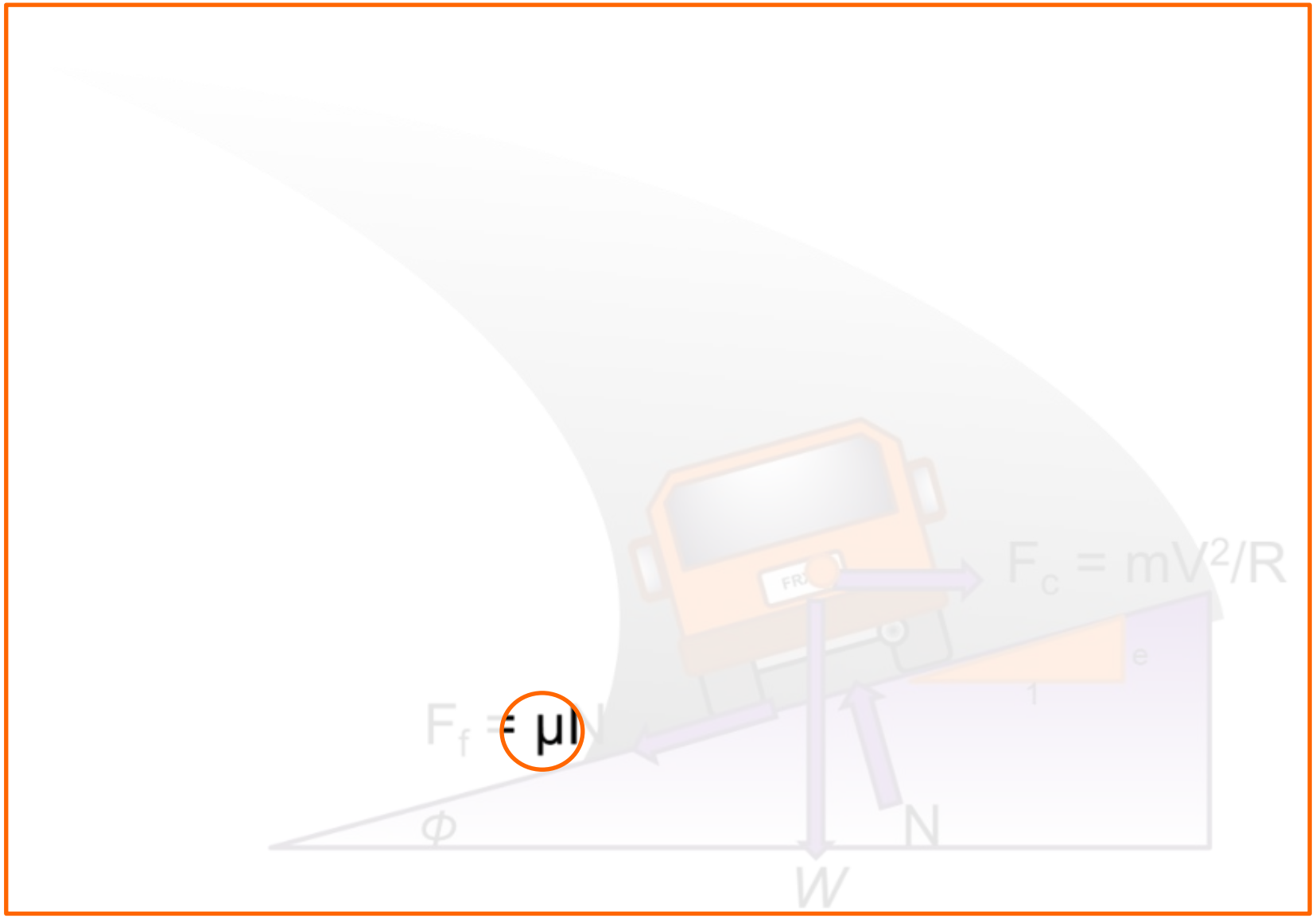
Ultra High-Performance Concrete (UHPC) as a High Friction Surface Treatment (HFST) Binder

Kyle F. Maeger, PhD Student
Adam R. Biehl, Masters Student
Prasad Rangaraju, Professor, PhD, PE, FACI
Clemson University

A Presentation for ACI 123 Research-in-Progress Session
30 October 2023

Introduction

- Design for roadway safety



Introduction

Calcined Bauxite Aggregate

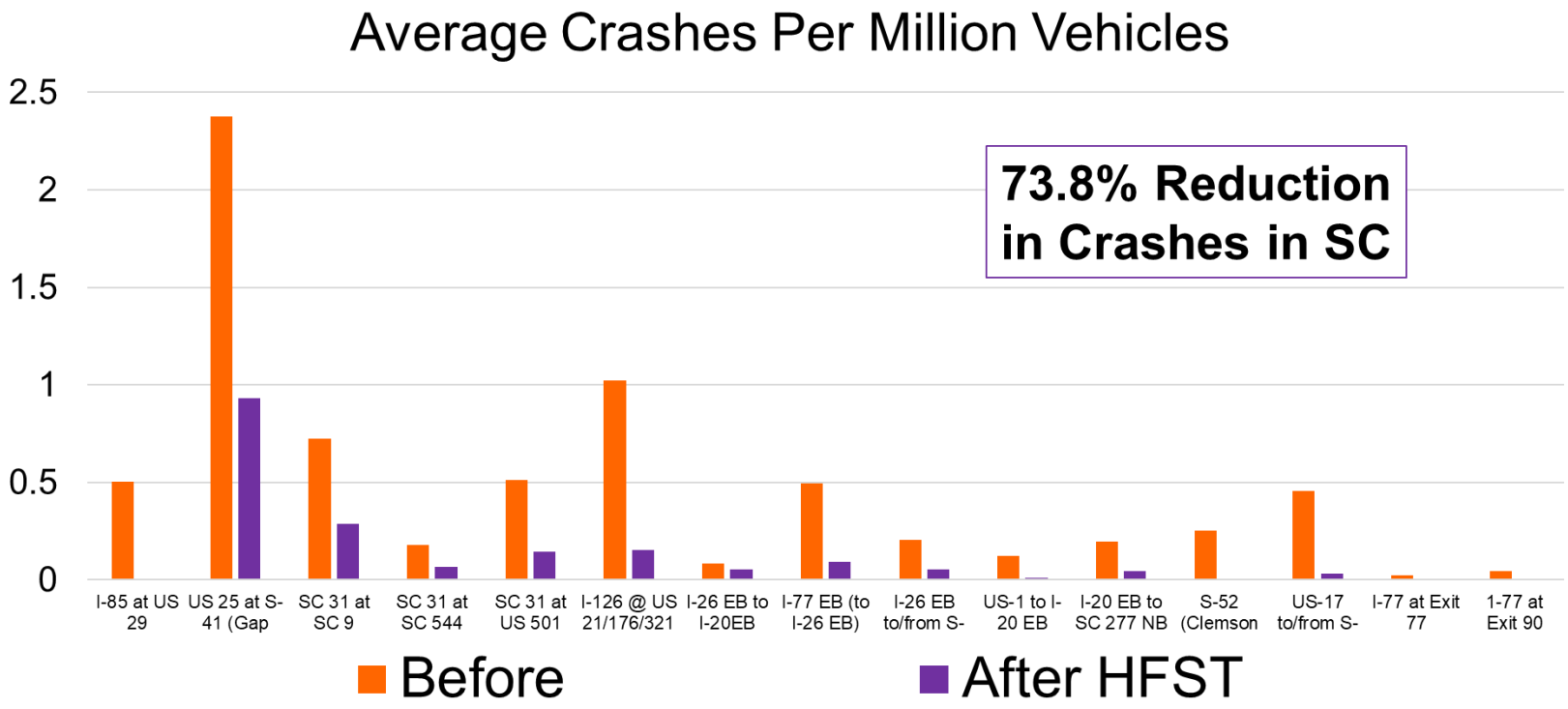
+

=

High-Friction Surface Treatment (HFST)

Introduction

- Recent FHWA studies estimate that HFST's "**reduce wet crashes by 83 percent and total crashes by 57 percent** (FHWA 2023)"(Merritt, David K. et al. 2020)
  - Ex: South Carolina



*Timespan for collection of data varied by section from 2003 to 2016, data is normalized by traffic count to account for this

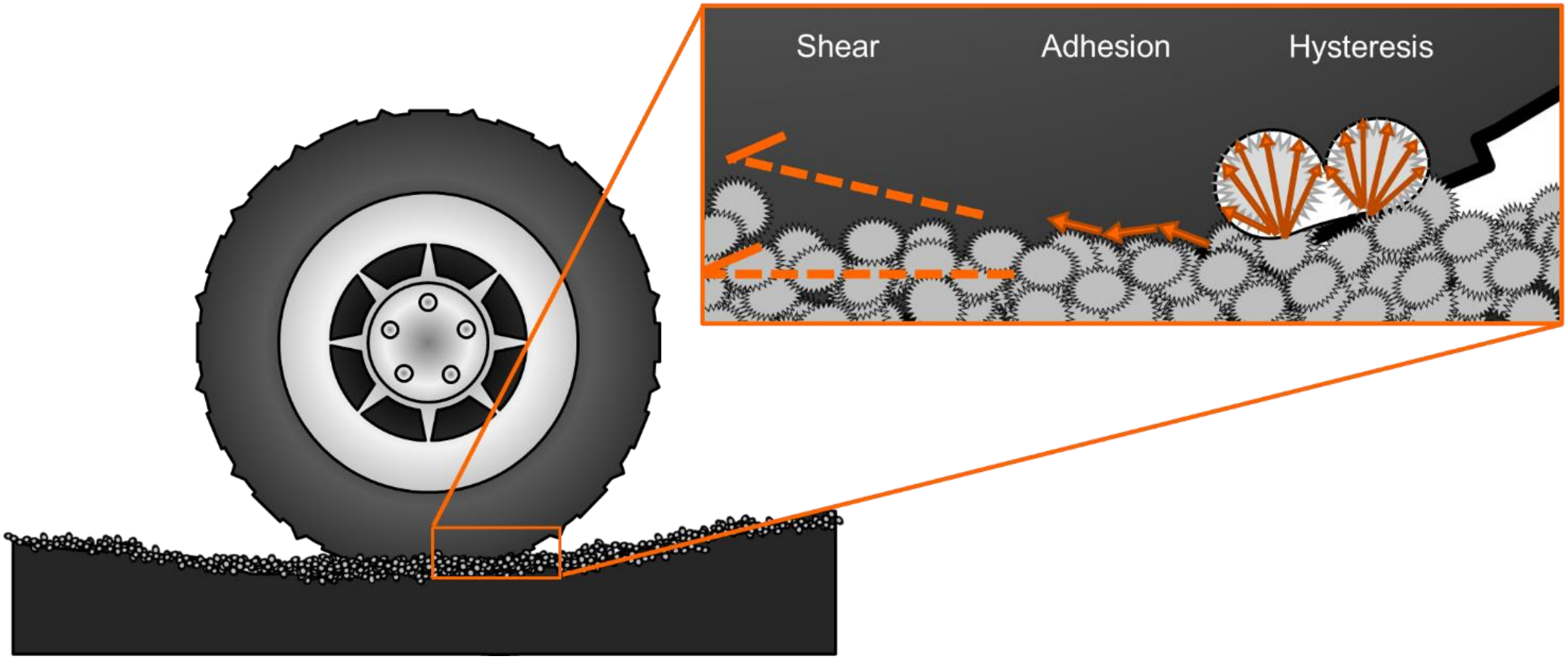
Problem Statement

- High cost relative to standard pavement maintenance
  - Calcined Bauxite **~$700/ton**
    - vs. ~$16-60/ton standard aggregate
  - Epoxy Resin **~$3.27/SF** at 0.06 inch thick
    - Vs. UHPC without steel $0.39/SF at 0.25 inch thick
- High Carbon Footprint
  - Calcination process of aggregate
  - Shipping (aggregate primarily sourced in China)
- Service life
  - Resin binder breaks down after 7-12 years resulting in lower or differential friction
- UHPC with locally sourced aggregates could be a suitable alternative

Objectives

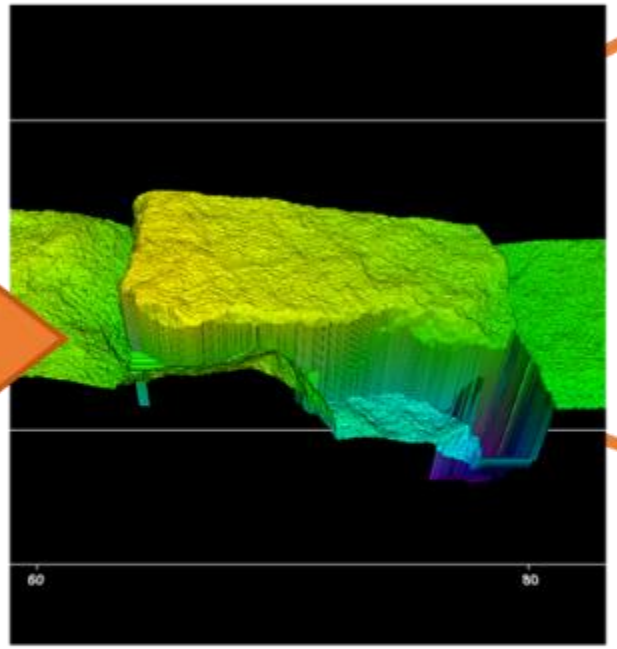
- Develop and assess a UHPC based HFST
  - 1) Evaluation of local aggregate
  - 2) Development of UHPC mix design
  - 3) Development and assessment of application to substrate methodologies
  - 4) Assess friction, texture and abrasion performance of UHPC based HFST

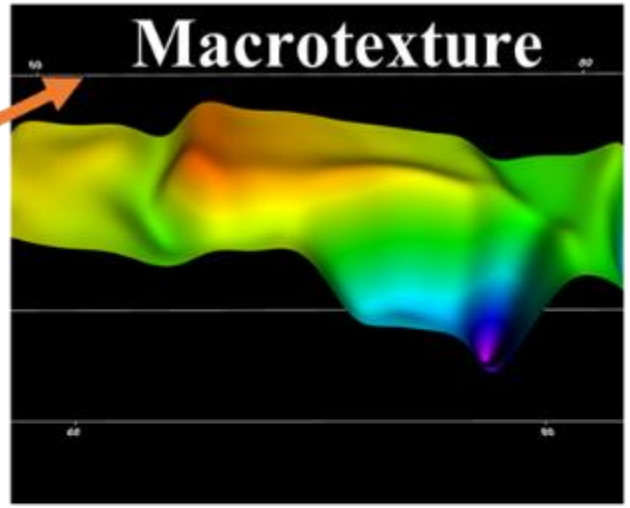
Friction and Texture

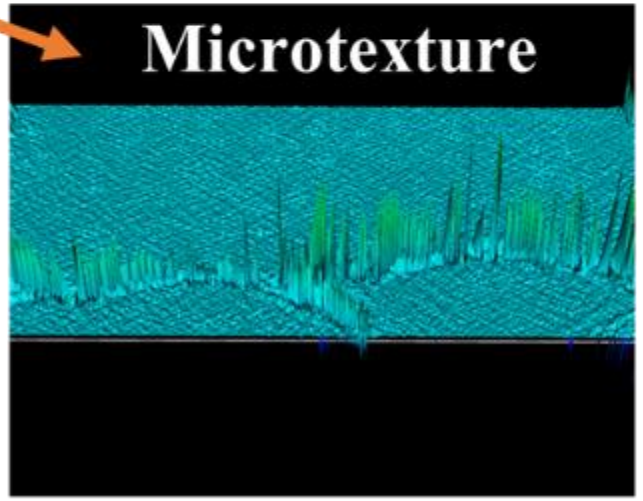


adapted from Andresen and Wambold 1999; *Hall et al. 2009*

Aggregate Testing Results







Aggregate Testing

Model Effects of:

Various Gradations of
Five aggregates

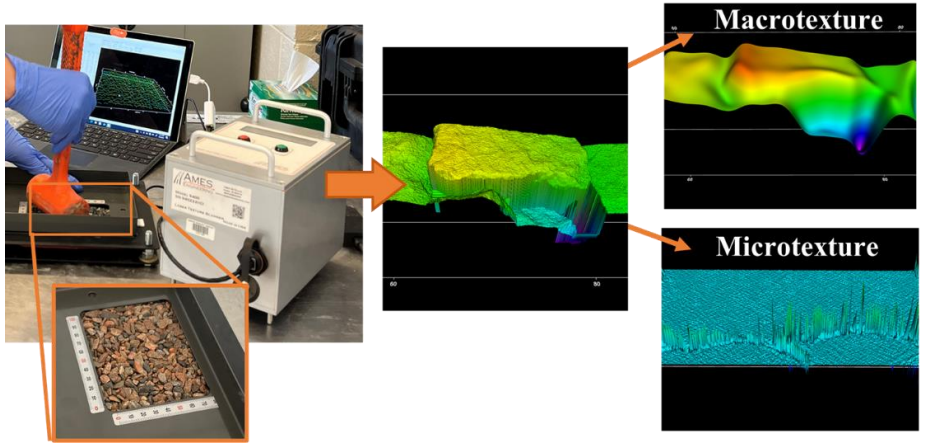
Micro-Deval Abrasion
(ASTM D7428-15)

https://www.globalgilson.com/micro-deval-apparatus

LA Abrasion
(ASTM C131-06)

https://store.forneyonline.com/los-angeles-abrasion-110-1-60

On:



Macro- & Microtexture

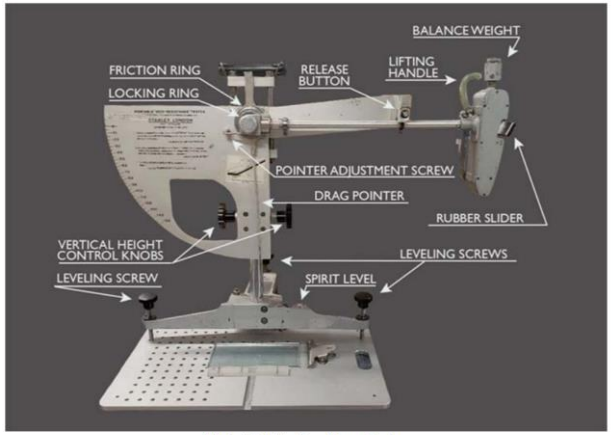


FIG. 1 British Pendulum Tester

Friction (ASTM E303-23)

Aggregate Testing Results

- Microtexture parameters were superior to macrotexture in modeling the BPT friction
- Calcined Bauxite remains premier choice (highest friction, lowest loss due to abrasion)
  - Two alternatives provided acceptable performance; maintained BPN >65
  - Slag had the greatest loss in friction (-28.8 BPN after MD) and texture relative to mass loss
  - Highlights shortcomings of mass loss as a quality measure

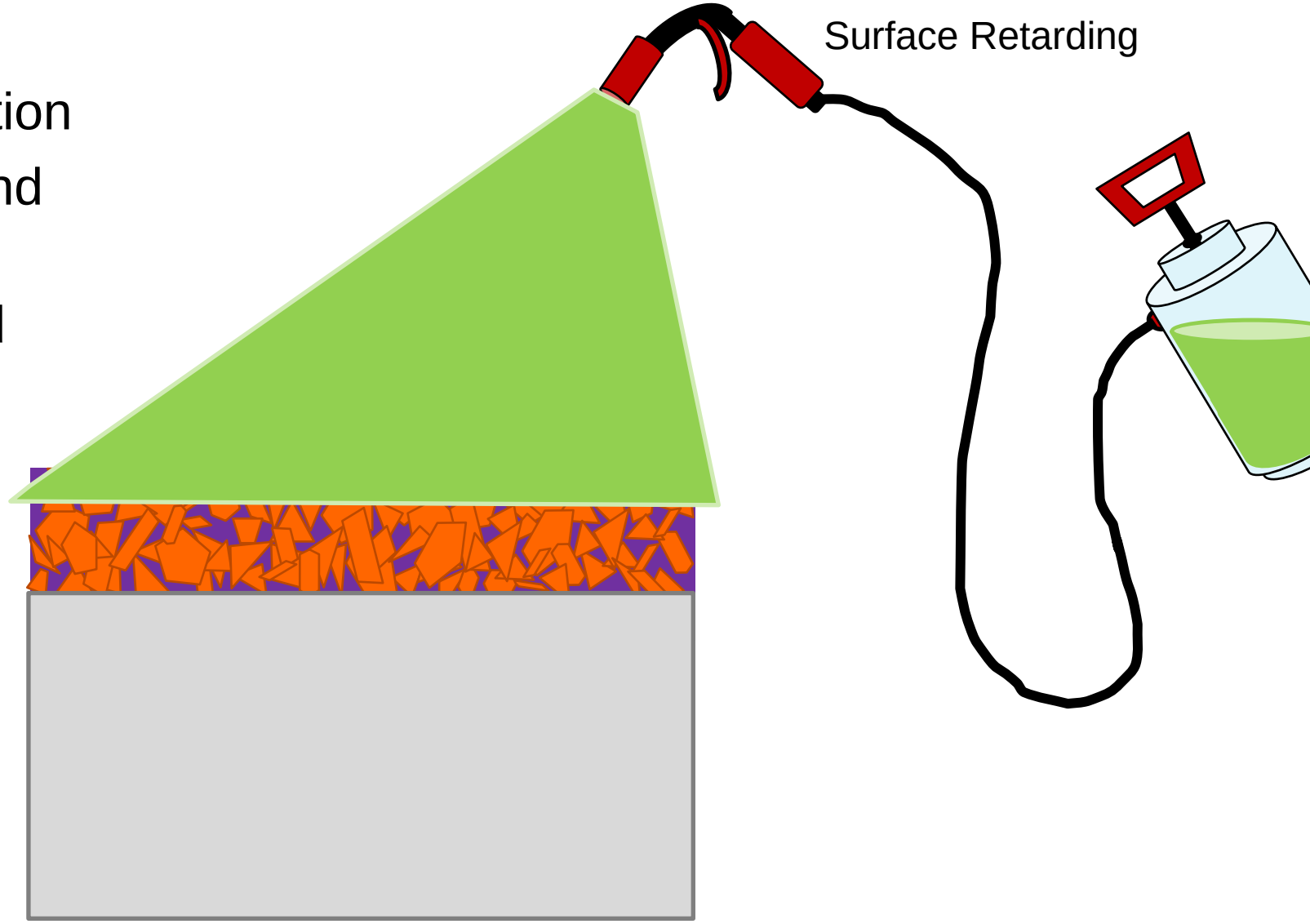
(a) Slag Before Abrasion

(b) Slag after 120 min of MD Abrasion

UHPC Surface Evaluation

- Factors Tested
  - Aggregate moisture condition
  - Broadcast method (with and without vibration)
  - Surface Retarder time and grade
  - Texture and Friction

Vibratory Trowel



Surface Retarder Set Time

5-hr

8.5-hr

12-hr

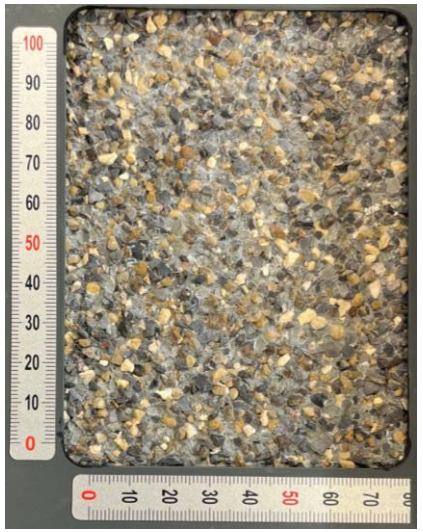
American Concrete Institute
Always advancing

Fall 2023 – Boston, MA

Surface Method Comparison

SMART CENTER
Sustainable Materials Research and Technology Center
CLEMSON
GLENN DEPARTMENT OF CIVIL ENGINEERING


Resin Based

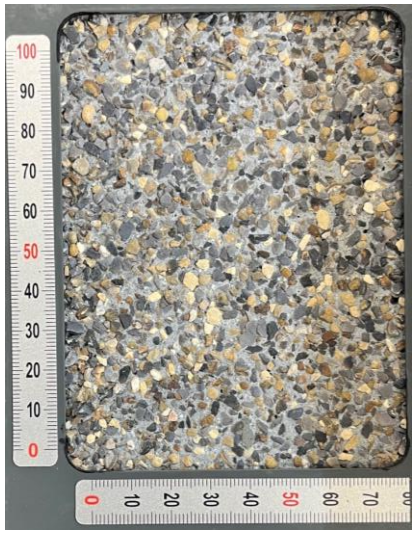

SSD Broadcast

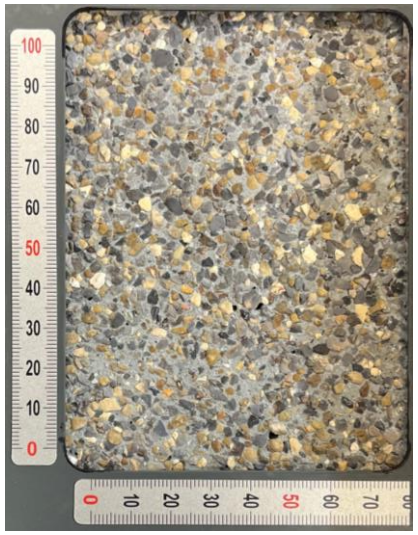

SSD Vibrated


OD Broadcast


OD Vibrated

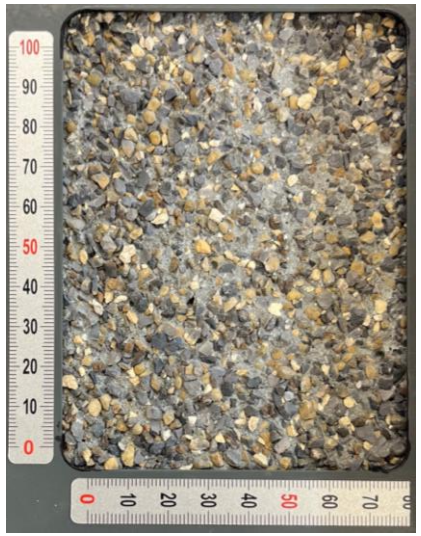

No Retarder w/Wash


VE-15


VE-25


SE-25


SE-50

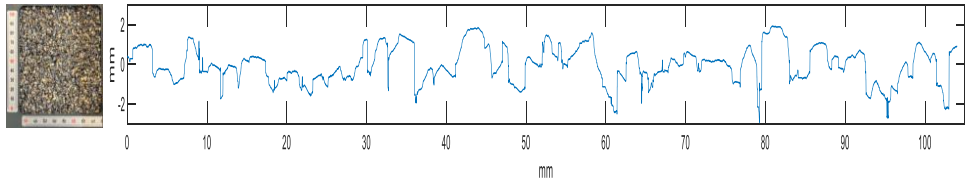

SE-125


SE-200

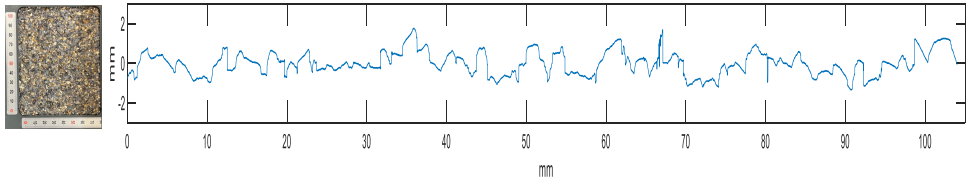
Fall 2023 – Boston, MA

Surface Method Comparison

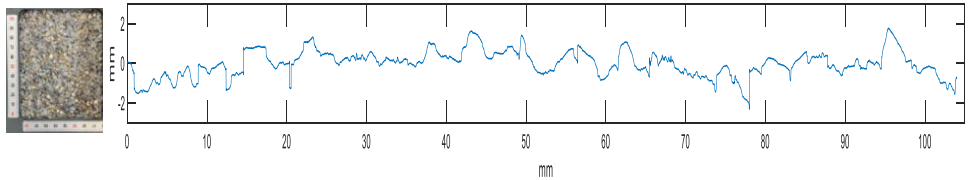
Resin Based



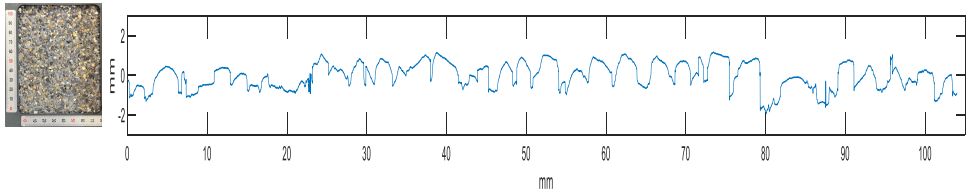
OD Vibrated



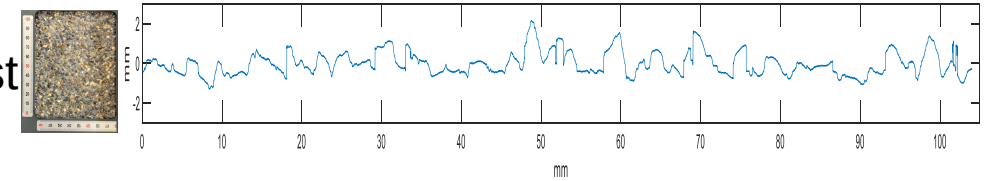
SE-200



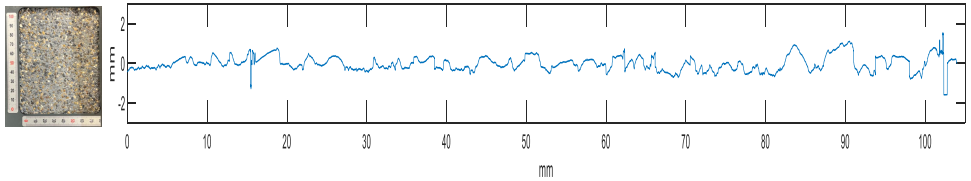
SE-50



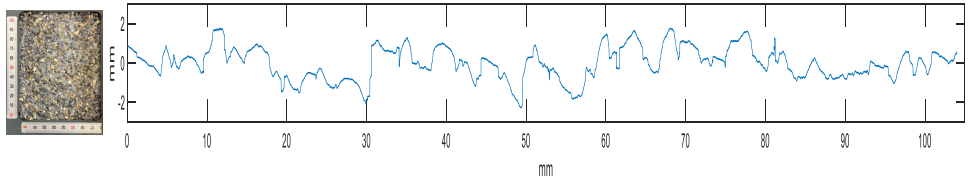
SSD Broadcast



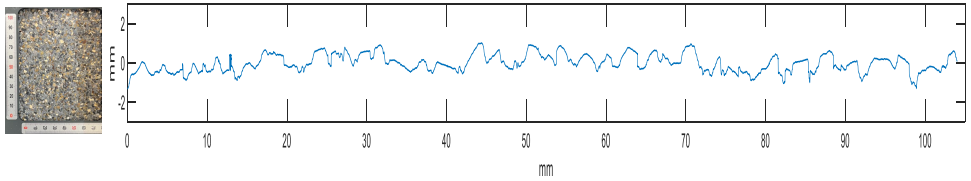
SE-25



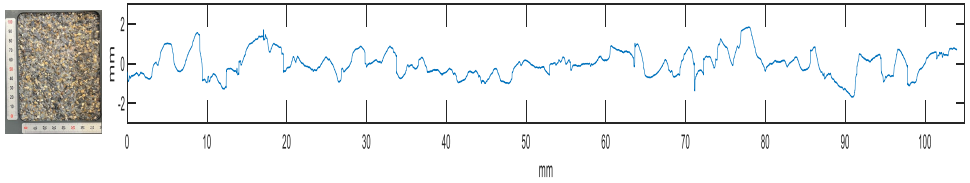
SE-125



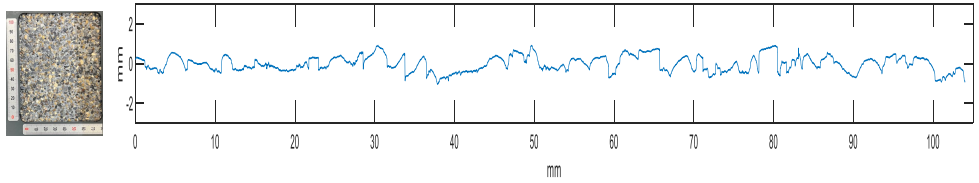
No Retarder



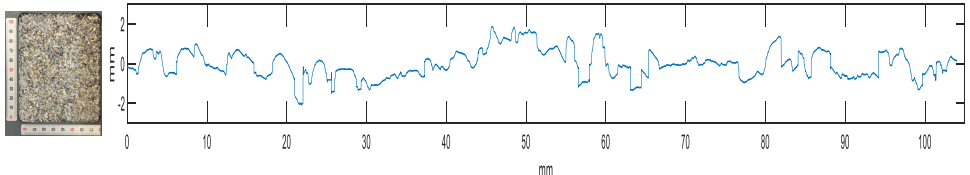
OD Broadcast



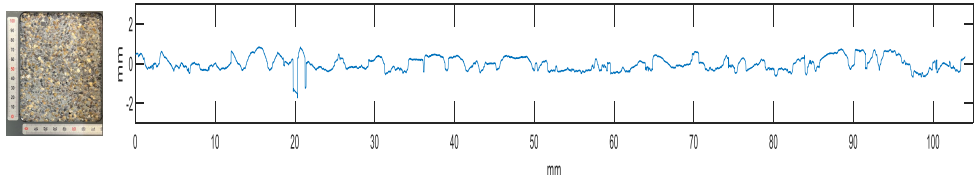
VE-15



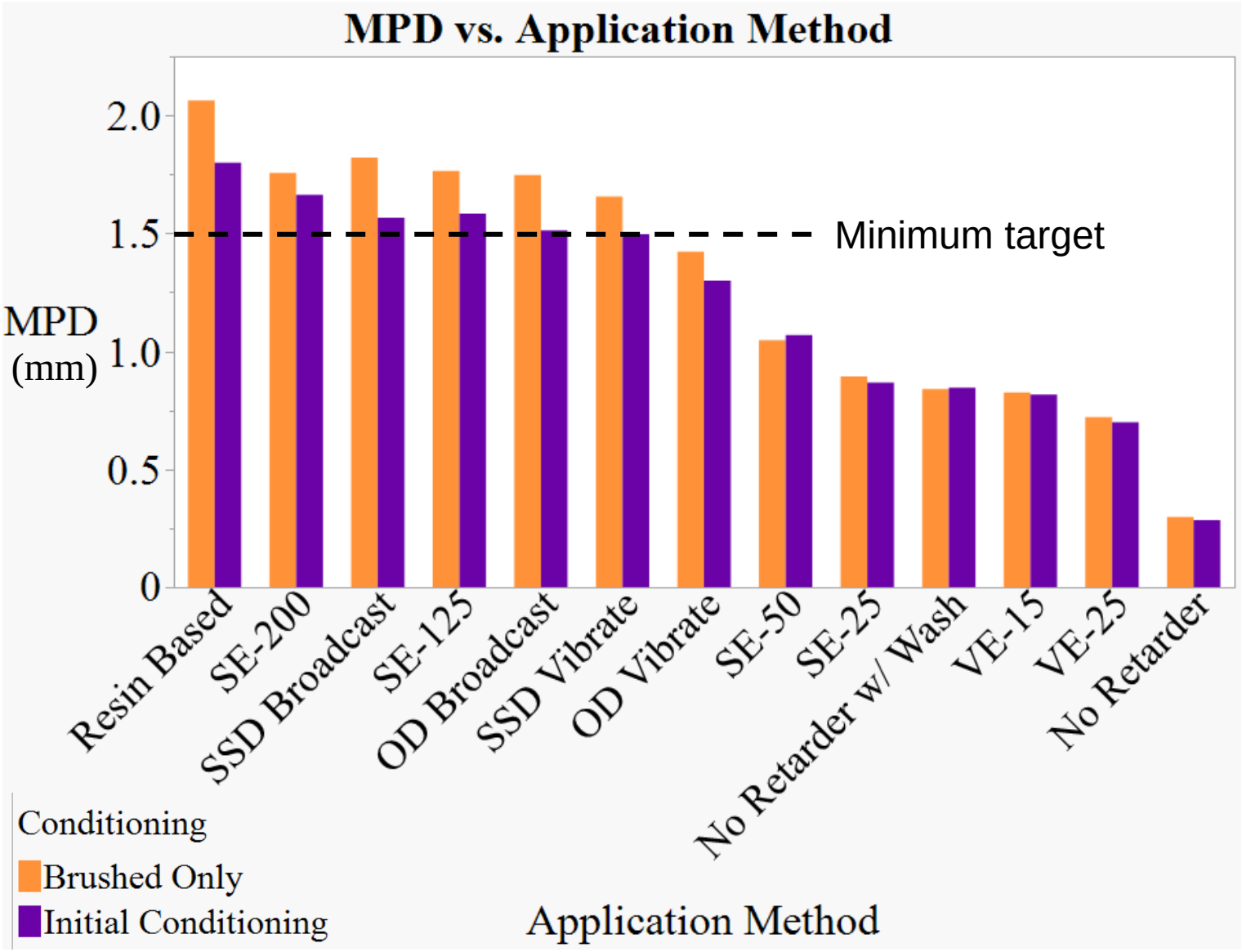
SSD Vibrated



VE-25



Macrotexture of Surfaces



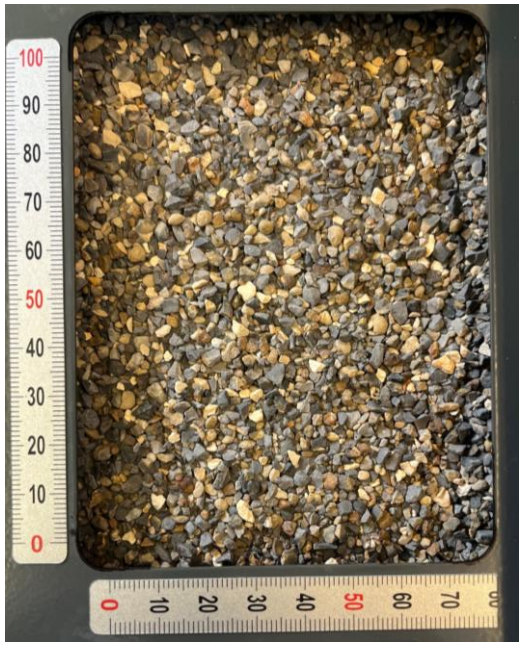
Tukey's HSD of Mean Profile Depth After Conditioning

Application Method							Least Sq Mean
Resin Based	A						1.799
SE-200	A	B					1.664
SE-125		B					1.584
SSD Broadcast		B					1.567
OD Broadcast		B					1.513
SSD Vibrate		B					1.497
OD Vibrate			C				1.300
SE-50				D			1.070
SE-25					E		0.867
No Retarder w/ Wash					E		0.846
VE-15					E		0.817
VE-25					E		0.700
No Retarder						F	0.285

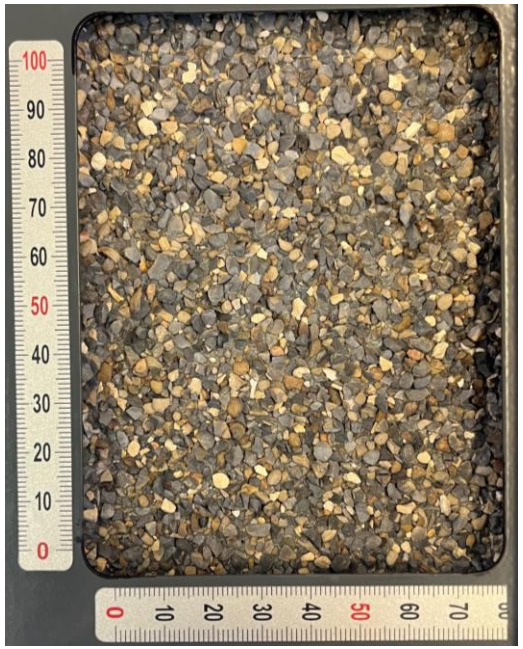
Methods not connected by same letter are statistically significantly different

Surface Method Comparison

- SSD Vs OD Aggregate
- White deposits seen on SSD aggregates
  - Heavier concentration on vibrated samples

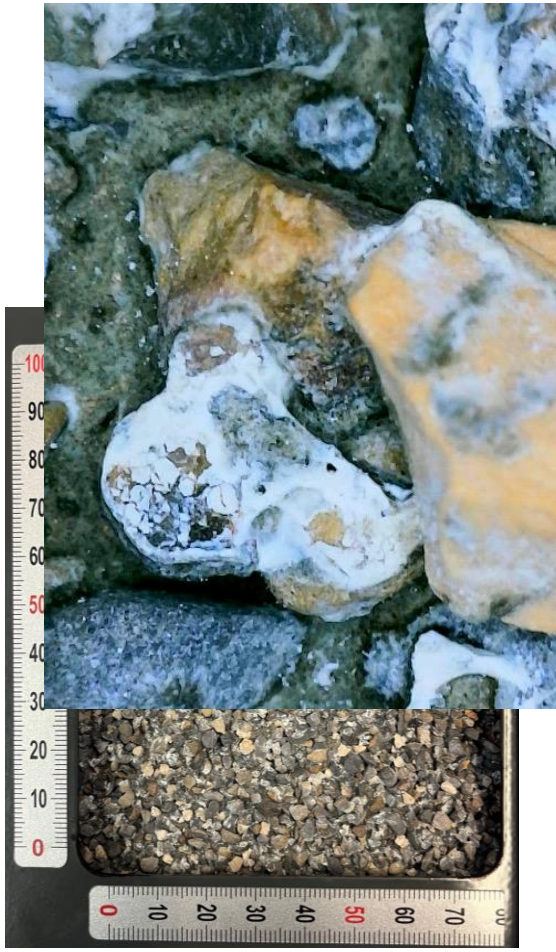


OD Vibrate In



OD Broadcast

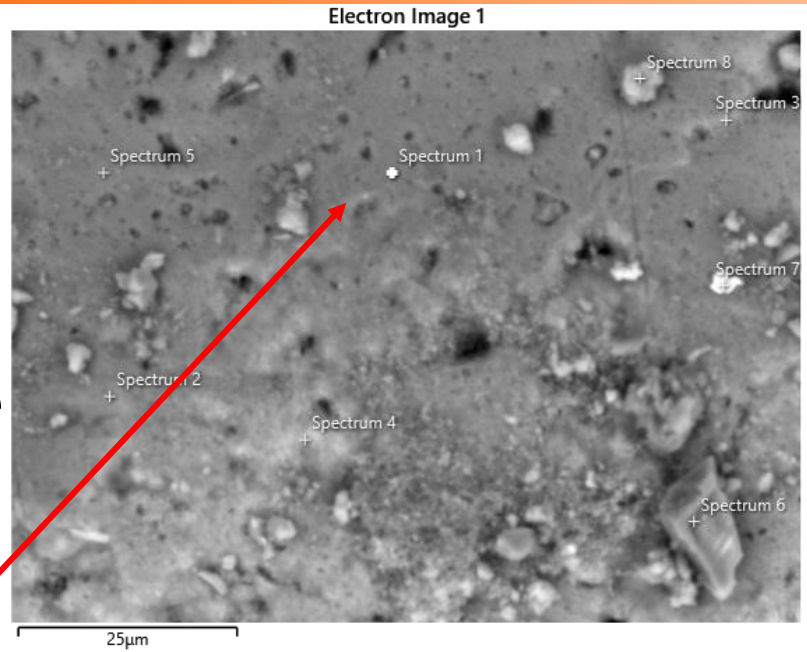
SSD Vibrate In

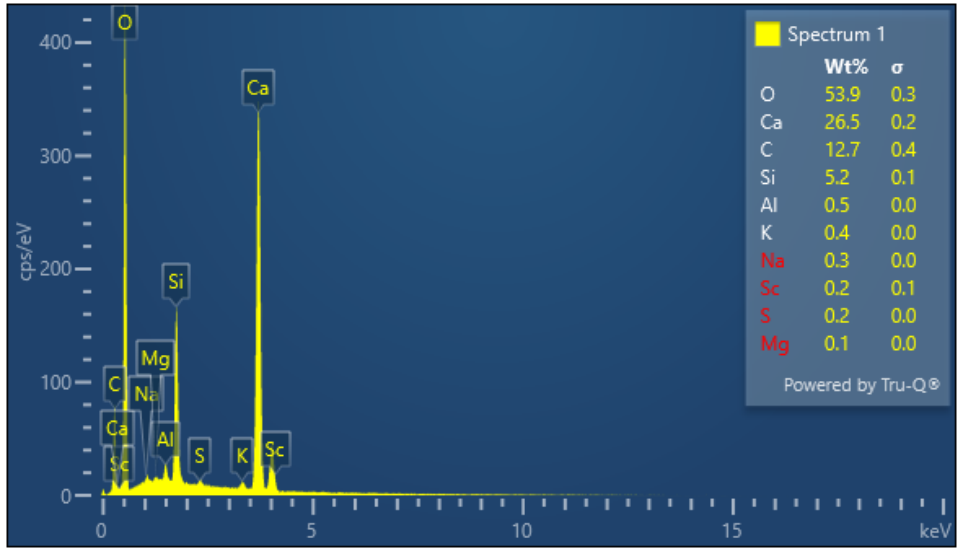


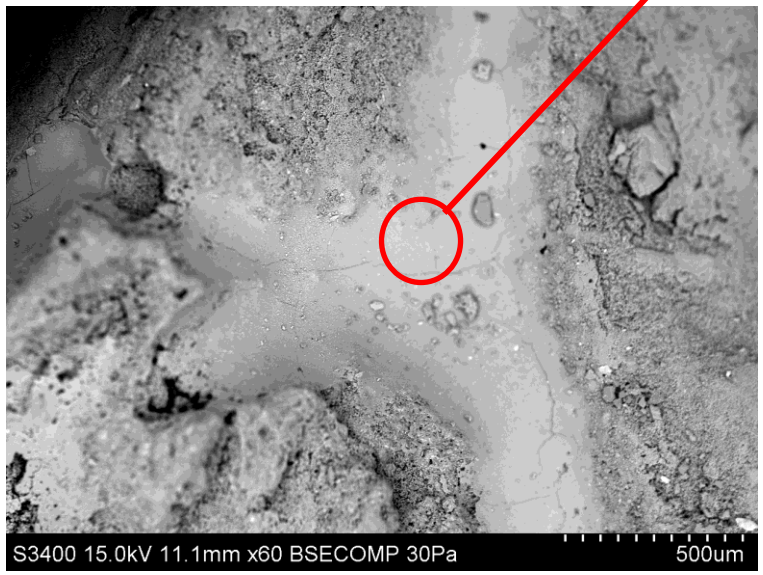
SSD Broadcast

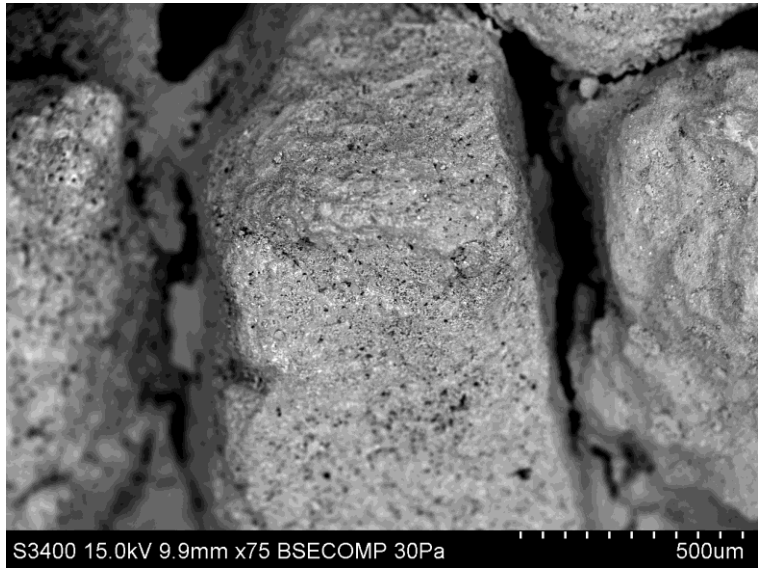
Surface Method Comparison

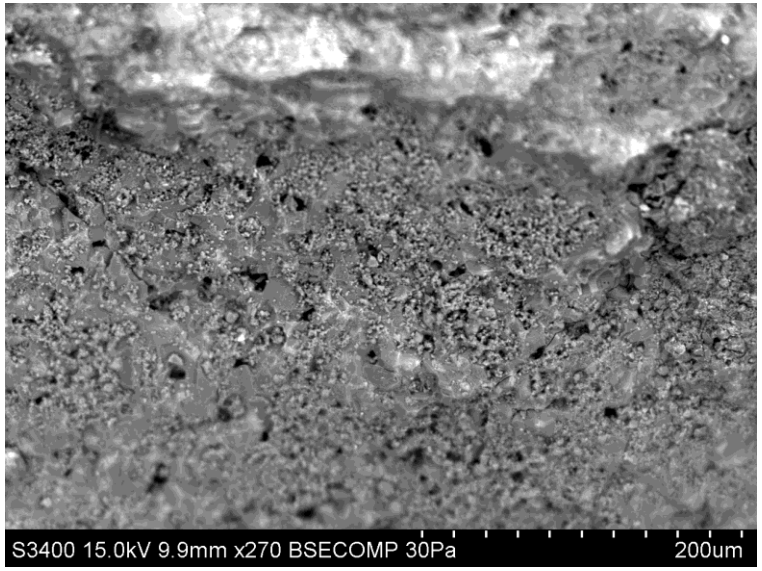
- SEM/EDS results on white deposits
  - Consistent with carbonated calcium hydroxide (high w/c cement deposits)





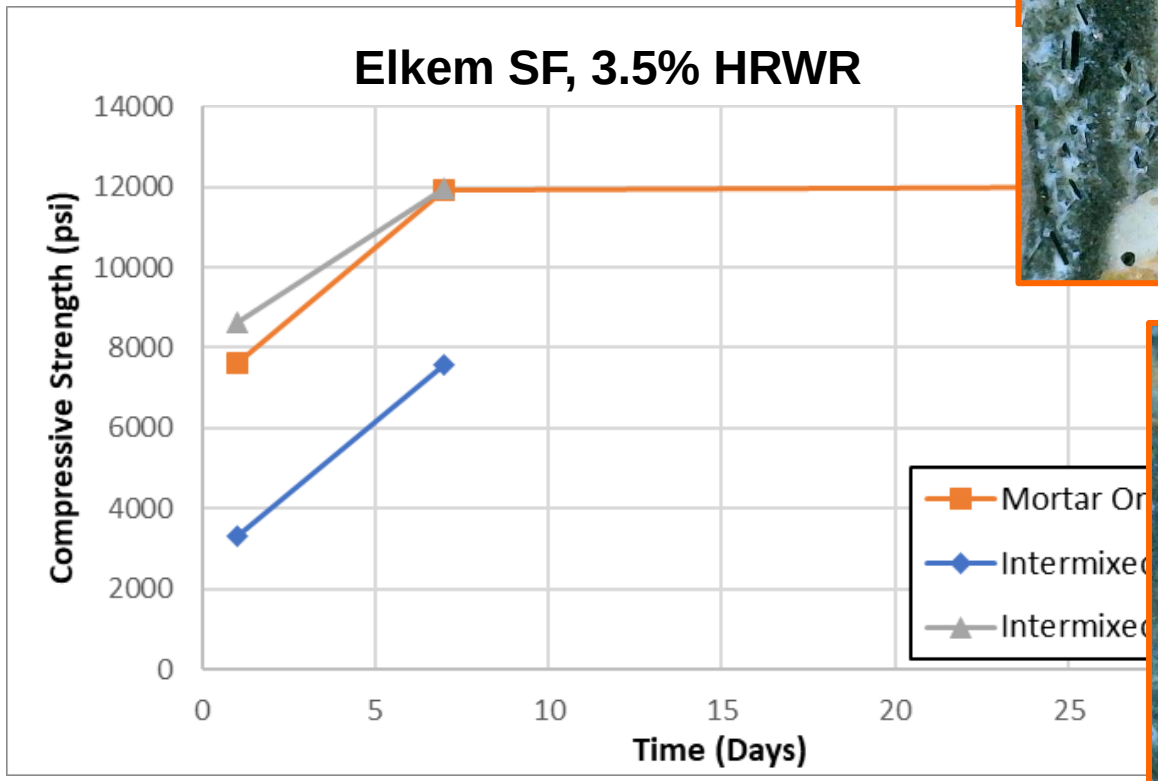


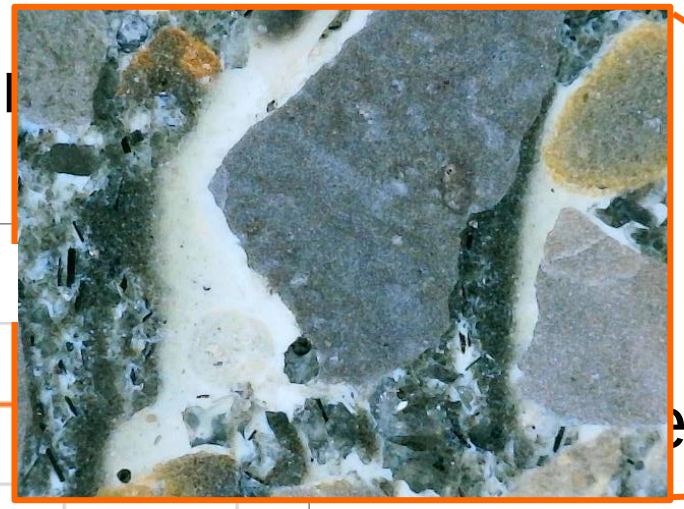




Surface Method Comparison

- Calcined Bauxite Absorptio



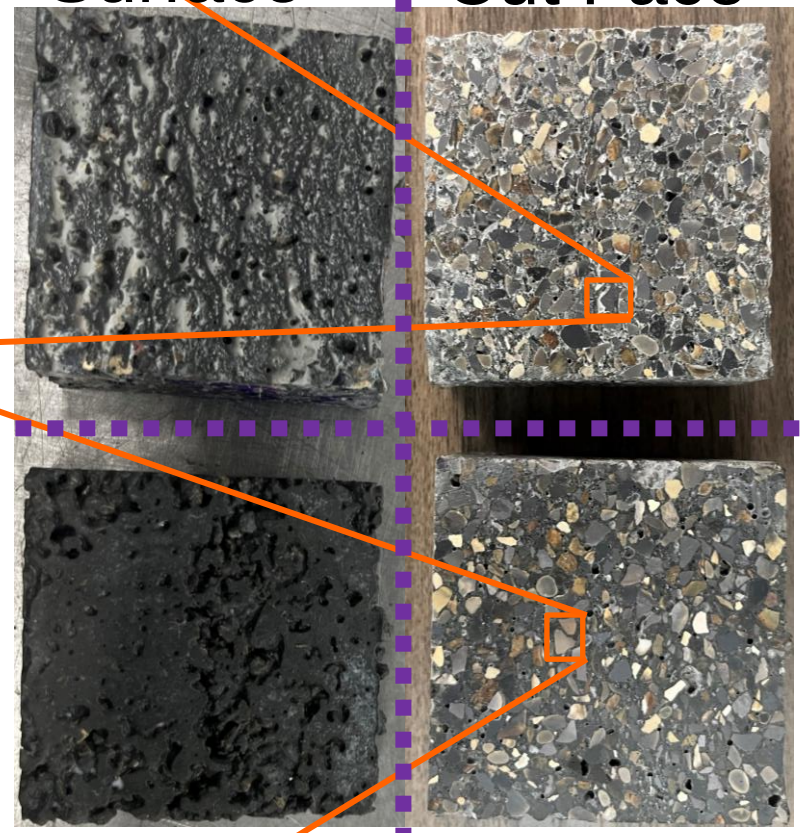


e

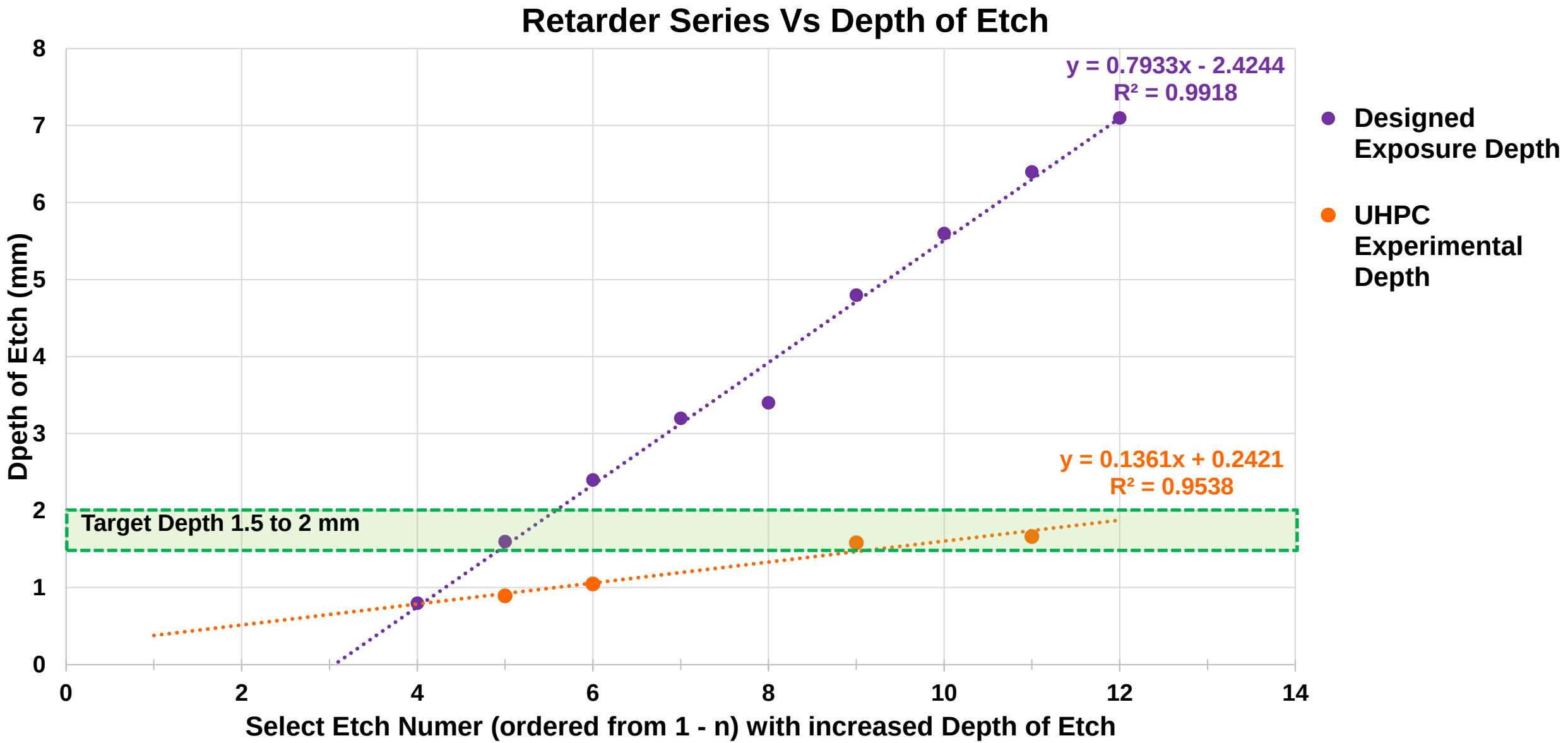
e

Outside Surface

Polished Cut Face



Low w/c Effect on Depth of Etch



Preliminary Conclusions

- Two alternative natural aggregates provided adequate friction and texture
- SSD condition calcined bauxite is not suitable for this application
- Adequate macrotexture can be achieved with UHPC binder using appropriate application methods
- Low w/c significantly reduces surface retarder effectiveness
  - Less depth of etch

Ongoing and Future Work

- Mix Design matrix
  - Flow
  - Compressive Strength
  - Shrinkage (free, autogenous, thin-layer)
  - Set Time
  - Bond Strength
- Surface Study
  - BPT of Surface Samples
  - Microtexture
  - 20”x20” surfaces for DFT/abrasion/pull-off
- Analysis
  - Performance
  - Cost
- Possible additional material characterization
  - Hydration kinetics
  - SEM
  - Permeability

Abrasion Testing

ASTM D7196

ASTM C944

Thin-Layer Shrinkage

Dynamic Friction Tester

Questions?

kmaeger@clemson.edu

Acknowledgements

Thanks to:

- SCDOT for sponsoring this research
- National Brick Research Center for use of the BPT
- Companies that provided sample materials for this work
  - Argos, Sika, Brickform, SpecChem, Ferroglobe, Elkem, Martin Marietta, Vulcan, FX minerals, Sunrock, Levy, Skidabrader