EVALUATION OF ALTERNATIVE SOURCES OF SUPPLEMENTARY CEMENTITIOUS MATERIALS FOR CONCRETE MATERIALS

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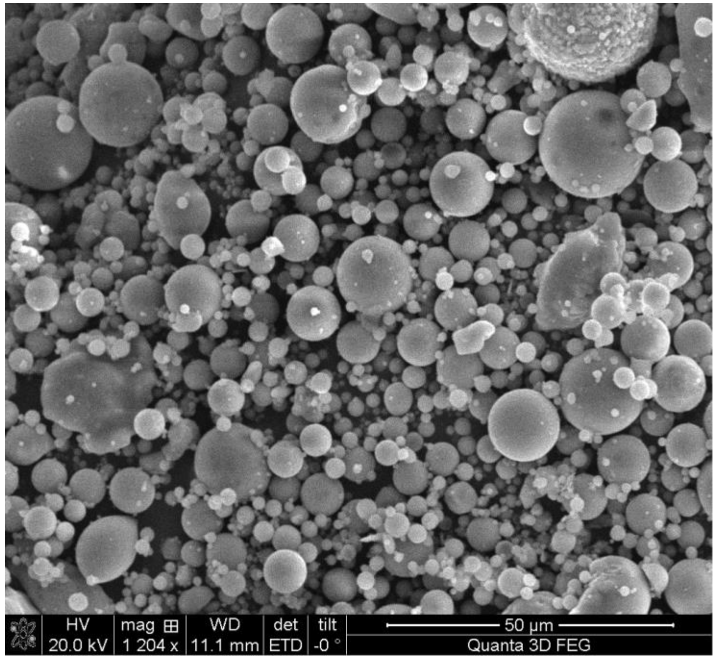
Presentation Outline

- Introduction
- Objectives
- Methodology
- Results
- Conclusions

INTRODUCTION

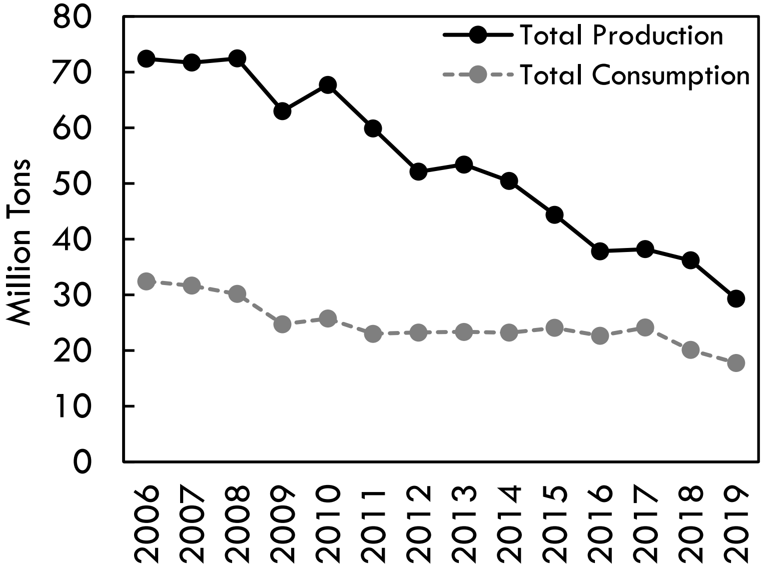
Fly Ash

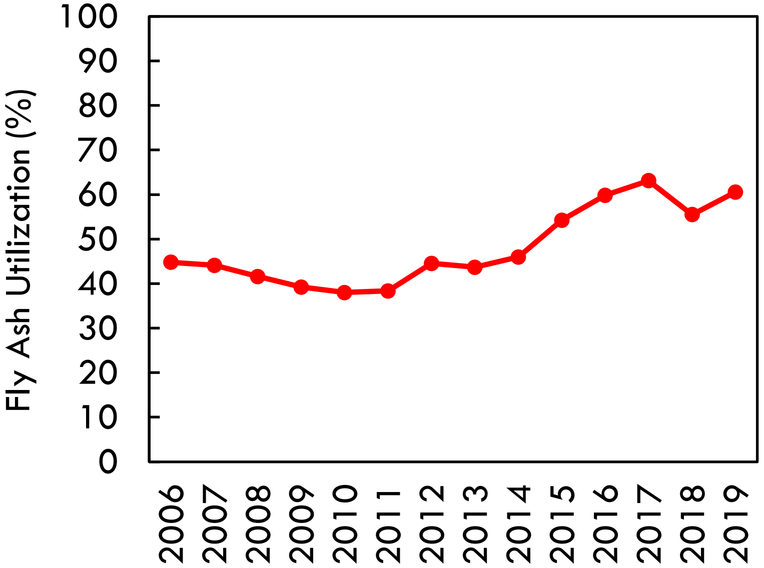
- Fly ash (FA) from coal-burning power production is the most widely utilized SCM in the US
- Its use in concrete:
  - Enhances concrete durability and long-term mechanical properties
  - Reduces concrete carbon footprint
  - Improves workability, reduces bleeding, and enhances pumpability
  - Mitigate alkali-silica reactivity (ASR)
    - Specially, highly pozzolanic **Class F fly ash**



Fly Ash Availability

- FA has become common practice in the US
- FA demand in the US is expected to increase
- Coal-fired power generation is declining
- Finding high quality and economical FA is becoming increasingly challenging
  - In a recent AASHTO survey (including the participation of 46 State DOTs), **80% of respondents indicated issues with fly ash supply**





Reclaimed Fly Ash and Bottom Ash

- Large amounts of coal ashes are disposed in landfills due to:
  - Market disparities (e.g., excessive seasonal supply)
  - Logistical challenges (e.g., storage space constrains)
  - Failure to meet specification (i.e., ASTM C618)
- FA from landfills can be dried and processed to meet specifications
  - This FA is referred to as reclaimed FA (RFA)
- More than 1000 million tons of FA in landfills and impoundments in the US
- Reclaimed bottom ash also has potential to be used as SCMs when appropriately processed
  - Reclaimed ground bottom ash (GBA)

Washingtonville RFA landfill

Problem Statement

- FA availability is a significant issue affecting the concrete industry
- Unconventional coal ash products (i.e., RFA and GBA)are promising alternatives
  - RFA and GBA properties can vary significantly depending on the supplier and source
- There is a need to explore alternative SCM sources to broaden the portfolio of alternatives

OBJECTIVES

Objective

- Evaluate alternative sources of SCMs for the manufacture of concrete for transportation infrastructure in Region 6.
- SCMs evaluated included:
  - Reclaimed fly ash (RFA)
  - Reclaimed ground bottom ash (GBA)
  - Conventional Class F fly ash (FA) as control

METHODOLOGY

SCMs Characterization

SCMs Evaluated

Reclaimed Fly Ash
(Georgia)

Ground Bottom Ash
(Texas)

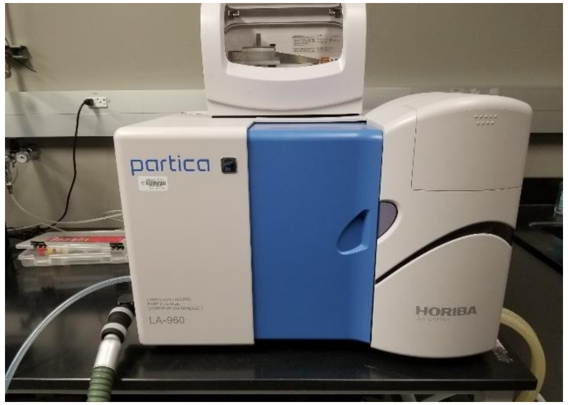
Class F Fly Ash
(Illinois)

Characterization

- Scanning Electron Microscopy (SEM)
- X-Ray Fluorescence (XRF)
- X-Ray Diffraction (XRD)
- Laser Scattering Particle Size Analysis
- Loss on Ignition (LOI)
- Moisture Content
- Strength Activity Index (SAI)
- Thermogravimetric Analysis (TGA)
  - $Ca(OH)_2$ and SCM (at 3:1 mass ratio) in 0.5 M KOH solution (at 0.9 liquid-to-solid ratio)
  - Tested after 10 days at 50°C

SEM/ EDS

Strength Activity Index



Particle Size Analyzer

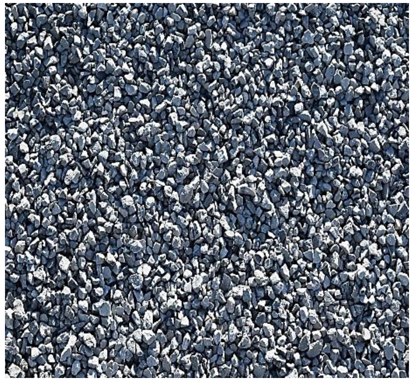
XRD

Concrete Testing

Materials

- Ordinary Portland Cement (OPC) Type I
- Limestone (SG of 2.68 & MAS of 19 mm)
- Silica sand (SG of 2.65 & MAS of 4.75 mm)
- SCMs
  - Class F Fly Ash (FA)
  - Reclaimed Fly Ash (RFA)
  - Reclaimed Ground Bottom Ash (GBA)
- High-Range Water Reducer (HRWR)
  - Polycarboxylate based

Cement



Limestone

Silica Sand

Fly Ash

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Experimental Matrix

- Concrete mixtures incorporating SCMs (i.e., RFA, GBA, MK, and FA) at 10, 20, and 30% cement replacement (by mass) were evaluated

- A total of 13 concrete mixtures were produced
  - 12 mixtures incorporating SCMs in binary systems (RFA, GBA, and FA)
  - 1 control mixture without SCMs

Control Concrete Mixture

- Louisiana DOTD Type A1 Structural Concrete
  - w/c=0.45
  - Target f'c=4500 psi (31 MPa)
  - Target slump= 4 inches
  - Target Air Content = 6%

Mixture Proportions						
ID	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)	HRWR (L/m^3)	AEA (L/m^3)
CO	344.1	1058.2	743.7	154.2	0.42	0.36

Mixture Proportions

ID	Cement (kg/m³)	SCM (kg/m³)	SCM (%)[a]	Coarse Aggregate (kg/m³)	Fine Aggregate (kg/m³)	Water (kg/m³)	HRWR (L/m³)	AEA (L/m³)
CO	344.1	0	0	1058.2	743.7	154.2	0.42	0.36
FA-10	309.7	34.4	10	1058.2	734.0	154.2	0.42	0.36
RFA-10	309.7	34.4	10	1058.2	738.5	154.2	0.42	0.36
GBA-10	309.7	34.4	10	1058.2	732.4	154.2	0.42	0.36
FA-20	275.2	68.8	20	1058.2	724.3	154.2	0.42	0.36
RFA-20	275.2	68.8	20	1058.2	719.1	154.2	0.42	0.36
GBA-20	275.2	68.8	20	1058.2	733.3	154.2	0.42	0.36
FA-30	240.8	103.2	30	1058.2	714.7	154.2	0.42	0.36
RFA-30	240.8	103.2	30	1058.2	706.7	154.2	0.42	0.36
GBA-30	240.8	103.2	30	1058.2	728.1	154.2	0.42	0.36

Concrete Testing

- Fresh Properties
  - Slump (ASTM C143)
  - Air Content (ASTM C231)
  - Fresh Density
- Hardened Properties
  - Compressive Strength (ASTM C39)
    - At 28 and 90 days
  - Surface Resistivity (DOTD TR233)
    - At 28 and 90 days
  - Drying Shrinkage (ASTM C157)
  - Alkali Silica Reactivity (ASTM C1567)

Slump

Drying Shrinkage

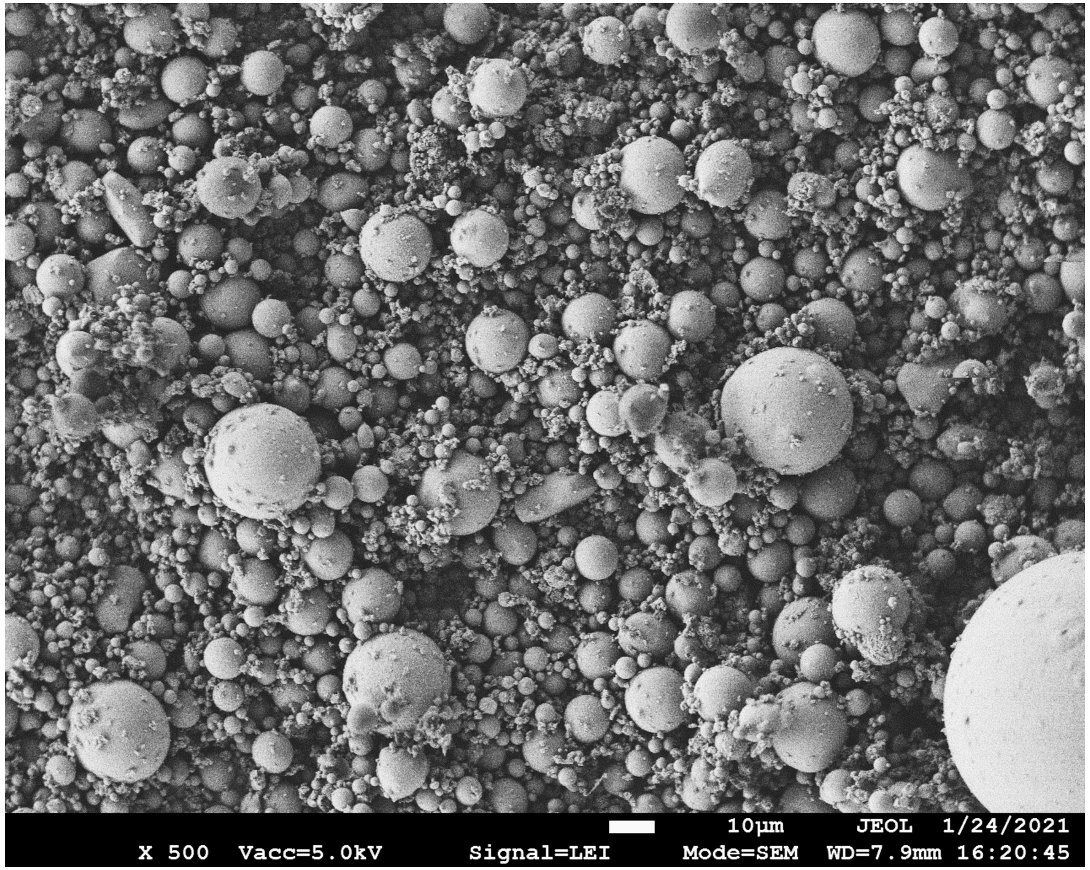
Surface Resistivity

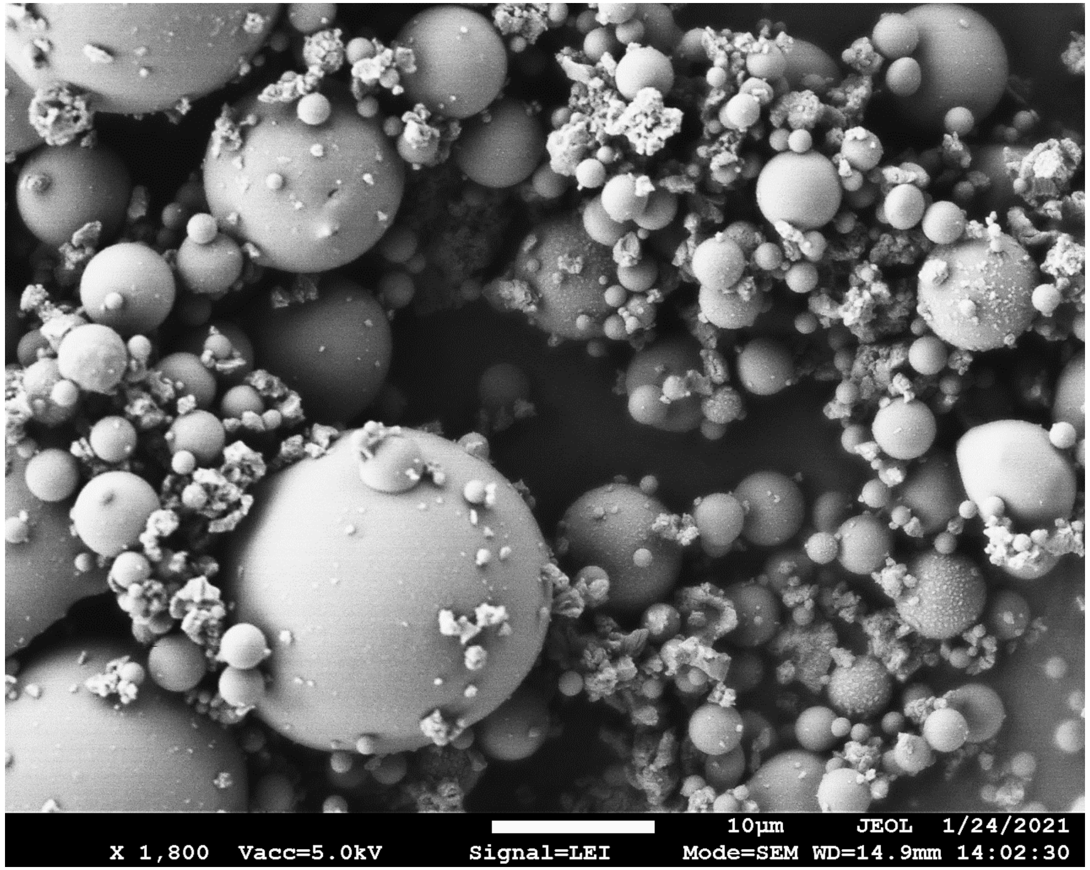
Compressive Strength

RESULTS

SCMs Characterization

SEM - FA





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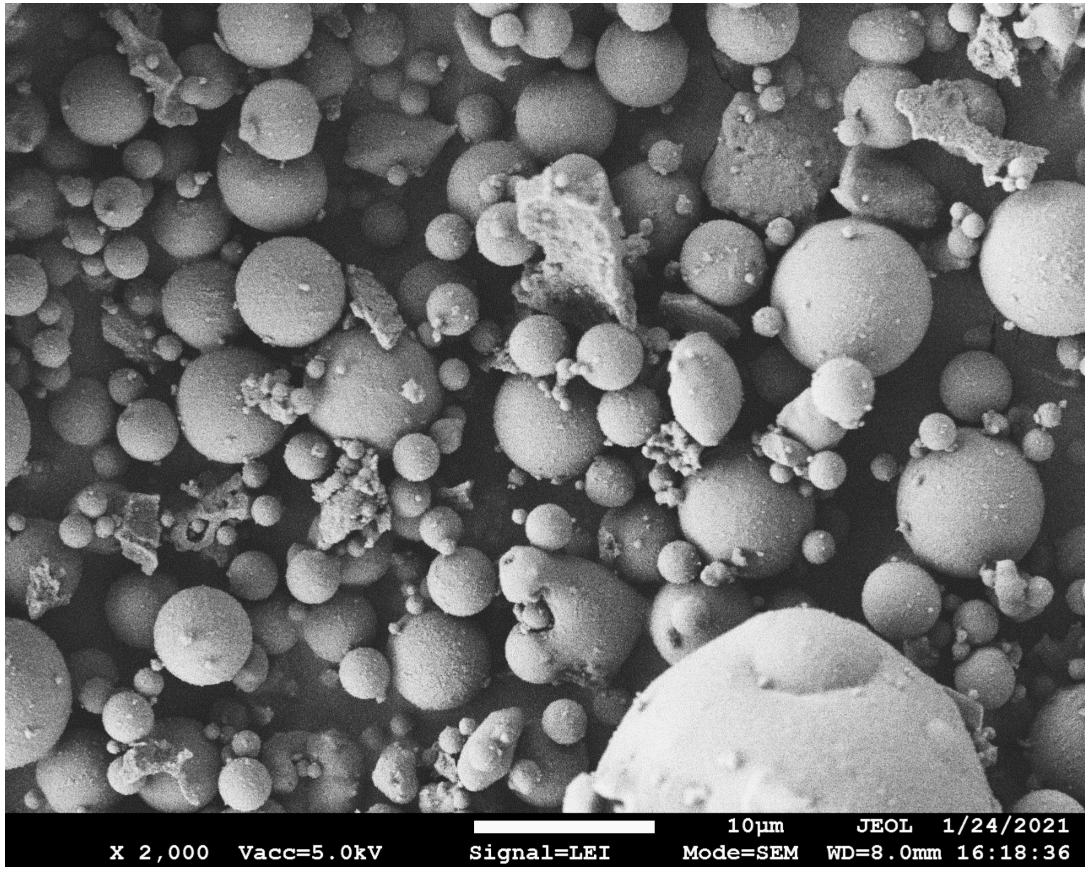
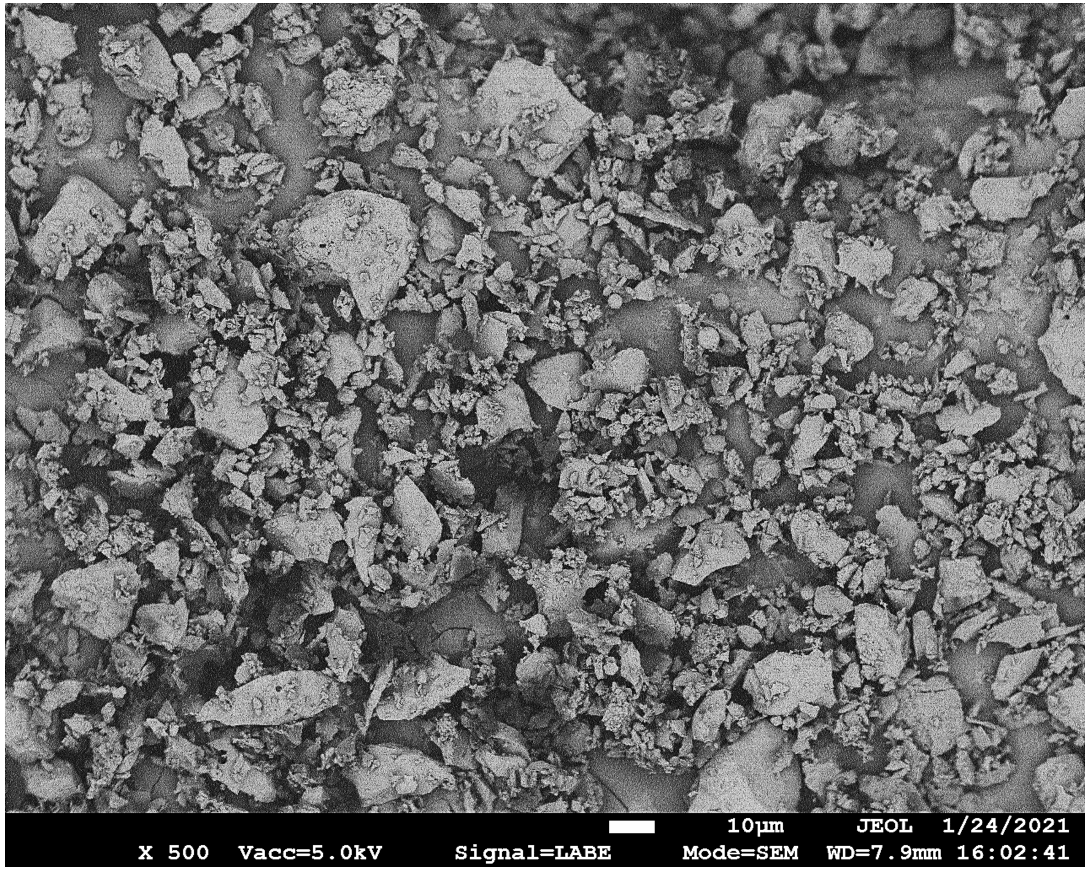
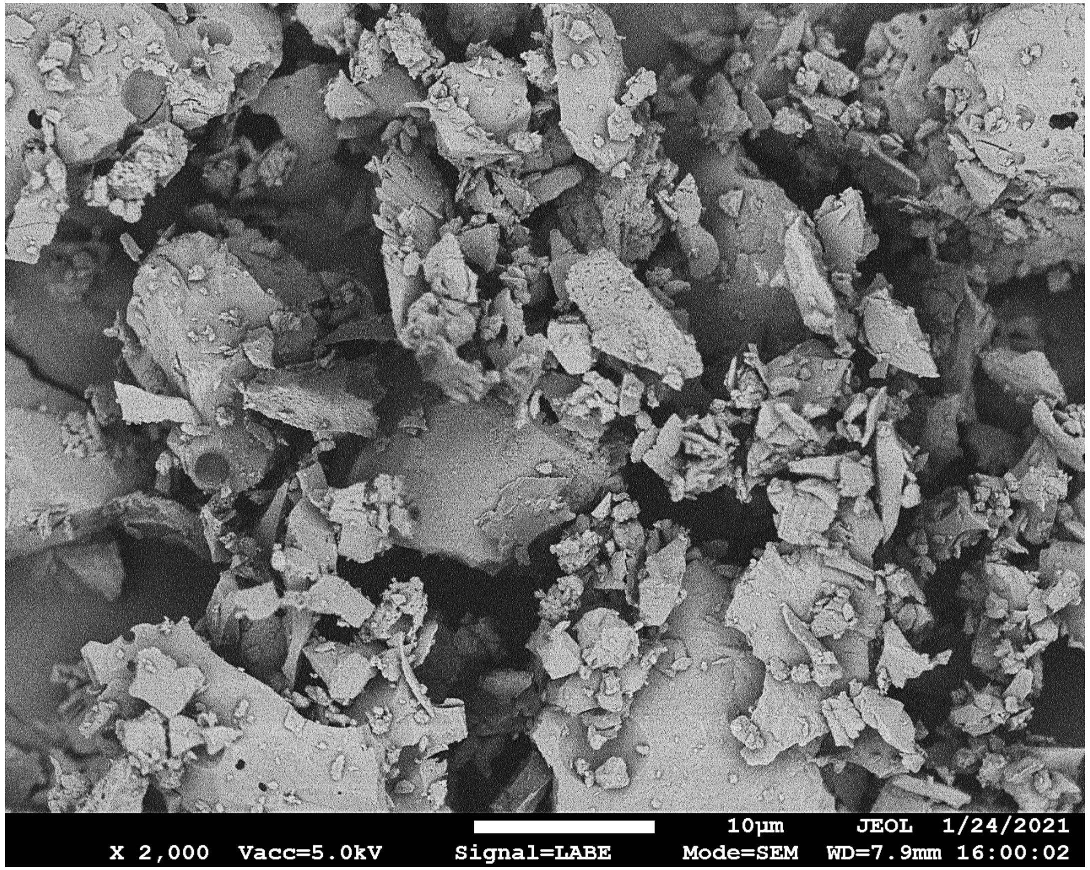
SEM - RFA


10µm JEOL 1/24/2021
X 500 Vacc=5.0kV Signal=LEI Mode=SEM WD=8.0mm 16:19:32


10µm JEOL 1/24/2021
X 2,000 Vacc=5.0kV Signal=LEI Mode=SEM WD=8.0mm 16:18:36

SEM - GBA





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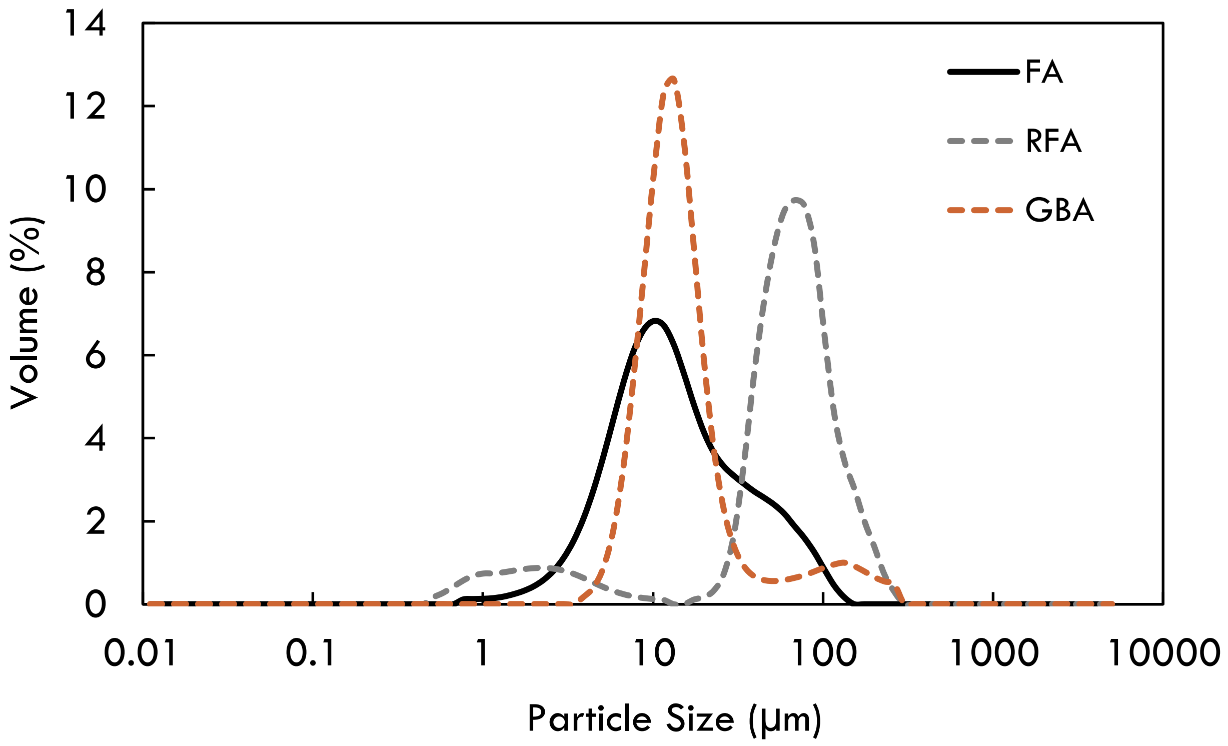
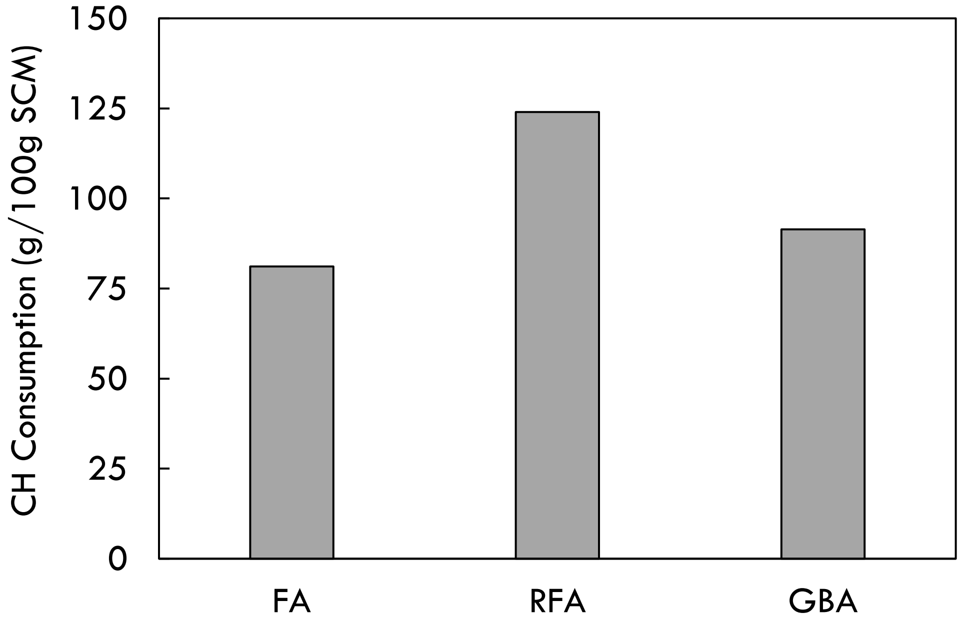
Particle Size Distribution



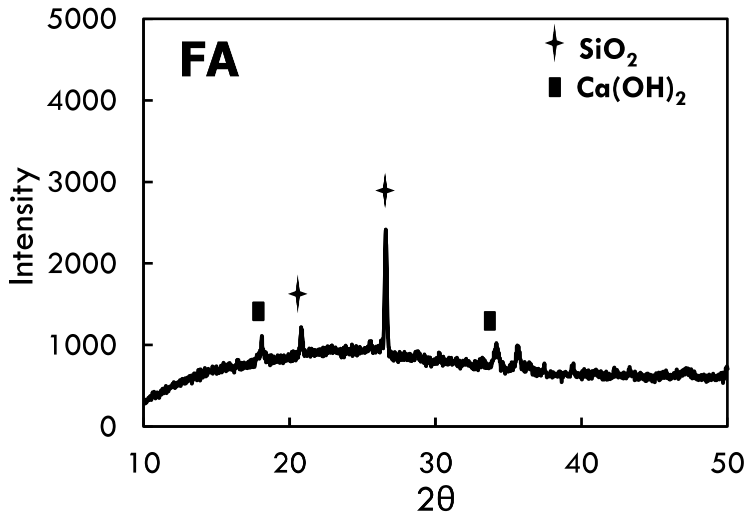
SCMs	Median (µm)	Mean (µm)	D10 (µm)	D90 (µm)
FA	11.5	19.2	4.4	47.0
RFA	58.8	64.5	3.3	119.3
GBA	12.5	23.2	7.3	39.2

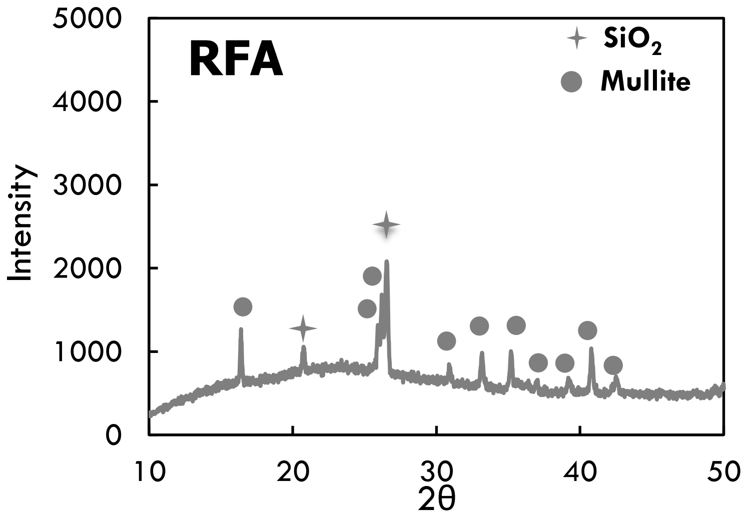
XRF and TGA

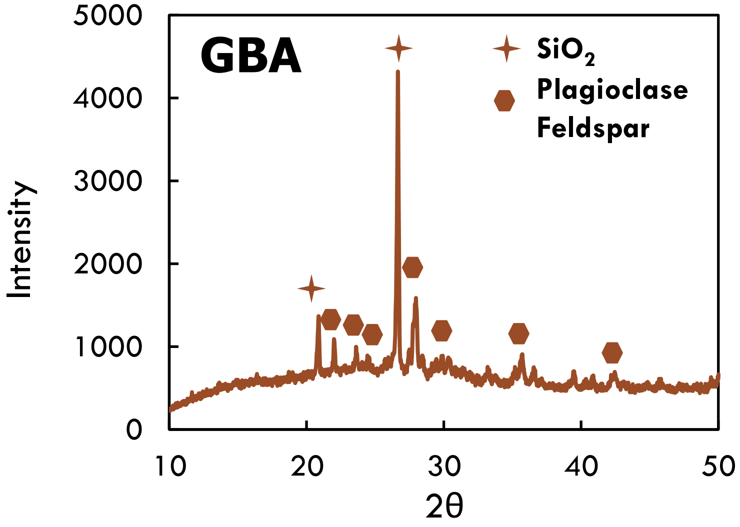
Material	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	K_2O	Na_2O	Pozzolanic Component (SiO_2+ Al_2O_3+Fe_2O_3)
FA	8.4	57.2	20.2	10.2	1.2	1.6	2.7	1.1	87.6
RFA	1.8	53.4	28.0	7.7	0.1	0.99	2.2	0.3	89.1
GBA	11.0	62.0	20.8	6.9	0.5	2.8	0.9	0.3	89.7



XRD







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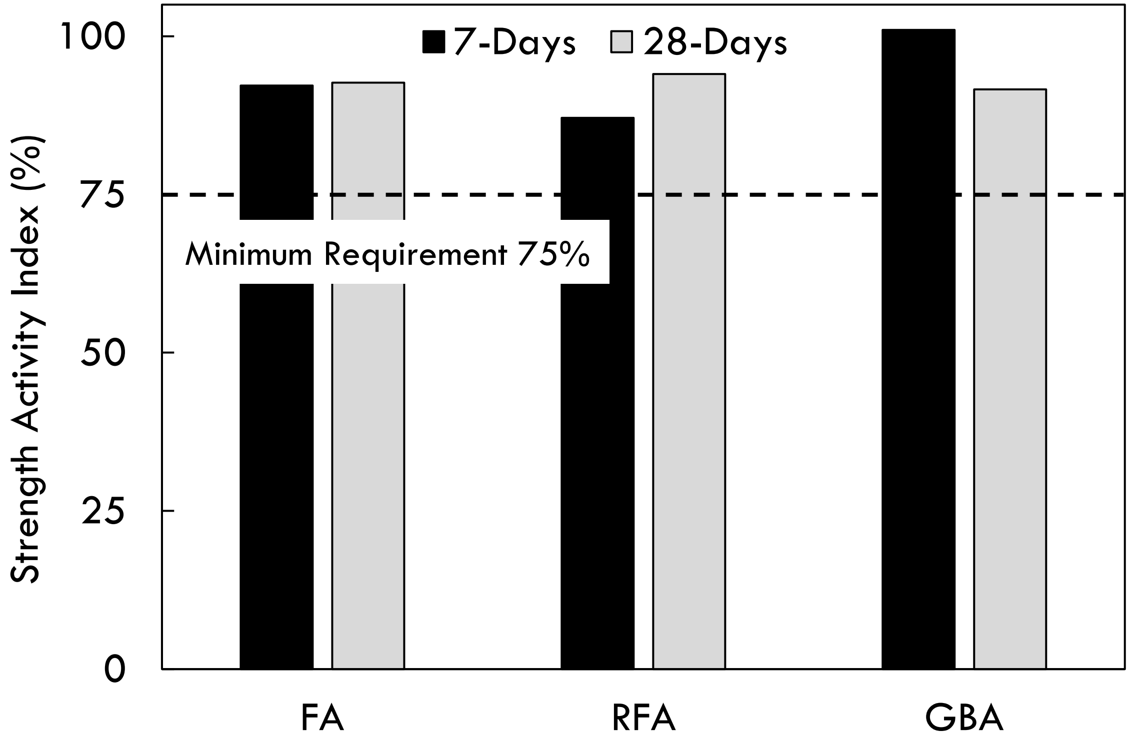
SAI, Water Requirement, Moisture Content, and LOI



Material	Water Requirement	Moisture Content	LOI
FA	89.2%	0.40%	1.42%
RFA	95.1%	0.06%	2.95%
GBA	96.3%	0.27%	0.92%

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Summary of SCMs Properties

SCM	Chemical Requirements			
	$SiO_2+Fe_2O_3+Al_2O_3$ (Min. 70%)	SO_3 (Max. 5%)	Moisture Content (Max. 3%)	LOI (Max. 6%)
FA	87.6 ✓	1.2 ✓	0.4 ✓	1.42 ✓
RFA	89.1 ✓	0.09 ✓	0.1 ✓	2.95 ✓
GBA	89.8 ✓	0.49 ✓	0.3 ✓	0.92 ✓

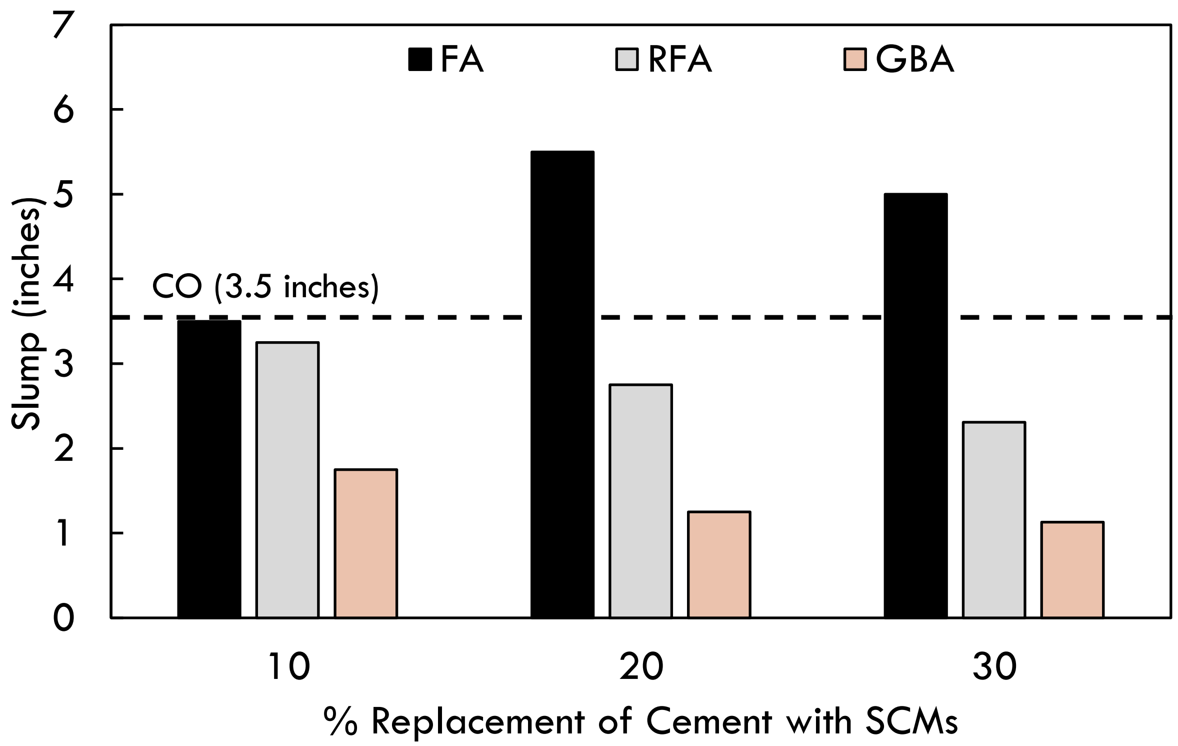
(✓) Met the requirement according to ASTM C618

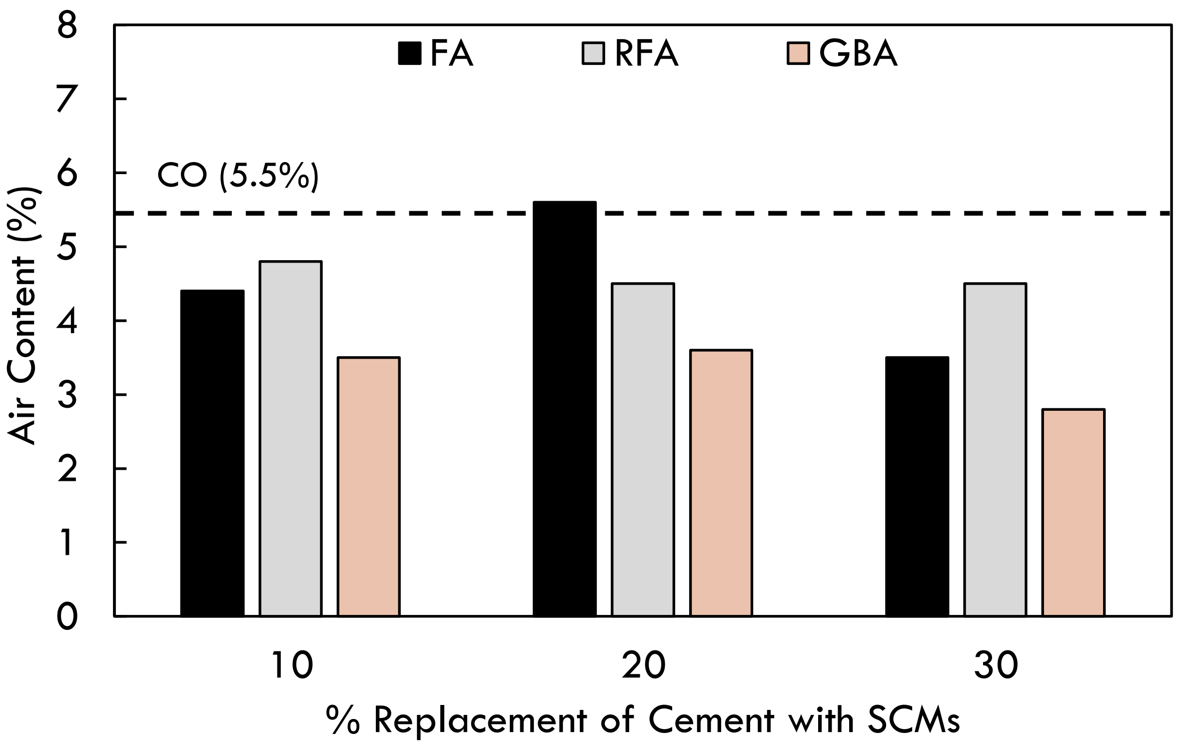
SCM	Physical Requirements		
	Strength Activity Index (Min. 75%)		Water Requirement (Max. 105%)
	7 Days	28 Days	
FA	92.2 ✓	92.7 ✓	89.2 ✓
RFA	87.1 ✓	94.0 ✓	95.1 ✓
GBA	101.0 ✓	91.6 ✓	96.3 ✓

(✓) Met the requirement according to ASTM C618

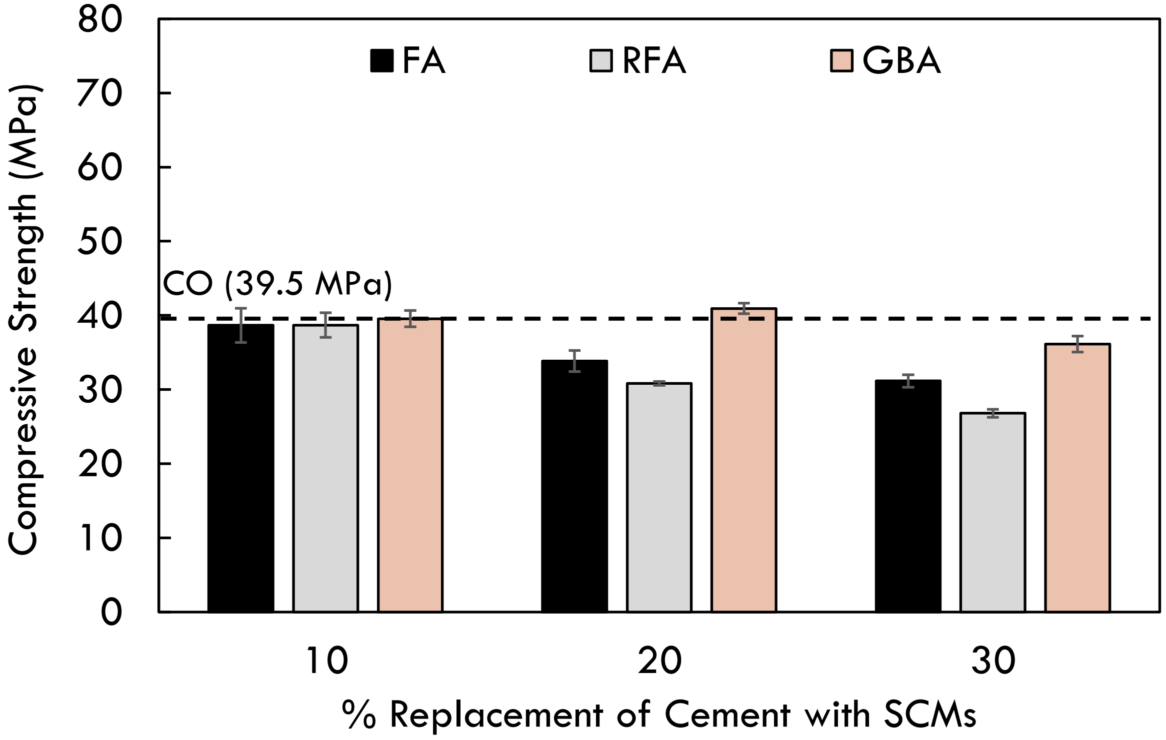
Properties of SCMs Admixed Concrete

Fresh Properties

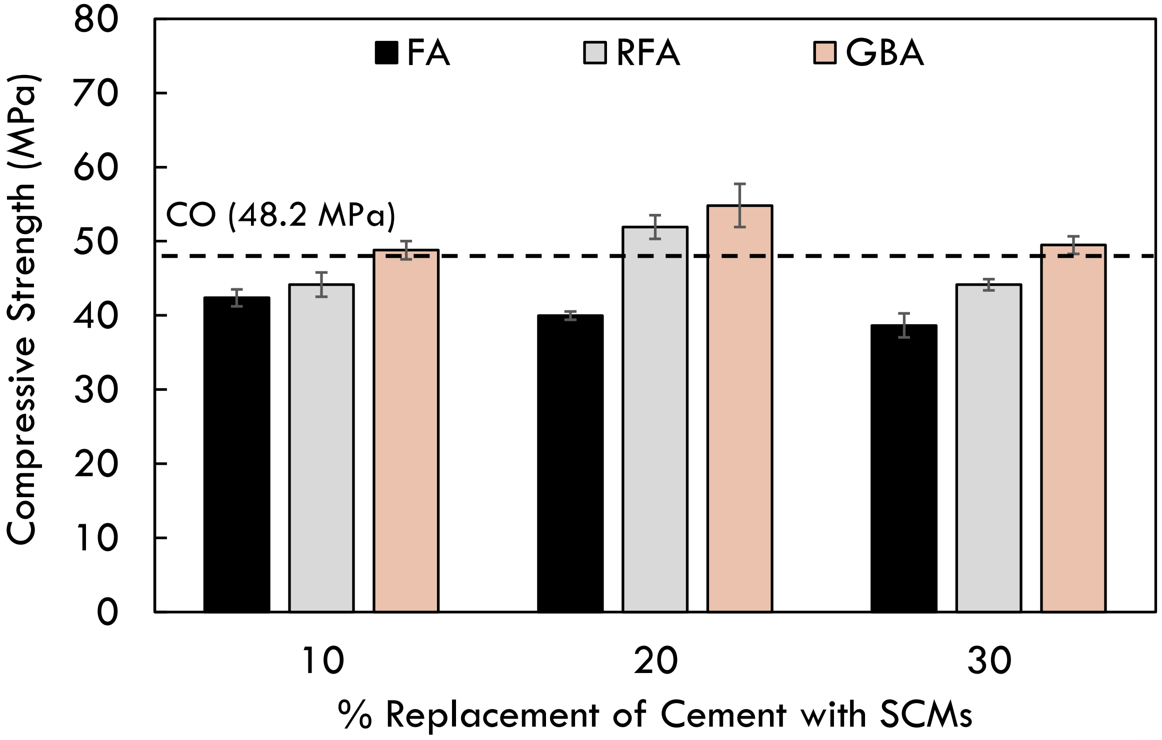




Compressive Strength

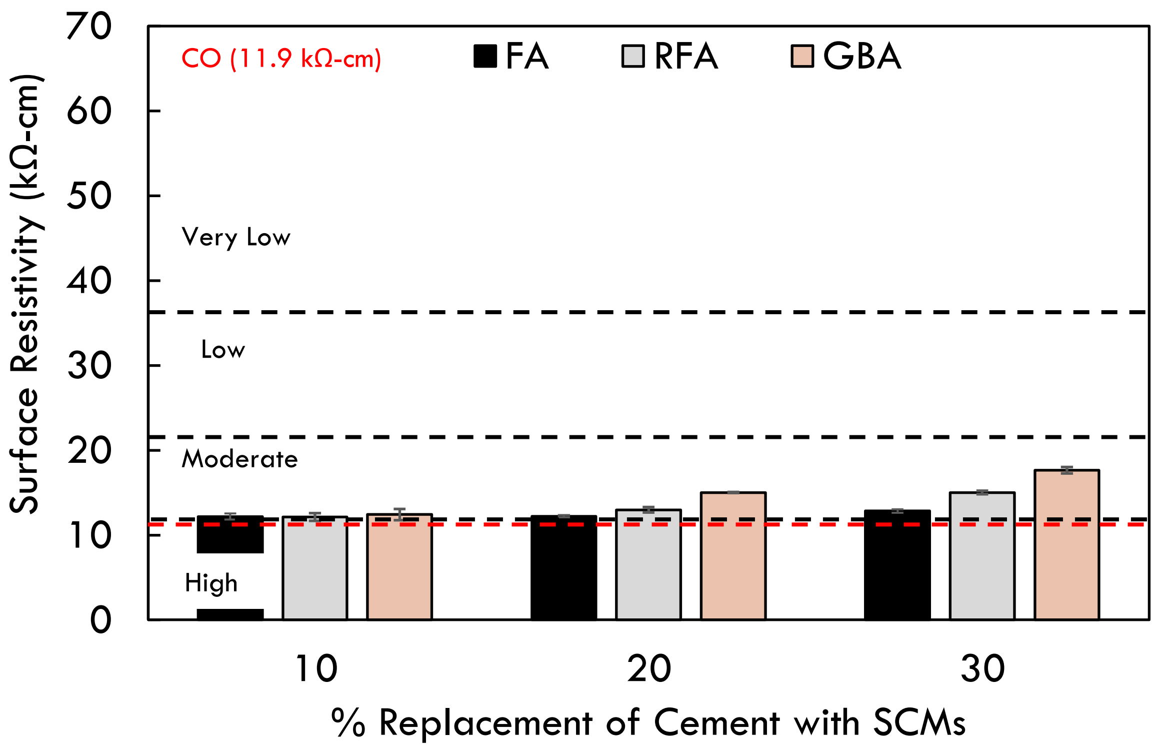


28 Days

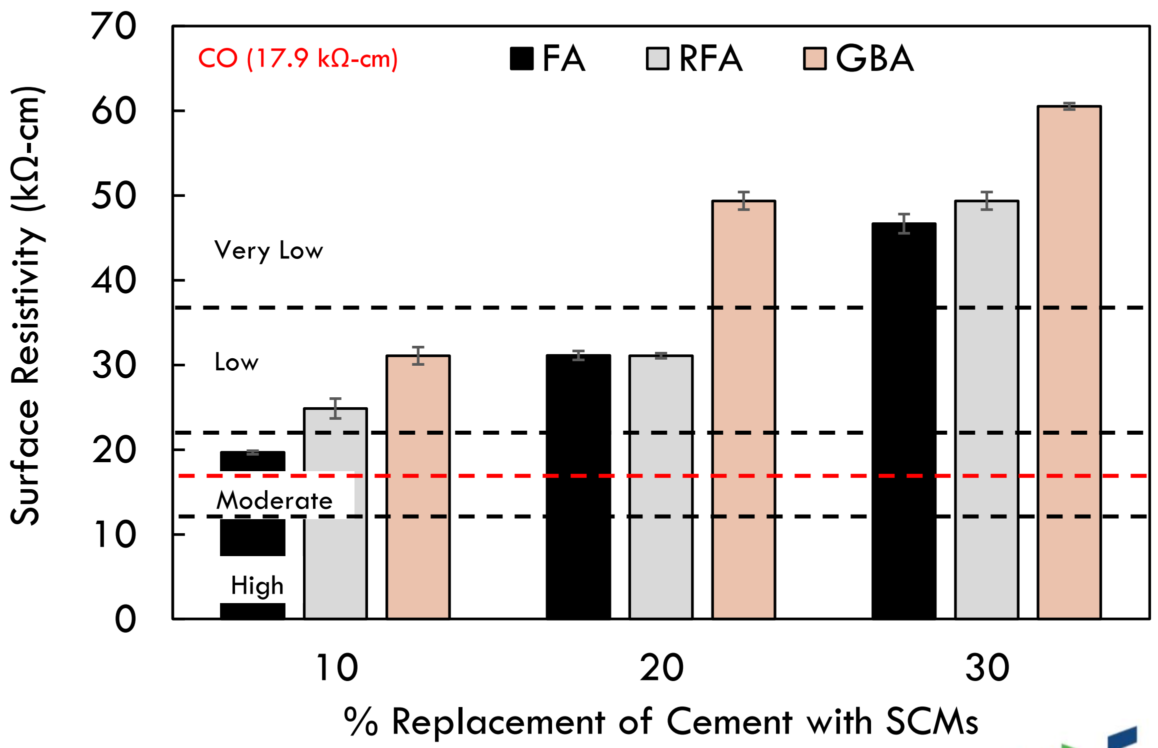


90 Days

Surface Resistivity



28 Days



90 Days

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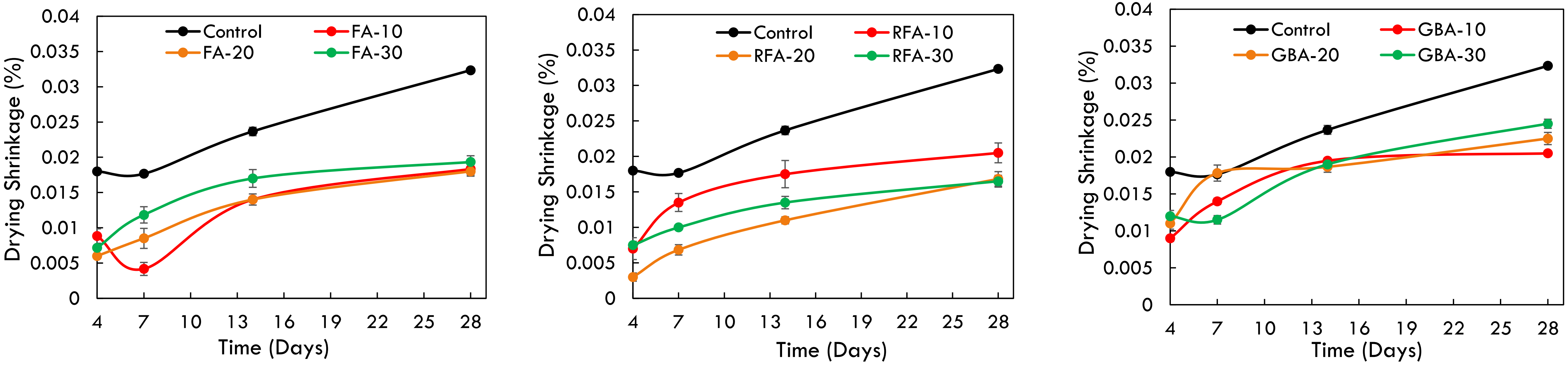
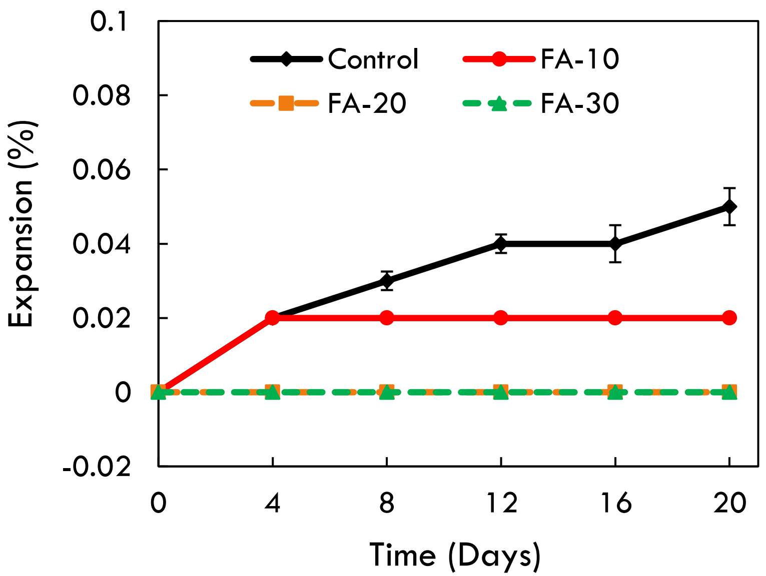
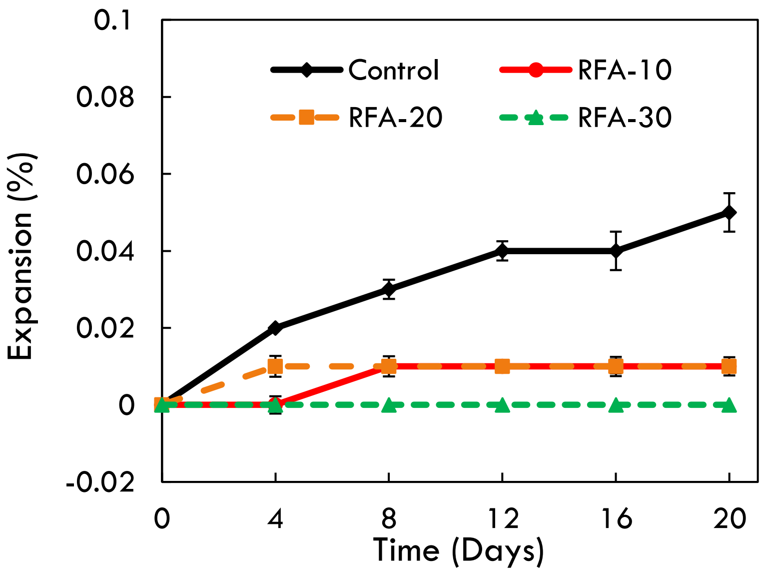
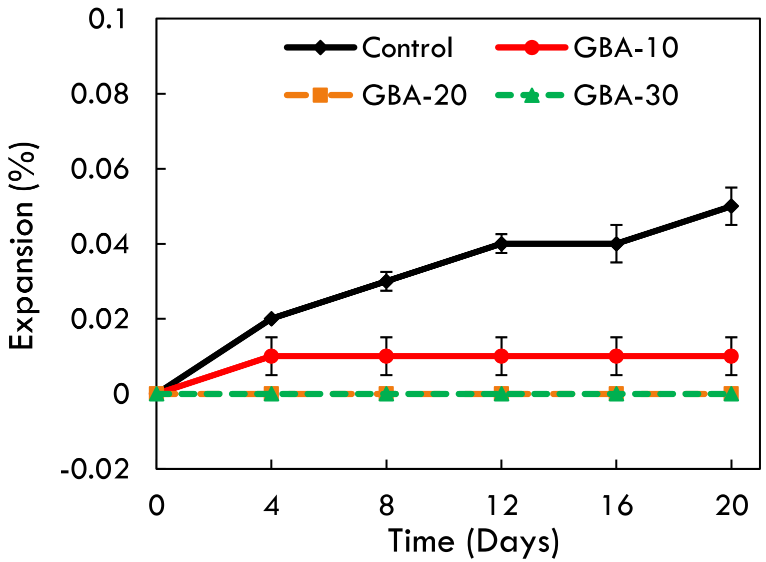
Drying Shrinkage



Alkali Silica Reaction







Summary of SCMs Effect on Concrete Properties

Materials	Fresh Properties		Hardened Properties				Shrinkage	ASR
	Slump	Air Content	28-Day f'c	90-Day f'c	28-Day SR	90-Day SR		
FA-10	--	X	--	X	--	--	✓	✓
FA-20	✓	✓	--	X	--	✓	✓	✓
FA-30	✓	X	X	X	--	✓	✓	✓
RFA-10	X	X	--	X	--	--	✓	✓
RFA-20	X	X	X	--	--	✓	✓	✓
RFA-30	X	X	X	X	--	✓	✓	✓
GBA-10	X	X	--	--	--	✓	✓	✓
GBA-20	X	X	--	--	--	✓	✓	✓
GBA-30	X	X	--	--	--	✓	✓	✓

(✓) Impact is positive, (X) Impact is negative, (--) Impact is neutral

CONCLUSIONS

Conclusions

- All SCMs evaluated are promising for their use in concrete materials
  - Depending on the SCM used and cement replacement level, adjustments in the concrete mixture design and/or admixture dosage may be necessary to meet specified fresh and hardened properties
- Generally, up to 20% cement replacement with RFA and GBA can be used without compromising concrete's long-term mechanical and durability properties
- While the SCMs evaluated presented a satisfactory performance, verification should be conducted on a supplier and source basis prior to implementation in concrete mixtures

Acknowledgements

- Transportation Consortium of South-Central States (Tran-SET)

- Louisiana Transportation Research Center (LTRC)

Thank You!