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## MIX PROPORTION DESIGN AND ENGINEERING APPLICATION OF SELF-COMPACTING FIBER-REINFORCED CONCRETE

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*Self-compacting concrete (SCC) has been developed and deployed over the past four decades to enable vibration free placement in congested reinforcement while maintaining durability. Its superior filling ability and stability have led to broad adoption across building and infrastructure projects. Multiple mix design frameworks have emerged internationally, reflecting differing assumptions about paste demand, aggregate packing, and viscosity control. This study synthesizes the principles and procedures of five representative proportioning approaches for self compacting fiber reinforced concrete (SFRSCC), highlighting how fiber type and dosage interact with rheology and robustness. An engineering application using C60 steel fiber SCC for the China Central Television (CCTV) Headquarters project in Beijing is presented to illustrate screening of constituent materials, determination of minimum effective fiber content, and on site verification of fresh and mechanical performance. The findings provide operational guidance for mixture selection and implementation of SFRSCC in demanding placement conditions.*

**Keywords:** self-compacting concrete, steel fiber, mix design, fresh properties, robustness, engineering application.

## ПРОЕКТИРОВАНИЕ СОСТАВА И ПРАКТИЧЕСКОЕ ПРИМЕНЕНИЕ САМОУПЛОТНЯЮЩЕГОСЯ ФИБРОБЕТОНА

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*Самоуплотняющийся бетон (СУБ) разрабатывался и применялся в течение последних четырёх десятилетий для обеспечения безвибрационной укладки в плотно армированные бетонные конструкции с сохранением прочности. Его превосходная заполняющая способность и стабильность обеспечили широкое применение в строительных и инфраструктурных проектах. В мире появилось множество систем подбора состава смеси, отражающих различные предположения о потребности в пасте, упаковке заполнителей и контроле вязкости. В данном исследовании обобщены принципы и процедуры пяти типичных подходов к дозированию самоуплотняющегося фибробетона (SFRSCC), демонстрируя, как тип и дозировка фибры влияют на реологию и прочность бетона. Представлен пример инженерного применения стальной фибры С60 для проекта штаб-квартиры Центрального телевидения Китая в Пекине, иллюстрирующий отбор компонентов, определение минимального эффективного содержания фибры и проверку на месте характеристик бетона в свежем виде и механических свойств. Результаты исследования служат практическим руководством по выбору смеси и применению SFRSCC в сложных условиях укладки.*

**Ключевые слова:** самоуплотняющийся бетон, стальная фибра, состав смеси, свойства свежесделанного бетона, прочность бетона, инженерное применение.

## **Introduction**

Self compacting concrete is designed to flow under its own weight and to fill complex formwork and congested reinforcement without mechanical vibration, which allows uniform placement and reliable consolidation in locations where conventional compaction is difficult or impractical [1]. When fresh properties are properly proportioned the material achieves high filling ability, passing ability, and segregation resistance, and the hardened concrete exhibits dense microstructure with reduced surface defects in members that demand high finish quality.

The development of self compacting concrete has been guided by two complementary pillars for proportioning and control, namely mixture design anchored in particle packing and paste rheology, and verification through standardized fresh tests that together represent the required performance in production and placement [2]. Integrating mixture design with these tests has clarified how aggregate grading, powder type, and superplasticizer demand influence flow stability and resistance to blocking, which supports transferable procedures for scale up and field implementation.

Compared with ordinary concrete, typical self compacting mixtures use a higher volume of fine powders combined with a lower water to binder ratio, which improves cohesiveness but increases sensitivity to autogenous and drying shrinkage and modifies creep and stiffness development during early age and service [3]. Comparative experiments between self compacting and conventional concretes have quantified differences in elastic modulus, strength development, shrinkage, and creep under sealed and air cured conditions, which motivates explicit management of shrinkage risk during construction and early service life.

The incorporation of fibers into self compacting concrete aims to enhance tensile capacity, toughness, and crack control while preserving the self compactability required for congested reinforcement and complex geometries [4]. Experimental programs on steel fiber reinforced self compacting concrete have reported consistent gains in splitting tensile strength and flexural response, together with measurable reductions in slump flow and passing ability as fiber volume fraction, length, or aspect ratio increase, which highlights the need to coordinate fiber selection with paste viscosity and aggregate packing [5]. Methods for proportioning that explicitly account for the presence of fibers include strength anchored approaches that treat fiber influence through rheology control and skeleton based approaches that consider aggregate and fibers as a combined solid framework supplied with just sufficient paste to maintain flow and stability, and these methods have been validated at material and structural scale [6].

Against this background, systematic study of mix proportion design routes for self compacting fiber reinforced concrete is essential for reliable quality control from raw materials to construction and for achieving targeted fresh and mechanical performance in engineering applications [7]. Recent reviews and case based analyses summarize direct strength anchored routes, packing based routes, and hybrid procedures that embed robustness checks against reasonable variability in water content, moisture of aggregates, and admixture efficiency, which provides a practical basis for selecting project specific paths that meet both placement requirements and structural targets [8].

### **1. Performance and Working Principle of Self-Compacting Concrete**

#### **1.1 Performance of self compacting concrete**

Self compacting concrete must flow under its own weight to fill the entire formwork without external vibration, and this behavior is obtained when the mixture combines low yield stress with adequate plastic viscosity so that the material moves freely and remains stable.

The essential performance targets are fillability, passing ability, and stability, which are commonly verified by slump flow with flow time for spreading, the J ring test for passing through

reinforcement, and companion observations or indices for segregation and bleeding [9]. Fillability denotes the ability of the fresh concrete to occupy all geometric spaces uniformly, and successful verification indicates that the mixture can consolidate by self weight without trapping air or leaving surface defects [9]. Passing ability refers to the capability to flow through congested reinforcement or narrow gaps without blockage, which is achieved by coordinating aggregate maximum size and grading with paste rheology so that the granular skeleton is lubricated throughout the path of flow [10].

### 1.2 Composition and selection principles of raw materials

Self compacting concrete is proportioned with cement, aggregates, mineral additions, admixtures, fibers when required, and water, and each constituent is chosen so that fresh performance and long term durability can be obtained together [10].

The admixture system is centered on a compatible high range water reducer to secure dispersion and flow retention, and a viscosity modifying admixture may be used when greater resistance to segregation is needed during transport and placing [9].

When fibers are introduced to enhance cracking resistance and toughness, the mixture must preserve self compactability by coordinating fiber type, length, aspect ratio, and volume with paste volume and aggregate grading so that uniform dispersion is maintained without loss of passing ability.

## 2. Mix Proportion Design of Self-Compacting Concrete in Construction

### 2.1 Basic Principles of Mix Proportion Design

The mix proportion design of SCC should satisfy fresh-state performance while meeting mechanical and durability targets of the hardened material. Adequate deformability is established so that the concrete levels under its own weight and fills formwork without external vibration. Slump flow and related spread classes are selected according to member geometry and placement method, with typical target bands for ordinary horizontal placements and higher bands for congested reinforcement to secure filling and passing ability [11]. Segregation resistance is controlled through a coordinated selection of aggregate grading, binder composition, and paste rheology so that stability is preserved during flow and after placement [12]. Passing ability is managed by controlling maximum coarse aggregate size, aggregate shape, and the mortar fraction relative to the narrowest obstacle in the flow path, ensuring unimpeded motion through bar grids and constrictions [13]. In parallel, the designer balances the water-to-binder ratio, binder type and volume, and admixture system to achieve the specified compressive strength and serviceability criteria, using rheology-based checks on yield stress and plastic viscosity to keep the mixture inside a workable processing window [14]. When steel or hybrid fibers are used, the mixture must maintain sufficient flow, the aggregate and paste volumes must be tuned to avoid blocking, and the fiber factor and aspect ratio must be kept within limits that preserve self-compaction while delivering the intended crack control and toughness [15; 16]. For robustness against material variability and site conditions, mixture choices benefit from factorial or response-surface optimization to identify stable regions of performance, and from monitoring thixotropy to anticipate the time-dependent evolution of lateral pressure and finishability in the field [12; 17]. Finally, the effect of particle size distributions of cement and supplementary materials on paste rheology is considered during proportioning so that target yield stress and viscosity are achieved with minimal sensitivity to batch changes [18].

### 2.2 Common Mix Proportion Design Methods for Self-Compacting Concrete

Traditional proportioning approaches centered on water–cement ratio, sand ratio, and unit water content are adapted for SCC by explicitly linking aggregate packing, paste volume, and rheology to flow and stability indices. Simple mixture procedures begin by fixing aggregate volumes and then back-calculating paste content and superplasticizer demand to secure self-

compaction, with verification by slump flow,  $T_{500}$ , segregation index, and passing tests [11]. Statistical design frameworks extend this idea by using factorial or response-surface methods to map how binder composition, limestone or other fillers, and admixture dosages affect fresh and hardened properties, allowing the designer to select a robust optimum for a given application [12; 13]. Rheology-guided proportioning treats yield stress and plastic viscosity as primary design variables so that the same performance can be reproduced across materials and placements by targeting a bounded rheological domain before casting [14].

For SFRSCC, direct proportioning methods incorporate fibers within the granular skeleton and adjust paste content to maintain coating and dispersion, while respecting upper bounds on fiber volume and aspect ratio that preserve flow and passing ability [15]. Thixotropy assessment and mixture robustness checks help ensure that selected compositions remain insensitive to modest fluctuations in fines content, moisture condition, and placement rate, thereby keeping formwork pressures and surface quality within acceptable ranges [17]. Finally, control of particle size distributions of cement and fly ash is used to fine-tune paste viscosity and reduce sensitivity to dosage errors, which supports consistent fresh behavior without compromising strength development [18].

In summary, practical SFRSCC proportioning draws on five recurring ideas: empirical fixed-volume or absolute-volume calculations tied to flow tests, response-surface optimization of key constituents, rheology-based targeting of yield stress and viscosity, explicit packing of aggregates and fibers to secure stability and passing, and robustness checks that account for thixotropy and particle-scale effects. The comparative logic of these methods and their typical advantages are synthesized in Table 1 for direct use in design and verification [11–18].

Table 1. – Mix Proportion Design Methods of SCC

Mix Proportion Design Method	Principle	Advantages and Disadvantages
Fixed Sand–Aggregate Volume Method	Fix bulk volume of coarse aggregate and target sand fraction, then compute binder and water; steel fibers replace an equal volume of coarse aggregate	Simple and quick; relies on empirical volume ranges and requires experienced formulators; sensitivity to aggregate grading may reduce robustness
Absolute Volume Method	Use absolute volumes for all constituents with fibers counted explicitly in the solid skeleton	Clarifies volume balance and improves control of sand ratio; still depends on assumed limits for aggregate volumes and may need trial adjustment for flow
Reverse Filling (Packing) Method	Determine densest packing of fines and mortar, then add coarse aggregate and finally supply paste to fill residual voids	Produces dense hardened structure and good stability; requires multiple packing tests and may need extra paste to recover flow when fibers are present
Direct Mix Design Method	Keep the water to binder ratio for strength, introduce fibers through an influence coefficient, and adjust paste and admixture to reach self compacting targets	Straightforward link to strength and rheology; initial version may under account for fiber effects on compressive strength and passing ability
Full Calculation Method	Build a volume model for paste, mortar, and aggregate, then compute unit water and sand ratio from derived formulas	Transparent quantification and reduced binder content; may yield high coarse aggregate and low sand ratio that hinder flow and passing, especially with fibers

### 3. Engineering Application

#### 3.1 Project context and raw materials

The outer frame tube of the main building of the China Central Television Headquarters consists of ninety seven inclined steel columns tied by inter column steel bracing. The above ground portions of the primary load bearing columns were designed as steel reinforced concrete composite members using C60 steel fiber reinforced concrete, with a maximum height of about two hundred and thirty meters for the self compacting placement zone. The structural geometry, the oversized cross sections, the intricate internal steelwork, and the dense outer reinforcement made mechanical vibration impractical, so a self compacting mixture was adopted to secure filling, passing, and surface quality during placement [19].

The project used materials common to the Beijing supply chain. The binder system comprised Grade 42.5 ordinary Portland cement and Class I fly ash. The fine aggregate was a blend of washed natural medium sand from the Chaohe River and manufactured sand from Sanhe with a fineness modulus not less than 2.3. The coarse aggregate was machine crushed gravel from Sanhe with continuous gradation and nominal particle sizes of five to ten millimetres and five to twenty millimetres. The admixture system was a polycarboxylate based high range water reducer suitable for pumping. The design specified cold drawn cut steel fibers with tensile strength greater than one thousand megapascal, aspect ratio greater than fifty, length between thirty five and fifty millimetres, and a dosage window of twenty to fifty kilograms per cubic metre. Dramix steel fibers and Harex steel fibers were selected for laboratory screening, and both products met the mechanical and geometric requirements for use in self compacting mixtures where dispersion and passing ability are critical [19].

#### 3.2 Concept and determination of mix proportion design

##### 3.2.1 Mix proportion strategy

The mixture development followed a stepwise path that began with a benchmark self compacting concrete without fibers. The powder composition, sand blend, and admixture dosage were tuned so that the fresh indices satisfied the construction targets for spread, passing, and stability. On this benchmark the steel fibers were introduced at several dosages to measure tensile strength, flexural strength, and toughness, and the minimum dosage that met mechanical targets was identified. With this minimum dosage, the mixture was fine tuned to recover self compactability and then re tested to confirm that both fresh performance and mechanical indices were satisfied. The final candidate was subjected to on site pump trials to verify that the mixture preserved flow and stability under shear histories representative of full height pumping and that the placement met constructability requirements [20].

##### 3.2.2 Mix proportion selection and test results

The laboratory procedure and acceptance checks conformed to self compacting test practice using slump flow, V funnel, J ring, and U box so that filling ability, passing ability, and segregation resistance were verified before field trials. The resulting benchmark and fiber modified mixtures are summarized in Table 2, which reports binder contents, aggregate grading, fiber type and dosage, admixture dosage, and mechanical properties at twenty eight and sixty days. During screening it was observed that introducing steel fibers reduced slump and spread relative to the plain benchmark and that the reduction increased with fiber dosage, which is consistent with the added internal friction from the three dimensional fiber network and the increased specific surface that raises paste demand [19]. The same tests showed measurable gains in compressive strength and splitting tensile strength over the benchmark as fiber content increased, which aligns with published trends for steel fiber reinforced self compacting mixtures when dispersion is uniform and passing ability is preserved [19].

Table 2. – Concrete mix design and test results [20]

group	Concrete mix Proportion (kg/m <sup>3</sup> )							compression strength / MPa		split tensile strength / MPa		28d Elastic modulus / GPa
	cement	flyash	natural sand	Small stone / Large stone	water	steel fibre	additive	28d	60d	28d	60d	
A	380	150	840	350/500	170	0	7.4	70.7	78.2	4.74	5.24	4.29
B	380	150	840	350/500	170	Dramix/20	8.0	74.2	83.4	5.38	6.32	4.85
C	380	150	840	350/500	170	Dramix/25	8.0	74.3	83.3	6.05	6.78	4.93
D	380	150	840	350/500	170	Dramix/30	8.0	75.3	85.1	6.54	7.14	4.75
E	380	150	840	350/500	170	Harex/25	8.5	72.5	81.0	5.62	6.41	4.82
F	380	150	840	350/500	170	Harex/30	8.5	74.5	84.0	5.97	6.68	4.97
G	380	150	840	350/500	170	Harex/40	8.5	76.7	85.0	6.42	7.11	4.94

Considering cost control, pumpability, and construction throughput, the minimum fiber dosage of twenty kilograms per cubic metre was selected for production design. At this dosage the fresh robustness was improved by replacing half of the natural sand with manufactured sand to increase the fines content and to enhance the stability of the spread while keeping the water to binder ratio and the rheology within the target window for self compactability [20]. The final production mixture per cubic metre was cement 380, fly ash 150, natural sand 420, manufactured sand 420, five to ten millimetres gravel 350, five to twenty millimetres gravel 500, mixing water 170, steel fiber 20, and high range water reducer 8.5 by mass. The measured fresh indices were slump 265 millimetres, slump flow 720 millimetres, V funnel time 21 seconds, and U box filling height 350 millimetres. The measured mechanical properties were compressive strengths of 72.4 and 82.1 megapascal at twenty eight and sixty days, splitting tensile strengths of 5.34 and 6.38 megapascal at twenty eight and sixty days, a twenty eight day flexural toughness index of 5.21, and a twenty eight day static elastic modulus of 4.82 gigapascal. The on site pumping confirmed stable flow and uniform filling at height under the selected placement rate, which is consistent with rheology based proportioning approaches for self compacting concretes with fibers [21].

**Conclusion**

Self compacting concrete improves constructability and surface quality when proportioning targets a rheological window that allows flow under self weight while resisting segregation. For steel fiber reinforced self compacting concrete, mixture design must balance workability with mechanical performance so that the concrete passes through congested reinforcement and still meets tensile and toughness requirements. A practical path is to establish a benchmark self compacting mixture, identify the minimum steel fiber content that satisfies mechanical indices, and then tune paste volume, aggregate grading, and admixture dosage to recover self compactability. Project scale pumping and placement confirm that the optimized mixture maintains stability, achieves uniform filling at height, and delivers the specified strengths and toughness. This workflow provides a transferable framework for similar applications that require high placement reliability and verified structural performance.

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