Development of a Rapid Setting, Self-Consolidating Concrete (RS-SCC) Mixture Design for Structural Repairs

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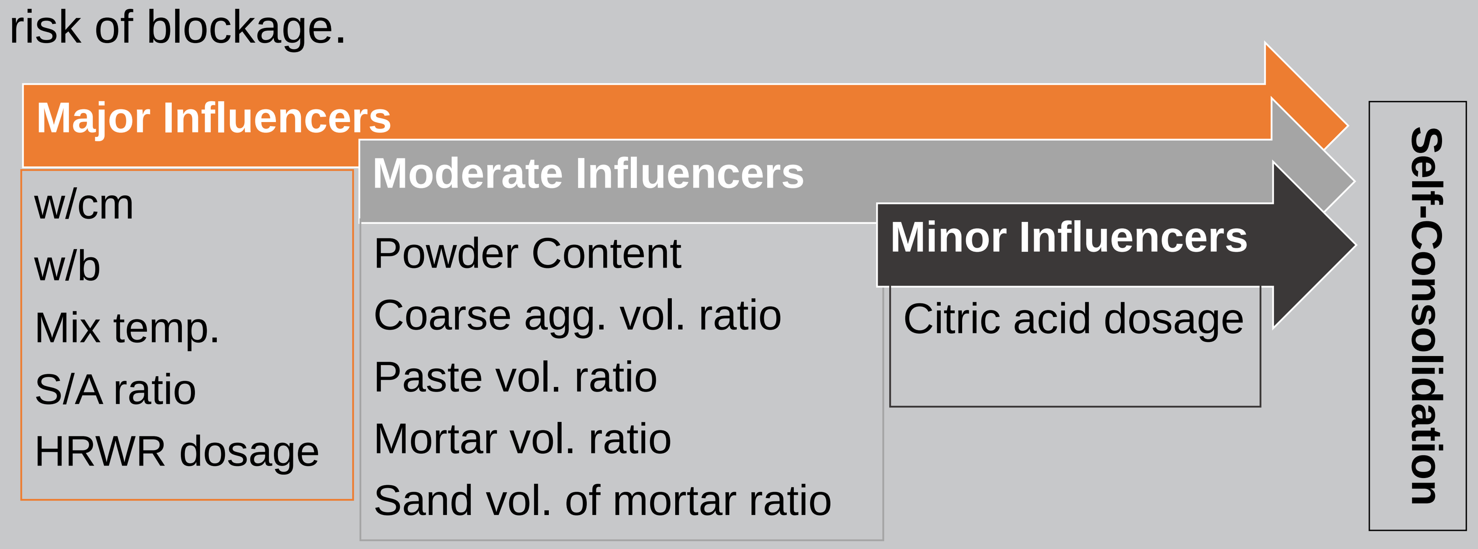
Rapid Set

INTRODUCTION

Self-consolidating concrete (SCC) is flowable and non-segregating such that it can fill formwork without the use of mechanical consolidation. Flowable and non-segregating characteristics are achieved through mix design proportioning that differs from conventional concrete [1]. A successful SCC mixture fulfills basic workability requirements: excellent deformability, good stability, and low risk of blockage.



Calcium Sulfoaluminate (CSA) cements are a family of alternative cements which, like portland cement, are hydraulic. CSA cements are known for high early strength and rapid-hardening. These properties are attributed Ye'elimite, $C_4A_3\hat{S}$ (CSA). Belitic CSA (BCSA) cement is a type of cement within this family. BCSA cement has a higher percentage of C_2S, Belite. Increased amounts of Belite contributes to late-age strength gain and shrinkage (which balances early expansion from the CSA) in concrete made with BCSA cement [2].

OBJECTIVES

The objective of this research is to develop a rapid-setting, self-consolidating concrete (RS-SCC) mixture design, as there has been no published research thus far to do so. These mixtures will be used to rapidly repair damaged structural concrete

METHODS

PC-SCC Control

- **Determine a suitable portland cement SCC (PC-SCC) mixture**
  - $f'c_{28\text{-day}} \geq 4000$ psi
  - Slump flow ≥ 24 in.
  - J-ring passing ability ± 2 in. of slump flow
  - Column segregation ≤ 10%

RS-SCC

- **Develop a RS-SCC mixture using BCSA cement**
  - $f'c_{4\text{-hour}} \geq 4000$ psi
  - Slump flow ≥ 24 in.
  - J-ring passing ability ± 2 in. of slump flow
  - Column segregation ≤ 10%
  - Slump flow retention ± 2 in. ≥ 45 min.

Comparison

- **$f'c_{28\text{-day}}$ to $f'c_{4\text{-hour}}$**
- Slump flow
- Column segregation
- Drying shrinkage
- Bond strength to conventional PC concrete

RESULTS – FRESH PROPERTIES

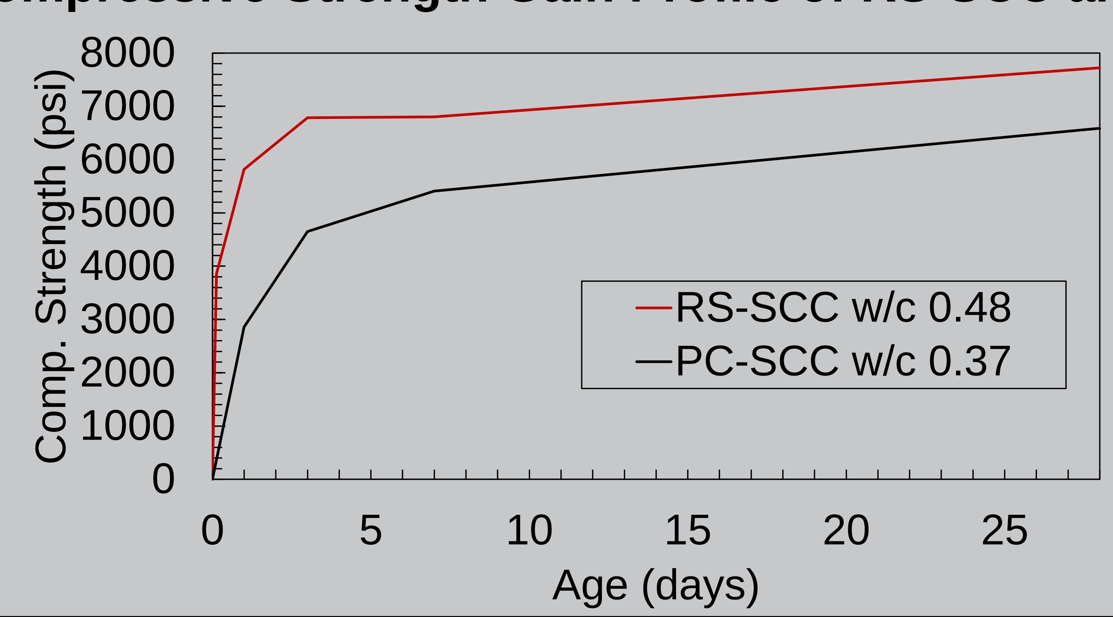
PC-SCC w/c 0.37
26.5 in. slump flow
26 in. J-ring passing ability
8% column segregation

RS-SCC w/c 0.48
26 in. slump flow
24 in. J-ring passing ability
3% column segregation

While all mixtures met the parameters set forth in the methods section, the performing PC-SCC mixture (lowest w/c, lowest column segregation, highest $f'c_{28\text{-day}}$) is being compared to the worst performing RS-SCC mixture (highest w/c, highest column segregation, lowest $f'c_{4\text{-hour}}$). Despite being the worst performing RS-SCC, this mixture had similar, if not better fresh properties than the best performing PC-SCC.

RESULTS – HARDENED PROPERTIES

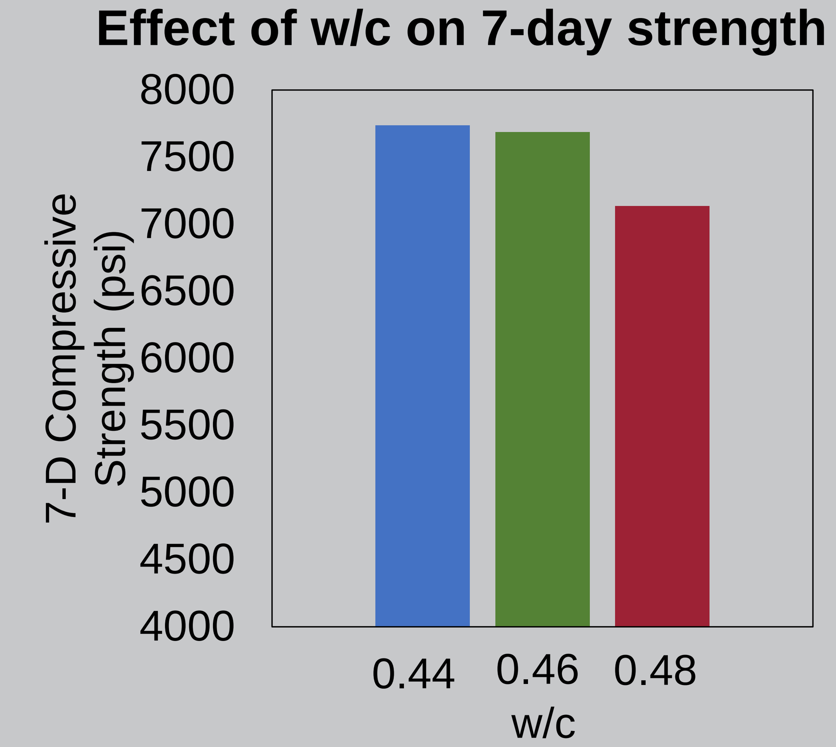
Compressive Strength Gain Profile of RS-SCC and PC-SCC



PC-SCC had high early age strength due to the large amount of cement. There was steady strength gain to 28-days. RS-SCC showed rapid strength gain within the first three days of curing, followed by steady strength gain to 28-days.

	PC-SCC	RS-SCC		
Cement, (lb/CY)	850	841	804	792
Coarse Agg. 3/8 in. chipped limestone (lb/CY)	1400	1430	1420	1400
Fine Agg. (lb/CY)	1414	1203	1245	1250
HRWRA (fl.oz./100 lb cement)	12	15	15	15
Citric acid solution (fl.oz./100 lb cement)	-	18	18	18
w/c	0.37	0.44	0.46	0.48

Effect of w/c on 7-day strength



Early-age strengths of RS-SCC were similar, regardless of w/c. For the sake of comparison and deviation in compressive strength values, 7-day compressive strength values were used to compare different w/c for RS-SCC

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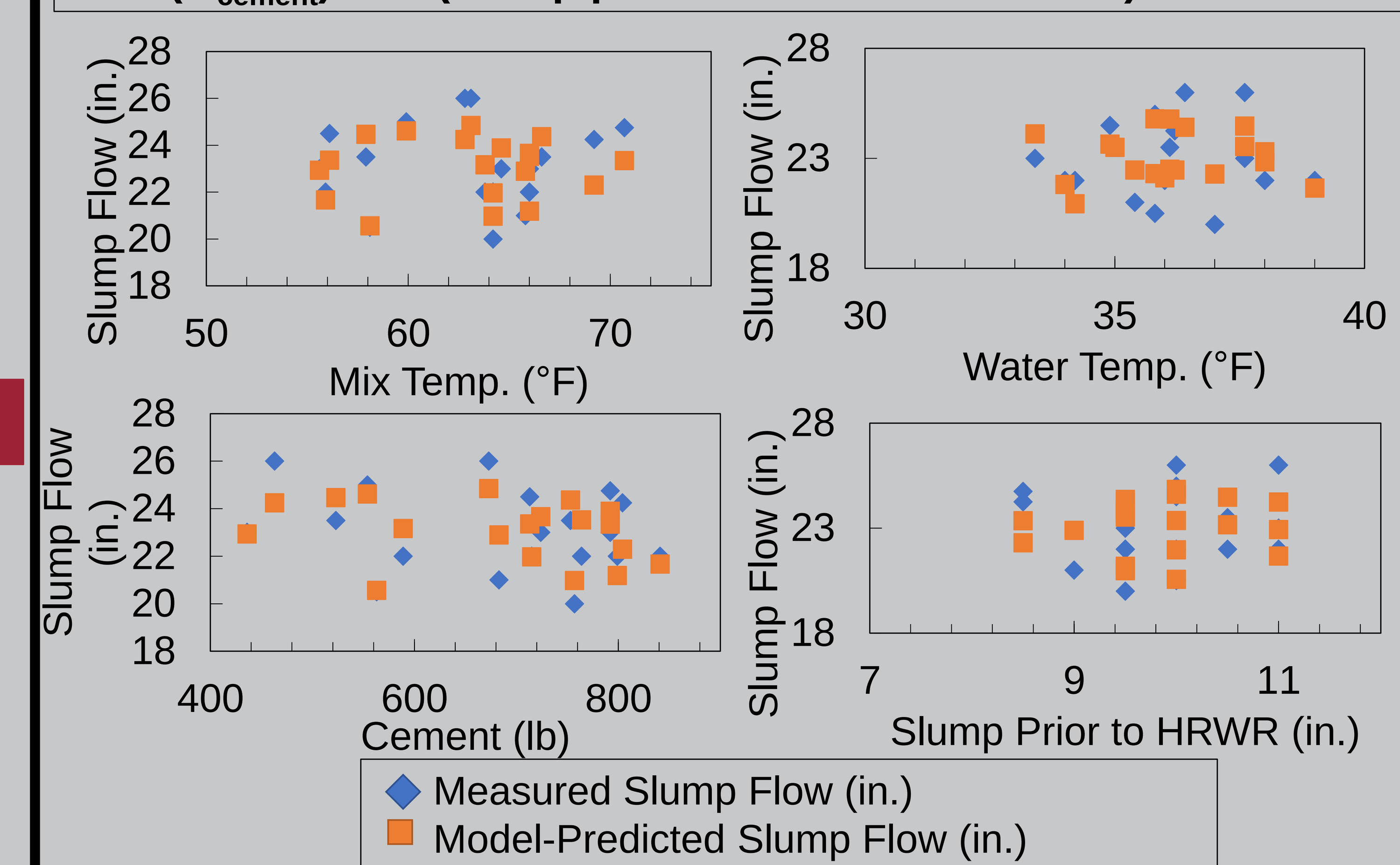
DISCUSSION

Since the objective of this research was to develop a RS-SCC mixture design, analysis of both concrete fresh properties and hardened properties must be performed. A multi-linear regression was performed to determine the effect of mixture proportioning and material properties on slump flow, a key characteristic of all SCC.
Major, moderate, and minor influencers in addition to ambient temperature, mix temperature, water temperature, and slump prior to the addition of HRWR were entered into the model. Variables were removed step-wise until all p-values ≤ 0.05.

Slump Flow (in.) = 39.4+0.19*(mix temp. °F) +0.32(water temp. °F) - 0.06*(w_{cement})+1.7*(slump prior to addition of HRWR)



This model indicates that the most significant contributors to slump flow are **mix temperature**, **water temperature**, **cement content**, and **slump prior to the addition of HRWR**.

CONCLUSIONS

- Successful mixture proportioning of RS-SCC is possible
- Despite higher water contents, segregation is inhibited in RS-SCC by its rapid-setting nature
- RS-SCC is a feasible substitute for PC-SCC in terms of compressive strength
- The early-age strength of RS-SCC is suitable structural repairs of infrastructure elements

FUTURE WORK

- Incorporation of SCM's to reduce cement content
- Flexural strength of RS-SCC
- Bond strength of RS-SCC with conventional PC concrete
- Interface preparation for RS-SCC repairs
- Lab-scale beam testing of repaired RS-SCC beams

REFERENCES

[1] K. H. Khayat, "Workability, Testing, and Performance of Self-Consolidating Concrete," *ACI Materials Journal*, vol. May-June, pp. 346–353, 1999.
[2] P. K. Mehta and P. J. M. Monteiro, *Concrete: Microstructure, Properties, and Materials*, Third. McGraw-Hill, 2006.