Introduction to Self Consolidating Concrete

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Grace Construction Products
February 12 2014

AGENDA

• What is SCC?
• Terminology
• How are SCC mixes developed?
  • Testing methods
• Applications for SCC
Definition:

“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.”

ACI International, Committee 237, SCC

What this means is that SCC is much more than flowable concrete.

SCC fills the formwork without vibration and with a significant reduction in labor.
### SCC Development began in the mid – 80’s

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1983</td>
<td>First considerations in Japan</td>
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<td>1986</td>
<td>First suggested solution by OKAMURA/Univ. Tokyo</td>
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<td>1988</td>
<td>First practical prototypes in Japan</td>
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<td>1989</td>
<td>First publication at EASEC-2</td>
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<td>1992</td>
<td>Publication CANMET &amp; ACI-Int’l Conference/Istanbul</td>
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</table>
| 1994 | ACI Workshop/Bangkok  
Start for worldwide research and development |
| 1995 | Beginning of intensive research in Netherlands and Scandinavia |
| 1997 | RILEM Committee for SCC |
| 1998 | Start of intensive activities in Design |
| 2000 | Introduction of technology to US |
| 2002 | PCI, ASTM, ACI standards underway |
| 2005 | ASTM C1611 Slump flow test approved |

### SCC in the U.S. – 21st Century

- **American motivations for using SCC** include increased potential for **reduced vibration**, and **automation** in precast factories, thus increasing **worker productivity** and limiting vibration health and safety issues.

- **Productivity, Health and Safety**, improved processes and **high quality** are key
SCC in USA – 21st Century

Precast/Prestressed Concrete Institute

- First and highest acceptance within concrete industry
- Guidelines for the use of SCC developed and published in August 2003 and updated 2011

SCC in USA – 21st Century

2008 Selected ASTM Standards for Precast Concrete

2008 Selected ASTM Standards for Precast Concrete

WHAT is Self-Consolidating Concrete?

- A mixture of concrete designed to flow by gravity without any mechanical vibration.
- Improves uniformity of placemat.
- High-fines content (≥10% by weight) helps eliminate bleeding.
- High PFA content (≥15% by weight) helps eliminate segregation.
- Good workability and durability.
- Improved workability.

NOW it SCC Achieved?

- Improved workability and reduced finishing.
- Improved durability and reduced maintenance.
- Improved environmental performance.
- Improved aesthetics.
- Improved performance.

CONCRETE in Practice

Concrete in Practice

CIP 37 - Self Consolodating Concrete (SCC)
SCC is more than flowable concrete - it is a highly engineered fluid with unique Rheological properties.

This is not SCC. You cannot just add water or admix and get SCC.

Rheology*

- “The science dealing with flow of materials, including studies of deformation of hardened concrete, the handling and placing of freshly mixed concrete, and the behavior of slurries, pastes, and the like.”
- *Cement and Concrete Terminology, ACI Publication SP-19
Viscosity*:

- “The property of a material which resists change in the shape or arrangement of its elements during flow, and the measure thereof.”
- *Cement and Concrete Terminology, ACI Publication SP-19

Technical Terminology related to SCC

TECHNICAL BULLETIN TB-1501

Definitions of Terms Relating to Self-Consolidating Concrete (SCC)

- Aggregate aspect ratio – The ratio of length to width of individual pieces of coarse aggregate. This ratio sometimes affects the characteristics of SCC. Aggregates characterized as “harder” tend to have higher aspect ratios.
- Aggregate blocking – see Blocking
- Air-migration – The undesirable condition in which entrapped air in fresh SCC migrates to the top surface causing a bubbling or boiling appearance. This is an indication of unstable air and a low viscosity mortar. Air-popping is another term used for this occurrence.
- Binder – see Powder
- Bingham fluid – A material that exhibits the behavior of having a yield stress. Thus a force must be overcome before movement occurs with a constant rate of shear under a constant stress and a slope.

This technical bulletin provides definitions to certain terms related to Self-Consolidating Concrete (SCC). Various sources, including ACI 116 and PCI’s “Interim Guidelines for the Use of Self-Consolidating Concrete in Precast/Prestressed Concrete Institute Member Plants,” were used in the compilation of this information. There are many terms covering similar aspects of performance being applied to SCC. We have tried to emphasize the more commonly agreed on terms by referring the reader to them when defining other terms. There is ongoing activity both in ACI and ASTM to develop consensus guides and standards; this technical bulletin will be revised as appropriate to reflect any consensus changes in terminology.
RHEOLOGY:
The science of the deformation and flow of materials.

\[ \tau = \tau_0 + \mu \gamma \]

- \( \tau_0 \): yield value (Pa)
- \( \mu \): plastic viscosity (Pa•s)
- \( \gamma \): rate of shear

SCC – Rheology Primer

1” Slump

Water

3” Addition

Viscosity

Strain Rate (Shear Rate)

Yield Stress

Viscosity

1”

3”

5”

7”

9”

American Concrete Pipe Association
Rheology and Conventional Concrete

- Chemical Admixtures are enabling for highly workable concrete
- Conventional Concrete is relatively forgiving (Large workability space)

Defining the SCC Workability Window

- SCC Workability Space
- SCC Technology
- 3” Slump
- 9” Slump
- 26” Slump Flow
Defining the SCC Workability Window

- 3" Slump
- 9" Slump
- Superplasticized Concrete
- Conventional Concrete
- 26" Slump

Yield Stress

SCC Workability Space

Strain Rate (Shear Rate)

Viscosity

Must Vibrate to Consolidate

Segregating

Moisture Tolerance and Stability reflected in concrete rheology

Rheology controlled by:
- admixtures (supers & VMAs)
- mix design (powder content, w/cm, aggregate & gradation)

Acceptable... but on the edge

Unacceptable

Superior... With good moisture tolerance & stability

Low Flow
More Stability

High Flow
Less Stability

Plastic Viscosity

Fast Flow
Less Stability

Slow Flow
More Stability

SCC Technology and Practice – Rheology and SCC
Which appears more stable?

Rolling edge vs. Flat edge

Aggregate particles have separated from mixture

Aggregate particles are suspended within the mixture and are present all the way to the perimeter.
‘Thixotrophic’ behavior vs. ‘Set’

• Thixotrophy is the tendency of a material to act as a semi-solid (gel) at rest and a fluid while in motion.
• A material is said to have thixotropic properties when it exhibits a decrease in viscosity with time when the material is subjected to a constant shearing stress.

*Important terms:*
• SCC is Thixotropic
• SCC likes Energy

Key Properties of SCC

**Filling ability** - The ability of the concrete to flow freely under its own weight, and to completely fill formwork of any dimension and shape without leaving voids
Plastic Properties

- **Filling Ability** is impacted by –
  - Slump Flow (20”-30”)
  - Viscosity (T20”)
  - Aggregate Shape
  - Aggregate Ratio
  - Placing Methods
  - Size and configuration of the Forms

Key Properties of SCC

**Passing Ability** – The ability of concrete to flow freely in and around dense reinforcement without blocking
Plastic Properties

- Passing Ability is Impacted by -
  - Slump Flow
  - Viscosity (T20”)
  - Aggregate
    - Shape
    - Ratio
    - Size
  - Placing Methods
  - Form or Rebar Spacing

Key Properties of SCC

Passing Ability – The ability of concrete to flow freely in and around dense reinforcement without blocking
Key Properties of SCC

**Resistance to Segregation** – During placement and while flowing, the concrete should retain its stability. There should be no separation of aggregate from paste or water from solids and no tendency for coarse aggregate to sink downwards through the fresh concrete mass under gravity. Resistance to segregation is the most difficult to achieve.

Key SCC Plastic Properties

- **Dynamic Stability** - The characteristic of fresh concrete that ensures uniform distribution of solid particles and air voids as the concrete is being transported and placed.

- **Static Stability** - The characteristic of fresh concrete that ensures uniform distribution of solid particles and air voids once all the placement operations are complete and until the onset of setting.
Plastic Properties

- Stability is Impacted by:
  - Slump Flow
  - Viscosity (T20)
  - Aggregate Size
  - Aggregate Ratio
  - Aggregate Specific Gravity
  - Powder Content
  - Air Content
  - Paste Content
  - Mortar Content
  - Transportation and Placing Methods
  - Admixture Content
  - Water Content

High Quality SCC Fundamentally changes the way concrete is produced and placed.
Where Can SCC Be Used?

- Precast Elements
  - Most constructive applications

- Benefits
  - Faster Placement
  - Better Consolidation & Finish
  - Little or No Vibration
  - Early Strength
  - Lower Repair Cost
  - Increased Productivity
  - Safety – Fewer people on scaffolds and forms for placement

SCC Technology and Practice – SCC Mixes

- Materials
  - Shape, texture, and gradation

- Mixture Proportioning Process

- Admixtures

- Production QA/QC
SCC mix development process

SCC is not prescriptive concrete, far from it.

- Developing SCC consists of material combinations and relationships of:
  - Admixtures
  - Sand / Aggregates
  - Cementitious Materials
    - Cement, Pozzolans
  - Water

SCC Mixture Design Development

- Aggregate Variability
  - Size and distribution
  - Angularity and aspect ratio
  - Water demand

SCC mixture success:
- Must use locally available materials
- Quality of the ingredients can vary dramatically
- One mix design does not fit all
SCC mix design approaches

There are currently three basic mixture-proportioning approaches for developing SCC mixtures:

1. High Powder Content and high-range water-reducing (HRWR) Admixture
2. Low Powder Content, HRWR Admixture, and Viscosity Modifying Admixture (VMA)
3. Combination Type: Moderate Powder Content, HRWR Admixture, w/wo Moderate VMA addition

SCC Technology and Practice – SCC Proportioning

- Higher percentage of Paste and Mortar

<table>
<thead>
<tr>
<th>SCC</th>
<th>Conventional</th>
</tr>
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<tbody>
<tr>
<td>Paste</td>
<td>Paste</td>
</tr>
<tr>
<td>Cement</td>
<td>Cement</td>
</tr>
<tr>
<td>Water</td>
<td>Water</td>
</tr>
<tr>
<td>w/cmt</td>
<td>w/cmt</td>
</tr>
<tr>
<td>Fine/total agg</td>
<td>Fine/total agg</td>
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<tr>
<td>35%</td>
<td>30%</td>
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<tr>
<td>700</td>
<td>650</td>
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<td>280</td>
<td>260</td>
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<td>0.40</td>
<td>0.40</td>
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<tr>
<td>0.50</td>
<td>0.42</td>
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</table>
SCC Proportioning Steps

- Determine required *slump flow*
- Select *coarse aggregate size*
- Determine the *required air content*
- Estimate the *required powder content*
- Estimate the *required water content*
- Calculate coarse and fine aggregate amounts after Powder, Water and Air contents are determined
- Calculate *paste* and *mortar volume*
- Adjust *coarse and fine aggregate weights* based on *paste* and *mortar volumes*
- Select *admixture types and dosage*
- *Batch Trial Mixture – Make adjustments and batch again*

### Possible Powder Content

<table>
<thead>
<tr>
<th>Slump Flow, in.</th>
<th>Powder Content Lb/yd³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump Flow, in.</td>
<td>&lt;22</td>
</tr>
<tr>
<td>&lt;650</td>
<td>650 - 750</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Absolute volume of coarse aggregate</th>
<th>28-32% (total mix volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paste Fraction (calculated on volume)</td>
<td>34-40% (total mix volume)</td>
</tr>
<tr>
<td>Mortar Fraction (calculated on volume)</td>
<td>60-70% (total mix volume)</td>
</tr>
<tr>
<td>Typical w/cm</td>
<td>0.32 – 0.45</td>
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<tr>
<td>Typical cement (powder content)</td>
<td>650-800 pounds</td>
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</tbody>
</table>
Software is used to design SCC mixes / evaluate properties

Aggregates

- Many coarse aggregates available in North America are Gap Graded, and thus have low volumes of No. 8 and No. 16 sieve size particles
- The optimized grading curve for SCC is much tighter than for conventional concrete
- Optimizing mix packing density is critical for many SCC mixes, so it is may be necessary to blend aggregate sources
Aggregate Grading

- An example of a typical No. 57 blend, indicating a Gap Graded Aggregate
- An optimized SCC aggregate grading with blended aggregates

SCC Mixture Proportioning

Aggregates and Gradation

- Smaller coarse aggregate - typically ¾” maximum nominal top size
- Rounded better than angular (marbles, not dice)
- Low aspect ratio better than high aspect ratio (dice, not dominos)
- Blend coarse aggregates to obtain nearly continuous grading
- Minimize void volume (maximize dry-rodded unit weight)
What is Blocking?

Size, volume, & blend of aggregate require sufficient volume of paste to flow

"Passing ability"

Aggregate Blockage – Spacing between reinforcement must be considered
SCC Polycarboxylate Superplasticizers
Excellent flowability with improved stability compared to superplasticizers for conventional concrete. Increased mix forgiveness.

Viscosity Modifying Agents
For difficult aggregates and production conditions such as low cementitious and paste volumes. Increases mix forgiveness / water tolerance.

Extended Slump Life Polycarboxylate Superplasticizers
Excellent flowability with improved stability; formulated for the concrete market for added workability retention

Common admixtures such as air entrainment, retarders, and accelerators also work with SCC
... inter-twined chains

\[ \text{YIELD} \quad \text{(high viscosity)} \]

Anti-segregation

(Highly Flowable Concrete, Self-Leveling Screeds)

AT REST...

UNDER SHEAR...

AT REST...

polymer chain alignment

LOW VISCOSITY

immediate reshaping of the network

pumpability

finishability
SCC Technology and Practice – Admixtures and SCC

Viscosity Modifier

• Acts as a ‘thickening’ agent
• Protects against segregation
• Dispense direct into mix
• No effect on set times or air content
• Provides flexibility of water contents

Different Superplasticizers and VMAs

• Same Mix Design

- Mixes made with different admixtures can have similar slump flow yet different rheology
- In general, for mixes with the same slump flow, those with higher viscosity are more stable

The edges of the Workability Box are dangerous

- Mixes with very low yield and viscosity may segregate
- Mixes with very high yield and viscosity may not “self consolidate”
Dispersion happens quickly – Viscosity takes time.
Mixing SCC in Twin Shaft Mixer
Admix Dosage to 0:30

Mixing SCC 0:30 to 0:60
Mixing SCC  0:60 to 0:90 discharge
24” Slump Flow

Producing SCC in Precast Mixers
How long is the right amount of mixing time?
Test Procedures and evaluating SCC

SCC - A very different concrete to test....
• Test methods to evaluate SCC in fresh state

- **Workability:** ASTM C-1611: “Standard Test Method for Slump Flow of Self-Consolidating Concrete”
- **Stability:** ASTM C-1610 Column Segregation Test
  - ASTM C-1712 Rapid Assessment Test for SCC Segregation
- **Passing Ability:** ASTM C-1621 J-Ring

**SCC slump flow test is widely accepted to check flow characteristics. ASTM C-1611**
SCC Slump Flow
ASTM C-1611

Procedure and Evaluation
‘Unofficial’ Finger test

VISUAL STABILITY INDEX

HIGHLY STABLE

STABLE

UNSTABLE

HIGHLY UNSTABLE
Apply the Visual Stability Index to this sample.
(this really happened!)

SCC Flow Characteristics
ASTM C-1621
- J-ring test (passing ability)
- Comparison of J-Ring flow and Slump flow tests
SCC J-Ring

Why the J-Ring test?
Evaluate passing ability.
Column Segregation Test – ASTM C-1610

ASTM C-1712
Rapid Assessment Method for SCC Segregation

Penetration Depth (PD) and Different Stability Levels

- Highly Stable (PD ≤ 10 mm)
- Stable (10 mm < PD ≤ 25 mm)
- Unstable (PD > 25 mm)
Cut Hardened Cylinders / Robustness test for Segregation Resistance

w/c = 0.35-0.39

w/c = 0.40-0.44

Lab tests – L Box
Lab tests - U Box Test

Concrete must reach at least 30 cm height after passing through rebar

Lab tests - V Funnel
Modified standard tests for SCC
Air Content, Strength Cylinders

Adjustments to SCC mixes

<table>
<thead>
<tr>
<th>Property</th>
<th>Powder Content</th>
<th>Water Content</th>
<th>Maximum Coarse Aggregate Size</th>
<th>Sand-to-Aggregate Ratio</th>
<th>VMA Dosage</th>
<th>HRWRA Dosage</th>
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<tr>
<td><strong>Fluidity</strong></td>
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<td>Too Low</td>
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<td><strong>Viscosity</strong></td>
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<td><strong>Insufficient Passing Ability</strong></td>
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<td><strong>Stability</strong></td>
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<tr>
<td>Excessive Segregation</td>
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<tr>
<td>Aggregate Pile Mortar Halo</td>
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↑: Increase, ↓: Decrease
PRODUCTION

Quality Control

• Make a commitment to QC
• Train key personnel in the “look and feel” of good SCC
• Continually evaluate stability
• Maintain control charts to establish materials and process control
• Test as required for your materials and process control

SCC Value: Labor / Time / Quality
Productivity Gains / Higher Quality

Highest Quality, Repair Reduction, Safety
SCC WORKS BECAUSE...

- Economic value is realized by the producer with:
  - Higher quality and improved productivity
  - Decreased labor, capital, and maintenance costs
  - Improved Health and Safety
  - Greater element design flexibility
- Remember: SCC IS concrete

Questions?

YOU ARE 150 YARDS FROM CENTER OF GREEN
YOU ARE 175 YARDS FROM A $200 GLASS WINDOW
CHOOSE YOUR CLUB CAREFULLY!