Vol. 8, No. 2, pp. 20-25, December 2009

International Journal of Safety
www.kosos.or.kr

An Experimental Study on the Mechanical Properties and Rebound Ratios of SFRS with Silica Fume

Young-Hyun Son* and Won-Kyu Chai[1]

SUHRIM Institute of Construction Technology, Hwasun-Up, Hwasun-Gun 519-803, Korea
[1]Department of Construction Information, Shingu University, Seongnam 462-743, Korea

(Received June 15, 2009; Accepted November 21, 2009)

Abstract: In this study, an experiment in the field was performed to analyze the mechanical properties and the influence of steel fiber and silica fume on the rebound ratios of shotcrete. The experimental parameters which are the reinforcing methods (steel fiber, wire mesh), steel fiber contents (0.0%, 0.5%, 0.75%, 1.0%), silica fume contents (0.0%, 10.0%), layer thickness (60 mm, 80 mm, 100 mm), and the placing parts (sidewall, shoulder, crown) were chosen. From the mechanical test, it was found that the flexural strength and toughness is significantly improved by the steel fiber and/or silica fume. According to the results for the side wall in this test, the larger the fiber contents are in case of steel fiber reinforced shotcrete, the less the rebound ratios are within the range of 20-35%, compared to the wire mesh reinforced shotcrte. And also, the reduced rebound ratios were very larger in using steel fiber reinforced shotcrete with silica fume content of 10%, and these results are true of the shoulder and the crown, respectively.

Key words: steel fiber reinforced shotcrete, wire mesh reinforced shotcrete, silica fume, rebound ratios

1. Introduction

In the case of traditional wire mesh reinforced shotcrete (WMRS), significant problem has taken place all over the world. People spend tremendous time on sticking the wire mesh to the rock face. When feasible air-pressure is not used, or the nozzle is not held at the proper distance from the rock face, shotcrete can build up on the face of the mesh, leaving voids and sand-pockets behind it [1, 2].

Since the shotcrete is a system of shooting the concrete at the rock face using the air compressor, it has many factors to deteriorate the quality compared to the normal concrete. The materials can be wasted by a spraying method. The operation efficiency can be declined, and the additional costs to clear away the rebounded materials may be required.

Similar to the traditional method a steel fiber reinforced shotcrere (SFRS) has a problem to deteriorate the quality, which has very serious influence on the reinforcing effects, although it makes the steel fiber reinforced shotcrete the SFRS improve the safety due mainly to production of the layer much faster and giving good anti-corrosion and an economical merits [3-7].

Fiber reinforcement provides distinct placement advantages over the WMRS. The placement advantages coupled with an improved material mechanical behavior have led to a widespread use of fiber-reinforced shotcrete in most of the industrialized nations [4, 6].

In this study, to maximize the effects of using the steel fiber as the shotcrete of reinforcement, and to compare the characteristics with the WMRS, a field experiment was performed with the parameters.

They are reinforcing methods, fiber contents by volume (V_f), silica fume contents (SF), spraying thicknesses and spraying parts.

*Corresponding author: coo@csmeng.co.kr

2. Test Program

2.1 Materials and Mix Proportion

The Ordinary Portland Cement was used (ASTM Type I) in the experiment. Specific gravity of the sample was 3.12. The aggregates used for making fiber-reinforced shotcrete were of crushed gravel and river sand. Bulk specific gravity of the sample was equal to 2.6 and 2.62. The maximum size of crushed gravel was

Table 1. Physical properties of silica fume

S.G	Density (kg/m³)	Fineness (m²/kg)	Diameter (m)	SiO_2
2.20	250-300	20,000	0.1-1.0	93%

* S.G : specific gravity

Table 2. Mix proportions of SFRS

S/a (%)		60
W/(C + SF) (%)		42
Cement (kg/m³)		400
Steel Fiber Contents (%)		0.0 (WMRS)
		0.5, 0.75, 1.0
SF/C (%)		0.0, 10.0
Adm. / C (%)		5.0

13 mm.

The steel fiber and the wire mesh were used as the reinforcements. The fiber (L : 30.0 mm, D : 0.5 mm, Aspect Ratio : 60) used in the test is commercially available in Korea.

The dimension of wire mesh is φ4.8 mm×100 mm×100 mm. The accelerator and the silica fume were also used as the admixtures.

2.2 Test

To obtain a specimen, we poured the normal concrete of design strength (35 MPa) into the forms up to 20 mm~30 mm from the base of the forms, after preparing the wooden forms of two types (850 mm×850 mm×150 mm and 700 mm×1400 mm×150 mm), and then the layer more than 100 mm over the base concrete was built.

One of the forms (700 mm×1400 mm×150 mm) was used for checking the rebound ratios, and another (850 mm×850 mm×150 mm) was used for testing flexural strength and acquiring the Load - Loading Point Displacement curve to calculate toughness indices.

The shotcrete was sprayed at the distance of 1.0 m~1.3 m from the forms with the shooting machine - ALIVA 260. The spraying parts were divided into three parts - sidewall, shoulder, and crown.

The forms of the sidewall were built with inclination of 70° recommended in Korean Standard Specification [8], while the forms of the shoulder and the crown were completely fixed at a height of 2.3 m and 2.6 m over a scaffold (Photo 1).

The rebound ratio was checked by weighing the material that was rebounded on the sheet (5 m×5 m) after the concrete was sprayed on each panel.

To examine the mechanical properties of the SFRS comparing with the WMRS for the curing ages, beam specimens of 100 mm×100 mm×400 mm were used for flexural strength and toughness index. Sawing and coring, similar to the method suggested by JCI-SF 4 [9], obtained the specimens.

The spraying scheme is shown in Photo 1.

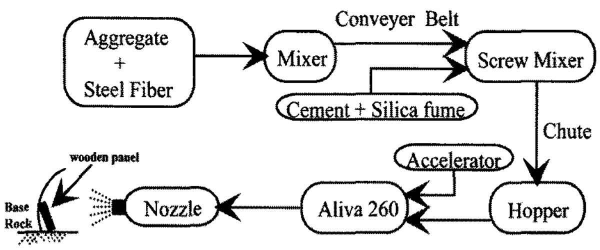


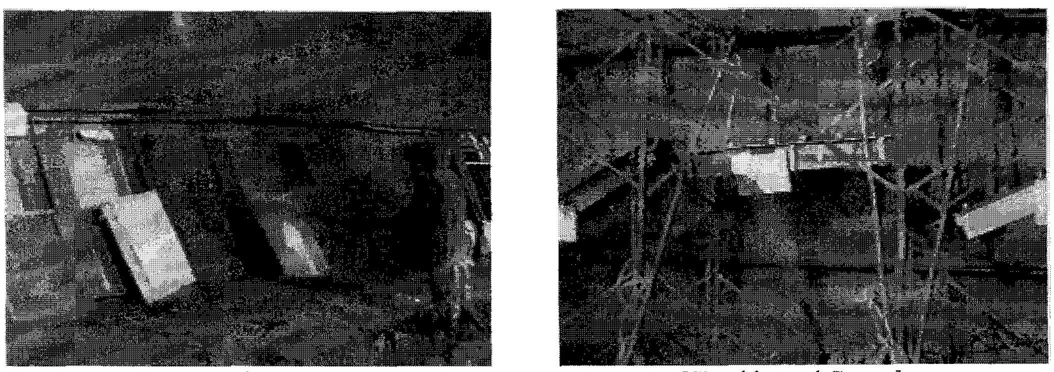
Fig. 1. Schematic diagram of shotcrete.

3. Mechanical Properties

3.1 Flexural Strength

The center-point loading method was used to obtain flexural strengths and load-displacement curves. The loading scheme is shown in Fig. 2.

In Fig. 3(a), the variation of the flexural strength for



[Sidewall] [Shoulder and Crown]

Photo 1. Spraying scheme.

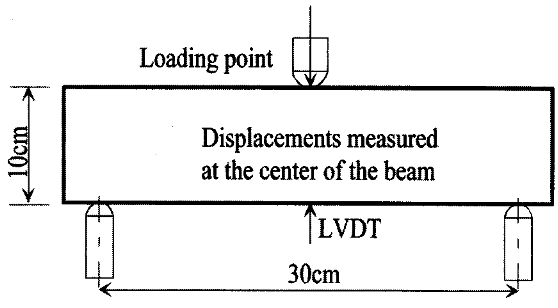


Fig. 2. Flexural testing scheme.

the layer thickness is shown, when the steel fiber contents by volume is 0.75%. The strength of the SFRS tends to increase gradually with the curing ages similar to the WMRS, irrespective of the spraying thickness.

In addition, the SFRS of 7- and 28-day shows higher flexural strength than the WMRS with thickness of 10 cm and 8 cm. However, the case for the thickness of 6 cm shows the reverse tendency.

The variation of the strength for the fiber contents is shown in Fig. 3(b).

This figure indicates that the strength is increasing with the increment of the fiber contents at the same curing age. The silica fume gives favorable effect to improve the flexural strength.

The results of the strength for the spraying thickness at 28 days at the fiber content fixed to 0.75%, is shown in Fig. 3(c). As the spraying part becomes higher, the strength of the SFRS becomes lower, similar to the WMRS, but the strengths of the SFRS keep higher level than those of the WMRS.

According to the results, in the case of the sidewall, the spraying thickness, 10 cm, of the WMRS may be reduced to the thickness, 8 cm, when the fiber content is 0.75% by volume.

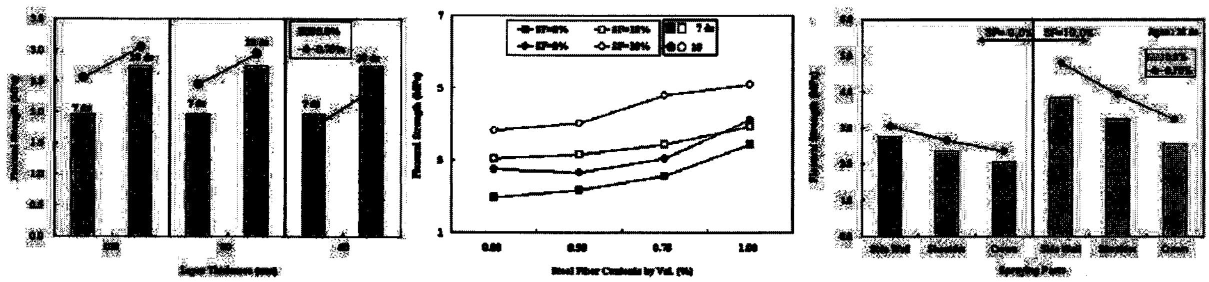
The best content of the steel fiber was determined as 0.75% by volume for improving the flexural strength, based upon the test result.

3.2 Load-carrying Capacity After Cracking

To compare the load-carrying capacity after cracking of the SFRS with the WMRS, the toughness indices were calculated by applying the method recommended by ASTM C 1018 [10].

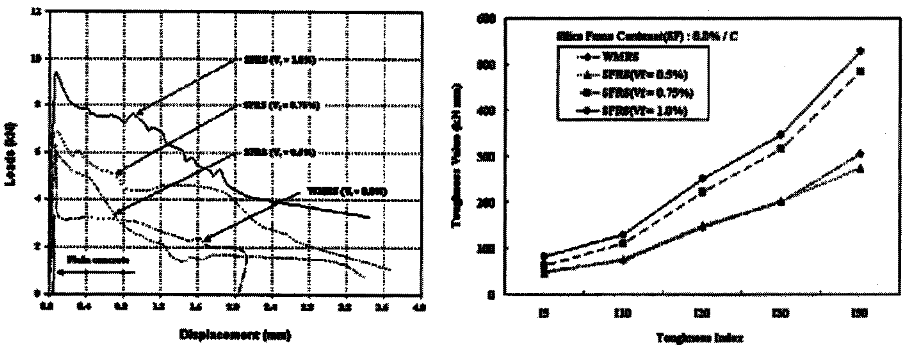
The index, $\mathbf{I}_N$, specified in ASTM C 1018 [11] is described as shown in Eq. (1) :

$$I_N = \frac{\int_0^{n\delta_c} P(\delta)d\delta}{\int_0^{\delta} P(\delta)d\delta} \quad (1)$$



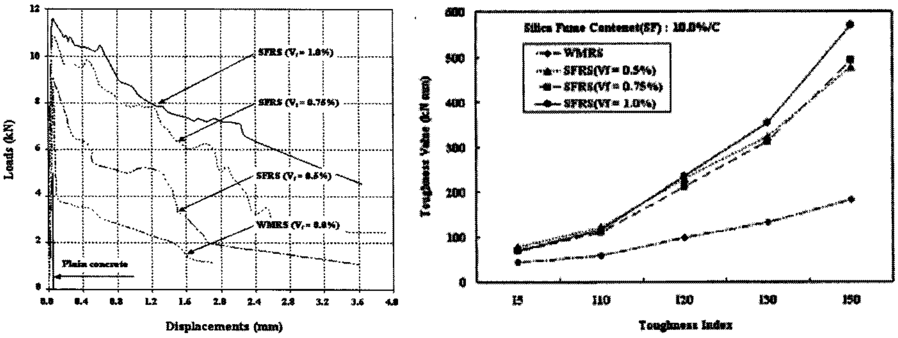
(a) (b) (c)

Fig. 3. Variation of flexural strength.



(a) (b)

Fig. 4. Load-displacement curve and Toughness Indices (silica fume content = 0.0%).



(a) (b)

Fig. 5. Load-displacement curve and Toughness Indices (silica fume content =10.0%).

where, **m** equals **0.5 x N + 0.5**, and δ_c is the displacement corresponding to the initial crack.

The typical load-loading point displacement curves (Fig. 4(a) and Fig. 5(a)) and the calculated indices (Fig. 4(b) and Fig. 5(b)) obtained from this test are shown, respectively.

According to the results, the SFRS with the fiber contents more than 0.75% enables the shotcrete to carry more load continuously after cracking than the WMRS when the silica fume was not even used. But it was difficult to expect to improve load-carrying capacity of the shotcrete when the fiber content was 0.5% by volume (Fig. 4).

When the silica fume was slightly added, the load-carrying capacity after cracking was improved on the whole, including the case of the fiber content of 0.5% by volume (Fig. 5).

From these results, when the silica fume is not used, the optimum fiber content is 0.75%. When the silica fume content is 10%, the optimum fiber content is 0.5%.

3.3 Required Thickness of Layer

Using the method recommended by JCI-SF 4 [9], the equivalent flexural strengths, $\mathbf{f_e}$, were calculated (Table 3). Using the calculated values, the required thicknesses of the SFRS against the WMRS were calculated to investigate the reduction effect of the spraying thickness.

According to the JCI method [9], using the area under the load-displacement curve up to δ=**L**/150, the equivalent flexural strength can be calculated as shown in Eq. (2) :

$$f_e = \frac{E_{L/150} \cdot L}{(L/150) \cdot bh^2} \tag{2}$$

where, $E_{L/150}$ is the area under the curve up to δ=**L**/150.

In this study, the required thicknesses of the SFRS ($\mathbf{T_{SFRS}}$) were calculated, and they were compared with the designed thickness, 20 cm, of the WMRS ($\mathbf{T_{WMRS}}$).

From this result, as the fiber contents increase, the required thicknesses decrease gradually. Especially, when the fiber content becomes 0.75%, it tends to decrease drastically and then this tendency becomes slowdown.

The steel fiber content of 0.5%~0.75% is the most effective to reduce the thickness of conventionally designed shotcrete.

Table 3. Calculated equivalent flexural strength

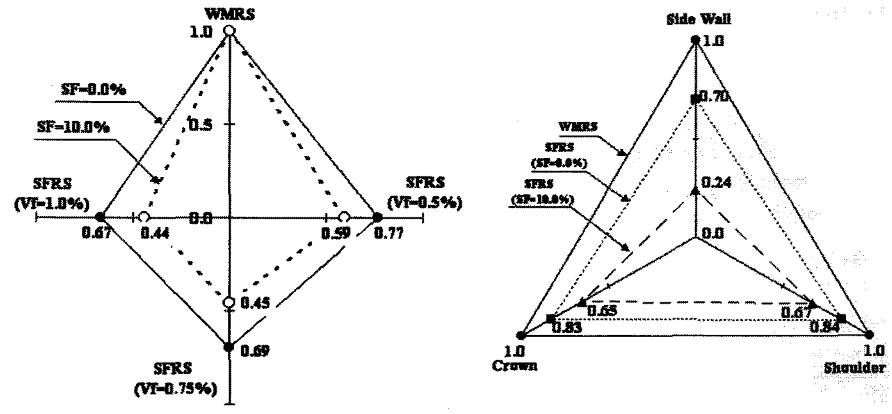
Silica Fume Content (%)	Equivalent Flexural Strength (MPa)			
	WMRS	SFRS (0.5%)	SFRS (0.75)	SFRS (1.0%)
0.0	0.86	0.89	1.50	2.10
10.0	0.70	1.50	2.40	2.60

Table 4. Required thickness

Silica Fume Content (%)	T_{SFRS} / T_{WMRS}			
	WMRS	SFRS (0.5%)	SFRS (0.75)	SFRS (1.0%)
0.0	1.0 (20 cm)	0.98 (19.5 cm)	0.82 (16.4 cm)	0.69 (12.8 cm)
10.0	1.0 (20 cm)	0.82 (16.3cm)	0.65 (12.9 cm)	0.61 (12.2 cm)

4. Effects of steel fiber and silica-fume on rebound ratios

When the spraying part is the sidewall, the rebound ratio of the SFRS decreases up to about 20%~34% compared to the WMRS as the fiber contents increase without mixing the silica fume. Furthermore, with mixing the silica fume, the ratio becomes significantly lower, up to 40~56%, and



(a) Placing part: sidewall (b) steel-fiber content(V_f): 0.75%

Fig. 6. Reduction effect of rebound ratio.

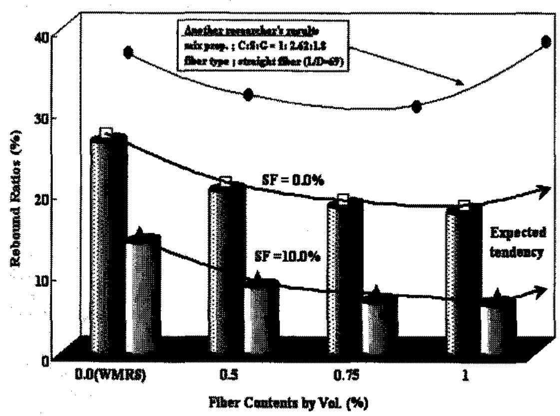


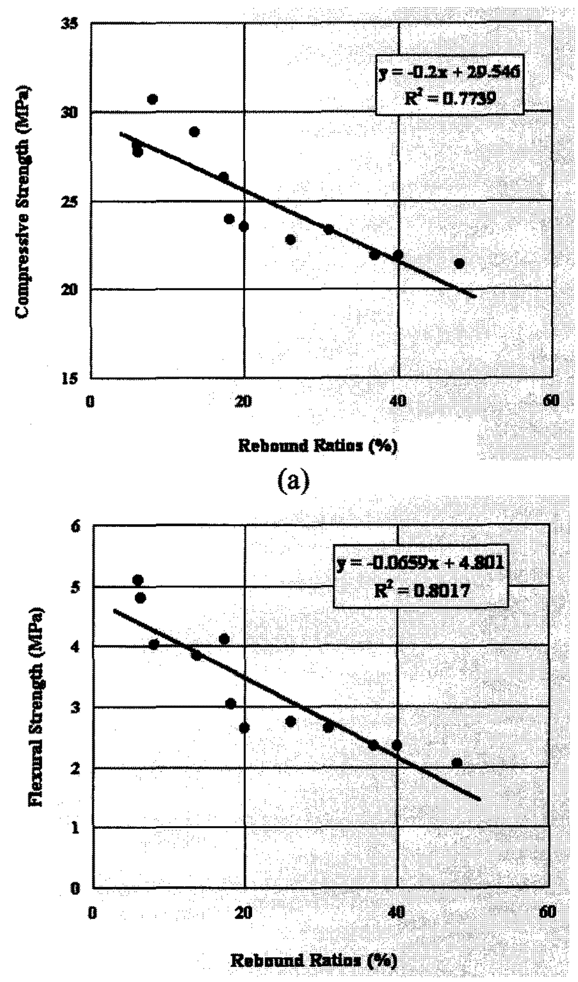
Fig. 7. Comparison with another researcher's result.

this tendency is similar to the parts of the shoulder and the crown (Fig. 6).

On the other side, when approaching to the fiber content of 1.0%, the reduction effect of rebound ratio is slow down. Those tendencies from the test result were also compared with other researchers' [12]. The tendency is all alike.

The tendency is that the rebound ratios decrease when the fiber content increases, but the decreasing effects become slowdown at the fiber content of 0.9%~1.0%. From these results, it can be estimated that the content of steel fiber in dry-mix method should not be more than 1.0% by volume (Fig. 7).

The relationships between the rebound ratios and the strengths are shown in Fig. 8. These figures indicate that the rebound ratios have close influence on the mechanical properties of shotcrete.



(a)

(b)

Fig. 8. Relationships between the rebound ratios and the strengths.

5. Conclusions

1. The flexural strength and the load-carrying capacity after cracking can be significantly improved by using the steel fiber mixed with or without the silica fume in the shotcrete.

2. The required thickness and the rebound ratio at all of the spraying parts can be significantly decreased when the steel fiber and the silica fume are sufficiently used.

3. The content of steel fiber in dry-mix method must not be more than 1.0% by volume.

4. The placement of the SFRS by Wet-mix method is more effective method for decreasing the material loss by rebounding than the placement by Dry-mix method.

References

[1] Norwegian Concrete Association-Committee, Sprayed Concrete for Rock Support-Technical Spec. and Guidelines, Norwegian Concrete Association, Norway, 1993.

[2] M. Vandevalle, Tunnelling the Wrold, N.V. BEKAERT S.A, Belgium, 1996.

[3] D.J. Hannant, Fibre Cements and Fibre Concretes, JOHN WILEY & SONS, 1978.

[4] D.R.Morgan,Dry-Mix Silica Fume Shotcrete in Western Canada, Concrete Int'l, p. 24-32, 1988.

[5] H.Armelin, Steel Fiber Reinforced Dry-Mix Shotcrete, Fiber Orientation and its Effect on Mechanical Properties, RILEM Proc. of 4th Int. Symposium, p. 266-276, 1992.

[6] Hyundai Institute of Construction Technology, A Study on the Steel Fiber Reinforced Shotcrete, Material Division, Korea, 1995.

[7] J.F. Trottier and N. Bantia, Toughness Characterization of Steel-Fiber Reinforced Concrete, ASCE J. of Materials (6-2), p. 264-289, 1994.

[8] Korean Stand. Spec. for Tunnelling, 1985.

[9] JCI Standards for Test Methods of Fiber Reinforced Concrete, 1984.

[10] ACI Committee 506, Guide to Shotcrete, 1995.

[11] ASTM Standards, ASTM C 1018, 1989.

[12] N.Bantia, J.F. Trottier, D. Wood, and D.Beaupre, Steel Fiber Reinforced Dry-Mix Shotcrete:Effect of Fibre Geometry on Fiber Rebound and Mechanical Properties, RILEM Proceeding of 4th Int. Symposium (1992).