

## Mixture Proportioning Self-Consolidating Concrete (SCC)

Self-Consolidating Concrete is a highly flowable, non-segregating concrete that can flow into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation. Congested reinforcement and good control of batching and placement make this an ideal concrete for precast applications. For cast-in-place applications, this technology poses more of a challenge because SCC is a tightly controlled mix with few options for adjustment on the job site. Still, many believe that SCC is the way of the future.

Segregation resistance, filling ability and passing ability characterize the plastic attributes of SCC. Achieving the proper balance of all three attributes creates an interesting mixture proportioning challenge.

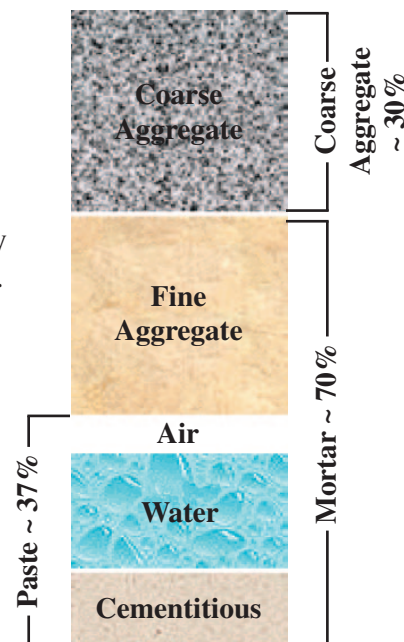
The three primary components of SCC include a properly proportioned mixture designed for the application, an appropriate high-range water reducer (HRWR), and sometimes a viscosity-modifying admixture (VMA). These components can be varied to achieve a wide range of results.

General experience has shown that SCC is more sensitive to any departure from the target recipe and mixing technique than conventional concrete. This means that the allowable deviations in weighing and dispensing are smaller, the allowable variations in concrete constituents (e.g. variations in aggregate shape and grading curves, moisture content, cement composition) are smaller, and batching sequence and mixing times should be followed more closely. Furthermore, greater diligence in documenting concrete and raw material properties is also required.

### Mixture Proportioning Process

The flowability of a concrete mix is a complex interaction between 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.

The general approach is to select the most consistent and best-graded and shaped aggregate economically possible, and to use high paste fractions to increase space between the



aggregate particles. The rheology is controlled by adjusting the water-to-powder ratio and using appropriate admixtures specifically designed for SCC production.

Estimating the required batch weights involves a series of steps that should yield a trial batch with the desired rheological properties of SCC. It is recommended practice to test the placement performance of the trial SCC mixture on a representative test section.

#### Steps to Successful Mix Proportioning of SCC:

1. Determine required slump flow (project specification)
2. Select and proportion coarse and fine aggregates (ACI 211, 301)
3. Estimate required powder and water content (determine paste & mortar volumes)
4. Select admixtures
5. Prepare trial batch
6. Test
7. Adjust mix proportions based on test results
8. Repeat steps 5–7 as necessary

<b>Table 1. Selection of SCC Properties Based on Concrete Member Characteristics</b>				
Suggested Starting Slump Flows		<560 mm (<22 in.)	560–660 mm (22–26 in.)	>660 mm (>26 in.)
Suggested Powder Contents		355–385 kg/m <sup>3</sup> (600–650 lbs/yd <sup>3</sup> )	385–445 kg/m <sup>3</sup> (650–750 lbs/yd <sup>3</sup> )	>445 kg/m <sup>3</sup> (>750 lbs/yd <sup>3</sup> )
Reinforcement Level	Low			
	Medium			
	High			
Shape Intricacy	Low			
	Medium			
	High			
Depth	Low			
	Medium			
	High			
Surface Finish Importance	Low			
	Medium			
	High			
Length	Low			
	Medium			
	High			
Wall Thickness	Low			
	Medium			
	High			
Coarse Aggregate Content	Low			
	Medium			
	High			
Placement Energy	Low			
	Medium			
	High			

## Determining Required Slump Flow

Before starting the proportioning of SCC, the project specifications should be reviewed. The review will establish the required slump flow, compressive strength and age when strength is to be attained, as well as the appropriate testing methods for acceptance.

The proportioning guidelines presented here will serve to produce a trial batch, which can then be evaluated to determine how well it meets the SCC attributes of stability, filling ability and passing ability for the intended use. Table 1 provides some guidance for choosing the initial slump flow target. Several characteristics of the concrete element are rated as low, medium or high. The green shaded areas of the table are potential problem areas, and should be avoided if possible.

## Coarse and Fine Aggregate Selection and Proportion

The nominal maximum size of the coarse aggregate must be chosen with respect to obtaining the desired passing ability and stability of the plastic concrete. When the use of a coarse aggregate larger than 12.5 mm ( $\frac{1}{2}$  in.) is required, it will generally be beneficial to blend two or more different aggregate sizes to obtain an optimum gradation. Typical nominal maximum size of aggregate used in SCC is 19 mm ( $\frac{3}{4}$  in.), although aggregates as large as 25 mm (1 in.) have been used. Aggregates with a nominal maximum size larger than 25 mm (1 in.) are not recommended for use in SCC.

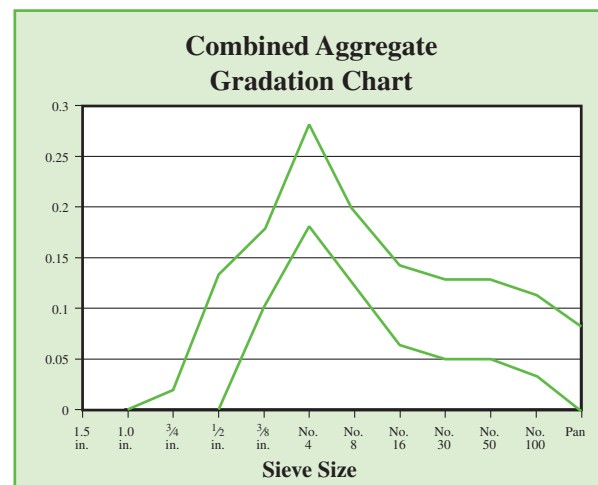
Particle shape of the coarse aggregate can have a significant impact on the performance of an SCC mix. A rounded coarse aggregate will impart greater filling ability to a mixture when compared to a crushed stone of similar size. All other parameters being equal, a higher volume of well-rounded natural aggregate could be used in a concrete mix than of an angular crushed aggregate having the same gradation.

SCC mixtures require special attention to the total gradation of the combined aggregates, and not just the separate coarse and fine aggregates. The chart above shows the recommended upper and lower limits for a blended gradation. Additional information on aggregate gradations may be found in TB-1502.

Unlike conventional concrete, when adjusting the proportions of an SCC mixture to achieve proper yield, all the constituent aggregates should be adjusted simultaneously, such that the overall gradation of the aggregates is not affected.

### Nominal maximum coarse aggregate size = 12.5 mm ( $\frac{1}{2}$ in.) and larger

As a starting point, fifty percent (50%) of the total concrete volume should be filled with the bulk volume of coarse aggregate. Use the dry-rodded bulk density of the coarse aggregate to determine the amount of coarse aggregate required.



**Example:**

Assuming a  $1600 \text{ kg/m}^3$  ( $100 \text{ lbs/ft}^3$ ) dry-rodded bulk density for the coarse aggregate (C.A.):

Amount of C.A. =  $1600 \text{ kg/m}^3 \times 0.50 = 800 \text{ kg/m}^3$

Amount of C.A. =  $100 \text{ lbs/ft}^3 \times 27 \text{ ft}^3/\text{yd}^3 \times 0.50 = 1350 \text{ lbs/yd}^3$

For normal density aggregates this typically yields an absolute volume that is 28–32% of the concrete volume, with the remaining 68–72% being mortar.

Size, gradation and surface texture will influence the volume of coarse aggregate that will permit acceptable passing and filling ability of the plastic SCC. Highly gap graded aggregate mixtures should be avoided as the SCC mix will have a tendency to bleed and/or segregate, and will increase the overall paste fraction requirement of the concrete.

**Nominal maximum coarse aggregate size = 9.5 mm ( $\frac{3}{8}$  in.) and smaller**

Frequently these smaller size-range aggregates are used in SCC applications with very congested steel reinforcing, or challenging concrete placing conditions. An initial proportion of approximately 50% sand and 50% coarse aggregate, by either weight or bulk volume, would be a good starting point for the first trial batch. Once the plastic properties of the trial batched are assessed, the sand-aggregate ratio may be adjusted.

**Powder and Water Content**

Powder includes Portland cement, supplementary cementitious materials and inert fillers passing a  $150 \mu\text{m}$  (No. 100) sieve. When designing an SCC mixture, the compressive strength requirements may not be the decisive factor when selecting the amount of cementitious material.

Inert fillers, obtained by grinding calcareous or siliceous aggregates, can be used to achieve better packing density. The fine fraction of these fillers will increase the specific surface of the blend, while the coarser fractions can help to bridge the gap between sand and Portland cement.

The replacement of a portion of cement with finely ground limestone filler has been shown to improve filling ability and stability, without affecting the one day compressive strength of the concrete mixture. Such a concrete can, however, exhibit up to 10% lower 28 day compressive strength versus similar concretes without filler.

The fineness and volume of the powder, in conjunction with the fine aggregate, help form a mortar matrix that supports the coarse aggregate. Characteristically, powder content for initial trial mixes should be in the  $295\text{--}365 \text{ kg/m}^3$  ( $650\text{--}800 \text{ lbs/yd}^3$ ) range. When performing trial batches it may be prudent to start with higher powder contents, and then optimize the mix for improved economy (see Table 1).

Initially, select a water content to obtain a “water-only-slump” in the 25–75 mm (1–3 in.) range. This would be the slump of the untreated (without HRWR) concrete mixture. The use of the selected HRWR should be at a dosage sufficient to ensure that the required slump flow is obtained under the expected environmental conditions. Generally, the cementitious powder content requirements for fresh SCC properties will yield a w/cm ratio that is low enough for most applications, however this water demand must be confirmed. Typically the water contents of most SCC mixes do not exceed a 0.45 w/cm ratio, or approximately  $200 \text{ L/m}^3$  ( $40 \text{ gal/yd}^3$ ).

To increase the slump flow of an SCC mixture, it may be necessary to not only use more water, but also to increase the powder content of the mix to prevent segregation. Generally, as the desired slump flow increases (for increased filling ability), the powder content required to achieve adequate passing ability and stability may also need to be increased. In the case of HRWR specifically designed for SCC, this adjustment requirement may be lessened. The use of an increased amount of HRWR may also be used to provide an increased slump flow.

Water tolerance (or water sensitivity) of SCC is the amount of water variation within the mixture that causes the characteristics of the SCC to change from acceptable to unacceptable. When performing trial batches, the water sensitivity of the mixture needs to be established. This water sensitivity range must be within the control capabilities of the concrete producer.

The volume of paste and mortar in SCC will generally be greater than in conventional concrete. The volume of mortar and its ability to carry the coarse aggregate in conjunction with the fluidity of the paste provide the overall filling ability, passing ability and stability of SCC mixtures. When adjusting trial mixes for slump flow, consideration should be given to changing the volume of mortar and paste, as well as making admixture and water adjustments.

Table 2 summarizes initial SCC mixture proportioning guidelines. It must be remembered that these are suggested initial values only, and will vary with local materials and the choice of admixtures to be used (such as using a VMA or HRWR designed for SCC).

<b>Table 2. Summary of Trial SCC Mixture Proportioning Target Parameters</b>	
Absolute Volume of Coarse Aggregate	28–32% of Total Mixture Volume
Absolute Volume of Mortar Fraction	65–72% of Total Mixture Volume
Absolute Volume of Paste Fraction	34–40% of Total Mixture Volume
Typical Powder Content	385–475 kg/m <sup>3</sup> (650–800 lbs/yd <sup>3</sup> )
Typical w/cm	0.32–0.45

### Admixture Selection

Polycarboxylate HRWR admixtures are recommended for use in developing and proportioning SCC mixtures. Viscosity modifying admixtures (VMA) are beneficial for adjusting the viscosity, and may be used to improve the stability of SCC mixtures. VMAs can also be advantageous when using lower powder contents, as well as when using gap graded, angular, flat and/or elongated aggregates.

In functional terms, HRWRs impart fluidity to the SCC mixture, while VMAs (such as V-MAR<sup>®</sup> 3) provide an increase in viscosity and cohesiveness to improve the mixture's stability. The use of a VMA in conjunction with a HRWR may also increase the water tolerance of a mixture.

In some cases, high range water reducing admixtures specifically designed for SCC (such as ADVA<sup>®</sup> 380 or ADVA Cast 555) will play a dual role in SCC mixtures by providing both fluidity and improved mixture stability.

An air-entraining agent (AEA) should be used as needed for freeze-thaw durability. Air entrainment can improve the viscosity of SCC mixtures and increase the paste volume, although in some cases air entrainment may adversely affect paste density which influences ability to float/suspend coarse aggregate.

## Mixture Adjustments

Trial batches should be tested to determine what adjustments might need to be made to the mixture proportions to ensure adequate fluidity and stability. Table 3 provides guidance in making adjustments to the mixture based on the test results from the initial trial batches. Once all requirements are fulfilled, the trial mix should be tested at larger volumes at the concrete plant or at a trial pour at the job site.

Table 3. Primary Mixture Adjustments							
		Powder Content	Water Content	C.A. Top Size	F.A./C.A. Ratio	VMA Dosage	HRWR Dosage
Fluidity	Too Low		+			—	+
	Too High		—			+	—
Viscosity	Too Low	+	—			+	+
	Too High		+			—	—
Aggregate Blocking		+	—	—	+	+	
Stability Rating	Too Low	+	—	—	+	+	+
	Aggregate Pile*	+	+/-	—	+	+	
	Mortar Halo*	+	—	—	+/-	+	—

The symbols indicate the direction of the potential adjustment to be made. A “+” indicates a potential increase in that category, while a “—” indicates a potential decrease. When HRWR is increased to increase viscosity or stability, water will have to be reduced.

\* Depending on mixture specifics, mortar halo may be addressed through either an increase or decrease in F.A./C.A. ratio.

Likewise, either an increase or decrease in water content may be called for to address aggregate piling.

In the event that satisfactory performance cannot be obtained, then consideration should be given to a fundamental redesign of the mix.

## Conclusion

SCC offers faster placement, ease of flow around congested reinforcement, and potentially enhanced concrete durability and surface appearance. SCC mixture development needs to take into account the characteristics of the local materials to be used in the concrete, the desired application, required performance, and expected environmental conditions at the time of concrete placement. The behavior of the chemical admixtures under the expected environmental conditions is an important aspect that the SCC producer must consider. SCC is less tolerant of production variability than conventional concrete, and may thereby limit successful production of SCC to plants where the equipment, operation and materials are suitably controlled.

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