Self-Consolidating Concrete

The Good, the Bad, and the Ugly

By Matthew D. D'Ambrosia and David A. Lange, Ph.D.

The Good: Self-Consolidating Concrete (SCC) is a new class of material designed to consolidate under its own weight, filling formwork without mechanical vibration. The use of SCC in the United States has grown substantially in the last several years. Engineers and practitioners are drawn to the benefits of SCC including high flowability, rapid placement, improved aesthetics, reduced labor cost, and enhanced durability due to better consolidation.

The Bad: When specifying this new class of materials, engineers must also be aware of the possible shortfalls of SCC, and have the proper training to recognize problems as they arise in the field. SCC is highly fluid and must be sufficiently cohesive to prevent segregation. With careful selection of mixture proportions and/or the use of viscosity modifying admixtures (VMA), it is possible to produce stable SCC. What happens when unstable SCC is delivered to a project? A test technique for segregation detection has been proposed that allows rapid identification of problems the field.

The Ugly: Mechanical properties are influenced by SCC strategies, such as increasing paste content and lowering *w/cm* ratio. Investigations of early age mechanical performance, including shrinkage and tensile creep, indicate that SCC mixture proportions may actually have a negative impact on durability. As with ordinary concrete, SCC can be produced with a wide range of volume stability and mechanical properties, and proportioning is the key.

What is SCC?

Self-consolidating concrete (SCC), also referred to as self-compacting concrete in Europe and Japan, has gained popularity quickly in North America over the past five years. SCC is a high-performance material designed to flow into formwork under its own weight and without the aid of mechanical vibration. It originated in Japan in the late 1980s to reduce labor costs associated with placing concrete and to improve overall quality and durability of construction. Research and development of SCC is widespread, but the goal of uniformity and acceptance for practice has not yet been fully realized.

SCC has many advantages over ordinary portland cement concrete (OPC). The high flowability of SCC facilitates rapid placement, reduces labor costs by eliminating the need for vibration, allows for filling of complex formwork shapes and tight reinforcement configurations, and reduces the need for surface repair work by eliminating voids and honeycombing. Other benefits include an improved aesthetic appearance of surfaces and reduced construction noise from the lack of vibrating equipment. Flowable properties are achieved largely through changing the mixture proportions and by using one or more specialized admixtures. The newest generation of superplasticizing admixtures, called polycarboxylates or "comb" polymers, allow the use of higher dosage rates without the negative affects of set retardation or bleeding that sometimes occurred with previous superplasticizer formulations. A viscosity-modifying admixture (VMA) can also be added to enhance resistance to segregation or reduce bleeding.

SCC proportioning strategies vary, but in most instances involve an increase in cementitious materials, possibly with mineral admixtures such as fly ash, ground granulated blast furnace slag, or silica fume, and careful selection of aggregate volume and gradation. *Figure 1* shows the fine aggregate to coarse aggregate ratio (FA/CA) and aggregate content (%) for SCC mixtures compiled from the literature to illustrate the common differences between SCC and OPC. A shaded oval on the figure represents normal concrete according to the ACI 211.1 mixture proportioning method. The average water to cementitious material ratio (*w/cm*) in the SCC database was 0.41, which is relatively low compared to normal concrete. The total aggregate content was lower for SCC than for typical concrete. Low aggregate volume and smaller coarse aggregate size are often needed to improve flow through steel reinforcement. There is also a tendency for a higher proportion of sand in the mixture, which is important for cohesiveness, uniformity, and segregation resistance. The hardened properties of SCC may be significantly influenced by the cementitious materials content, which affects strength gain, elastic modulus, creep, and shrinkage (autogenous and drying). Although the chemical admixtures are not expected to change hardened properties, segregation that occurs in the fresh state can lead to a poorly consolidated or inhomogeneous material that will have diminished strength and durability.

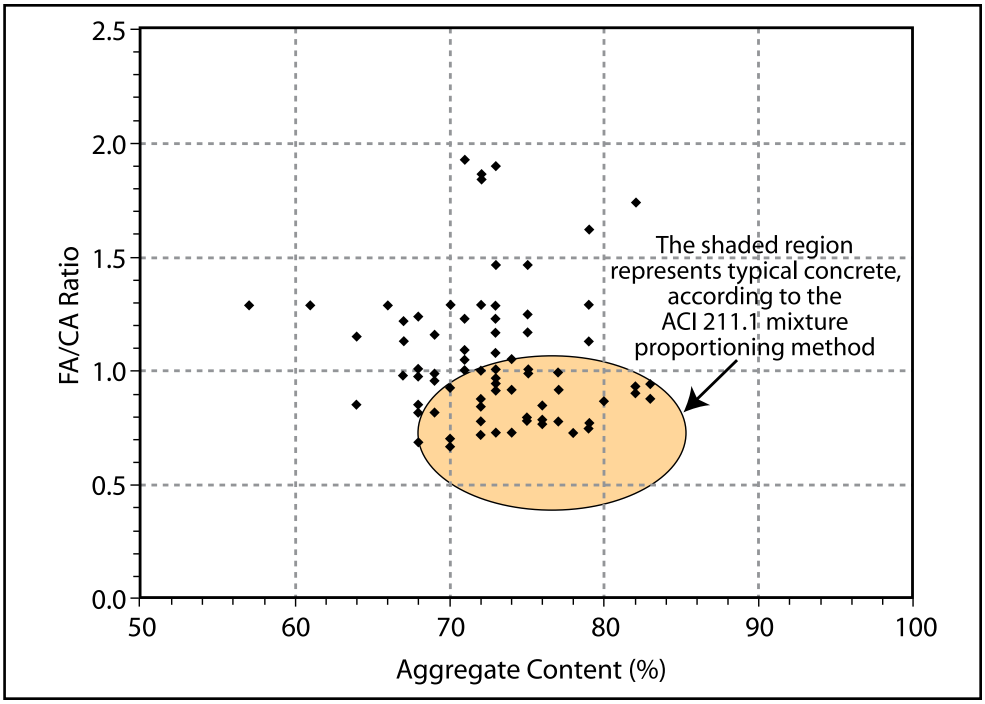

Figure 1: A database of SCC mixtures compiled from literature illustrates differences in proportioning when compared to ordinary concrete

Figure 2: The slump flow test (ASTM C1611) demonstrates the high flowability of SCC

The Good: Flow Characteristics

The fluid behavior of SCC has been studied extensively, and several standard tests have been developed to quantify the ability of SCC to fill formwork effectively. The slump flow test (ASTM C1611) (*Figure 2*) is simple to perform and uses the same apparatus as the common slump test. The slump flow test is the most common method of checking quality in the field. The test can be performed either upright, as in the normal slump test, or inverted, which allows the weight of the concrete to hold the cone in place. The final diameter of the concrete, usually designed to fall within 24 to 28 inches, is measured instead of the change in height. The rate of the concrete flow can also be measured by recording the time (T50) it takes to reach a diameter of 50 cm (20 inches). A longer T50 time is an indication of higher concrete viscosity. Other tests, such as the L-box, indicate the passing ability of SCC. Using the various test methods available, a designer can have reasonable confidence that a particular SCC mixture will fill formwork completely.

The Bad: Segregation

Segregation of coarse aggregate from the cement paste in concrete can be a problem for some SCC mixtures. A visual inspection of the slump flow test, with a rating system based on the presence of a cement paste "halo" around the concrete or a pile of aggregate in the center, helps detect segregation in SCC. However, a rating system based on visual inspection is highly subjective, and the test may not be sensitive enough to detect segregation in all SCC mixtures. The column segregation test (ASTM C1610) was developed to characterize segregation in the laboratory. The apparatus (*Figure 3*) is filled with concrete, allowed to sit undisturbed for 15 minutes, and then separated into sections vertically. The aggregate distribution is measured by washing the concrete over a No. 4 sieve and measuring the weight of aggregate in each section. A non-segregating concrete will have a uniform distribution from top to bottom. Although the column segregation test is sufficient to measure segregation in the laboratory, it takes too much time to be an adequate field test. The ideal test method must also be fast and repeatable in order to be useful for field quality control.

With this in mind, a new test method has been developed, called the segregation probe, which gives a direct measurement of concrete segregation in the fresh state. The apparatus consists of a thin wire (*Figure 4*) which is placed on the surface of a fresh sample of SCC. The probe is allowed to settle for two minutes, and then depth of penetration is recorded. This simple test can be performed rapidly and has been directly correlated to segregation by examining hardened concrete cylinders. The hardened cylinder shown in *Figure 5* was sawn in half, allowing for aggregate content to be measured quantitatively using image analysis. Having a direct, accurate measurement of segregation in the field provides a means of quality control that will help engineers develop confidence in SCC performance.

Rapid segregation detection is also useful for the evaluation of SCC robustness with respect to segregation (stability) in the laboratory. Robustness is the ability of SCC to resist changes in fresh properties due to slight fluctuations in water or admixture dosage. Some SCC mixtures, due to their high flowability, may be more susceptible to stability problems than normal concrete. By performing a series of laboratory measurements of segregation while slightly changing the water content or admixture dosage, a robustness profile can be created for a specific SCC mixture. If more robustness is desired, the mixture proportions or aggregate gradation can be adjusted to enhance stability, and the tests can be repeated until satisfactory results are obtained.

The Ugly: Early Age Cracking

The impact of SCC strategies on hardened properties must be determined to design effectively with this new material and to assess long-term durability. Properties that may be affected include strength, shrinkage, and creep. It was shown by examination of the database in *Figure 1* that SCC, on an average basis, tends to have lower *w/cm* and higher cement paste content than normal concrete. Strength is a function of *w/cm*, and therefore it can be expected that SCC will, on average, develop greater strength. However, it is important to note that the relationship between *w/cm* and strength generally still holds, and SCC can be produced with a wide variation in strength, just like normal concrete.

Shrinkage and creep are time-dependent deformations in concrete caused by internal or external applied stress. The phenomenon of shrinkage can be subdivided into external drying shrinkage and internal drying (autogenous) shrinkage. In either case, the cause for deformation lies in the viscoelastic response of the hardened cement paste phase of concrete, and therefore both shrinkage and creep are a function of the cement paste content. Aggregate acts to restrain deformation, so as the paste content increases, the amount of deformation due to shrinkage and creep will increase. This is especially important for the design of prestressed concrete structural members, which will undergo some loss of the prestressing force that is dependent on the amount of creep and shrinkage deformation that occurs.

If the *w/cm* is too low in SCC, autogenous shrinkage will cause a significant amount of early age deformation. If that deformation is restrained, significant stress can build up and create a high risk for early age cracking. Early age cracking significantly reduces long-term durability by allowing rapid ingress of water, chloride ions, and other substances that will promote corrosion of reinforcement. One way to prevent early age cracking is to put a lower limit on the *w/cm* to avoid excessive autogenous shrinkage. If this limit is set in the 0.38 to 0.42 range, one can be reasonably sure that autogenous shrinkage will not cause cracking. It can also be written into the specifications that the paste content cannot exceed a predetermined amount. An upper limit on paste content in the range of 30-34% by volume will help keep both shrinkage and creep deformation at reasonable levels.

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Figure 3: The column segregation test (ASTM C1610) can be used for detecting static segregation in SCC

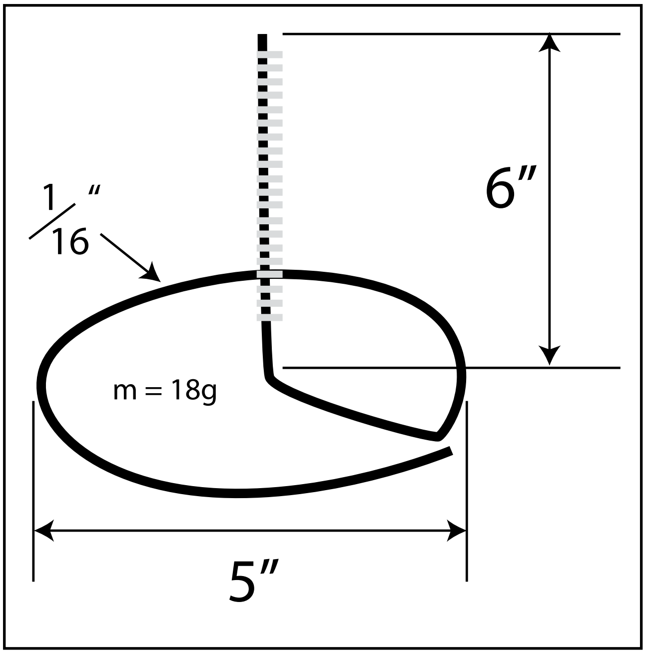

Figure 4: The segregation probe can be used for rapid detection of

Summary

SCC offers many advantages over OPC such as high flowability, rapid placement, improved aesthetics, reduced labor cost, and enhanced durability due to better consolidation. SCC is quickly gaining favor for many types of applications and has been touted by many as the concrete of the future. It is important that as we step into uncharted territory for material performance that the mechanical properties are not overlooked.

Segregation problems in SCC can be avoided with proper testing in the lab and field. A test method has been proposed that makes rapid measurement of static segregation easier in the field and can be used in the lab to examine the robustness of different SCC mixtures. Better measurements will lead to better materials in the lab and in the field.

The mechanical properties of SCC are influenced by increasing the paste content and lowering *w/cm*. With careful proportioning, SCC can be produced with a variety of mechanical properties just like ordinary concrete. Autogenous shrinkage is a major driving mechanism for early age cracking, so limitations on the *w/cm* and paste content may be necessary to avoid cracking and ensure acceptable long-term performance.▪

Figure 5: Concrete cylinder sawn longitudinally for analysis of segregation using quantitative image analysis

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