TB-1500 — An Introduction to Self-Consolidating Concrete (SCC) Technical Bulletin

Self-Consolidating Concrete (SCC) is a rapidly developing research area with literally hundreds of published papers. This technical bulletin provides a "primer" on SCC. It is not an all-encompassing document but is an introduction to the subject providing general information. SCC technology has required the use of many terms new to the concrete industry. Please refer to the companion Technical Bulletin, TB-1501: "Definitions of Terms Relating to Self-Consolidating Concrete" for definitions and explanations of these terms.

What is SCC?

Self-Consolidating Concrete has properties that differ considerably from conventional slump concrete. SCC is highly workable concrete that can flow through densely reinforced and complex structural elements under its own weight and adequately fill all voids without segregation, excessive bleeding, excessive air migration (air-popping), or other separation of materials, and without the need for vibration or other mechanical consolidation.

What about highly flowing concrete? Is that SCC?

ASTM C1017 defines flowing concrete as "concrete that is characterized as having a slump greater than 190 mm (7½ in.) while maintaining a cohesive nature". Flowing concrete can be proportioned with an even higher slump to be self-leveling, which means that it is capable of attaining a level surface with little additional effort from the placer. According to ACI 212, these self-leveling characteristics "have given rise to a false belief that such concrete does not require vibration". ACI 212 stresses that, unlike SCC, to obtain a properly consolidated self-leveling concrete, "some compaction will always be required". Thus SCC is always "highly flowing", but "highly flowing" may not qualify as SCC. The same is true of "self-leveling" concrete.

What are the reasons for the sudden popularity of SCC in North America?

There are many situations in today's construction market that make SCC an interesting alternative to conventional slump concrete. In general, cost savings and/or performance enhancement tend to be the driving forces behind the added value of SCC. Contractors, producers and owners are under great pressure to produce better quality construction at lower costs of labor, materials and equipment. They are also faced with tougher environmental and safety regulations, and increased insurance costs. The economic benefits of a less intensive construction environment results in labor savings, time savings from higher productivity, and greater flexibility of design.

How is SCC different from conventional slump concrete?

SCC must be highly workable so that it can move under the force of gravity without vibration, during mixing, transportation, handling, and placement. It is so highly flowable that the conventional slump test cannot distinguish between different levels of SCC flowability – all would be 280 mm+ (11 in.+) in slump. However, SCC must also be viscous enough so that the mortar suspends and carries coarse aggregate, maintaining a homogenous, stable mixture, resistant to segregation, bleeding, excessive air migration, or paste separation. It must have dynamic stability during mixing, transportation, handling and placement, and static stability during protection and curing. SCC's workability is a function of its rheology. Conventional concrete brought to 280 mm+ (11 in.+) slump does not have this stability.

SCC offers some help in all of the following areas.

1. Reduced in-place cost

- Productivity Improvements – SCC can increase the speed of construction, improve formed surface finish and thus reduce repair and patching costs, reduce maintenance costs on equipment, and provide faster form and truck turn-round time.
- Reduced labor costs – SCC reduces labor demands and compensates for lack of skilled workers to perform the rigorous work required for quality concrete construction.

2. Improved work environment and safety

SCC eliminates the use of vibrators for concrete placement, thus minimizing vibration and noise exposures. It eliminates trip hazards caused by cords. It reduces fall hazards, as workers do not have to stand on forms to consolidate concrete.

3. Improved aesthetics

SCC provides unequaled formed surfaces.

How long has SCC been around and where did it originate?

In the early 1980s, Japan faced a lack of skilled workers who could construct durable concrete structures. Professor Hajime Okamura (University of Tokyo, now Kochi Institute of Technology) advocated the use of SCC as a solution to this problem. SCC technology in Japan was based on using conventional superplasticizers to create highly fluid concrete, while also using viscosity-modifying agents (VMA) which increase plastic viscosity thus preventing segregation up to a level of fluidity that would normally cause segregation.

When the technology reached Europe in the 1990s, their approach was to add powders (cement, supplementary cementitious materials, and inert materials such as limestone, dolomite and granite dust) passing the 150 µm (No. 100) sieve to increase plastic viscosity. The advent of polycarboxylate superplasticizers and further development in optimizing aggregates improved SCC quality and reduced material cost, often without the use of a VMA.

How does an understanding of SCC's rheological properties help in the field?

In practice, SCC's rheological properties are manifested in three ways:

1. Filling ability: SCC must flow into forms and around obstacles such as reinforcing steel under only the force of gravity. This does not mean that all SCC is self-leveling, however.
2. Passing ability (resistance to blocking): SCC must pass through various obstacles and fill open spaces in the formwork without blockage due to aggregates being restricted from passing through narrow openings. Typical aggregate size to opening size relationships are at least 1:2, such that, for example, a 6.4 mm (1⁄4 in.) maximum nominal size aggregate would require a 12.5 mm (1⁄2 in.) or larger opening.
3. Stability (segregation resistance): SCC must have dynamic stability by remaining homogenous throughout mixing, transportation, placing, and have static stability during finishing and curing.

What are the economic considerations for SCC?

The cost/benefit analysis of SCC balances the increased cost of the concrete against substantial labor savings and asthetic benefits. The benefits of SCC are apparent at many levels of the construction process, from production, to placement, to quality of the finished product. Modification of production and construction practices may be required to show the full impact of product benefits. Due to generally higher strengths resulting from the high powder content needed for SCC, the economic benefit has been most obvious where high strengths were already needed for design reasons. Thus the greatest current application for SCC is in precast/prestressed concrete production. This is also true because the increased material cost and labor savings all appear on the same balance sheet, so the connection between SCC performance and cost savings is easier to make. As more experience is gained in the field with the cost benefits of ready-mix SCC, this application is expected to grow.

When should Ready-Mix SCC be considered for a construction project?

While many projects can be converted to SCC mixes during the construction phase, it is best to consider its use as early as possible. SCC construction requires teamwork. The owner and designer, the contractor, formwork supplier, and finisher, the producer and material suppliers must all work together to produce a quality SCC project that realizes the economic benefits for all concerned.

What are the limitations of SCC?

Application

Caution should be taken when using SCC in flatwork as it has limited bleeding characteristics and may be subject to plastic shrinkage cracking if not properly protected and cured. Higher powder contents bleed less than conventional concrete and can also lead to plastic shrinkage cracking if not properly cured.

Production and Quality Control

SCC requires a higher level of quality control than conventional slump concrete. Combined aggregate grading, tightly controlled mix water, controlled cement source, and the use of advanced admixtures require a greater awareness on the part of all production personnel. Processes must be put in place to compensate for normal variation of materials. Key items to monitor are:

- Coarse and fine aggregate grading
- Coarse aggregate void volume
- Aggregate moistures

In North America, SCC is being produced using all of these approaches. In addition, some large silica fume composite design concrete projects in the late 1980's utilized SCC concrete prior to the name being applied.

What is Rheology?

Rheology is the science of the deformation and flow of materials. It is a complex discipline used to understand the workability characteristics of SCC. Special test devices called RHEOMETERS are used in the laboratory to research the workability properties of SCC. The two most important properties of SCC's rheology are:

- Yield stress–the measure of the amount of energy required to make SCC flow. To be considered SCC, concrete must flow easily under its own weight, so its yield stress must be very low.
- Plastic viscosity–the measure of the resistance of SCC to flow due to internal friction. SCC must have a high viscosity in order to suspend aggregate particles in a homogenous manner within the concrete matrix without segregation, excessive bleeding, excessive air migration, or paste separation.

In summary, SCC must have low-yield stress and high viscosity.

Conventional Mix

SCC Mix

What are some important parameters for a successful SCC mix?

The flowability of a concrete mix is a complex interaction of the interparticle friction in the aggregate phase, and the fluidity of the paste phase. The water-to-powder ratio and admixtures control the fluidity of the paste phase. If the aggregate particles have too much friction due to poor grading or shape, the paste will have to be very fluid to compensate and achieve the desired concrete flowability. If the paste is too fluid, segregation will result. Thus, the general approach is to select the best grading and shaped aggregate economically possible, to use high-paste contents to increase space between the aggregate particles, finally controlling the rheology of the mix by adjusting the water-to-powder ratio and using appropriate admixtures.

Although the definition of SCC varies with the particular application, these are some general parameters of mixes that our experience shows are required to produce trial mixes for quality SCC:

- **Coarse aggregate content** – For normal-density aggregates this typically results in a specific volume that is 28%–32% of the concrete volume, with the balance (68–72%) being mortar.
- **Paste fraction** – Approximately 35%–37% of the mix. For rounded well-graded fine aggregate this will be lower, for poor grades or manufactured fine aggregate this will be higher.
- **Powder** (cement, supplementary cementitious materials and inert powder materials with particle sizes passing the 150 mm (No. 100) sieve) – Powder contents will generally be in the 385–475kg/m^3 (650–800 lbs/yd^3) range.
- **Fine aggregate** – Some people track fine aggregate to total aggregate ratio – which usually turns out to be approximately 45%–55%, with 50% being typical. (Fine aggregate is that which passes the #8 sieve.).
- **Water content** – For first mix, as needed to get 25–75 mm (1–3 in.) slump in concrete without SCC admixtures. This would include water-reducing admixture or retarders for set control.
- **W/C ratio** – As needed for durability. Generally, powder content requirements for SCC properties will mean that W/C is low enough, and resultant strength high enough for most applications; however this must be confirmed.
- **Air** – Air content should be as needed for durability. Air can improve the viscosity of a mix and increase the paste volume, but may adversely affect paste density. There are many industry organizations at work developing specifications, test methods, and practices for SCC. As new information becomes available, this document will be updated accordingly.

Last Updated: 2023-06-28
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