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Quality Control and Robustness of SCC, Part 1

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Dr. Khayat was Professor in the Department of Civil Engineering at the Universite de Sherbrooke in Quebec, Canada. During his 21 years there, he served as the Director of the Center of Excellence on Concrete Infrastructure Engineering and Head of the Integrated Research Laboratory in Valorization of Innovating and Durable Materials and Structures.

He received his B.S., M.Eng., and M.S. in civil engineering with emphasis in structural engineering, construction engineering and management and a Ph.D. in civil engineering with emphasis in civil engineering materials, all from the University of California at Berkeley. This was followed by a post-doctoral fellowship at the same institute.

Dr. Khayat is active on several technical and code committees, including Chair of ACI 237 and RILEM Technical Committee 228. He served as member of the Canadian Standards Association Committee A23.1/A23.2 and a number of TRB Committees. He was elected fellow of ACI in 2004.

Evaluation of Robustness of SCC to Variations in Sand Humidity and Superplasticizer Dosage

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High-Performance Flowable Concrete with Adapted Rheology (2008-2013)

Owners: Ministère des Transports Québec; Ville de Montréal; Hydro Québec

Material Suppliers: Association Canadienne du Ciment / Cement Association of Canada; Euclid Chemical; Handy; Sika

Engineering Firms: SNC·LAVALIN; Teknika HBA

Testing Labs: Qualitas; Laboratoires Shermont; SM; Inspec-Sol; LVM; Laboratoire A.B.S. inc.

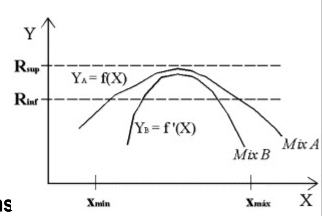
Prefab: Saramac

Innovative materials and sustainable development

Introduction

Robustness of concrete is defined as capacity of the material to tolerate certain variations in material characteristics and mixture parameters

Robust concrete has lower sensitivity to such variaitons



Sand moisture content and SP dosage are considered as major parameters affecting robustness of SCC

Objectives

1. Evaluate effect of SP-VEA combinations on robustness of SCC subjected to small variations in sand humidity and SP dosage
2. Propose methodology to evaluate robustness
3. Identify test methods suitable for robustness evaluation

5 Types of VEAs

Codification	Type	Maximum diameter of VEA powder
PS1	Aninonic polysaccharide (Diutan gum-based)	180 µm (coarser grind)
PS2		75 µm (finer grind)
PS3	Aninonic polysaccharide (Welan gum-based)	180 µm
CEL	Cellulose-based	< 212 µm
MS	Modified starch	-

Reference SCC

8 SP-VEA combinations:
PNS and PCE + 5 VEA types

SP	VEA type	VEA dosage (%)
PNS	-	-
	PS1	0.02
	PS2	0.03
	PS3	0.03
PCE	-	-
	PS1	0.02
	CEL	0.05
	MS	0.03

SSD condition (kg/m³)	
w/c	0.37
Type GU cement	470
Water	175
Coarse agg. (MSA 14 mm)	900
Sand	870
PNS	≈ 6 L/m³
PCE	≈ 3 L/m³
VEA (mass of water)	0.02% - 0.05%

Scope of Work

Robustness of SCC

Phase I. Variations in sand humidity
- -1% from SSD (*w/cm* = 0.35)
- SSD (*w/cm* = 0.37)
- +1% from SSD (*w/cm* = 0.39)

Phase II. Variations in SP dosage
- -10% less SP
- 0% (Reference)
- +10% more SP

8 SP-VEA combinations
- SP: PNS vs. PCE
- VEA: 3 polysaccharides VEAs
  1 modified starch
  1 cellulosed-based VEA
- Total 24 SCC mixtures

2 selected SCC
- 1 PNS + selected VEA1
- 1 PCE + selected VEA2
- Total 6 SCC mixtures

Workability
Rheological properties
Mechanical properties

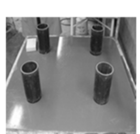
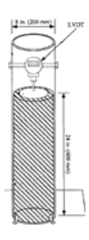
Testing Program

	SP	Variation (*w/cm*)	VEA	Measurement: Fresh	Measurement: Hardened
Phase I: Variation in sand humidity slump flow of 630 ± 20 mm	PNS (12 SCC)	SSD (0.37) SSD – 1% (0.35) SSD + 1% (0.39)	Control PS1 PS2 PS3	Slump flow (10-45 min) Air content (10-45 min) Unit weight (10-45 min) T-50 (10-45 min) VSI (10-45 min) J-Ring (10-45 min) Settlement Rheology Portable vane Inclined plane Slump flow with cylinder	Compressive strength at 7, 28, and 56 days Flexural strength at 56 days
	PCE (12 SCC)	SSD (0.37) SSD – 1% (0.35) SSD + 1% (0.39)	Control PS1 CEL MS		
Phase II: Variation in SP dosage	PNS (3 SCC)	SSS (0.37), -10%, 0, +10% SP	Selected VEA		
	PCE (3 SCC)	SSS (0.37), -10%, 0, +10% SP	Selected VEA		

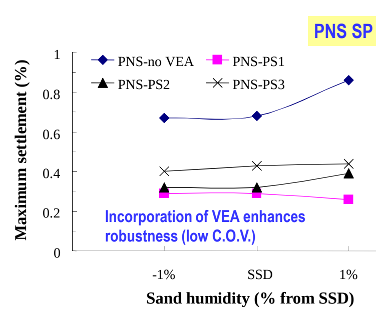
Test Methods

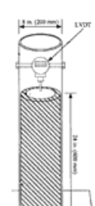



Portable vane

Inclined plane

Slump flow with cylinder


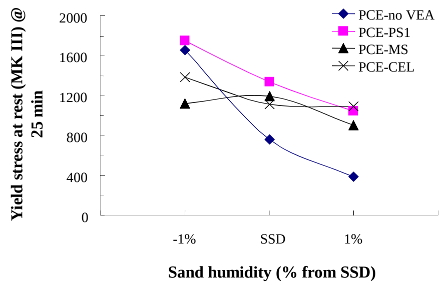
Effect of Sand Humidity on Surface Settlement





Effect of Sand Humidity on Yield Stress at Rest

PCE-no VEA exhibits higher sensitivity in yield stress at rest to variation in sand humidity



Robustness Rank Using C.O.V.

Workability (8 properties)		PNS				PCE			
		No VEA	PS1	PS2	PS3	No VEA	PS1	CEL	MS
Air content (Vair)	C.O.V.	35.5	3.5	13.6	21.6	17.3	5.6	24.2	25.1
	Rank	8	1	3	5	4	2	6	7
T-50	C.O.V.	11.8	66.9	69.8	16.7	40.8	39.9	44.7	30.7
	Rank	1	7	8	2	5	4	6	3
J-Ring	C.O.V.	4.3	6.9	0	5.5	3.9	8.8	4.8	3.0
	Rank	4	7	1	6	3	8	5	2
Cylinder slump flow	C.O.V.	5.5	9.4	13.4	15.8	48.6	7.7	7.8	10.3
	Rank	1	4	6	7	8	2	3	5

Robustness Rank Using C.O.V.

Workability (8 properties)		PNS				PCE			
		No VEA	PS1	PS2	PS3	No VEA	PS1	CEL	MS
ΔVair	C.O.V.	84.6	15.8	70.5	60.3	94.4	43.3	33.3	96.1
	Rank	6	1	5	4	7	3	2	8
Slump flow – J-Ring	C.O.V.	32.5	33.3	0	37.5	20.0	54.0	25.6	13.1
	Rank	5	6	1	7	3	8	4	2
ΔCylinder slump flow	C.O.V.	33.3	15.8	35.7	26.2	55.3	12.5	12.5	17.6
	Rank	6	3	7	5	8	2	1	4
Settlement	C.O.V.	14.5	6.2	5.6	4.9	6.4	7.7	14.4	7.8
	Rank	8	3	2	1	4	5	7	6

Robustness Rank Using C.O.V.

Rheology		PNS				PCE			
		No VEA	PS1	PS2	PS3	No VEA	PS1	CEL	MS
τ_0 @ 10 min	C.O.V.	38.4	9.2	4.3	14.0	8.4	19.5	29.8	24.0
	Rank	8	3	1	4	2	5	7	6
μ_p @ 10 min	C.O.V.	50.7	65.5	36.6	10.3	32.4	32.7	37.5	44.4
	Rank	7	8	4	1	2	3	5	6
$\tau_{0\ rest}$ (MK III) @ 25 min	C.O.V.	43.0	35.7	7.1	19.1	70.0	25.7	13.5	14.1
	Rank	7	6	1	4	8	5	2	3
τ_0 @ 70 min	C.O.V.	9.3	25.2	24.6	54.0	6.2	14.7	23.0	10.0
	Rank	2	7	6	8	1	4	5	3

Robustness Rank Using C.O.V. (total 20 properties)

Mechanical properties		PNS				PCE			
		No VEA	PS1	PS2	PS3	No VEA	PS1	CEL	MS
7-d fc'	C.O.V.	3.1	6.2	3.5	6.5	9.8	7.0	9.2	6.0
	Rank	1	4	2	5	8	6	7	3
28-d fc'	C.O.V.	5.0	4.8	2.6	5.9	7.8	6.4	9.0	5.3
	Rank	3	2	1	5	7	6	8	4
56-d fc'	C.O.V.	5.3	5.6	6.9	5.7	7.9	3.6	7.0	6.0
	Rank	2	3	6	4	8	1	7	5
56-d fr	C.O.V.	7.3	7.7	6.1	6.0	8.2	3.6	7.4	4.7
	Rank	5	7	4	3	8	1	6	2

Ranking and Classification of Robustness to Sand Humidity

SP-VEA	Sum of ranks, SR_i	Robustness Ranking	Normalized sum of ranks*
PNS-PS2	27	1	100%
PNS-PS3	38	2	75%
PNS-PS1	40	3	71%
PCE-PS1	42	4	66%
PCE-MS	48	5	52%
PNS	62	6	21%
PCE-CEL	68	7	7%
PCE	71	8	0%

*Normalized sum of ranks (%) = (Max. SR – SR_i) / (Max. SR – Min. SR) ×100

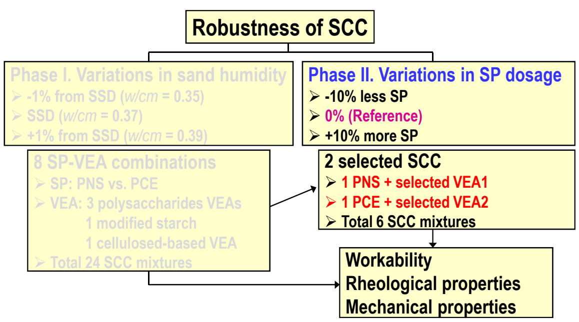
Ranking and Classification of Robustness to Sand Humidity

Normalized sum of ranks (%)	Category	Robustness	VEA
81 – 100	Category I	Very high	PNS-PS2
61 – 80	Category II	High	PNS-PS3 PNS-PS1 PCE-PS1
31 – 60	Category III	Medium	PCE-MS
≤ 30	Category IV	Low	PCE-CEL PNS-No VEA PCE-No VEA

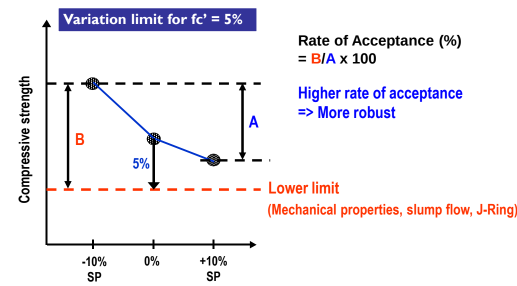
Objectives

1. Evaluate effect of SP-VEA combinations on robustness of SCC subjected to small variations in sand humidity and SP dosage
2. Propose methodology to evaluate robustness
3. Identify test methods suitable for robustness evaluation

2 SCC Mixtures for Phase II (Variation in SP dosage)



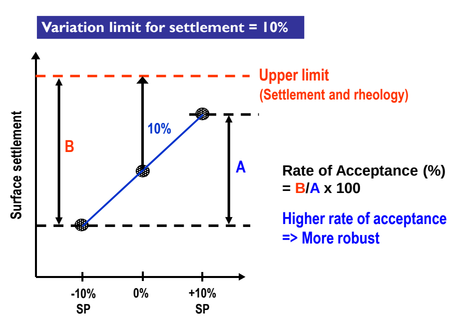
Methodology to evaluate Robustness C.O.V. and Deviation from Targeted Limit Value



Rate of Acceptance (%)
= B/A x 100

Higher rate of acceptance
=> More robust

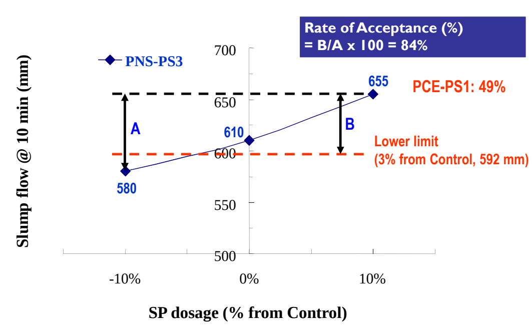
Deviation from Targeted Limit Value



Rate of Acceptance (%)
= B/A x 100

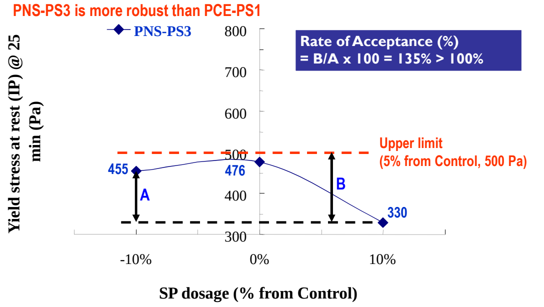
Higher rate of acceptance
=> More robust

Slump flow



Yield Stress at Rest (Inclined Plane)

PNS-PS3 is more robust than PCE-PS1



Rate of Acceptance Values

Phase II	Rate of Acceptance (%)	
	PNS-PS3	PCE-PS1
7-d fc'	81	100
28-d fc'	68	100
56-d fc'	101	100
56-d fr	55	100
Slump flow at 10 min	84	49
J-Ring at 10 min	60	100
Settlement	100	75
T-50 at 10 min	38	72
$\tau_{0\ rest}$ (MK III) @ 25 min	100	100
$\tau_{0\ rest}$ (IP) @ 25 min	100	37
$\tau_{0\ rest}$ (MK III) @ 70 min	100	17
Mean	80.6	77.3

Robustness (C.O.V. and Rate of Acceptation)

Properties	Coefficient of Variation (%)		Rate of Acceptance (%)	
	PNS-PS3	PCE-PS1	PNS-PS3	PCE-PS1
7-d fc'	3.2	0.6	81	100
28-d fc'	4.1	1.0	68	100
56-d fc'	3.6	1.6	100	100
56-d fr	6.7	5.1	55	100
Slump flow at 10 min	6.1	6.8	84	49
J-Ring at 10 min	11.1	8.8	60	100
Settlement	2.3	6.3	100	75
T-50 at 10 min	27.9	31.3	38	72
$\tau_{0\ rest}$ (MK III) @ 25 min	31.5	43.9	100	100
$\tau_{0\ rest}$ (IP) @ 25 min	18.9	36.5	100	37
$\tau_{0\ rest}$ (MK III) @ 70 min	37.4	14.2	100	17
Mean	13.9	14.2	80.6	77.3

Objectives

1. Evaluate effect of SP-VEA combinations on robustness of SCC subjected to small variations in sand humidity and SP dosage
2. Propose methodology to evaluate robustness
3. **Identify test methods suitable for robustness evaluation**

Properties selected for robustness evaluation

20 properties
1. 7-d fc'
2. 28-d fc'
3. 56-d fc'
4. 56-d fr
5. Vair at 10 min
6. T-50 at 10 min
7. J-Ring at 10 min
8. Cylinder slump flow 25 min
9. ΔVair
10. Slump flow – J-Ring at 10 min
11. ΔCylinder slump flow
12. Settlement
13. τ_0 @ 10 min
14. μ_p @ 10 min
15. $\tau_{0\ rest}$ (MK III) @ 25 min
16. τ_0 @ 70 min
17. μ_p @ 70 min
18. $\tau_{0\ rest}$ (MK III) @ 70 min
19. $\tau_{0\ rest}$ (PV) @ 25 min
20. Rate of structural buildup (PV)

Kendall's Coefficient of Concordance

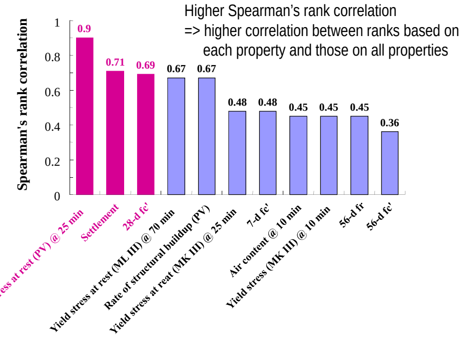
Spearman's Rank Correlation

11 properties
1. 7-d fc'
2. 28-d fc'
3. 56-d fc'
4. 56-d fr
5. Air content (Vair) at 10 min
6. Settlement
7. τ_0 @ 10 min
8. $\tau_{0\ rest}$ (MK III) @ 25 min
9. $\tau_{0\ rest}$ (MK III) @ 70 min
10. $\tau_{0\ rest}$ (PV) @ 25 min
11. Rate of structural buildup (PV)

Robustness of SCC Incorporating Different Viscosity-Enhancing Admixtures, ACI Materials Journal, 108 (4), 2011, pp. 432-438.

11 Properties for Robustness Evaluation

Higher Spearman's rank correlation
=> higher correlation between ranks based on each property and those on all properties



Conclusions

- SCC made with PNS is more robust than SCC with PCE
- Incorporation of VEA enhances robustness
- Mixtures made with polysaccharide VEAs are more robust than those prepared with modified starch and cellulosed-based VEAs
- Either COV or rate of acceptance methodology can be used to evaluate robustness

Conclusions

- Sstatistical approach based on Kendall's coefficient of concordance and Spearman's rank correlation was used to identify key properties of SCC that can be used to assess robustness of SCC.
- Characteristics that can be used to evaluate robustness include air volume, J-Ring, surface settlement, static yield stress (PV), rheometer, as well as flexure and compressive strengths.
- Min. testing program to evaluate robustness should include:
  - Compressive strength at 28 days
  - Surface settlement
  - Yield stress at rest (concrete rheometer or portable vane)