the addition of SBR, the flexural strengths of concretes are generally higher than these of SFC. For series I (containing 1 vol.% steel fibers), the flexural strengths of concretes incorporating 3,5, 10 wt.% SBR are 12.75, 13.05, 11.1 MPa, about 32%, 33%, 15% higher than these of SFCI, respectively. For series II (containing 2 vol.% steel fibers) and III (containing 3 vol.% steel fibers), the flexural strengths of concretes incorporating 3, 5, 10 wt.% SBR are about 1%, 15%, 9%, 11%, 19%, _6% higher than these of SFC, respectively. However, the compressive strengths are generally decreased with the addition of SBR. For series I, II and III, the compressive strengths of concretes incorporating 3, 5, 10 wt.% SBR are about 1.06, 1.05, 0.88, 0.99, 0.94, 0.86, 1.01, 0.94, 0.84 times as high as these of corresponding SFC, respectively.

It is worth noting that both the mixes PSCIa and PSCIb have higher flexural strengths than SFCII, while containing a lower content of steel fibers. Due to this property, these

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two mixes are attractive for engineering applications. Nowadays, the price of steel fibers in China is about ¥ 5000 per tonne, the SBR about ¥ 13,000 per tonne, and Ordinary Portland Concrete about ¥ 250 per m3. The costs of all mixes are shown in Table 4.1. It is seen that both PSCIa and PSCIb are cheaper than SFCII. This indicates that the appropriate addition of SBR to a concrete can enhance its flexural property, and lower specific gravity and price. The optimal addition of SBR is about 5 wt.%, which achieves the highest flexural strength. Probably due to the higher air content in concretes, the increasing addition of SBR and steel fibers does not enhance both compressive and flexural strength. In engineering applications, PSC is usually subjected to compression. Fig.4.1 shows the load–displacement curves of concretes under uniaxial compression, which were obtained at the age of 28 days with cubic specimens of 100 x 100 x 100 mm^3. It is seen that the addition of both fibers and SBR does not have much influence on the behavior of a hardened concrete before peak load. However, a significant improvement in energy absorption (defined as the area under the compressive load–displacement curves after peak load) is observed after peak load. Both the ultimate deformation and dissipated energy increase with increasing dosage of fibers. The load–displacement curves without SBR decreases much more sharply with the increase of displacement, indicating that the concretes with SBR possess better ductility.

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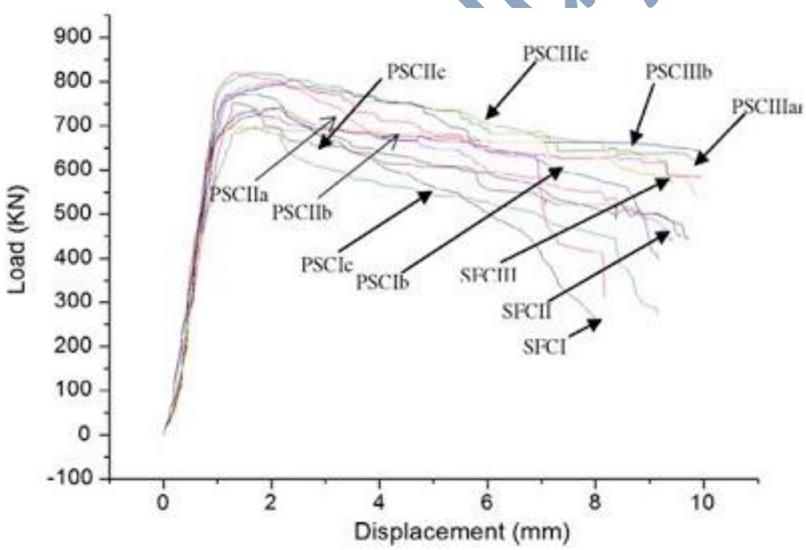

Fig.4.1. Comparison of compressive load displacement curves of concrete specimens with and without SBR (properties of PSFC, Li, Zhao)

Porosity and pore size distribution

Porosity and pore size distribution for SFCI, PSCIa, PSCIb, and PSCIc after 28 days' curing are shown in Table 4.2. Obviously, the porosity and pore size distribution are influenced by the incorporation of SBR. The overall porosity increases with the increasing dosage of SBR, but does not as it was expected. This fact might be due to the application of MIP test method itself, which uses high pressure capable of damaging the thin polymeric films and compacting the concretes. The magnitudes of overall porosity are 8.24%, 8.26%, 8.37% and 9.44% for SFCI, PSCIa, PSCIb and PSCIc, respectively. The pores with a size less than 50 nm are designated as ‘‘gel’’ porosity or medium shrinkage. While the pores larger than 50 nm are designated as large capillaries or entrained air and will affect mainly strength and permeability. Table 5 shows that the magnitudes of gel or medium capillary porosity for SFCI, PSCIa, PSCIb and PSCIc are 4.67%, 6.70%, 6.87% and 4.60%, respectively. However, the values of large capillary porosity become 3.90% for SFCI, 2.02% for PSCIa, 2.35% for PSCIb, and 5.26% for PSCIc. The large capillary porosities for PSCIa and PSCIb are lower, and therefore higher strengths are achieved (Table 4.1).

Mixes	Total intruded volume (*ml/g*)	Total surface area (m^2/g)	Mean radius (*nm*)	Mode radius (*nm*)	Median radius (*nm*)	Porosity (%)	Pore size distribution (%)			
							<10 *nm*	10*nm*-50*nm*	50*nm*-1μ*m*	>1μ*m*
SFCI	0.0327	10.968	8.909	2.33	14.76	8.24	2.00	2.67	2.41	1.49
PSCIa	0.0339	7.255	7.035	2.091	11.53	8.26	2.63	4.07	1.86	0.16
PSCIb	0.0344	9.430	7.190	2.113	11.8	8.37	2.63	4.24	2.25	0.10
PSCIc	0.0409	11.060	12.37	2.717	32.01	9.44	1.42	3.18	4.25	1.01

Table 4.2 Porosity, mean radius and pore size distribution of concretes (properties of PSFC, Li, Zhao).

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CONCLUSION

Mechanical behaviours and microstructures of the materials were analyzed. It is concluded that

1. Addition of steel fibres to a concrete will improve both its flexural and compressive strength. The strengths increase significantly with fibre content.
2. The flexural strength increases greatly when containing 3-10 wt.% SBR. The optimal use of SBR is 5 wt.%, which achieves the highest flexural strength. However, the compressive strength may decrease with the addition arrives 10 wt.%, a 16% reduction is observed.
3. Polymer films are observed in concretes when incorporating 5 or 10 wt.% SBR, and act as bridges across pores and cracks. Morover, the polymer films in concrete incorporating 10 wt.% SBR are thicker and more coherent.
4. The pore size distribution curves of specimens exhibit at least two peaks, which locate in the ranges of 5-20 nm and 50-1000 nm, respectively. Higher addition of SBR leads to a larger peak magnitude in the range of 50-1000 nm.
5. The overall porosity increases with the increasing dosage of SBR.

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