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Steel Fiber Concrete-Introduction & Case Study

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Features

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- Self-Compacting Concrete (SCC) Mix Proportioning, Placing, Consolidation & Curing

Concrete is strong in compression and weak in tension, therefore the tensile forces have to be carried by the steel reinforcement. In addition, the tensile failure strain of the reinforced concrete is significantly lower than the yield strain of the reinforcing steel and concrete will crack before any significant load is transferred to the steel. Steel fibers can bridge this gap by the dispersion of a large number of short steel strands that my take up the load, long before the actual steel rebars come to play. By adding fiber to concrete , the mechanical resistance and ductility are improved. It also reduces the plastic shrinkage, thereby improving the resistance to abrasion, fire, impact etc.

There are many type of fibers used in the concrete such as, glass, wood, carbon, natural , steel, etc , and each type of fiber has their own mechanical or physical properties.

What Is Steel Fiber Concrete?

SFRC is a composite material made of hydraulic cements, water, fine and coarse aggregate, and a dispersion of short steel fibers. It may also contain pozzolans and admixtures commonly used with conventional concrete. All admixtures meeting ASTM specifications for use in concrete are suitable for use in SFRC. Calcium chloride and chlorides from other sources should be limited to amounts permitted to be added to conventional structural concrete as shown in ACI 318.

Unlike welded wire reinforcement or rebar which is specifically located in a single plane, steel fibers are distributed uniformly throughout the concrete matrix. The primary function of steel fibers is to modify micro and macro cracking. By intercepting cracks at their origin, the steel fibers inhibit crack growth. For this reason, SFRC can be used to replace welded wire reinforcement or rebar which is used to control temperature or shrinkage cr.

Dosages are typically in the range of 20-30kg/m3 for jointed floors and 40-50kg/m3 for joint less floors. Fiber dosage will depend upon project loadings and types of steel mesh which are being replaced.

Types of Steel Fibers

Steel fibers are short, discrete lengths of steel with an aspect ratio (ratio of length to diameter) from about 20 to 100, and with any of several cross sections. Some steel fibers have hooked ends to improve resistance to pullout from a cement-based matrix. (ASTM A 820 classifies four different types based on their manufacture. Type I – Cold-drawn wire fibers are the most commercially available, manufactured from drawn steel wire. Type II – Cut sheet fibers are manufactured as the name implies: steel fibers are laterally sheared off steel sheets. Type III – Melt-extracted fibers are manufactured with a relatively complicated technique where a rotating wheel is used to lift liquid metal from a molten metal surface by capillary action.

Fig 01. Steel Fiber Concrete

The extracted molten metal is then rapidly frozen into fibers and thrown off the wheel by centrifugal force. The resulting fibers have a crescent-shaped cross section. Type IV – Other fibers. For tolerances for length, diameter, and aspect ratio, as well as minimum tensile strength and bending requirement.

Fig 02. Types of Steel Fibers .

Applications of Steel Fiber Concrete

Steel fibers are most commonly used in airport pavements and runway/taxi overlays. They are also used in bridge decks, industrial floors, and highway pavements. Structures exposed to high-velocity water flow have been shown to last about three times longer than conventional concrete alternatives. Steel fiber concrete is also used for many precast concrete applications that make use of the improved impact resistance or toughness imparted by the fibers. In utility boxes and septic tanks, steel fibers replace conventional reinforcement.

Advantages of Steel Fibers in Concrete

1- Increased load bearing capacity of concrete
2- Reduction of concrete slab thickness
3- Increased durability
4- Reduce cracks
5- Improved flexural properties

Technology For Producing SFRC

Typically, the fibers are added at the batch plant, just after all concrete aggregates are being mixed. Some people would request to have the fiber added at the jobsite, but then the QA/QC should have more control on how much fiber is added. The steel fiber manufacturer can provide guidance on how to mix and the amount needed to be obtained desired results.

When you add fibers to a concrete mix, be aware that there will be some changes on the way you manage this concrete. First, the slump will be affected and it is recommended to add a super plasticizer to enhance the slump and make the concrete a little more fluid. Not all steel fiber can be used as a substitute for steel reinforcement.

In general, the problems of both workability and uniform distribution increase with increasing fiber length and volume. One of the chief difficulties in obtaining a uniform fiber distribution is the tendency for steel fibers to ball or clump together. Clumping may be caused by listed factors:

1- The fibers may already be clumped together before they are added to the mix; normal mixing action will not break down these clumps.

2- Fibers may be added too quickly to allow them to disperse in the mixer.

3- High a volume of fibers may be added.

4- Mixer itself may be too worn or inefficient to disperse the fibers.

5- Introducing the fibers to the mixer before the other concrete ingredients will cause them to clump together.

Fig 03. Clump Steel Fiber with Concrete

To obtain a uniform fiber distribution in the concrete Special pumps are used to add the steel fiber to concrete called “conveyers”.

Fig 04. Pump Conveyers

In general, we use conveyer pump when we add steel fibers to concrete on the site. The quantity of steel fibers to be added to mix depend on the specification of mix design and steel fiber manufacture.

Technical engineer should be experienced to know how to use conveyer pumps, and should be present on the site during adding the steel fibers to concrete to avoid any problem in working conveyer pump.

Brief Case Study:

Saudi ready mix concrete company already supplied steel fiber concrete to many projects in Saudi Arabia like Almarai project in Makkah and SIBCO Mega Plant in Jeddah by total more than 7000 M^3, steel fibers were added on the site to each mix by using conveyer pump and professional.

We faced many challenges while producing steel fiber concrete. The first challenge was a drop in concrete slump after adding steel fiber. So, the concrete slump should be high before adding steel fibers. Another challenge was difficulty in obtaining a uniform fiber distribution after mixing steel fiber with concrete inside the mixer. Therefore, this type of concrete needs more mixing time to distribute the steel fibers and avoid showing steel balls or steel clumping.

If the steel fibers are not mixed properly with concrete, balls inside mixer will show and will affect the pumps during pumping steel fiber concrete to structure and may make block the pump so that pump engineer should be present on the site during pumping the concrete structure to avoid any problem in the pumps.

AL-Maraee Warehouse Project - Makkah

The project consists of main warehouse for manufacturing Almarai dairy products. First it was awarded to Saudi contacting company. The design consultant specified steel fiber concrete for flooring area.
Total quantity of steel fiber concrete around 1350 m^3, the area of flooring divided into 4 area by average quantity around 330 m^2 concrete per area.

Fig 05. Floor of Project – Almarai Project Makkah

Requirements of Project:

1- Target Strength = 350 kg/cm^2 @ 28 days B.S
The recommended slump to be 250±40mm before pumping and after adding fibers.

2- Steel fiber type is 4D 30kg/m3 as per shown in the photo.

Fig 06. 4D Steel Fiber

Mix Design:

The main objective in designing a structural fiber concrete mix is to produce adequate workability, ease of placing and efficient use of fibers as crack arrestors, besides the other objectives desired in any normal concrete.

Preliminary trial mixes indicated that the addition of steel fibers to a properly designed concrete mix reduced the slump. To maintain the level of workability and to ensure adequate bond of the fibers to the concrete mix, it was concluded that the addition of steel fiber to the concrete mix should be accompanied by the addition of cement paste. The amount of added cement paste depends on three principal factors
as follows:

1- Amount of fibers.
2- Shape and surface characteristics of the fibers.
3- Flow characteristics of the cement paste.

The mechanistic mix proportioning design method was based on three principles:

1- The addition of steel fibers should be accompanied by the addition of an amount of cement paste sufficient to coat the fibers and to ensure their bond in the concrete mix.

2- The added fibers and cement paste should be treated as a replacement for an equivalent volume of the plain concrete mix and.

3- Water cement ratio in both plain and SFRC mixes remains unchanged.

in our project, trial mixes conducted on 35 mpa mix with steel fiber to achieve specification of project and due to quantity steel fiber high as project specification we increase quantity of cement in the mix to avoid any formation of ball/lump after adding and mixing with steel fiber.

The distance between batch plant and project around 40 km and mixer driver will take time 50 Min to reach the site so to avoid any drop in the slump , washed sand used in the mix design and increasing amount of superplasticizer to the mix.

Mix Design & Result of Trial Mix:

Mix design 35 Mpa with SF	
Material	**Weight**
Cement	450 Kg
Aggregate	1050 Kg
W.Sand	780 Kg
Water	170 L
Retarded	2 L
Superplasticizers	10 L

Fresh Concete Properties After Adding And Mixing 30 Kg Steel Fiber				
Time	**Unit**	**Initial**	**30 Min**	**60 Min**
Slump	mm	260	235	210

Average Compressive Strength Results				
Type	**Age Type**	**Age Value**	**Density (Kg/m^3)**	**Strength Kg/cm^2**
Cube	Days	3	2459	325
Cube	Days	7	2564	385
Cube	Days	28	2597	456

Challenges During Concrete Supply:

1- The drop in the concrete slump after adding steel fiber.
2- Formation of balls/lumps from steel fiber after adding and mixing with concrete which affects the consistency of concrete.

3- Pumping problems of the concrete during pumping of concrete to structure, Especially the pumping will take time due to slow process conveyer pumping.

Solution:

1- Add adequate amount of superplasticizer and retarder to mix design at the batch plant to increase slump to solve problem dropping in the slump after adding steel fibers the slump should on site min 210 mm.

Fig 07. Slump Test On site 240mm

2- To avoid formation of balls or lump, the drum mixer need optimum speed 200 RPM after adding steel fiber in to concrete mixer to obtain uniform fiber distribution in the concrete. The mixing time should be around 10 to 15 min after adding steel fiber in to concrete mixer.

3- Process and handling of adding steel fiber to concrete on the site is slow. So, enough number of manpower is required during the process of adding the steel fiber to mixer.

Results :

1- We completed pouring the floor with steel Fiber Concrete as per specifications, without any delay.

2- All results of slump test after adding steel fiber was with tolerance limit 250±40 mm and no concrete rejected.

3- All results compressive strength achieved more than 100% at 28 days.

4- We did not face pumping problem during the pouring concrete.

Self-Compacting Concrete (SCC) Mix Proportioning, Placing, Consolidation & Curing

By Moises Sumalbag - Technical Engineer

Self-compacting concrete (SCC) is an innovative concrete that does not require mechanical consolidation for concrete placing. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. SCC is composed of Portland cement, fine aggregates, coarse aggregate, water, chemical admixtures, and typically supplementary cementitious materials such as silica fume, fly ash, slag, and metakaolin.

Benefits and Advantages

1. Reduced equipment costs as no vibration are required.
2. Reduced manpower costs.
3. Early strength gained.
4. Gives good finishing as compared to ordinary concrete without any mean of compaction and no honeycombing.
5. Proper compaction even in congested areas.
6. Improved durability and decreased permeability.
7. More rapid placement of concrete and accelerated construction time.
8. Reduce noise on the job site.
9. Decreased employee injuries by facilitating safer working environment.
10. Enable more flexibility in spreading placing points during casting, etc.

Mix Proportioning

Specification guideline ACI 237R.

The three basic mixture proportioning approaches for developing SCC mixtures:

1. High powder content and High Range Water Reducing Admixture (HRWRA).
2. Low powder content, HRWRA, and Viscosity Modifying Admixture (VMA).
3. Moderate powder content, HRWRA, and moderate VMA dose (stability can be controlled through blending of aggregates, lowering water content, or using by a VMA).

Raw Materials

- **Cement –** Cements allowed should meet one of the following specifications: ASTM C 150, C 595, C 1157.

- **Silica Fume –** Silica fume can increase the stability of SCC mixtures, and should be meet ASTM C1240 specification.

- **Fly Ash –** Fly ash may enhance the workability or slump flow of SCC, and meet material specifications requirement ASTM C 618, BS 3892 Part 1, BS EN 450.

- **Ground Granulated Blast Furnace Slag (GGBFS) –** GGBFS shall be meet specification requirement ASTM C 989.

- **Coarse Aggregate –** Coarse aggregates size and the volume of coarse aggregates are influential in obtaining the passing ability of the concrete. Specification requirement shall be meet ASTM C 33.

- **Fine Aggregate –** Fine aggregates are beneficial to improve SCC plastic properties, and where VMA or higher powder contents will be used to promote stability. Requirement specification shall be meet ASTM C 33.

Admixture

The most typically used to developing SCC mix are High Range Water Reducing Admixture (HRWRA), or Viscosity Modifying Admixture (VMA).

- **Water –** Water shall be clean or potable.
- **Air Content –** air content can have an impact on slump flow.

The direction and magnitude of this relationship depends on the materials, mix design, and the amount of air.

SCC mix Design Trend According to European(AX SCC Design Trend Reference)

Trend Property	Minimum Trend	Maximum Trend
W/CM (VL)	0.850	1.100
Cementitious Qty. (Kg)	380	600
Coarse Agg. Qty. (Kg)	750	1,000
Coarse Agg. Vol. (Lt)	270	360
% Fine Agg. (WT)	48	55
Paste Volume (Lt)	300	380

Test Methods

The main four characteristics of SCC.

- Ability to fill a mold or form under its own weight.
- Resistance to segregation (Stability).
- Ability to flow through reinforcing bars or other obstacles without segregation and without mechanical vibration.
- Surface quality and finishability.

Test method being develop that measure characteristics of SCC.

Test Name	Category	Characteristics	What test measures
Slump flow	Free flow	Filling ability	Flow distance
Visual stability index (VSI)	Static condition	Resistance to segregation	Visual stability of the mixture
T50	Free flow	Filling ability	Rate of flow
J-ring	Confined flow	Passing ability	Flow rate
L-box	Confined flow	Passing and filling ability	Flow rate & distance
V-funnel	Confined flow	Filling ability	Flow rate
U-box	Confined flow	Passing and filling ability	Flow rate and distance
Column segregation test	Confined flow	Resistance to segregation	Segregation of aggregates

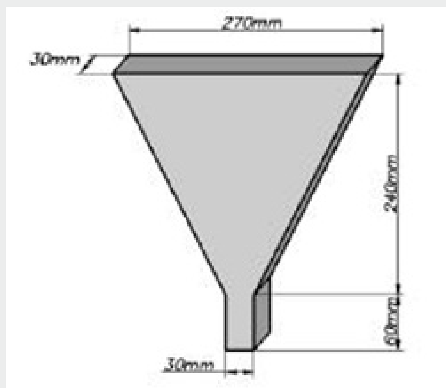
Slump Flow Test

Visual Stability Index (VSI)

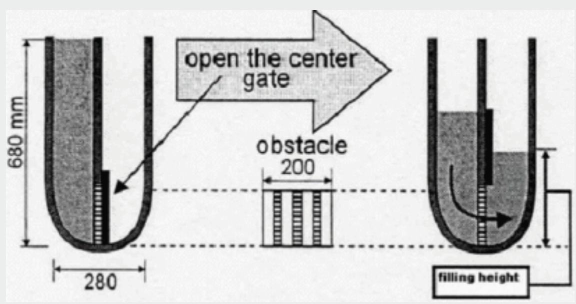
J-Ring Test

L-Box Test

V-Funnel Test



U-Box Test



Column Segregation Test

Placing

The following points can be made regarding the standard methods of placement.

• **Truck mixer chute –** revolving drum mixer can result in the further flowing distances and enhanced filling capacity and is effective in placing a wide range of fluidity levels.

• **Crane and bucket –** This application method is widely used and does not require a special concrete mix, but crane and bucket has limitations regarding the amount of concrete which can be applied in a certain period of time.

• **Pumping –** pumping truck is a common and modern method of concrete placement nowadays and can used any kinds of concrete mixes.Slump Flow Test

Figure #1. Truck Mixer Chute

Figure #2. Crane & Bucket

Figure #3. Concrete Pump

Consolidation

Self-compacting concrete (SCC) – is a concrete that without influence of additional consolidation energy, flows and completely fills the spaces between the reinforcement and the formwork only under the influence of its own mass.

Figure #1. Placing concrete using pump without any using mechanical vibration.

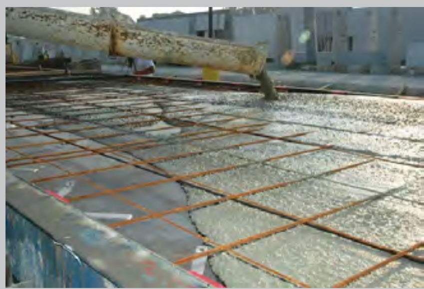


Figure #2. Placing concrete using truck chute which is concrete flowing freely on the slab.

Figure #3. Congested reinforcement concrete completely filling and achieving full compaction.

Figure #4. Reduced manpower needed for consolidating and placing concrete.

Curing

Curing is essential, and early protection of exposed surfaces is key to preventing rapid moisture loss that could lead to plastic shrinkage cracking. For SCC, the established guidelines for curing in ACI 308R should be followed.

Initial curing methods:

- Fogging
- Liquid-applied evaporation reducers

Final curing measures:

- Sprinkling the surface of the concrete
- Ponding or immersion
- Burlap, cotton mats, and other absorbent materials
- Sand curing
- Straw or hay
- Final curing methods based on moisture retention
- Plastic film
- Reinforced paper
- Liquid membrane-forming compounds
- Linseed oil-based curing compounds

Different curing methods photographs:

Figure #1. Covering wet burlaps & water sprinkling

Figure #2. Ponding or immersion & sand curing

Figure #3. Plastic film

Figure #4. Liquid applied evaporation reducers