Getting it Right: Successful SCC Production Practices

by C.R. Cornman, H. Koyata, and A.A. Jeknavorian

Synopsis: The challenge in producing successful self-consolidating concrete (SCC) is based on consistently achieving high flow *and* high stability. The foundation of high quality SCC production is the suitability of the underlying materials and a mixture design that is optimized for those materials and the application. Not all applications require relatively high slump flows in the range of 28-30 inches (700-750mm), where control measures need to be especially well managed. Furthermore, even the best mixture designs can have stability limitations. To assure that SCC applications proceed with minimal difficulties, the concrete producer must anticipate variations in materials and production operations through effective quality control procedures. Changes in cement reactivity, aggregate properties (gradation, shape, and water demand), free moisture, and extra sources of moisture that may be present, for instance, in the truck, and the mixing process need to be carefully monitored. This paper will discuss specific examples that demonstrate best practices in mixture design, QA/QC, and production techniques.

Keywords: admixtures; gradations; mixture proportioning; quality control; rheology; troubleshooting

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Introduction

Self-Consolidating Concrete (SCC) has gained much attention in recent years because the "in place" cost of SCC can be dramatically lower than that of conventionally vibrated concrete. The economic benefits of SCC arise for the most part from the decreased labor associated with placing and finishing the concrete, quicker placement time, and improved form finish requiring fewer repairs. The ACI Committee on SCC, ACI 237, is currently developing a document and defines SCC as follows:

> *"Self-consolidating concrete (SCC) is highly flowable, yet stable concrete that can spread readily into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation and without undergoing any significant separation of material constituents."*

Due to these performance attributes, SCC has been called *high performance concrete in the plastic state*. As with most *high performance* materials, the quality of SCC is sensitive to the materials and methods of production. Inconsistent quality can lead to inadequate performance, returned trucks, and slow acceptance of this valuable technology. However, by following some simple guidelines, the success rate for SCC production can be very high. Described herein are practices that have proven successful in the commercial production of Self-Consolidating Concrete.

Rheology and SCC

Rheology, the science of the deformation and flow of materials, is important to understanding the performance of SCC. The rheology of SCC is more sensitive than conventional concrete to variability in materials and poor production practices. Figure 1 illustrates how SCC is generally characterized by a lower yield stress and higher plastic viscosity than conventionally vibrated concrete. Since conventional concrete will be consolidated by vibration, the "rheological window" within which the concrete can be successfully placed is relatively large -- if conventional concrete is too stiff for a particular placement, increased vibration can be used for consolidation. However, since vibration is not required as per the definition of SCC, the designed performance window for self-consolidation is confined to a narrower range bordering on segregation at one extreme to inadequate flow at the other end of the rheology spectrum. In the laboratory, rheometers can be used to characterize the rheological properties of SCC. However, field measurements such as slump flow and T20 can also provide insight into the "flow and deformation" of the concrete, and are considered far more practical control measurements for concrete producers (Figure 1, right). Higher flow is generally associated with a lower yield stress and lower viscosity. For any specific set of materials, a shorter T20 generally corresponds to a lower plastic viscosity.

To stay within the rheology window of SCC, good material control and production practices must be followed. As with any production operation, control of the variability in materials and production processes is critical. Pre-job trials to qualify the SCC mixture design, coupled with a quality control program to assure consistent quality of materials, batching operations, and mixing and handling processes will dramatically improve the production, transport, placement, and service life of SCC.

SCC Mixture Proportioning

The details of effective mixture proportioning for SCC is discussed in a separate paper in this symposium. Most importantly, to avoid problems of poor quality SCC, mixture designs should be based on *"performance", not "prescription"* concrete. SCC must be designed for specific applications taking into account the required engineering performance, the element characteristics, the placement techniques, and the materials and production process to be used. In general, SCC mixture proportions have a higher paste and mortar content, lower maximum aggregate size, and a higher sand/total aggregate ratio than conventional concrete. A smooth total aggregate gradation curve without gaps generally contributes to SCC mixtures having more consistent and acceptable flow behavior, passing ability, and stability. An appropriate aggregate gradation is most easily achieved by blending two sizes of coarse aggregate with one fine aggregate. Natural, rounded aggregate is preferable to crushed, angular aggregate, and aggregates with a low aspect ratio are preferable to ones with a high aspect ratio. Coarse aggregates should be blended to minimize void volume, *i.e.* maximize dry-rodded unit weight. While higher quality aggregates contribute to SCC with more uniform slump-flow, passing ability, and stability, a wide range of materials and gradations have been successfully used by concrete producers. Figure 2 illustrates a range of aggregate gradations that have been used for commercial SCC production in the Precast/Prestressed (PC/PS) concrete industry. The aggregate gradations used in the North American concrete industry tend to have a slight gap in the region of the Nos. 8, 16, and 30 sieves. Additionally, significant deviations from the average gradation indicate that many different aggregate combinations can be used to produce SCC.

Admixtures for SCC

Polycarboxylate ether-based high range water reducing admixtures (PCE superplasticizers) are most commonly used to achieve the highly fluid properties of SCC. Naphthalene or melamine-based superplasticizers are still used in some cases; however, the "tunability" of the PCE polymer structure, especially with regard to concrete viscosity and fluidity retention, has led to their dominance in the market. Figure 3 provides a general depiction of the PCE chemical structure and the so-called "comb" polymer architecture wherein the comb backbone adsorbs on to the cement surface and the comb teeth extend into the pore water between cement particles. Teeth length (Z), teeth density (Y/X+Y), and backbone length (X+Y) are three of the many parameters that can influence performance.

Figure 4 provides data showing the impact of PCE structure on the rheology of SCC. The superplasticizer PCE B was designed to impart increased viscosity to the SCC mixture, and thereby higher stability. Relative to PCE A, superplasticizer PCE B has longer teeth, higher teeth density and longer backbone length. With these differences in comb polymer structure, for any slump flow (or admixture dose) the mixes made with PCE B had a higher viscosity. The mixtures with 20" (500mm) flows have poor passing ability and would probably would not be *self consolidating*. The mix with 27" (635 mm) flow was near segregation.

Hydraulic cement-based materials such as SCC have inherently a limited time for placeability – once water and cement are mixed, the concrete remains in a highly fluid state until the hydration process causes sufficient microstructure to contribute yield stress to the mortar fraction. This limitation is especially important for cast-in-place applications of SCC. Again, the PCE structure can have a dramatic impact. Figure 5 shows the percentage decrease in slump flow over time for three different PCE-based dispersants. While PCE 3 may be suitable for PC/PS concrete production with relatively short transportation times, PCE 1 is much more suitable for a cast-in-place application especially in the case of long transportation time. Given the sensitivity of SCC to materials and processes, mix adjustments (such as retempering) at the job site should be avoided if at all possible.

Viscosity modifying admixtures (VMAs) can be used to improve the segregation resistance of an SCC mixture, and in some instances, provide the added robustness needed for trouble free production. However, in many cases, the mixture design itself – with relatively high powder content, low water-to-cementitious ratio, and/or relatively high paste and mortar fraction – can provide adequate segregation resistance. The function of VMAs is furthered discussed in a separate paper in this symposium.

Materials QA/QC and Batching

All materials and processes used to make concrete have inherent variability that can significantly impact the plastic and hardened performance of the concrete mixtures, which is far more prevalent for SCC versus conventional concrete mixtures. Thus, to produce consistently good quality SCC, one should minimize variability where possible by measuring and tracking key material properties (e.g. gradation), understanding the tolerable limits of variation prior to a performance failure, and be able to proactively adjust for changes where variability is unavoidable (*e.g.* aggregate moisture level).

The single most important concern with SCC is segregation resistance. The ability to control moisture content dramatically influences SCC segregation resistance. Moisture management includes the water added to a batch, variations in sand moisture, the inadvertent water from a previous load of concrete, and fluctuation in the water demand of the concrete materials. An example of the impact of even "a little" water can be enlightening:

> In general, the addition of one gallon of water per cubic yard of concrete can increase the slump flow of SCC by 2-3" (50-75mm). If one considers a mix design with 1500 lbs/yd (890 kg/m^3) of sand, 1% sand moisture represents nearly two gallons of water with the potential to increase slump-flow by 4-6" (100-160mm). Thus, if a moisture meter is accurate to +/- 0.5% (which is quite optimal), then the slump flow could vary by as much as 4-6" (100-160mm) from batch-to-batch. If an SCC mixture is designed for a high flow of 28", then the batch-to-batch variability can lead to slump flows from 25-31" (635-787mm). While the 25" (635mm) batch may have satisfactory stability (not segregating), it is likely that the SCC with a 31" (787mm) flow will be dangerously close to segregation.

Several simple practices can dramatically improve the quality of SCC production:

- Establish *and follow* a Standard Operating Procedure (SOP) that defines the steps taken to minimize, or adjust for, variability. Train everyone that comes in contact with the SCC what good and bad SCC looks like along with cause and effect parameters.
- Control charts should be maintained to confirm the consistency of materials and processes.
- Ensure that all water is backed out of the transport vehicle.
- Use moisture meters and adjust every batch for changes in aggregate moisture. Pay strict attention to the calibration and maintenance of the meters.
- Understand any changes in the water demand of your materials. When qualifying an SCC mixture design, the water demand of the materials should be ascertained (i.e. the water required to produce a 1" (25mm) concrete).
- Remember that aggregate water demand can change even if gradation appears constant. Additional tests such as void volume, slump measurement, and clay content by methylene blue, can be used to further detect reasons for changed water demand.

- If the concrete is produced with a central mixer, use an accurate amp meter to monitor the moisture content. Identify a target reading for the SCC mixture being made and hold back a little water that can be used to trim the mix.
- SCC may require a slightly longer mixing cycle than conventional concrete. Flow and viscosity may develop at different rates, and this can be materials dependent. Dose high range water-reducing admixtures (and viscosity modifying admixtures) by mix-water or delayed addition according to the supplier's guidelines.
- Polycarboxylate-based superplasticizers especially designed for SCC production should be used per the admixture company recommendations to assure maximum batch-to-batch performance with respect to flow, passing ability, and mixture stability.
- Establish a process for troubleshooting SCC that is based on your knowledge of the materials and process variability of your production operation.

SUMMARY

SCC is high performance concrete in the plastic state. Mixture proportioning and chemical admixtures work in combination to achieve the defining properties of SCC, namely high fluidity, excellent passing ability, and segregation resistance (stability). SCC is performance, not prescription concrete and must be designed with the application in mind. If high fluidity is not needed for the application, a lower fluidity SCC can minimize risks associated with segregation resistance. Adjusting the mixture proportions or using appropriate admixtures (*i.e.* superplasticizers or viscosity modifying agents that increase concrete viscosity) can also decrease the risk of segregation, even with highly fluid mixes. As with all high performance materials, the quality of SCC is sensitive to the inherent variability in materials and production processes. SCC is more sensitive than conventional concrete, and the successful producer will implement processes to minimize variability (*i.e.* SOPs, sufficient training, engineering controls for materials, processes for troubleshooting). Moisture management during material inventory, batching, mixing operations, transport, and placement is critical to assure consistently high quality SCC.

References

(1) Proceedings of the First North American Conference on the Design and Use of Self-Consolidating Concrete, Chicago, USA, 2002.

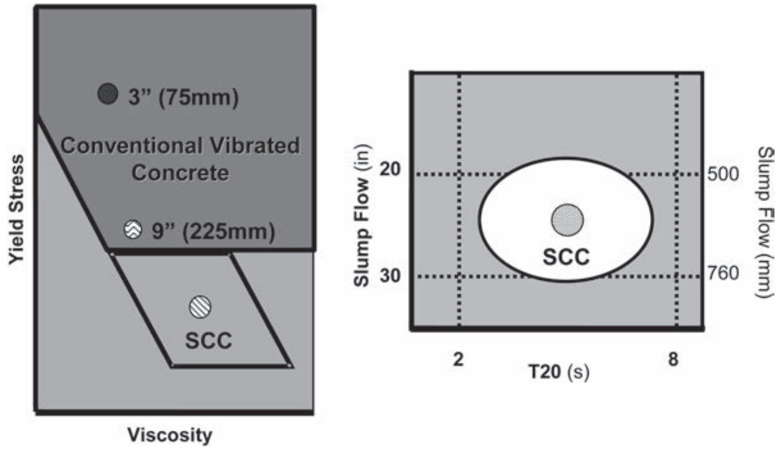

Figure 1. Rheology of SCC using a concrete rheometer (left; yield stress vs. plastic viscocity) or a Slump Cone (right; Slump Flow vs. T20)

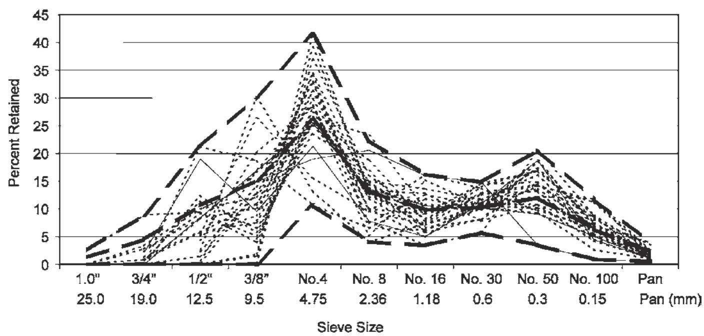

Figure 2. Gradations used in the PC/PS industry (2002 Grace Analysis). Dashed lines represent the upper and lower extremes and the average for each sieve size.

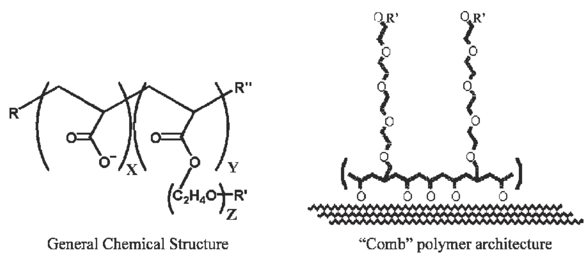

Figure 3. Chemical structure and architecture of PCE superplasticizers.

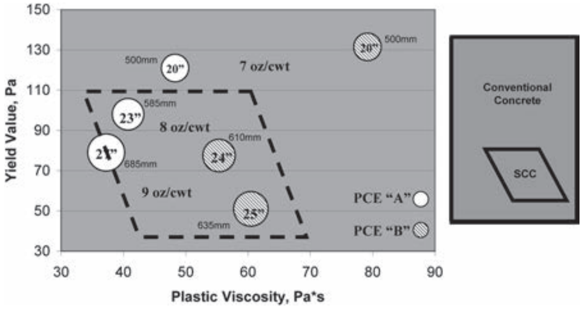

Figure 4. Impact of PCE structure on rheology of SCC. Mixture proportions are identical (750 lb/yd³ (445 kg/m³) cement; *w*/*c* = 0.39) except for the type of comb polymer (superplasticizer PCE A vs. PCE B). The dashed trapeziod represents the region of acceptable SCC.

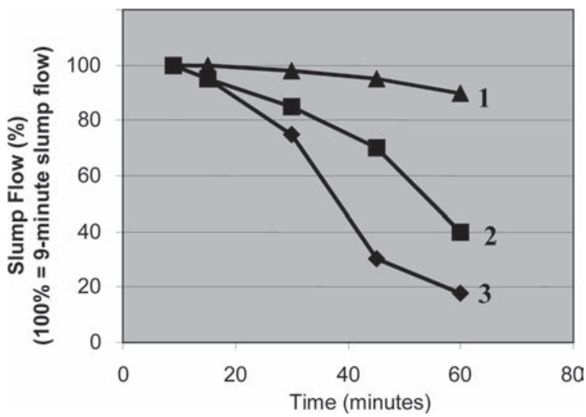

Figure 5. Representation of percentage slump flow decrease over time for different PCE-based dispersants.

The Influence of Viscosity-Modifying Admixture (VMA) on the Performance of Self-Consolidating Concrete (SCC)

by B.J. Christensen and F.S. Ong

Synopsis: The stability of highly fluid self-consolidating concrete (SCC) can be achieved by using a viscosity-modifying admixture (VMA). Currently, there are several types of VMAs available in the market place. Three of the most common ones are based on cellulose-ethers, biopolymers and synthetic polymers. The properties of these three types of VMAs were studied and compared. Specifically, the influence of these three types of VMAs on the properties of self-consolidating concrete (SCC was studied. Particular attention was placed on the influence of each VMA on the following characteristics of the SCC: 1) dose response of high range water reducer (HRWR), 2) dose response of air entraining agent (AEA), 3) stability of the mixture, 4) effects on time of setting and 5 compressive strength development.

Keywords: air-entraining admixture (AEA); bleeding; compressive strength; high-range water reducer (HRWR); segregation index; self-consolidating concrete (SCC); time of setting; viscosity-modifying admixture (VMA); visual stability index

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1. INTRODUCTION

The application of self-consolidating concrete (SCC) technology has been steadily growing since 1998 (1, 2). The unique properties of SCC in its fresh state are high fluidity and consolidation under self-weight, segregation resistance and non-blocking characteristics when the concrete flows through gaps between reinforcement. Segregation of SCC can be controlled by the careful selection and proportioning of materials, as well as use of a viscosity modifying admixture (VMA) (3). VMAs are typically high molecular weight soluble polymers that change the viscosity of cementitious mixtures by their interaction with the water phase or particle surfaces. These compounds have been used previously to decrease segregation and/or bleeding in cement pastes or mortar (4). Since similar characteristics are desired in highly fluid concretes, such as SCC, they are now finding additional applications.

VMAs are based on a number of different chemistries (5-12). One class is the natural polymers. These include such materials as polysaccharide gums (welan, xanthan, etc.). Welan gum was one of the first biopolymers used as a VMA in SCC applications (13). The effect of welan gum on the hardened concrete properties was further studied (14), and it was concluded that SCC containing welan gum and an air content of 4% could exhibit adequate resistance to freezing and thawing cycles. Recently another biopolymer called diutan gum (3) was introduced. Welan gum