Rheological Properties of Self-Consolidating Concrete at Freezing Temperature

Aljhon Morana
Center for Research and Education in Advanced Transportation Engineering Systems
Department of Civil & Environmental Engineering
Henry M. Rowan College of Engineering
Rowan University

Collaborators

- **Shahriar Abubakri**
  CREATES, CEE, Rowan University
- **Gilson Lomboy**
  CREATES, CEE, Rowan University
- **Danielle Kennedy**
  CRREL, ERDC
- **Benjamin Watts**
  CRREL, ERDC
- **Seth Wagner**
  CRREL, ERDC

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Introduction

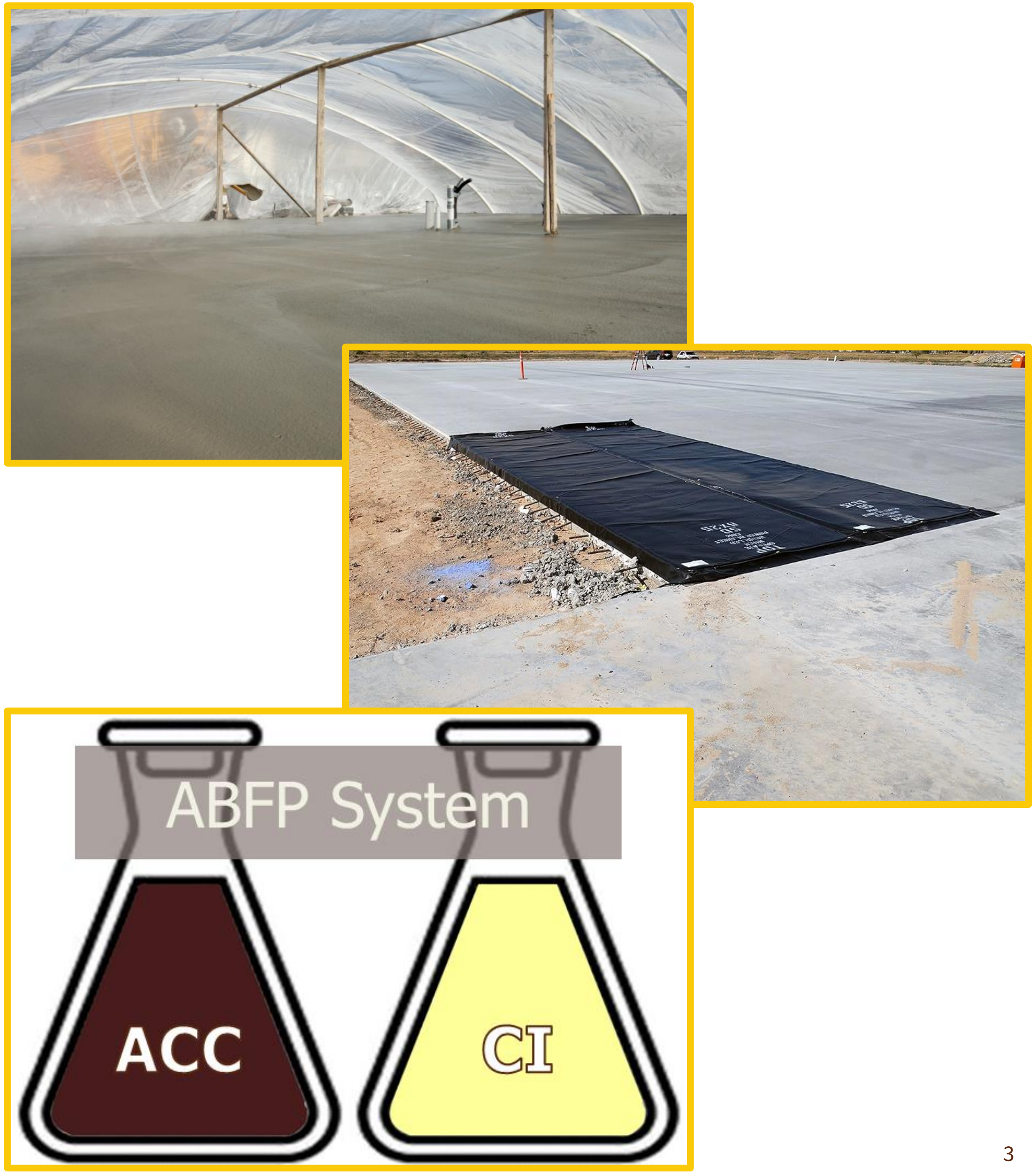
Concrete Protection from Cold-Weather (below 4°C)

- Heated enclosures, heated blankets, heated materials

    energy-intensive leading to higher cost and CO_2 emissions

- Cold-weather admixtures systems

    use of accelerators to hasten hydration and reduce needed protection period



Introduction

Self-Consolidating Concrete

- **highly flowable** and **non-segregating concrete** that does not need mechanical consolidation to fill forms and encapsulate reinforcement
- filling ability, passing ability, stability
- low dynamic yield stress, sufficient plastic viscosity

Introduction

Benefits of Self-Consolidating Concrete for Cold Weather

- Faster concrete placement and accelerated construction
- Easier placement and consolidation for heavily reinforced structures
- Reduced equipment need
- Improved work safety

Objectives

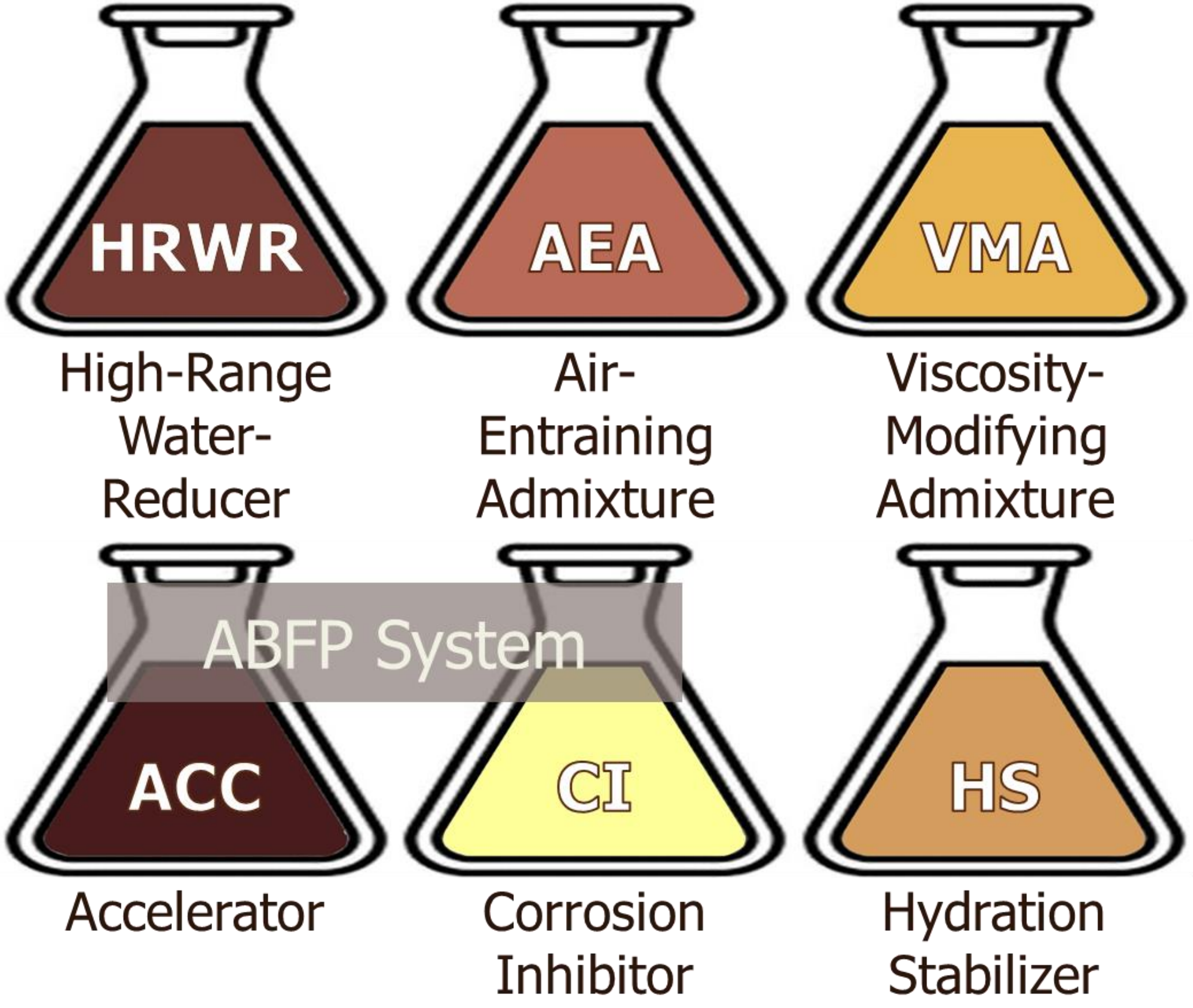
To study self-consolidating concrete (SCC) capable of **MIXING**, **CASTING**, and **CURING DURING COLD WEATHER** with minimum precautions required to prevent frost damage

Specific Objectives:

1. To investigate the **effects of additive-based frost protection** on the fresh properties of SCC
2. To measure the **effects of cold temperatures** on the fresh properties of SCC
3. To determine the **mixing procedures** for cold weather SCC

Materials

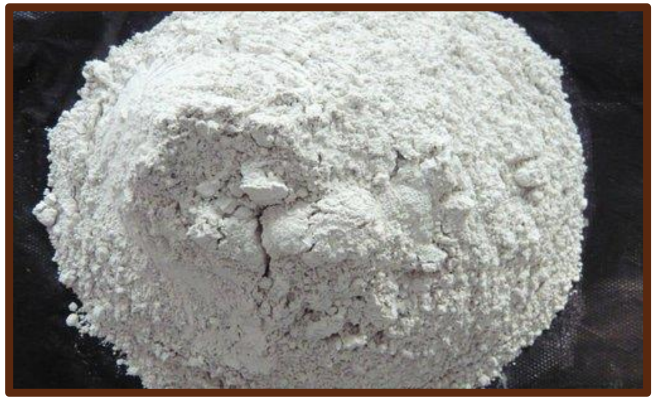
Chemical Admixtures



Cementitious Materials

Portland Cement (PC)

Fly Ash (FA)

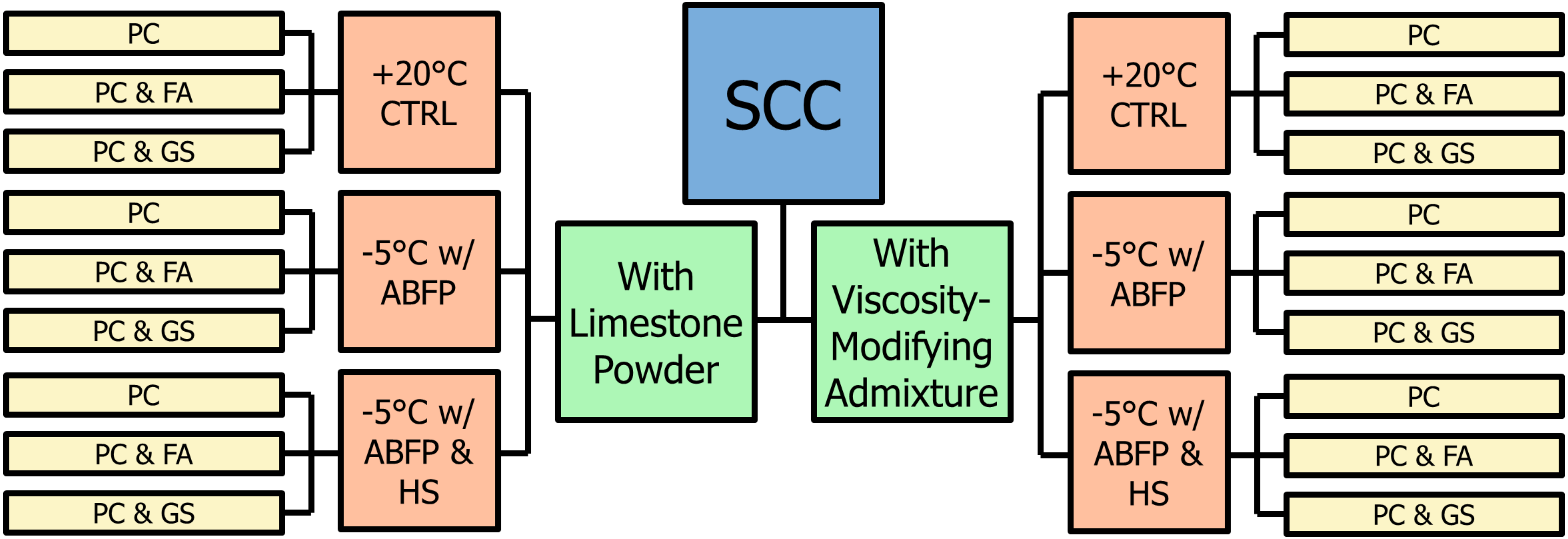


Ground Granulated Blast Furnace Slag (GS)

Research Plan

SCC

Research Plan



SCC

With Limestone Powder

+20°C CTRL
PC
PC & FA
PC & GS

-5°C w/ ABFP
PC
PC & FA
PC & GS

-5°C w/ ABFP & HS
PC
PC & FA
PC & GS

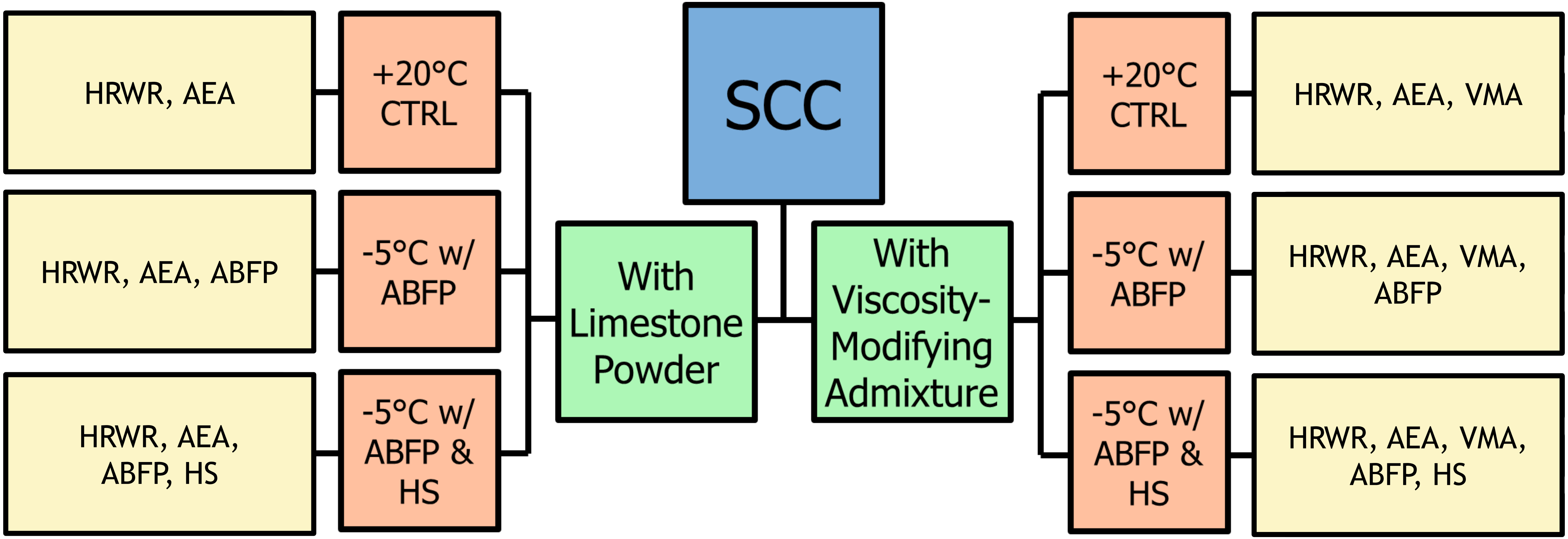
With Viscosity-Modifying Admixture

+20°C CTRL
PC
PC & FA
PC & GS

-5°C w/ ABFP
PC
PC & FA
PC & GS

-5°C w/ ABFP & HS
PC
PC & FA
PC & GS

Research Plan



SCC

With Limestone Powder

- +20°C CTRL
  - HRWR, AEA
- -5°C w/ ABFP
  - HRWR, AEA, ABFP
- -5°C w/ ABFP & HS
  - HRWR, AEA, ABFP, HS

With Viscosity-Modifying Admixture

- +20°C CTRL
  - HRWR, AEA, VMA
- -5°C w/ ABFP
  - HRWR, AEA, VMA, ABFP
- -5°C w/ ABFP & HS
  - HRWR, AEA, VMA, ABFP, HS

Desired Properties

Fresh Property	Test Method	Criteria			Reference
		Good	Acceptable	Bad	
Filling Ability	Slump Flow	22 to 30 in	-	<22 or >30 in	ASTM C1611
Passing Ability	Slump Flow and J-Ring Flow	ΔD ≤ 1 in	ΔD = 1 to 2 in	ΔD > 2 in	ASTM C1621
Static Stability	Visual Stability Index (VSI)	0 to 1	-	> 1	ASTM C1611
Segregation Resistance	Cylinder Penetration	0 to 0.4 in	0.4 to 1.0 in	> 1.0 in	ASTM 1712
Freezing Point	Cooling Curve	≤ -5 °C	-5 to -2 °C	> -2 °C	Curing Temp -5 °C
Air Content	Pressure Method	7.5%	6% to 9%	<6% or >9%	ACI 211.1-22 ASTM C94-22

Tests

Slump Flow
T50

J-Ring Flow

Segregation
Resistance

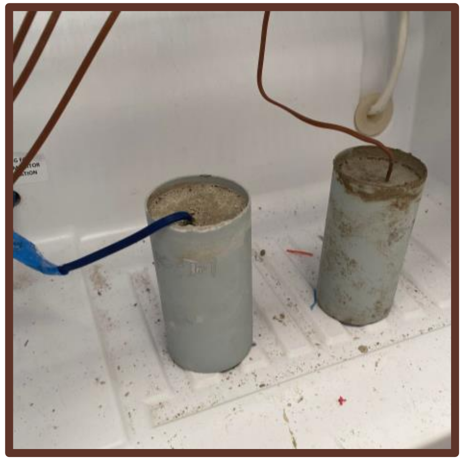
Yield Stress
Viscosity
Thixotropy

Temperature

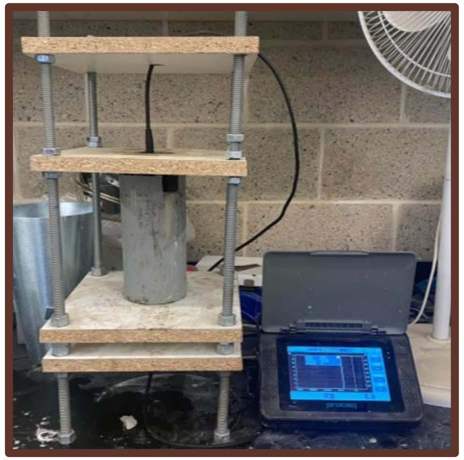
Performed at 0, 15, 30, 45, and 60 minutes after the mixing process.

Tests


Air Content


Freezing Point


Setting Time


Ultrasonic Pulse Velocity

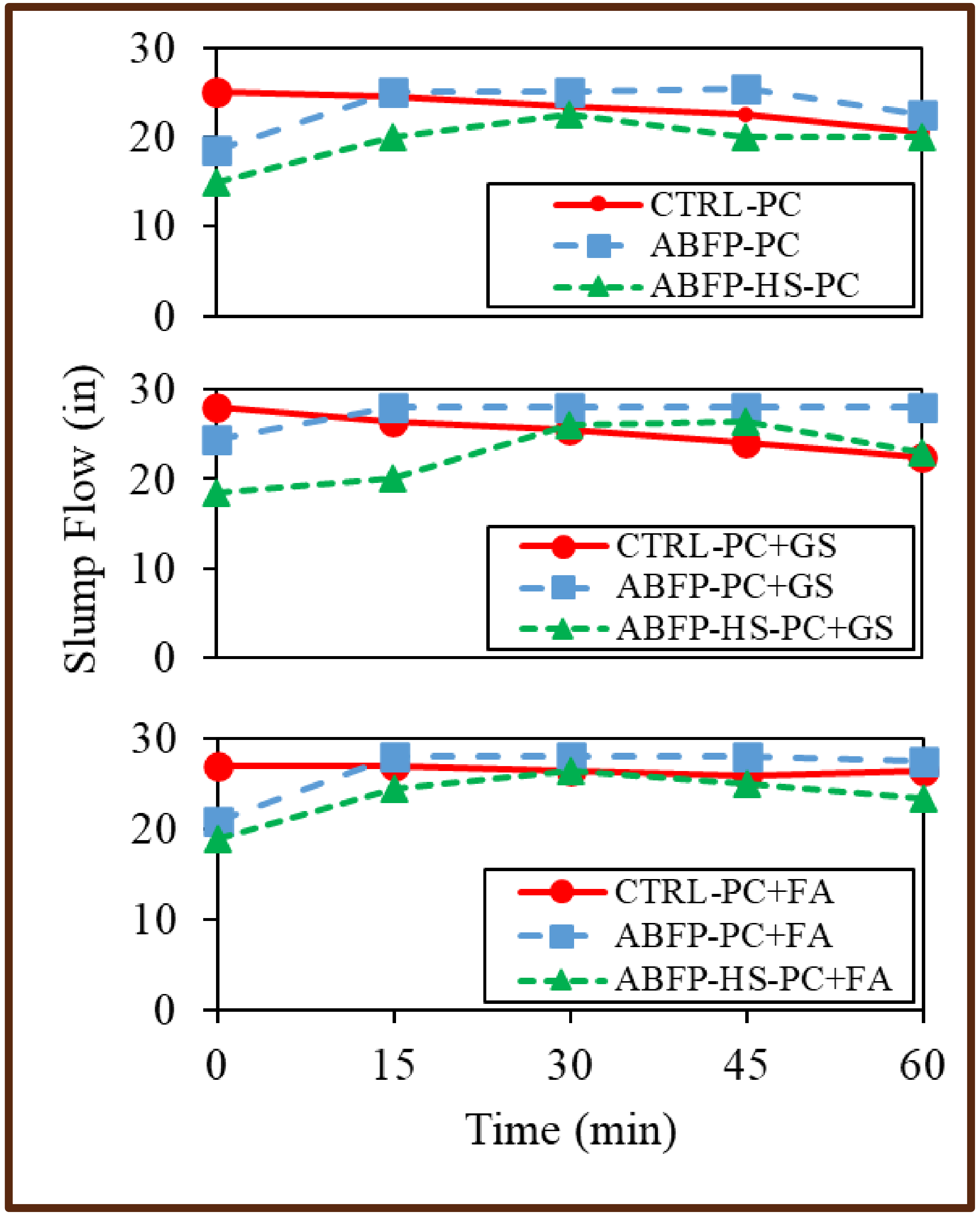

Compressive Strength

Compressive strength test is performed a 3, 7, 28, 56, and 90 days.

Current Results

SCC with Limestone Powder

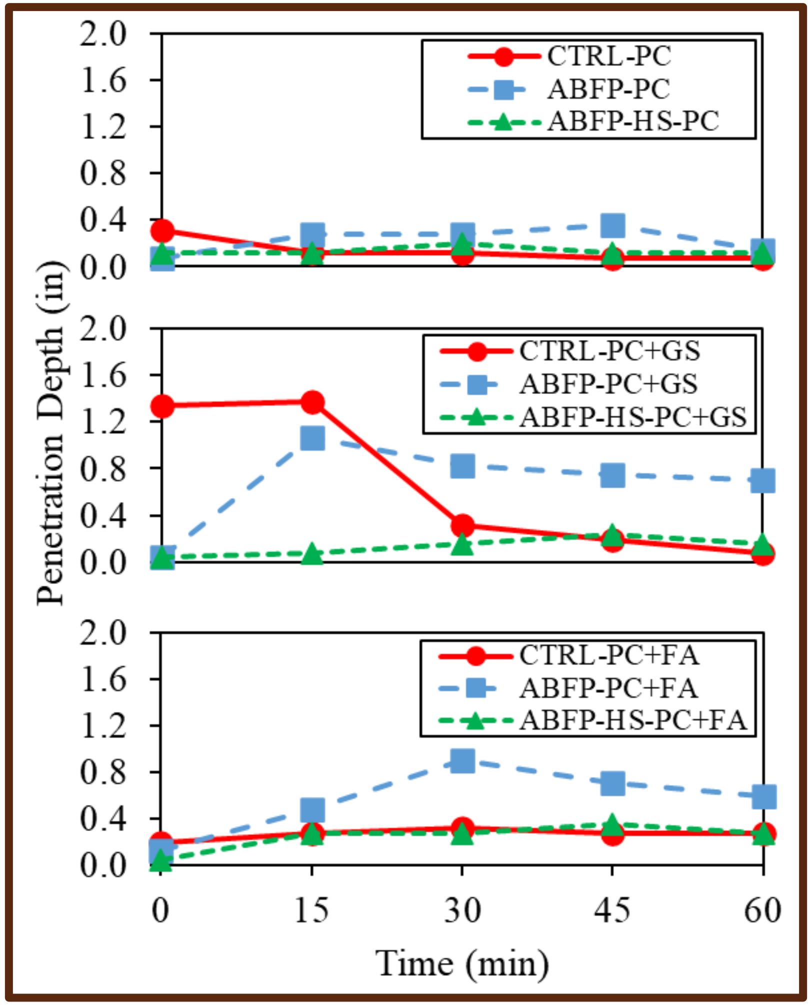
- Mixtures at 20 ° C were most flowable right after mixing and continuously lose slump flow
- Mixtures at -5°C with ABFP exhibited significant gain in slump 15 minutes after mixing
- Adding hydration stabilizer reduces workability and delays the peak slump flow at 30 to 45 minutes after the mixing process



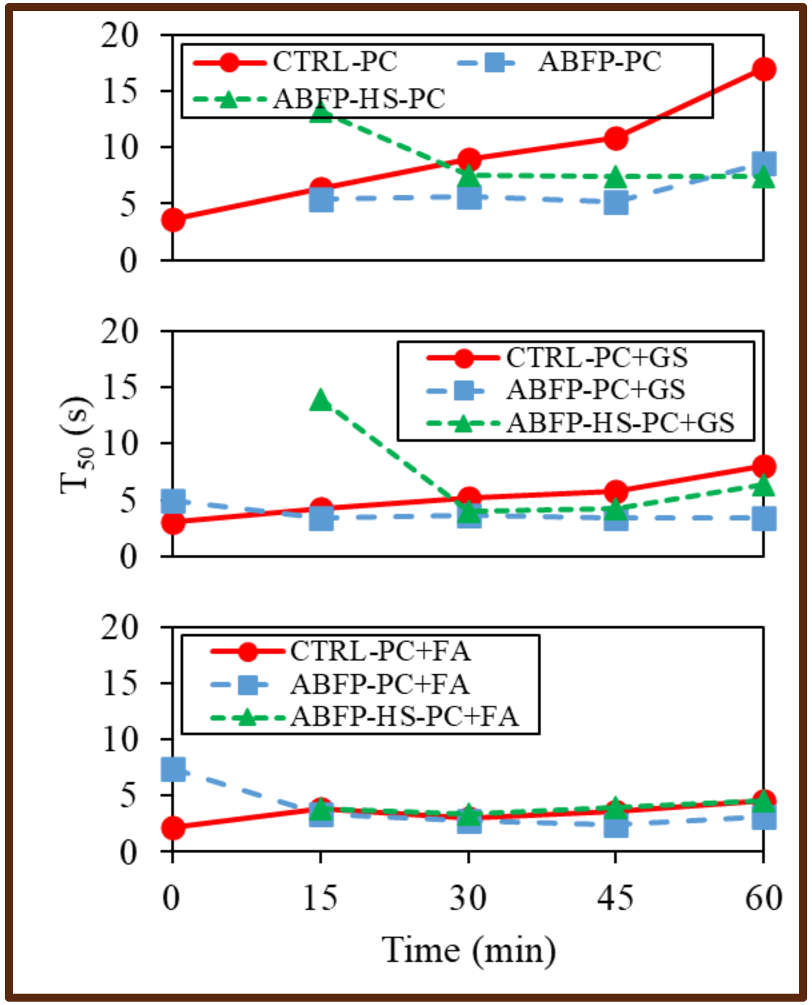
Slump Flow vs. Time

Current Results

SCC with Limestone Powder



Penetration Depth vs. Time

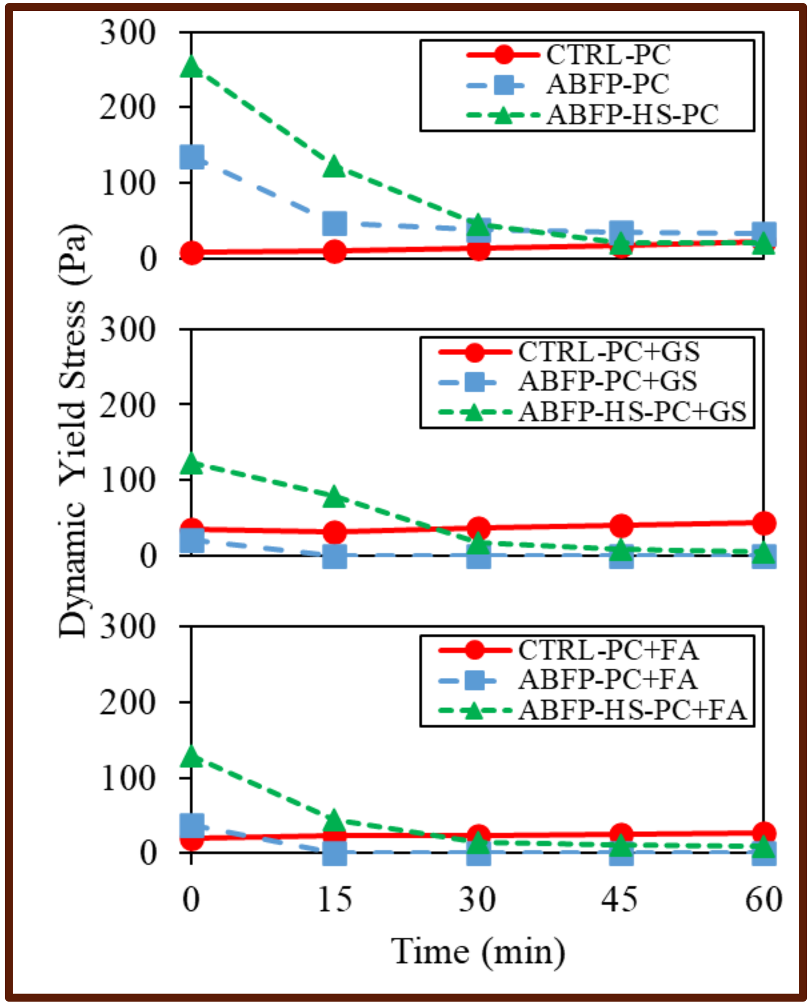


T_{50} vs. Time

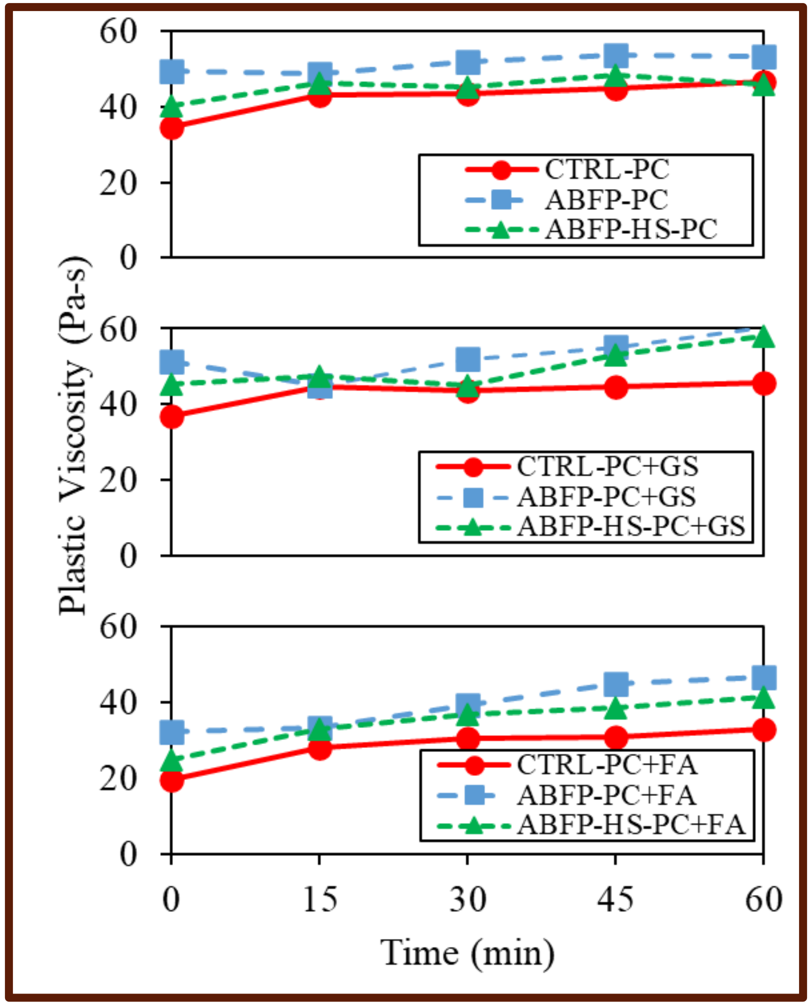
- At -5°C, segregation resistance improved when hydration stabilizer was added
- At -5°C, the T_{50} of mixtures with hydration stabilizer becomes acceptable 30 minutes after the mixing process

Current Results

SCC with Limestone Powder



Dynamic Yield Stress vs. Time

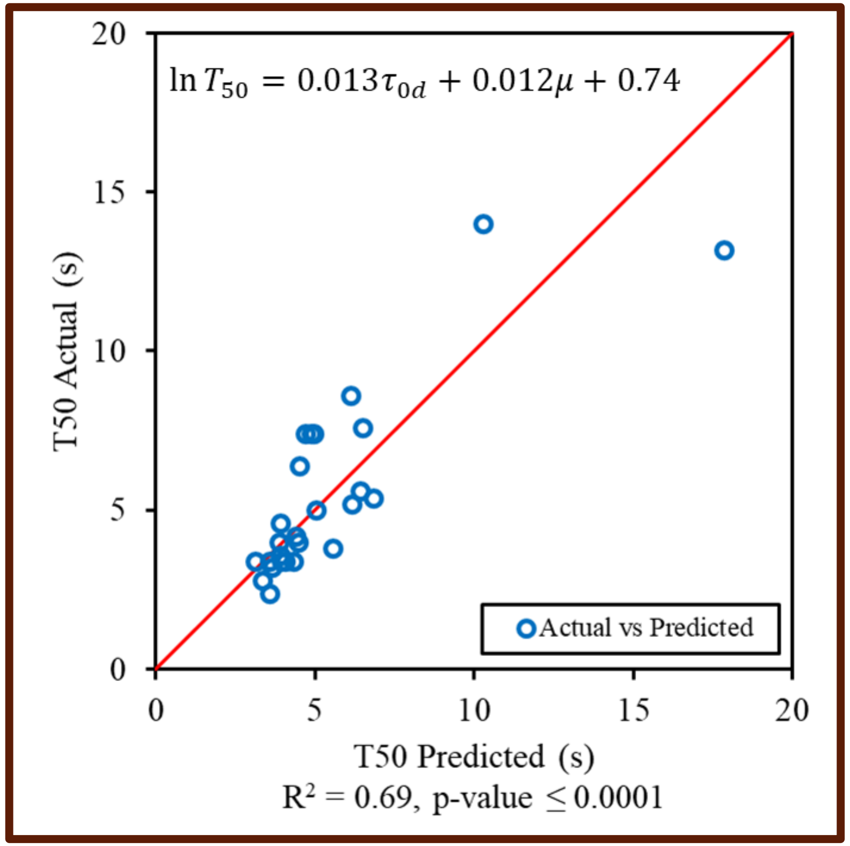


Plastic Viscosity vs. Time

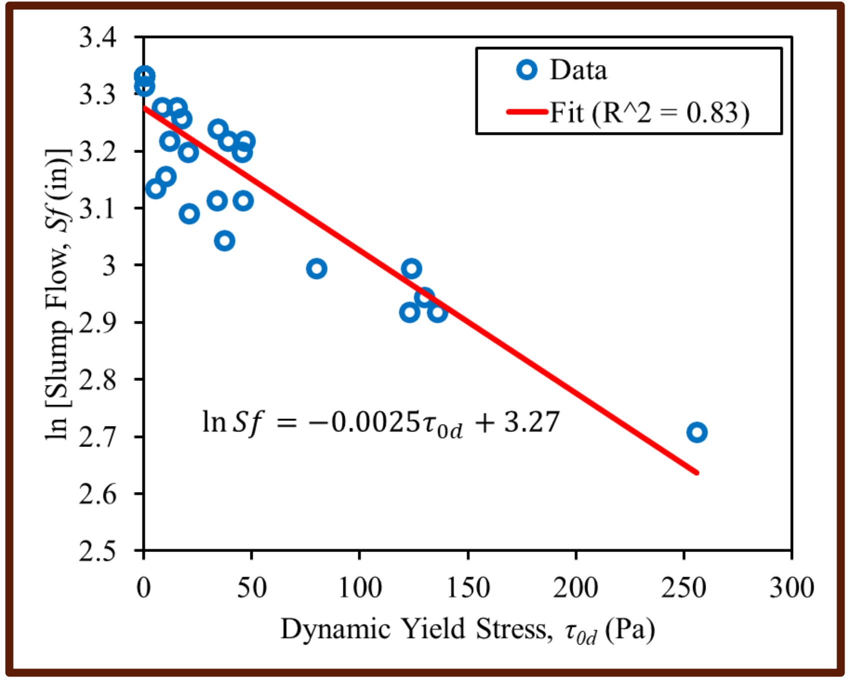
- For mixtures done at -5°C, dynamic yield stress significantly decreases during the first 30 minutes
- Plastic viscosity gradually increases for all mixtures

Current Results

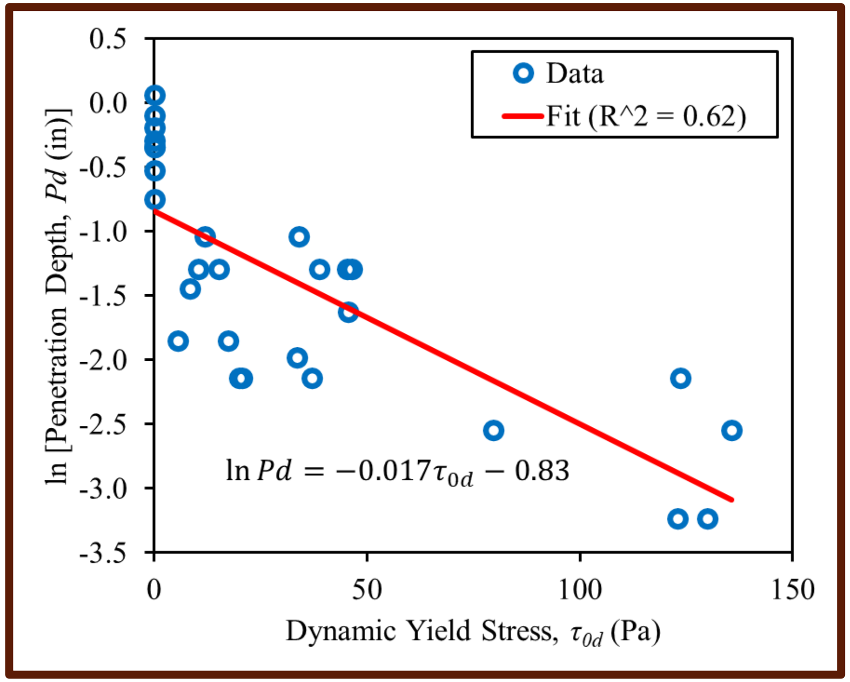
SCC with Limestone Powder



Predicting T_{50} based on Dynamic Yield Stress and Plastic Viscosity



Slump Flow vs. Dynamic Yield Stress



Penetration Depth vs. Dynamic Yield Stress

- Dynamic yield stress influences both slump flow and penetration depth
- T50 may be predicted by dynamic yield stress and plastic viscosity

Conclusion

- From 15 to 60 minutes after the mixing process, SCC at -5°C maintains filling ability, passing ability, and segregation resistance requirements.
- The flow behavior of SCC at -5°C is determined by its dynamic yield stress and plastic viscosity.

Future Work

- Analyze cold-weather SCC mixtures with viscosity-modifying admixture
- Compare ultrasonic pulse velocity and penetration resistance of cold-weather SCC under freezing temperature
- Analyze isothermal calorimetry data of cold-weather SCC
- Assess CO_2 emissions of various cold-weather concreting techniques
- Develop fiber-reinforced cold-weather SCC

END