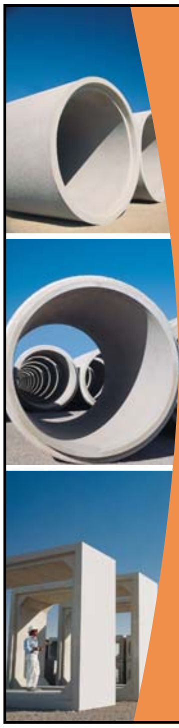

Introduction to

Self Consolidating Concrete

Ed Mansky

Grace Construction Products

February 12 2014

Ver 1.1

American **Concrete Pipe** Association

Self Consolidating Concrete

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.

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SCC Development began in the mid – 80's

1983	First considerations in Japan
1986	First suggested solution by OKAMURA/Univ. Tokyo
1988	First practical prototypes in Japan
1989	First publication at EASEC-2
1992	Publication CANMET & ACI-Int'l Conference/Istanbul
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

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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.**

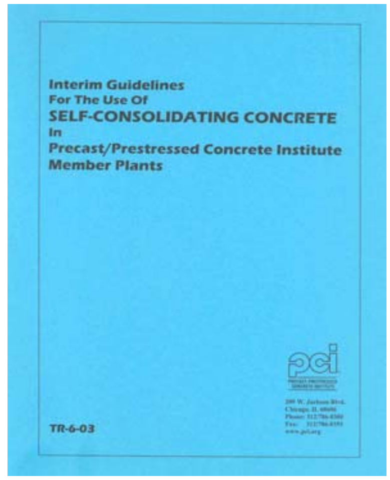
- **Productivity, Health and Safety, improved processes and high quality are key**

SCC in USA – 21st Century

7

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


Interim Guidelines
For The Use Of
SELF-CONSOLIDATING CONCRETE
In
Precast/Prestressed Concrete Institute
Member Plants

TR-6-03

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SCC in USA – 21st Century

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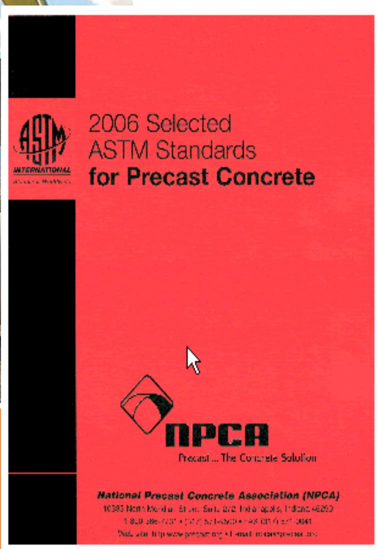

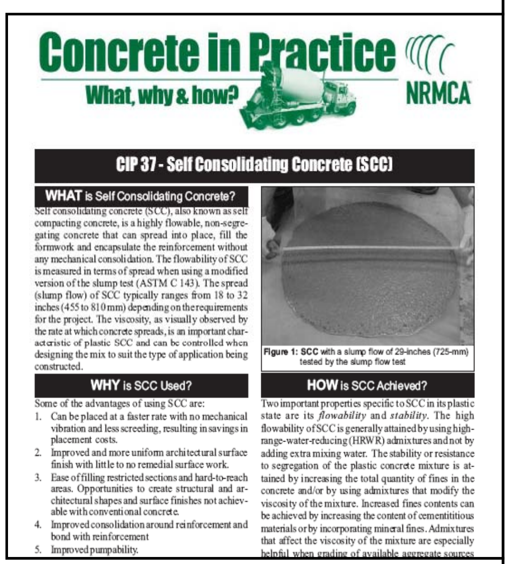
Concrete in Practice
What, why & how?
NRMCA

CIP 37 - Self Consolidating Concrete (SCC)

WHAT is Self Consolidating Concrete?

Self consolidating concrete (SCC), also known as self compacting concrete, is a highly flowable, non-segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any mechanical consolidation. The flowability of SCC is measured in terms of spread when using a modified version of the slump test (ASTM C 143). The spread (slump flow) of SCC typically ranges from 18 to 32 inches (455 to 810 mm) depending on the requirements for the project. The viscosity, as visually observed by the rate at which concrete spreads, is an important characteristic of plastic SCC and can be controlled when designing the mix to suit the type of application being constructed.

Figure 1: SCC with a slump flow of 29-inches (725-mm) tested by the slump flow test

WHY is SCC Used?

Some of the advantages of using SCC are:

1. Can be placed at a faster rate with no mechanical vibration and less screeding, resulting in savings in placement costs.
2. Improved and more uniform architectural surface finish with little to no remedial surface work.
3. Ease of filling restricted sections and hard-to-reach areas. Opportunities to create structural and architectural shapes and surface finishes not achievable with conventional concrete.
4. Improved consolidation around reinforcement and bond with reinforcement
5. Improved pumpability.

HOW is SCC Achieved?

Two important properties specific to SCC in its plastic state are its *flowability* and *stability*. The high flowability of SCC is generally attained by using high-range-water-reducing (HRWR) admixtures and not by adding extra mixing water. The stability or resistance to segregation of the plastic concrete mixture is attained by increasing the total quantity of fines in the concrete and/or by using admixtures that modify the viscosity of the mixture. Increased fines contents can be achieved by increasing the content of cementititious materials or by incorporating mineral fines. Admixtures that affect the viscosity of the mixture are especially helpful when grading of available aggregate sources

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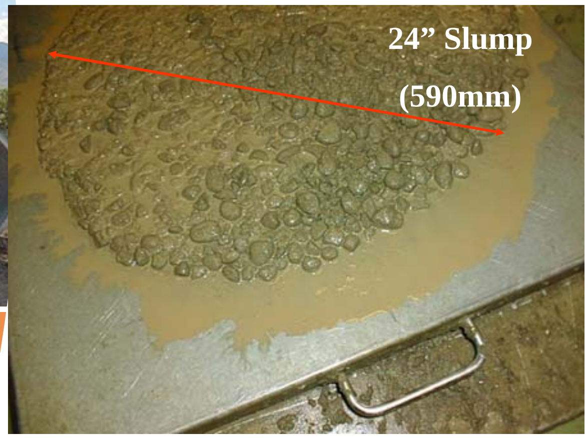
SCC is more than flowable concrete - it is a highly engineered fluid with unique Rheological properties



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

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Rheology*

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- **“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**

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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**

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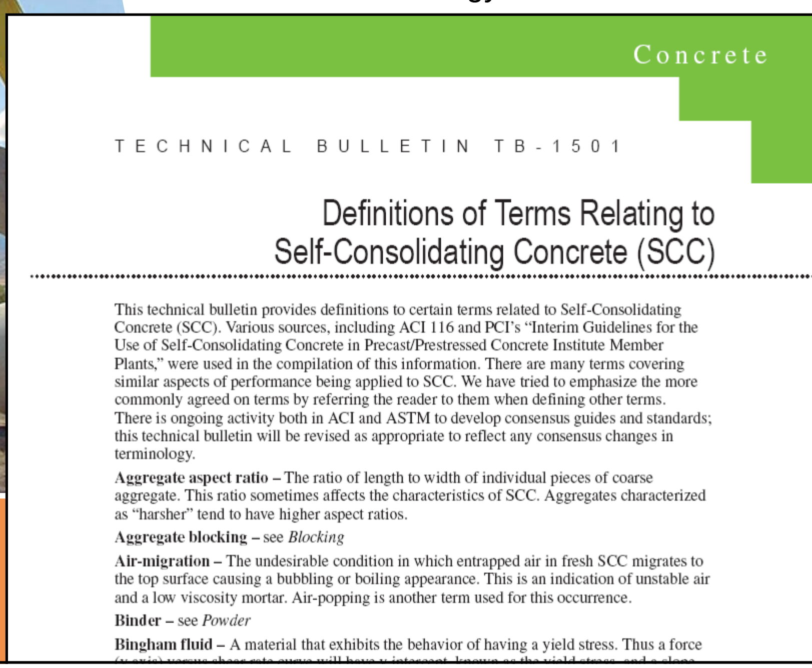
Technical Terminology related to SCC



Concrete

TECHNICAL BULLETIN TB-1501

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

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.

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 "harsher" 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

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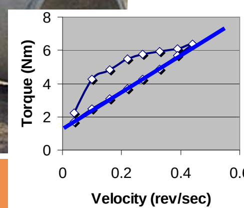
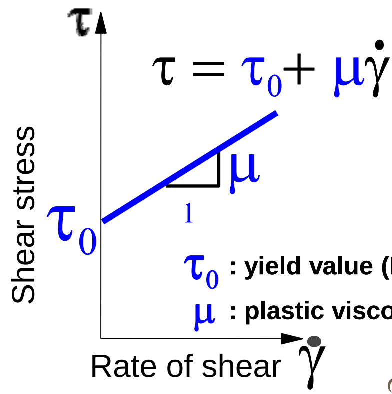
Rheology and SCC

RHEOLOGY:
The science of the deformation and flow of materials.



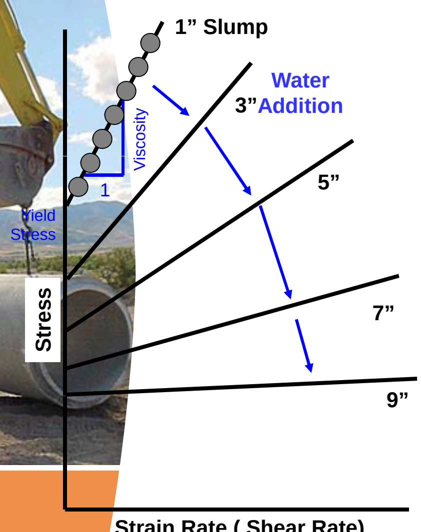


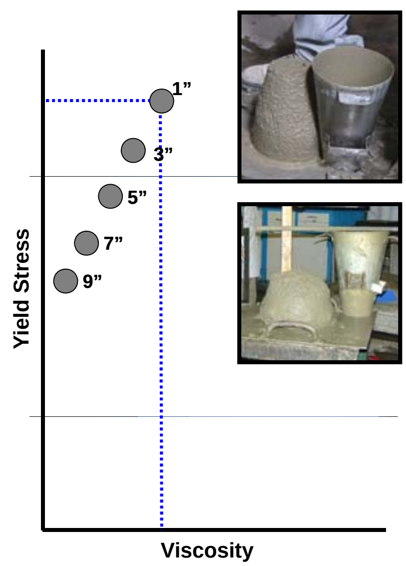
$$\tau = \tau_0 + \mu\dot{\gamma}$$

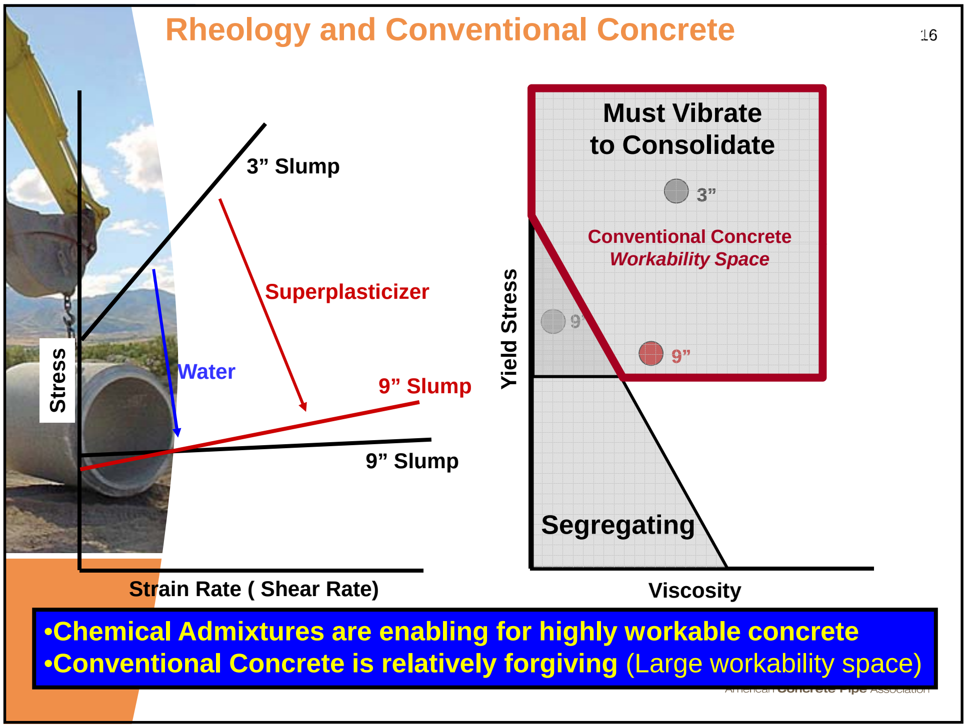
τ_0 : yield value (Pa)

μ : plastic viscosity (Pa•s)

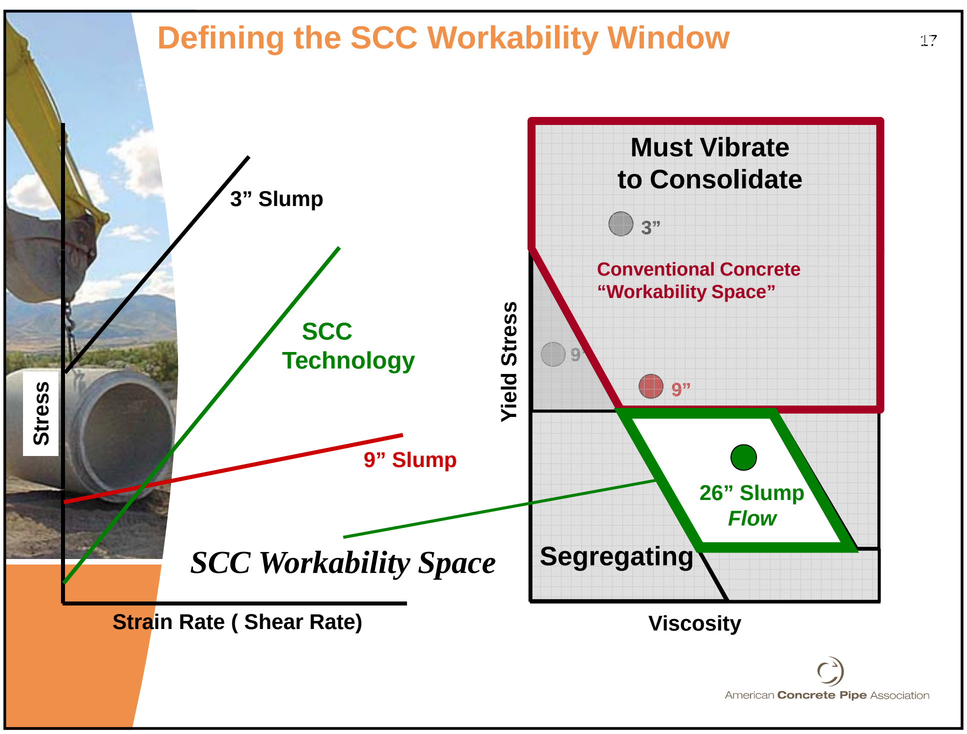
SCC – Rheology Primer







Rheology and Conventional Concrete
16
Must Vibrate to Consolidate
3”
Conventional Concrete
Workability Space
9”
3” Slump
Superplasticizer
Water
9” Slump
9” Slump
Stress
Yield Stress
Segregating
Strain Rate (Shear Rate)
Viscosity
•Chemical Admixtures are enabling for highly workable concrete
•Conventional Concrete is relatively forgiving (Large workability space)



Defining the SCC Workability Window
17
Must Vibrate to Consolidate
3”
Conventional Concrete
“Workability Space”
9”
3” Slump
SCC
Technology
9” Slump
Stress
Yield Stress
26” Slump
Flow
SCC Workability Space
Segregating
Strain Rate (Shear Rate)
Viscosity
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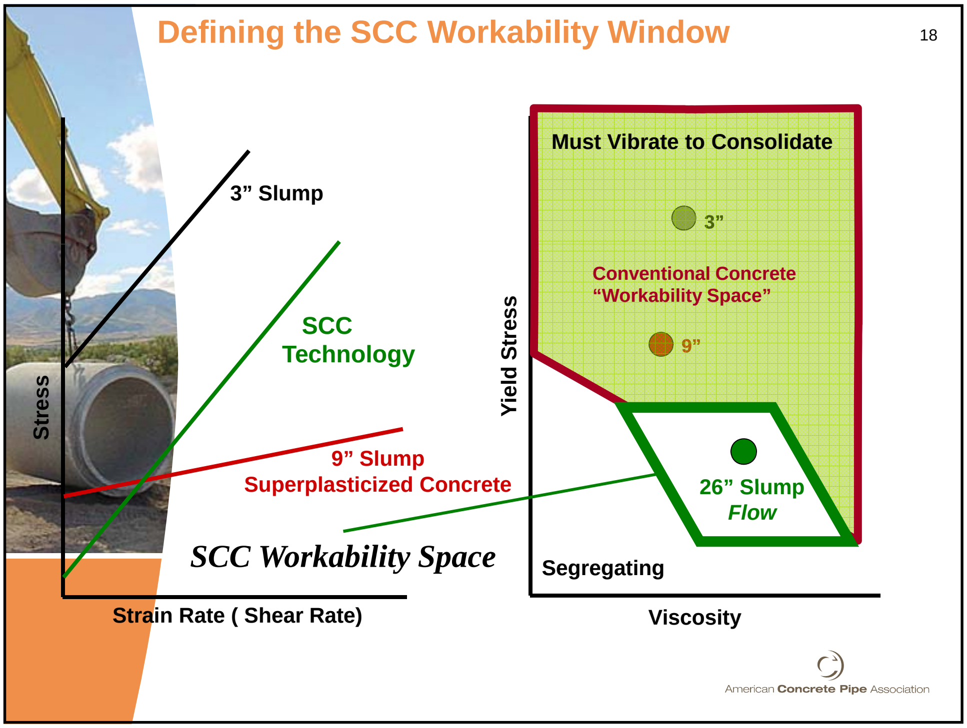

Defining the SCC Workability Window
18
3" Slump
SCC
Technology
9" Slump
Superplasticized Concrete
SCC Workability Space
Stress
Strain Rate (Shear Rate)
Must Vibrate to Consolidate
3"
Conventional Concrete
"Workability Space"
9"
26" Slump
Flow
Yield Stress
Segregating
Viscosity
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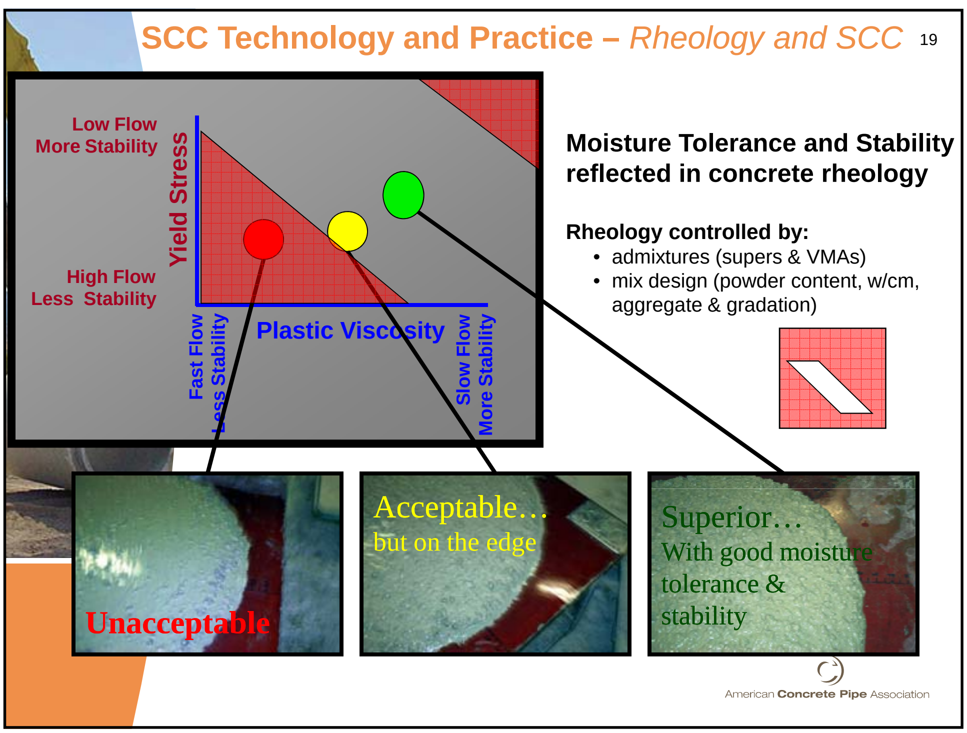

SCC Technology and Practice – Rheology and SCC
19
Low Flow
More Stability
High Flow
Less Stability
Yield Stress
Plastic Viscosity
Fast Flow
Less Stability
Slow Flow
More Stability
Moisture Tolerance and Stability reflected in concrete rheology
Rheology controlled by:
• admixtures (supers & VMAs)
• mix design (powder content, w/cm, aggregate & gradation)
Unacceptable
Acceptable…
but on the edge
Superior…
With good moisture tolerance & stability
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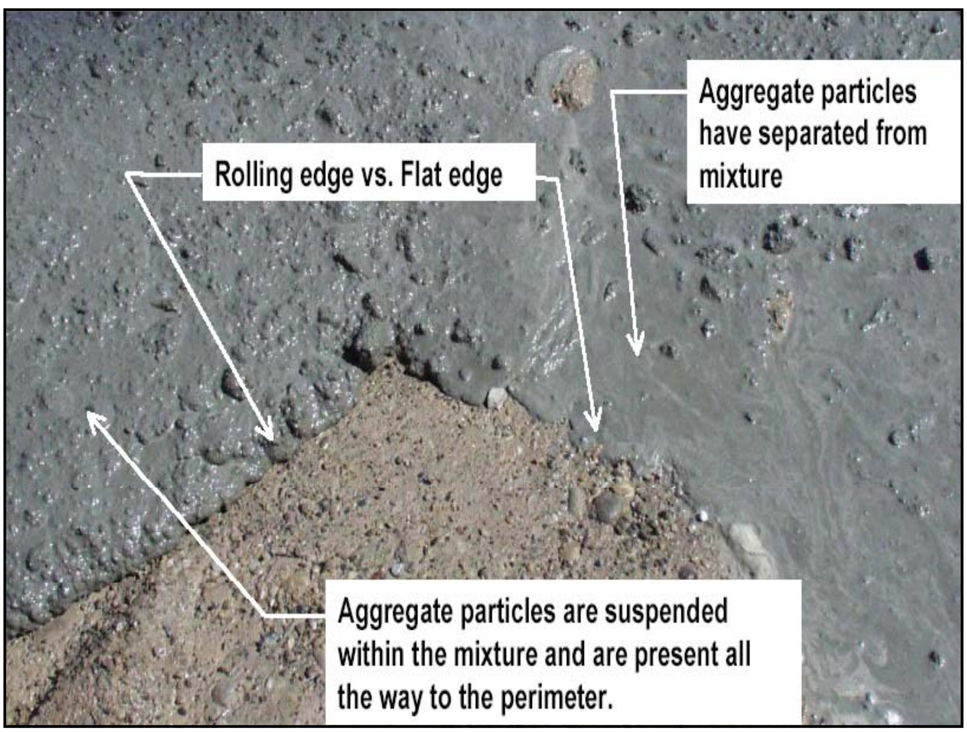
Which appears more stable?



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‘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 thixotrophic 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

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Key Properties of SCC

<u>Filling ability</u> - 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

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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

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Key Properties of SCC

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

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Plastic Properties

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

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Key Properties of SCC

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

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Key Properties of SCC

<u>Resistance to Segregation</u> – 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

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Key SCC Plastic Properties

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

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

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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**

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High Quality SCC Fundamentally changes the way concrete is produced and placed.

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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

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SCC Technology and Practice – *SCC Mixes*

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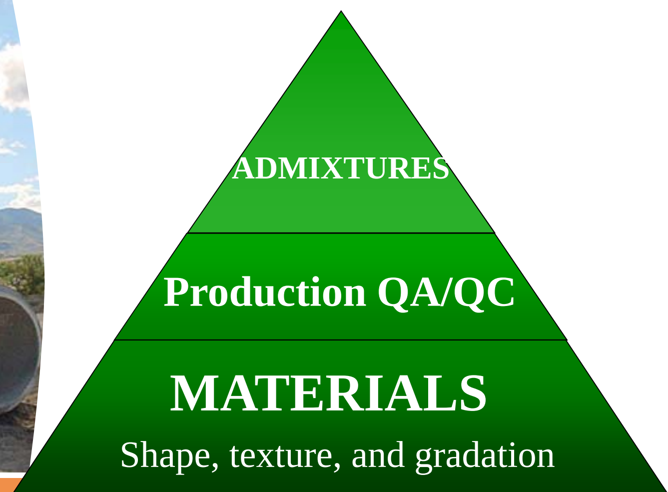

Mixture Proportioning Process

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SCC mix development process

SCC is not prescriptive concrete, far from it.

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

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SCC Mixture Design Development

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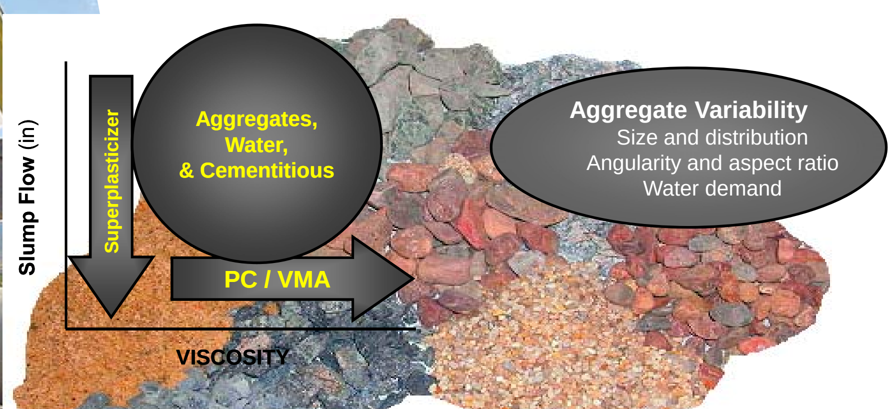

SCC mixture success:

- **Must use locally available materials**
- **Quality of the ingredients can vary dramatically**
- **One mix design *does not* fit all**

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SCC mix design approaches

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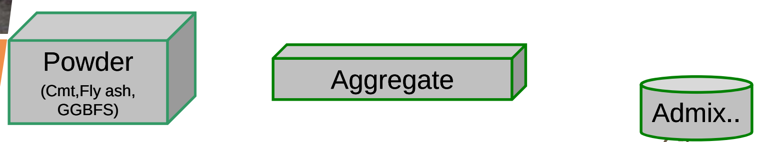
There are currently three basic mixture-proportioning approaches for developing SCC mixtures

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



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SCC Technology and Practice – *SCC Proportioning*

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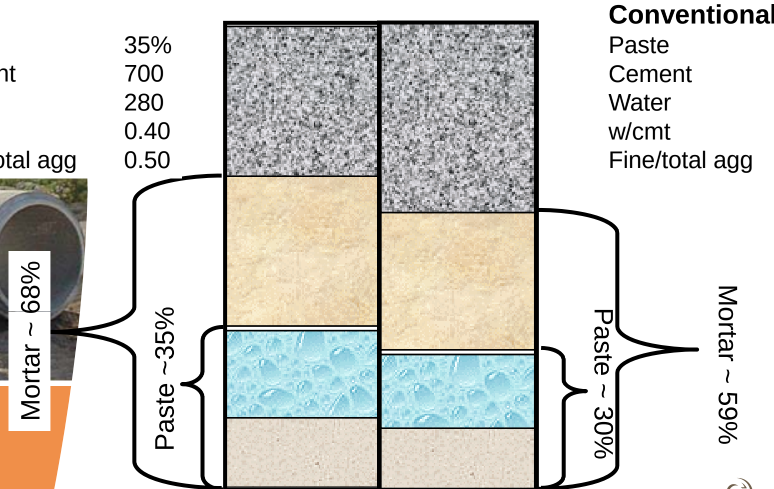
• Higher percentage of Paste and Mortar

SCC	
Paste	35%
Cement	700
Water	280
w/cmt	0.40
Fine/total agg	0.50

Conventional	
Paste	30%
Cement	650
Water	260
w/cmt	0.40
Fine/total agg	0.42



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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*

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Possible Powder Content

	Slump Flow, in. <22	Slump 22-26, in 22-26	Slump Flow, in. >26
Powder Content Lb/yd^3	< 650	650 - 750	750 +

Absolute volume of coarse aggregate	28-32% (total mix volume)
Paste Fraction (calculated on volume)	34-40% (total mix volume)
Mortar Fraction (calculated on volume)	60-70% (total mix volume)
Typical w/cm	0.32 – 0.45
Typical cement (powder content)	650-800 pounds

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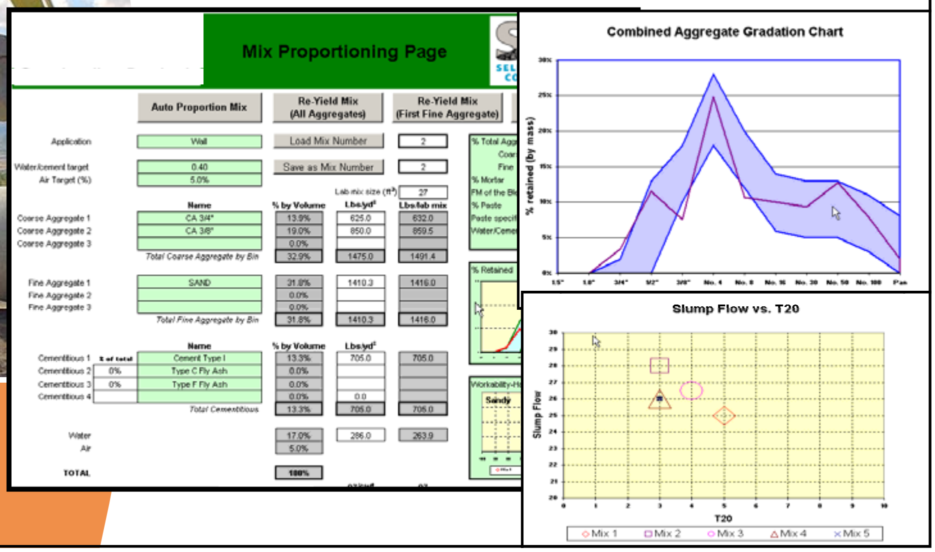
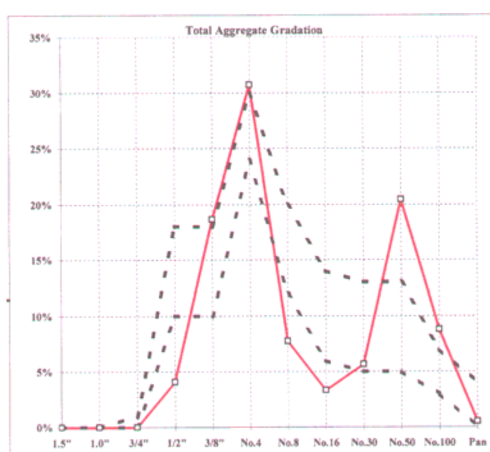
Software is used to design SCC mixes / evaluate properties



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



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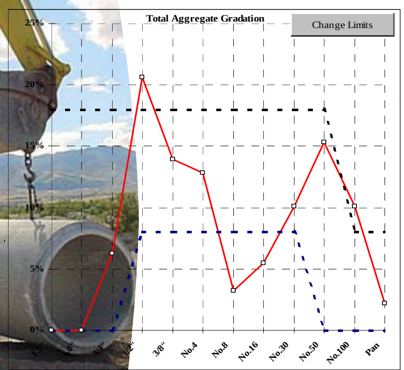
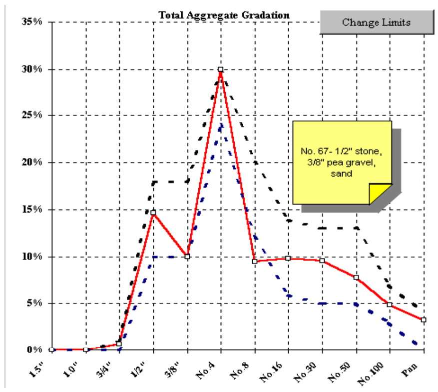
Aggregate Grading





- An example of a typical # 57 blend, indicating a Gap Graded Aggregate
- An optimized SCC aggregate grading with blended aggregates

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SCC Mixture Proportioning

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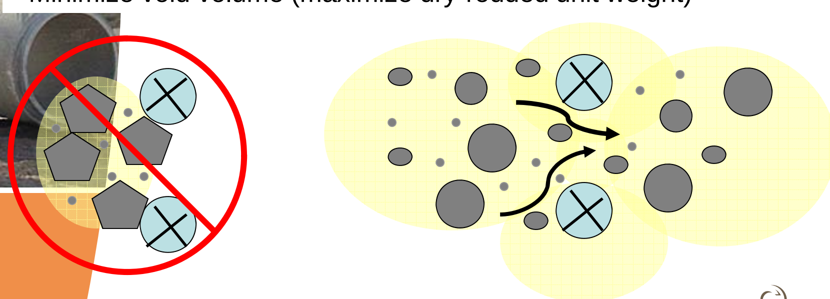
Aggregates and Gradation

- 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)



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What is Blocking?

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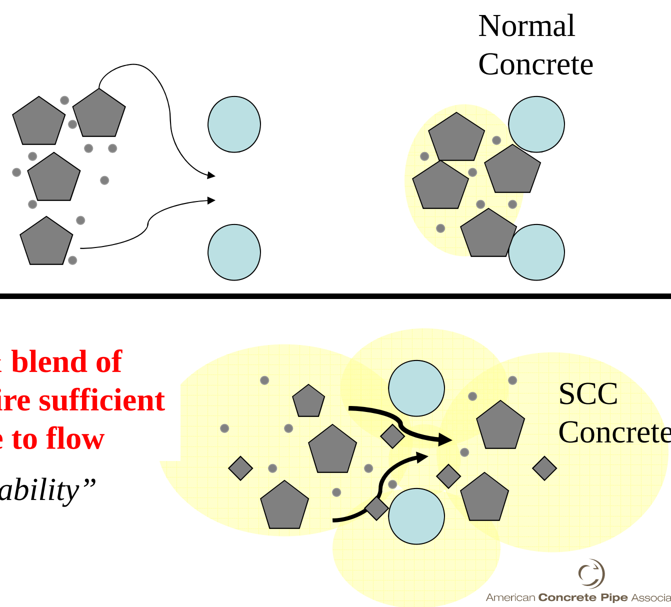

Size, volume, & blend of aggregate require sufficient volume of paste to flow

"Passing ability"

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Aggregate Blockage – Spacing between reinforcement must be considered

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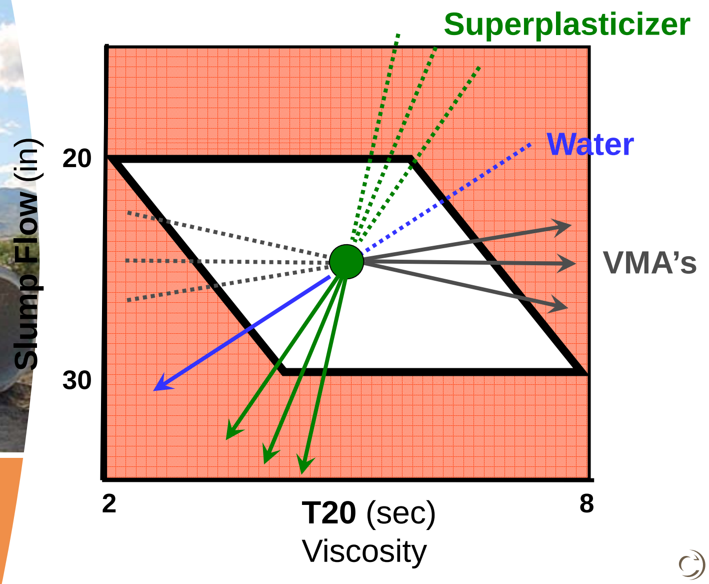
SCC Technology and Practice – *Admixtures and SCC* 46

Effect on the Workability Box



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SCC Technology and Practice – *Admixtures and SCC* 47

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

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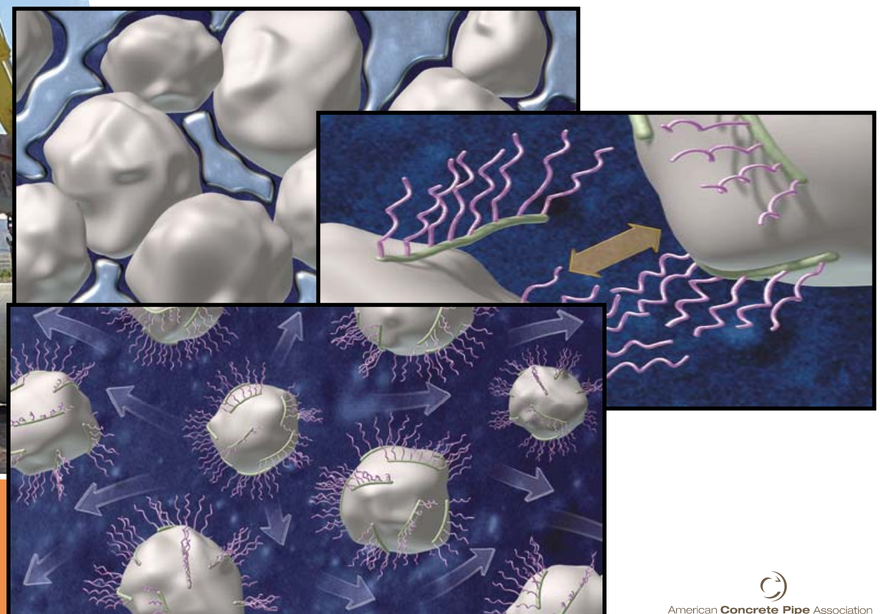
SCC Technology and Practice – *Admixtures and SCC* 48



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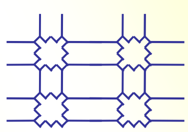
SCC Technology and Practice – *Admixtures and SCC* 49

AT REST.... → UNDER SHEAR... → AT REST....

AT REST....



... inter-twined chains

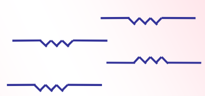
↓

YIELD
(high viscosity)

↓

Anti-segregation
(Highly Flowable Concrete, Self-Leveling Screeds)

UNDER SHEAR...



polymer chain alignment

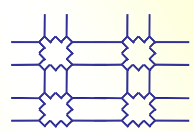
↓

LOW VISCOSITY

↓

pumpability
finishability

AT REST....



immediate reshaping of the network

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SCC Technology and Practice – *Admixtures and SCC* 50

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

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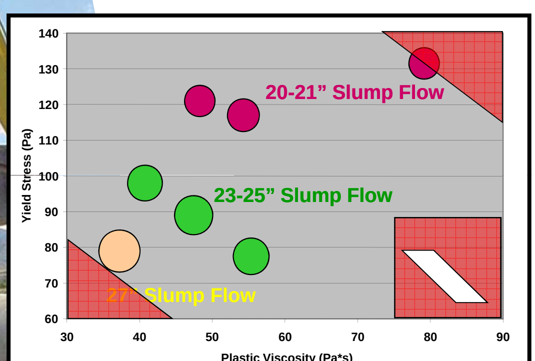
SCC Technology and Practice – *Admixtures and SCC* 51



- **Same Mix Design**
- **Different Superplasticizers and VMAs**

- 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"

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Dispersion happens quickly – Viscosity takes time.
Mixing SCC in Twin Shaft Mixer
Admix Dosage to 0:30

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Mixing SCC 0:30 to 0:60

Mixing SCC 0:60 to 0:90 discharge

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24” Slump Flow

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Producing SCC in Precast Mixers

How long is the right amount of mixing time?

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Test Procedures and evaluating SCC

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SCC – A very different concrete to test….

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- 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*

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

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SCC Slump Flow ASTM C-1611

Procedure and Evaluation

‘Unofficial’ Finger test

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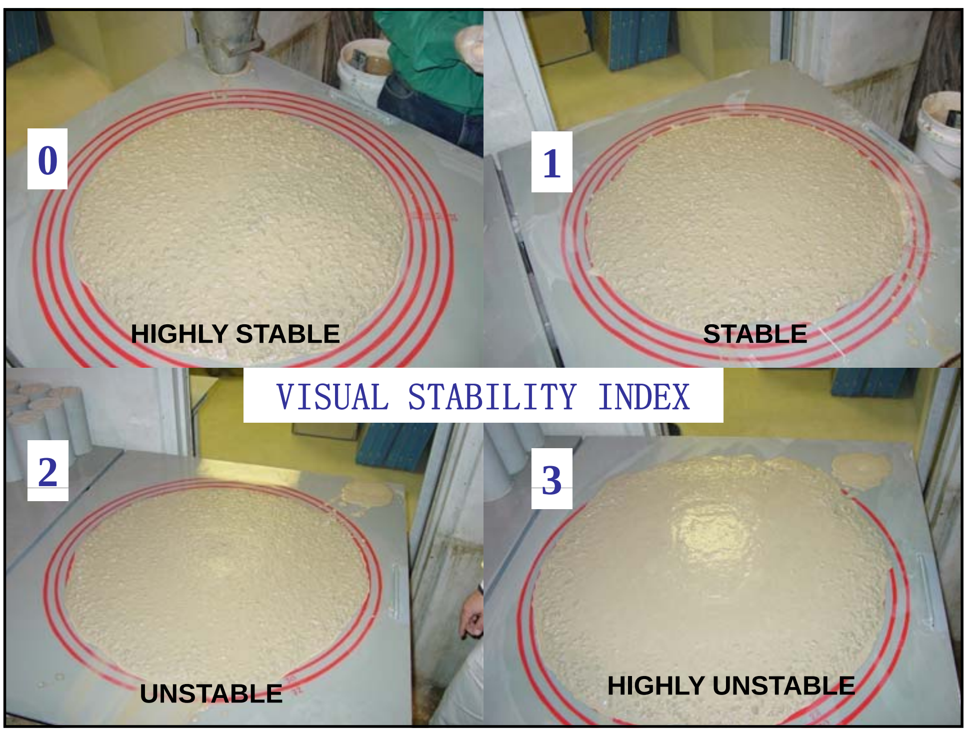

Apply the Visual Stability Index to this sample.
(this really happened!)

SCC Flow Characteristics ASTM C-1621

- J-ring test (passing ability)
- Comparison of J-Ring flow and Slump flow tests

SCC J-Ring

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Why the J-Ring test?

Evaluate passing ability.

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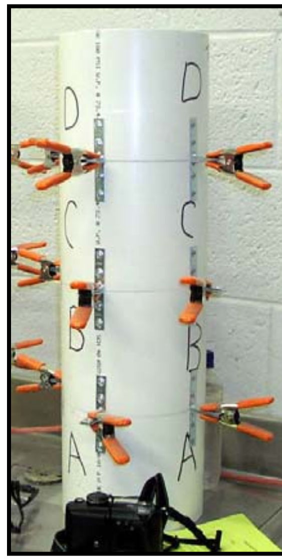
Column Segregation Test – ASTM C - 1610



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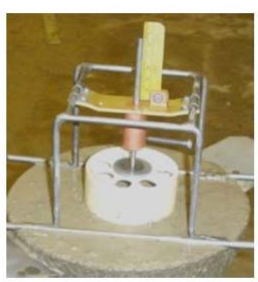
ASTM C-1712

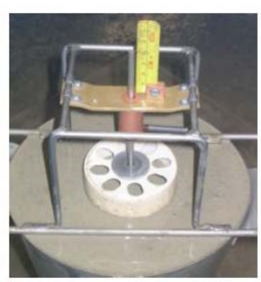
Rapid Assessment Method for SCC Segregation

Penetration Depth (PD) and Different Stability Levels

Highly Stable
(PD ≤10 mm)



Stable
(10 mm < PD ≤ 25 mm)



Unstable
(Pd > 25 mm)

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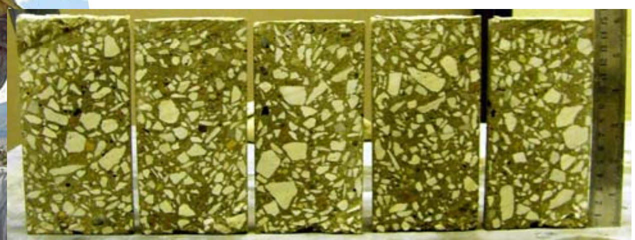
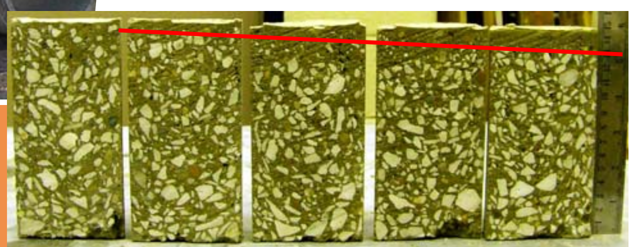
Cut Hardened Cylinders / Robustness test for Segregation Resistance



w/c = 0.35-0.39



w/c = 0.40-0.44

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Lab tests – L Box

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Lab tests - U Box Test

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

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Lab tests - V Funnel

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Modified standard tests for SCC
Air Content, Strength Cylinders

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Adjustments to SCC mixes

Property	Powder Content	Water Content	Maximum Coarse Aggregate Size	Sand-to-Aggregate Ratio	VMA Dosage	HRWRA Dosage
Fluidity						
Too Low		↑			↓	↑
Too High		↓			↑	↓
Viscosity						
Too Low	↑	↓			↑	
Too High		↑			↓	
Insufficient Passing Ability	↑	↓	↓	↑	↑	
Stability						
Excessive Segregation	↑				↑	
Aggregate Pile			↓	↑		
Mortar Halo	↑	↓			↑	↓

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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

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Productivity Gains / Higher Quality

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Highest Quality, Repair Reduction, Safety

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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* <u>concrete</u>**

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Questions?

Shortcut to SCC video clips Loop.wmv.lnk

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