

II. GUIDELINE FOR CONSTRUCTION OF STEEL FIBER REINFORCED SHOTCRETE

CHAPTER 1 GENERAL

Article 1 Scope

This guideline describes the general standards for construction methods of steel fiber reinforced shotcrete (SFRS). Items not specified in this guideline shall be in accordance with JSCE "Recommendation for Design and Construction of Steel Fiber Reinforced Concrete."

Article 2 Definitions

Shotcrete shall be defined as mortar or concrete shot onto a surface by means of compressed air or others.

Dry mix process - shall be defined as a method in which the dry materials such as cement, aggregate, steel fibers, etc. are thoroughly mixed in a mixer, and shot through the delivery hose by compressed air, and water is added at the nozzle using the water supply system.

Wet mix process - shall be defined as a method in which all materials such as cement, water, aggregate, steel fibers, (except accelerators) etc. are mixed in a mixer, and shot through the delivery hose. In case an accelerator is used, it is added at the nozzle by a separated hose.

Specified mix proportion - shall be defined as a mix proportion which is to be as directed by the supervisory engineer, in which aggregate is in a surface-dried condition. Fine aggregate is that which passes through 5 mm sieve, and coarse aggregate is that which remains on 5 mm sieve.

Discharged mix proportion - shall be defined as a mix proportion shot from the nozzle. The mix proportion shall be calculated from the weight of materials and added water at the nozzle.

Adhered mix proportion - shall be defined as a mix proportion of mortar or concrete which is adhered to the surface.

CHAPTER 2 QUALITY OF STEEL FIBER REINFORCED SHOTCRETE

Article 3 General

Steel fiber reinforced shotcrete shall have the required strength, toughness, durability and shall not vary widely in its quality.

(Commentary) As a matter of course, strength, toughness, durability, etc. of SFRS shall satisfy the required design values of the structure. Especially because the objective of using steel fibers in concrete is to improve tensile, bending, shearing strengths, etc., and in addition, an item on toughness is added to improve the performance against deformation.

Since the difference between discharged mix proportion and adhered mix proportion of SFRS which is effected on "rebound", a characteristic peculiar to the shotcrete method, steel fiber content also differs. Its extent is affected by many factors and in particular, materials, mix proportion, equipment, condition of surface to be shotcreted, etc. have a large influence on it, to which attention must be given.

Article 4 Strength

- (1) Strength of steel fiber reinforced shotcrete shall in general be the flexural strength and compressive strength of concrete at the age of 28 days.
- (2) Flexural strength test and compressive strength test of steel fiber reinforced shotcrete shall be done in accordance with JSCE Standards "Method of Tests for Flexural Strength and Flexural Toughness of Steel Fiber Reinforced Concrete" and "Method of Tests for Compressive Strength and Compressive Toughness of Steel Fiber Reinforced Concrete," respectively.

(Commentary) As the quality of SFRS cannot be expressed only by compressive strength, it is to be expressed by both flexural strength and compressive strength. One of the distinctive features of SFRS is that most of shotcreted steel fibers tend to orient in the direction of plane (direction in parallel with the shotcreting surface) and orientation of steel fibers in shotcrete shows the near two dimensional random orientation.

Therefore, notice shall be made beforehand that the quality attained is as required.

CHAPTER 3 MATERIALS

Article 5 Cement

- (1) Cement to be used for steel fiber reinforced shotcrete shall be ordinary Portland cement in conformity with JIS R 5210.
- (2) Cement other than (1) above shall be used after confirming if it is suitable to attain required quality of concrete.

Article 6 Admixture

- (1) An accelerator used as admixture shall have required performance and shall not erode steel fibers.
- (2) Admixtures other than (1) above shall be approved by the supervisor prior to use. Quality and methods of use shall be as directed by the supervisor.

Article 7 Steel Fibers

Steel fibers used shall be in accordance with JSCE Standards "Steel Fibers for Concrete" and suitable for shotcrete method.

(Commentary) There are cases where steel fibers are bent at the time of mixing and shooting, and required strength and toughness cannot be expected although the required steel fiber content had been secured. Therefore, steel fibers used for shotcreting must be of shape and size so as to cause less bending in mixing, pumping and shooting and troubles such as plugging up the hose, etc.

Article 8 Fine Aggregate

Fine aggregate used shall be clean, rigid and durable with suitable grading and shall not contain detrimental amounts of dust, mud, organic impurities, salt, etc.

Article 9 Coarse Aggregate

Coarse aggregate shall be clean, rigid, durable, suitably graded and shall not contain detrimental amounts of thin stone pieces, lean and long stone pieces, salt, etc., and shall be graded in the range of 15 ~ 5 mm and 10 ~ 55mm.

CHAPTER 4 MIX PROPORTION

Article 10 General

- (1) Mix proportion shall be selected so as to attain required strength, toughness and watertightness of adhered concrete with required steel fiber content.
- (2) Mix proportion shall be expressed by weight with regard to discharged mix.
- (3) Amount of addition of accelerator shall be the minimum required.

Article 11 Mix Designed Strength

Mix designed strength of steel fiber reinforced shotcrete concrete shall be that of design strength σ_{ck} multiplied by a suitable modification factor.

(Commentary) Strength of shotcrete varies widely as compared to ordinary concrete. Though deviation factor can be different depending on concrete mix proportion and conditions of construction, it falls in the range 10 ~ 15% in case it is well controlled and 15 ~ 20% in general.

Article 12 Mix Design

- (1) In selecting the mix proportion, the following items shall be taken into consideration so that the adhered concrete shall have as small a rebound as possible and good workability within the range that adhered concrete can meet the required strength and toughness:
 - (a) Steel fiber content
 - (b) Water-cement ratio
 - (c) Maximum size of coarse aggregate
 - (d) Fine aggregate ratio
 - (e) Cement content
 - (f) Type of admixture and content
- (2) In selecting the mix proportion, either reference shall be made to the values obtained from the experience to date or tests shall be carried out prior to the execution of construction.

(Commentary)

Regarding (1) The relationship between the mix proportion and quality of SFRC has not thus far been established, but in determining the mix, considerations shall be given so that the adhered concrete not only possess required quality, but also the rebound shall be as small as possible, and workability and working environment can be improved with consideration given to economy.

(a) Steel fiber content In case of SFRC, it is necessary to enlarge steel fiber content of discharged mix. To refrain from obtaining small steel fiber content of an adhered mix becomes smaller than that of discharged mix due to rebound. According to experience to date, the content of steel fibers of an attached mix is within the range of about 80 ~ 90% of that of shooting mix when a proper control of construction is exercised.

(b) Water-cement ratio In the wet mix process, effect of water-cement ratio against the quality of concrete may be considered the same as that of ordinary concrete. According to construction experience to date, the range of water-cement ratio is about 50 ~ 60%. In the dry mix process, on the other hand, even though the worker controls water content freely by the condition of shotcreting surface, it is desirable that water-cement ratio be controlled by a flow matter in order to obtain the required water-cement ratio. The range, based on construction experience to date, is 45 ~ 55%.

(d) Fine aggregate ratio In selecting the fine aggregate ratio, the relationship with the maximum size of coarse aggregate and fine aggregate grading is considered important. The range, based on construction experience to date, is $s/a = 60 \sim 100\%$.

(e) Cement content As the cement content greatly affects workability and economy of concrete, e.g. the quality of concrete, rebound, hose clogging, etc. its selection is a matter of importance.

In the case of using a dry process shotcrete equipment, it may be considered that there is almost no difference in water-cement ratio as long as the maximum size of coarse aggregate, fine aggregate ratio and cement content of concrete are the same even though steel fibers are added to the concrete. When the fine aggregate ratio is increased, however, it is required to increase the cement content in order to obtain the same water-cement ratio as in the case of the ordinary concrete. Based on construction experience to date, the range of cement content is 350 ~ 450 kg/cm² when the water-cement ratio is 45 ~ 55%.

In the case of using a wet process shotcrete equipment, the cement content differs depending on the type of equipment used, hose length, etc. to attain the required water-cement ratio. Where compressed air is used, the water-cement ratio of SFRC does not differ greatly as compared to the case of dry process method. But, where pumping method is used, the water content increases considerably as the consistency decreases due to addition of steel fibers. Therefore, it is necessary that cement content be increased considerably. Based on construction experience, the range is 450 ~ 500 kg/cm² when the water-cement ratio is 55 ~ 60%.

(f) Type of admixture and content Even though various accelerators as admixture are sold on the market, their performance and standard content are different, respectively. Therefore, suitable type and content of admixture are required to be determined in consideration of condition of the place of construction, method of construction, temperature, etc.

Regarding (2) In designing the mix proportion, either reference shall be made to the values obtained through experience to date or tests shall be carried out prior to the execution of construction.

To do so, it is important to consider the shotcreting equipment. As has been described in (1), quality of concrete, rebound and workability differ depending on various factors of mix proportion. To construct important structures or structures of large scale, it is desirable to determine the final mix proportion by carrying out tests prior to the execution of construction or carrying out construction work combined with tests in the initial stage. Tests shall be carried out in accordance with a series of JSCE Standards with regard to SFRC.

The test results, performed by various research organizations to date, shows that the quality of concrete attained varies depending on the type and capacity of the equipment used in addition to the mix proportion of concrete.

Examples of the mix used are as shown in Commentary Table-1. It is necessary that the equipment used be selected considering the circumstances of place of construction. Examples for wet process shotcrete show that there is a considerable difference between pumped method and air conveyed method; cement content is considerably large in pumped method due to the pumping of concrete.

Commentary Table - 1 Proportions and Properties of Typical Mixes for Shotcrete

Type	Maximum Size of Coarse Aggregate (mm)	W/C (%)	s/a (%)	Cement Content (kg/cm ²)	Fiber Content (% vol)	Shape and Size of Steel Fibres (mm)	Results of Strength Test (28 days)			Subject Structure	Remarks
							Compressive strength	Flexural strength	Shearing strength		
Dry-Process	15	50.0	70	350	1.5	0.5 x 0.5 x 20	375	54	-	Slope stabilization of cut face	
	15	50.0	70	350	1.0	0.5 x 0.5 x 30	343	59	60	Main body of underground power plant	
	10	48.7	70	380	1.0	0.5 x 0.5 x 20	206	43	40	Tunnel lining	
	10	50.0	70	400	1.0	0.5 x 0.5 x 25	310 ~ 320	51	55	Tunnel lining	
	5	50.0	100	380	1.0	0.3 x 0.3 x 25	250 ~ 280	40 (tensile strength)	-	Tunnel lining	
	15	60.0	80	350	1.0	0.5 x 0.5 x 25	310	60	-	Tunnel lining	Air conveyed, water reducing agent is used, slump = 14~16 cm
Wet-Process	10	52.0	70	380	1.5	0.5 x 0.5 x 30	310	49	-	Slope stabilization	Air conveyed, no accelerator is used, slump = 1.5 cm
	10	50.0	75	380	1.5	φ0.5 x 30			-	Slope stabilization	Air conveyed, no accelerator is used, slump = 1~2 cm
	5	57.0	100	485	1.0	0.25 x 0.5 x 25	303	67	-	Tunnel lining	Pumped, water reducer is used, slump = 10~14 cm
	5	60.0	100	480	1.0	0.25 x 0.5 x 25	295	59	-	Tunnel lining	Pumped, water reducer is used, slump = 8~14 cm
	5	59.8	100	480	1.0	φ0.5 x 20	344	69	51	Tunnel lining	Pumped, water reducer is used, slump = 10~12 cm

CHAPTER 5 SHOTCRETE EQUIPMENT

Section 13 Batching Equipment

Batching of materials shall be carried out by weight.

Section 14 Shotcrete Equipment

Shotcrete equipment shall be safe against inner pressure of concrete and able to transport the mixed materials continuously.

Section 15 Auxiliary Equipment

Auxiliary equipment shall be such that shotcrete equipment can demonstrate the required performance.

(Commentary) Auxiliary equipment as herein stated are as follows: supplying device of shotcrete materials and accelerator, batching and feeding device of steel fiber, air-compressor, scaffolding, etc.

In practice, it is effective to keep the specified quality of SFRC by using equipments and devices to regulate the water (in the dry-mix process) and accelerator in proportion to cement content, and a robot, to hold the nozzle in right angle and to keep proper distance from the surface to be adhered.

CHAPTER 6 PLACING

Section 16 General

Steel fiber reinforced concrete shall be shotcreted paying particular attention to the material properties, mix proportion, the equipment used, and proper curing to gain sufficient strength shotcrete. The shotcrete shall be performed continuously without interruption.

Section 17 Preparation of Materials

- (1) Materials mixed shall be shotcreted within an allowable time.
- (2) In the dry-mix process, aggregate shall have suitable amount of water on its surface.

Section 18 Mixing

Steel fiber reinforced concrete shall be thoroughly mixed such that the specified quality can be attained.

Section 19 Addition of Accelerator

Addition of accelerator shall be carried out properly depending on the process (the dry-mix process or the wet-mix process) and the type of equipment for shotcrete.

Section 20 Preparation of Surface to be shotcreted

Surfaces to be shotcreted should be cleaned thoroughly of all loose material and all dirt, scale and other contaminations to keep the safety of operators, to gain the better adhesion of SFRC shotcreted to the surface and to obtain the specified quality of concrete.

Section 21 Shotcrete Operation

- (1) At the time of operation, care shall be exercised to shotcrete steel fiber reinforced concrete in some layers with suitable thickness and finished to the required thickness so as not to have shotcreted concrete dangling or falling off from the adhered surface.
- (2) The nozzle shall be held at right angle to the surface to be adhered and suitable distance therefrom shall be maintained.
- (3) At the time of operation, care shall be exercised so as not to wrap rebound.
- (4) At the time of operation, proper measure shall be taken to keep the safety of operators.

(Commentary)

Regarding (1) The suitable thickness of a single layer depends on the condition of the face to be adhered (location, unevenness, wet or dry), materials (whether or not an accelerator is used), and shot-direction (space between nozzle and the face to be covered). But, attention must be given so that thorough adhesion to the surface and between the layers can be obtained. In general, thickness of one layer of shotcreting is 5 ~ 15 cm for overhanding face and 5 ~ 30 cm for vertical face. In shotcreting of SFRC, if the face to be covered is not smooth, honeycomb can easily be formed. Therefore, shotcrete shall be started from the hollow part. The first layer is to be shot by mortar or concrete so as to make the surface to be covered as smooth as possible.

Regarding (4) At the time of shotcrete operation, there is possibility of injury to operators caused by rebound of steel fibers and aggregate, and working environment can be worse due to the dust generated. In addition, since the accelerator commonly used is strongly stimulus and strong alkali, thorough care must be exercised, and also sufficient consideration must be given to the use of auxiliary equipment, scaffolding and protective device, etc. In general, auxiliary devices such as, windshield goggle, waterproof clothes, dustproof mask, movable scaffolding, dust collector at facing, etc. are used.

CHAPTER 7 QUALITY CONTROL AND INSPECTION

Section 22 General

To keep the specified quality of steel fiber reinforced shotcrete, materials for concrete, steel fibers, equipment and operation shall be controlled.

Section 23 Regulation of Water Volume in the Dry-Mix Process

In the dry-mix process, proper regulation shall be maintained so that optimum content of water is mixed to keep the water-cement ratio specified.

Section 24 Test and Inspection

- (1) Prior to commencing production, to obtain the optimum mix proportion of steel fiber reinforced concrete, tests shall be carried out under the supervision of a supervisory engineer, and performance of equipment and devices shall be confirmed.
- (2) The following tests shall be carried out under the supervisory engineer during the production:
 - (a) Aggregate Test
 - (b) Slump Test (in the wet-mix process)
 - (c) Unit Volume Weight Test (in the wet-mix process)
 - (d) Test for Steel Fiber Content
 - (e) Strength Test
 - (f) Toughness Test
 - (g) Other Tests
- (3) Upon completion of the production of shotcrete, non-destructive test and tests using the test pieces cut off from the structure shall be carried out if requested by a supervisory engineer.
- (4) During the production of shotcrete and upon completion of it, the following tests shall be carried out under the supervisory engineer.
 - (a) Thickness of the steel fiber reinforced shotcrete
 - (b) Others