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The Role of Sugarcane Bagasse Ash as a Supplementary Cementitious Material on the Mitigation of Temperature Crossover Effect

Research in Progress

ACI Spring Convention 2024

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PURDUE UNIVERSITY | Lyles School of Civil Engineering

VELAY Research group

BACKGROUND

Problem/Issue

Currently …

Cement Production

- Cement production contributes to 8% of the global CO_2 emissions [1].
- Stages of production and transportation.
- How to ***decrease*** carbon footprint?

Solutions …

- Supplementary cementitious materials (**SCMs**) can be used as a partial cement replacement, reducing the carbon footprint of concrete.

- **Coal fly ash** is one of the most used SCMs.
- By-Product of coal-combustion energy generation

However, …

- Outlook indicates a ***decrease*** in coal production and availability.
- Fly Ash is becoming a limited resource.

Alternative Solutions ?

Alternative Solutions

- **Biomass Ash can serve as an alternative Supplementary Cementitious Material (SCM).**
- **What is Biomass Ash?**
  - *"Ash is one of the by-products generated during biomass burning." [2]*
  - *"Agricultural biomass ash is a waste material produced by incineration of residue from fields after harvesting crops." [3]*

- **Examples of Biomass Ash:**
  - Wood
  - Corn Husk
  - Various Agriculture Crops
  - **Sugar Cane Bagasse**

Sugar Cane Bagasse Ash (SCBA)

Sugar Cane Bagasse

Thermal Energy Plant

Sugar Cane Bagasse Ash (SCBA)

- Pozzolanic Material
- Siliceous Composition

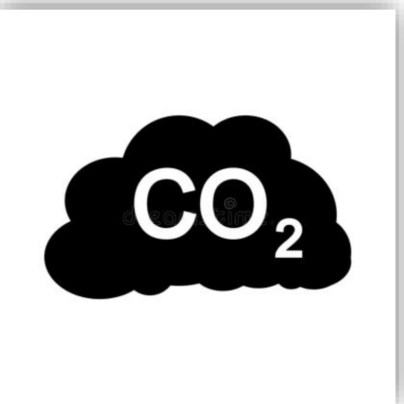
[4], [5], [6]

- "Recent estimation found the global sugar crop acreage is around 31.3 million hectares " [5]
- One ton of bagasse can generate approximately 25–40 kg of bagasse ash. [5]

Environmental Benefits

- Lower CO_2 emissions from concrete due to a lower amount of cement use;
- SCBA is currently treated as a waste-product and ends up in land fill;
- SCBA is carbon neutral and will be always be produced.

Waste Valorization



Economical Benefits

- Cement is an expensive material, lowering the amount of cement used will decrease the cost of concrete;
- SCBA has a potential to have its own market, if proven to be a useful SCM.

OBJECTIVES

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Previous Research

- The use of Biomass Ash increases porosity, which decreases density and lowers mechanical strength. [7]
- Lower water/binder ratio are the most affected by the Biomass Ash due to the high-water absorption which reduces the Workability and decrease the Mechanical Behavior. [7]
- Replacement Level of 25% using Biomass Fly Ash has similar compressive strength to Coal Fly Ash from 7 to 365 days, and to OPC concrete from 28 to 365 days. [8]

Unknowns

Although characteristics of bagasse ash have been discovered → There are still Unknowns → The Curing Temperature Effect of SCBA on a Cementitious Composite's Performance

Objective

Understanding the role of high-temperature curing on the sugarcane bagasse ash (SCBA) effect in mortar's strength

Materials

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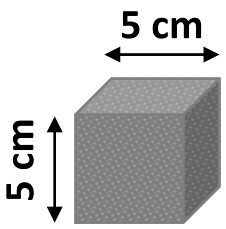
Mixture Proportioning

18 x Mortar Cubes → 6 Cubes per mixture design



1. Water

2. Fine Aggregate (FA)

3a. Ordinary Portland Cement Type I (OPC-I)

3b. Sugar Cane Bagasse Ash (SCBA)

*** Grounded & Sieved to 45 µm

Binders

Mixture Design per 1 m³ (w/b: 0.50)

SCBA [%]	ID	Mass [kg]			
		Effective Water	Oven-Dry FA	OPC-I	SCBA
0%	REF	486	243	1459	0
10%	SCBA-10	438	232	1459	26
20%	SCBA-20	389	221	1459	53

Curing Conditions:

- Temperatures (T) → T_1 = 21 ºC or T_2 = 45 ºC
  - T_1 → 3 Cubes per mixture design
  - T_2 → 3 Cubes per mixture design
- Duration → **28 Days**
- Relative Humidity (RH) → **RH > 95 %**

Methods

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Testing Methods

1. Particle Size Analysis (PSA)

PSA 1090 Series

3. Compressive Strength [ASTM C349]

MTS Universal Testing Machine

2. X-Ray Fluorescence (XRF)

Lab X500 XRF Analyzer

4. X-Ray Diffraction (XRD)

Siemens D500 diffractometer

4. Thermogravimetric Analysis (TGA)
5. Loss of Ignition (LOI) [ASTM C311]

2050 Thermogravimetric Analyzer

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RESULTS & DISCUSSION

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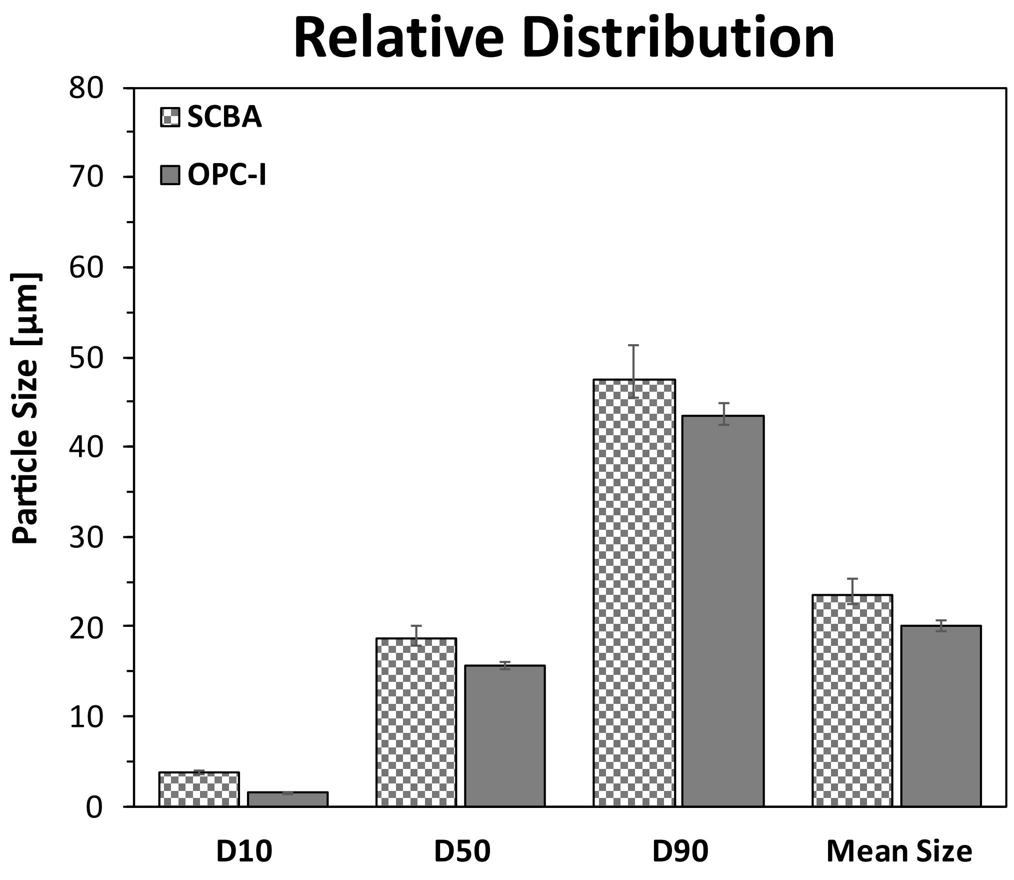
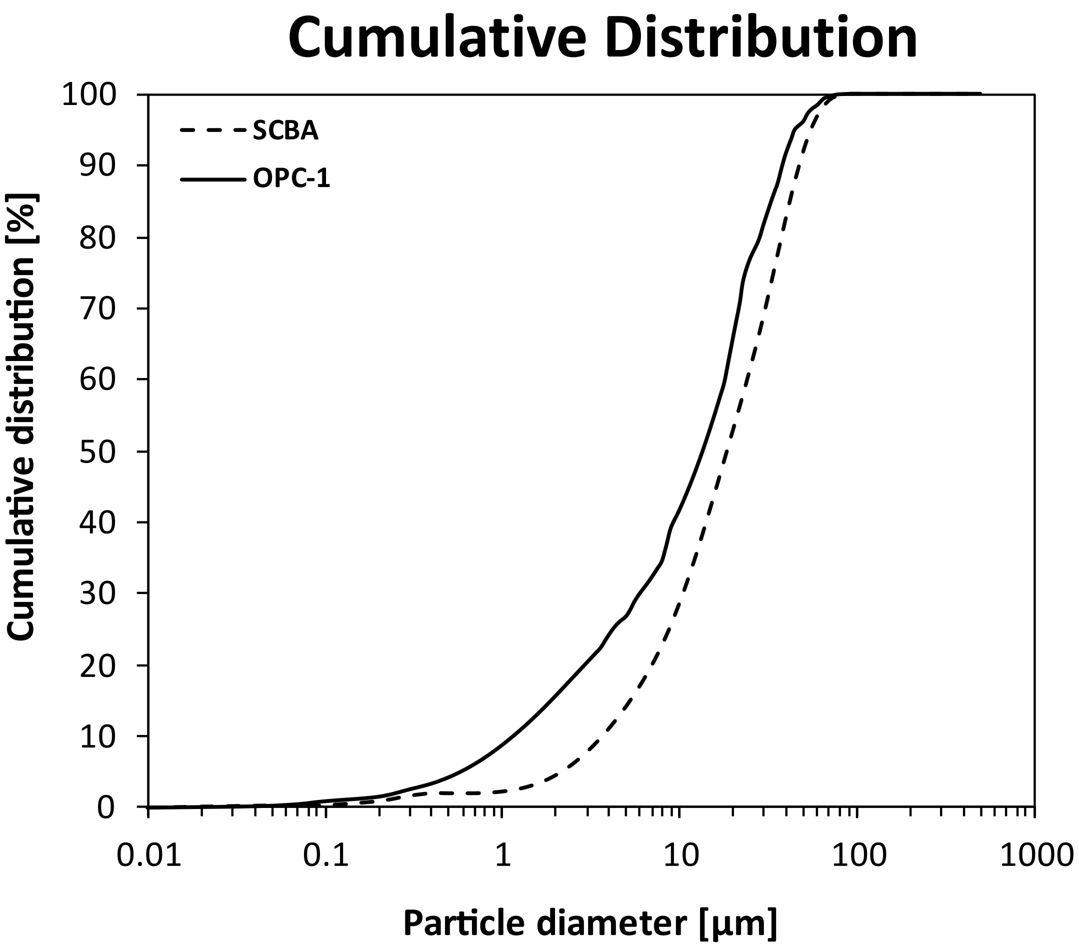
PSA - Particle Size Distribution





XRF – Chemical Composition

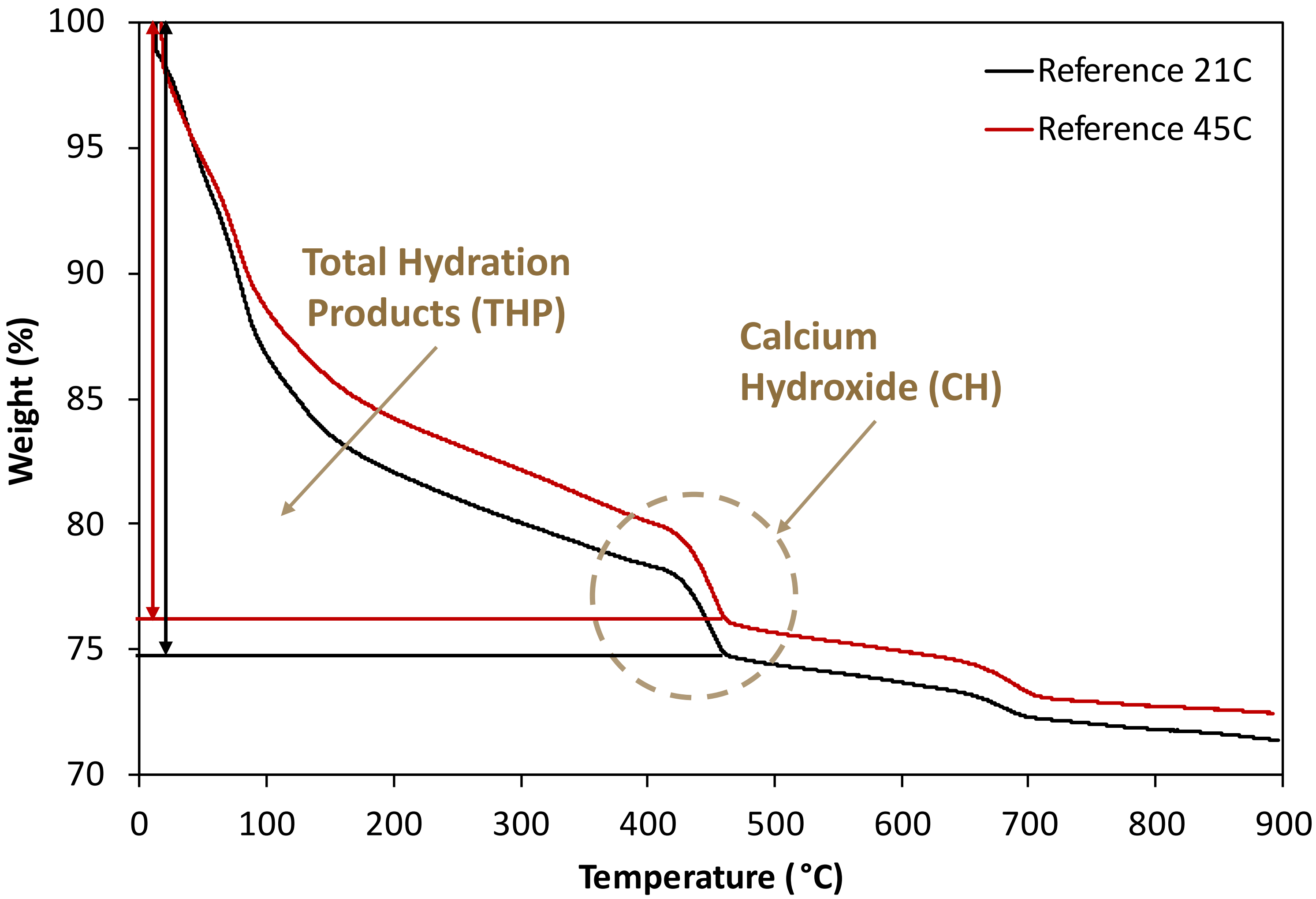
** ASTM C618

Compound [%]	SCBA	Class N	Class F	Class C
CaO	10.0	✓ -	✓ < 18.0	✗ > 18.0
SO_3	0.9	✓ < 4.0	✓ < 5.0	✓ < 5.0
$SiO_2 + Al_2O_3 + Fe_2O_3$	77.4	✓ > 70.0	✓ > 50.0	✓ > 50.0
Loss of Ignition (LOI)	13.8 – 16.6	✗ < 10.0	✗ < 12.0**	✗ < 6.0

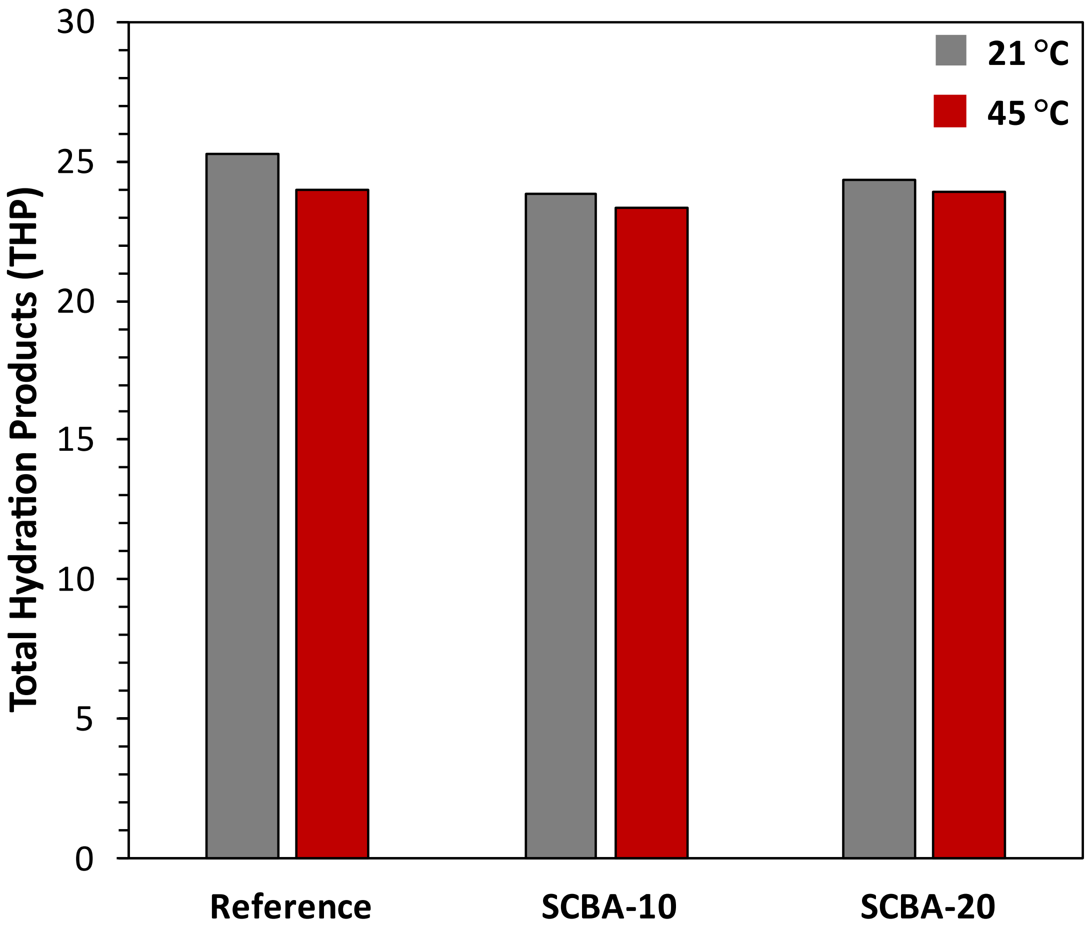
***** Acceptable if physical requirements met… Strength Activity Index (SAI)***

Thermogravimetric Analysis (TGA)

*** Kim-Olek Method [9]*



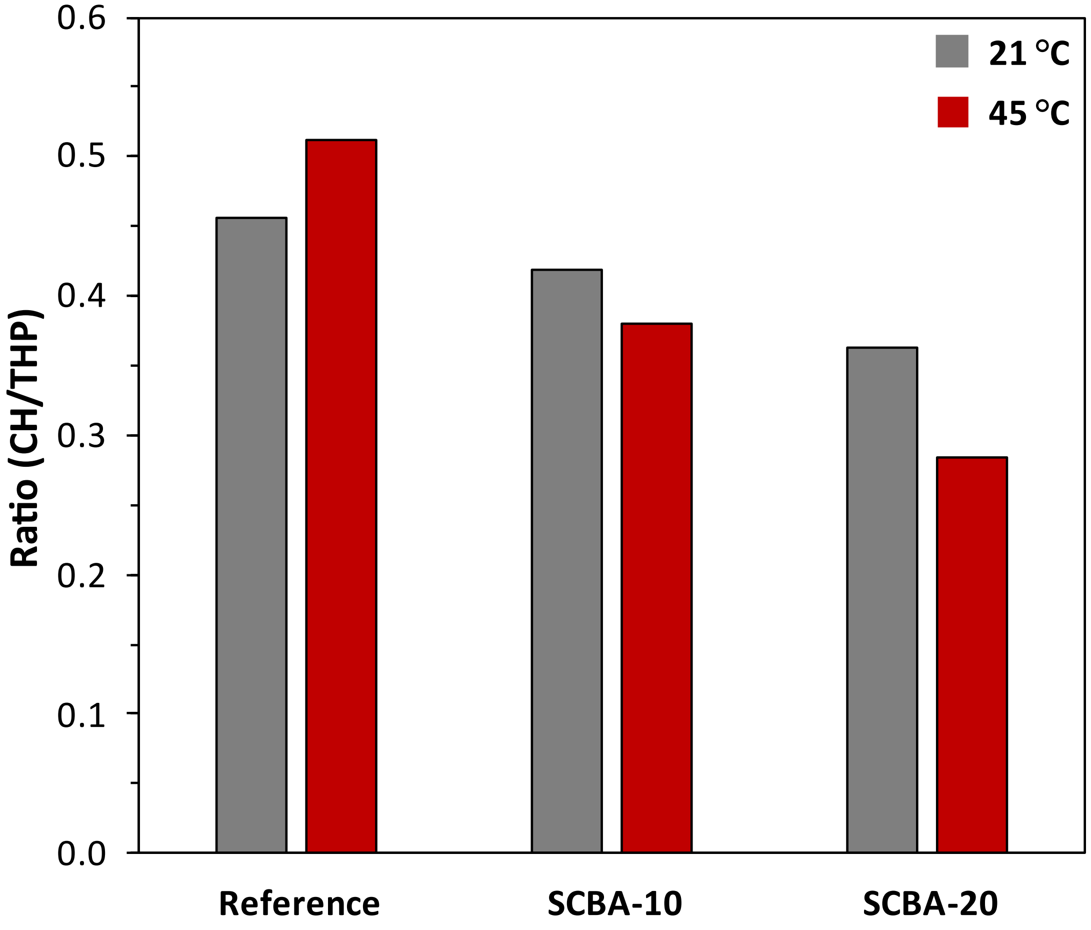
Total Hydration Products (THP)



- Regardless of SCBA replacement amount, the ***THP*** is **lower** when cured at **45 ºC** versus at **21 ºC**.
- However, higher SCBA replacements **mitigated** the loss of ***THP*** when cured at **45 ºC** in comparison to **21 ºC**.

	THP [g/100 g]		Δ
	21°C	***45°C***	***[%]***
Reference	25.31	23.98	-5.25
10% SCBA	23.84	23.37	-1.97
20% SCBA	24.35	23.92	-1.77

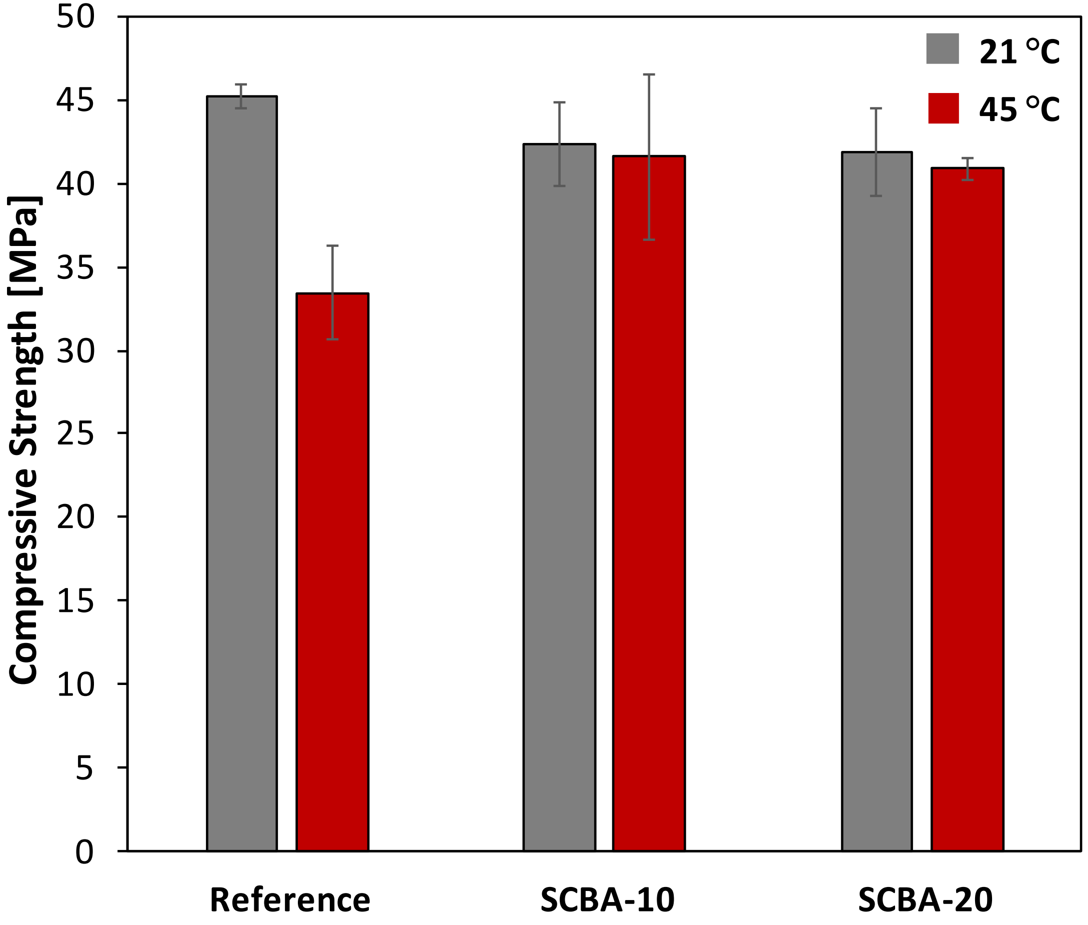
Calcium Hydroxide (CH)



- Lower amounts of SCBA results in a greater ***CH-to-THP***, regardless of curing temperature.
- Using SCBA as a replacement, ***CH-to-THP*** is lower when cured at **45 ºC** versus at **21 ºC**.
- When SCBA is not used, the ***CH-to-THP*** is greater when cured at **21 ºC** versus at **45 ºC**.

	CH-to-THP		Δ
	21°C	***45°C***	***[%]***
Reference	0.46	0.51	12.37
10% SCBA	0.42	0.38	-9.27
20% SCBA	0.36	0.28	-21.99

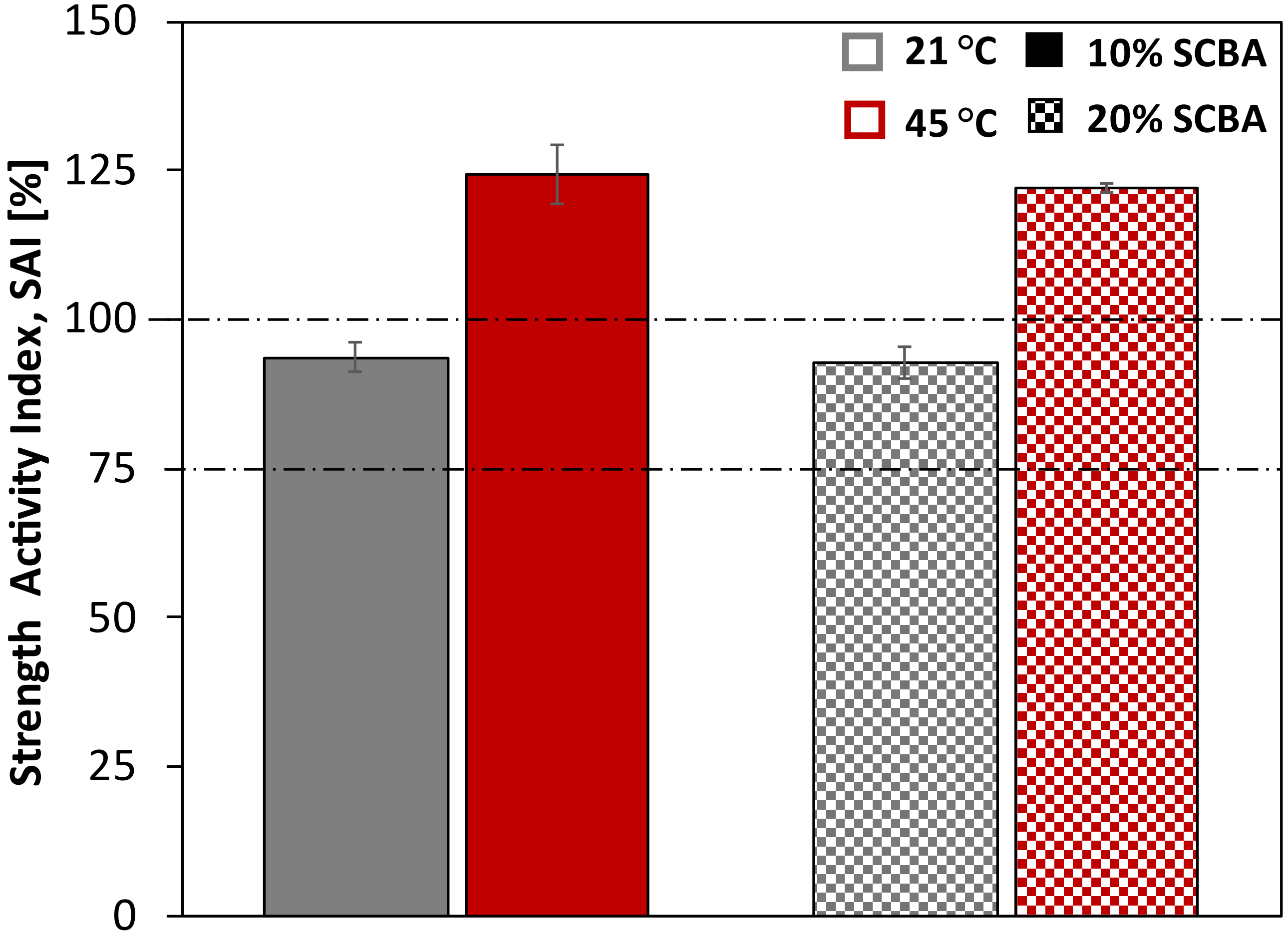
Compressive Strength



- Increasing the amount of SCBA results in a **lower compressive strength** when cured at **21 ºC**.
- The use of SCBA results in a **greater compressive strength** when cured at **45 ºC**.
- The use of SCBA **mitigates** the loss in **compressive strength** when cured at **45 ºC** versus at **21 ºC** .

	Compressive Strength [MPa]		Δ
	21°C	*45°C*	*[%]*
Reference	45.20	33.44	-26.02
10% SCBA	42.37	41.62	-1.77
20% SCBA	41.88	40.88	-2.39

Strength Activity Index (SAI) ** ASTM C311



- The **SAI** minimum of 75% is achieved for both SCBA replacements 10% and 20%; regardless of curing temperature.
- However, for each SCBA replacements 10% and 20%; **SAI** was much **higher** when cured at **45 ºC** versus at **21 ºC.**
- At both **21 ºC** and **45 ºC**; the SAI is **slightly higher** for SCBA replacement of 10% versus at 20%.

CONCLUSION

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Conclusions

- When curing at high temperatures (45 ºC), the use of SCBA **increases compressive strength** compared to reference mixtures at the same curing temperature.

- SCBA **mitigates** the decrease in **compressive strength** in the experienced cross-over effect.

- At high temperatures, the use of SCBA produced a higher decrease of the **Calcium Hydroxide (CH**) -**total hydration products (THP) ratio**, indicating a greater pozzolanic activity than at reference temperature.

- At high temperatures (45 ºC), SCBA significantly **increases** the **strength activity index (SAI)**.

FUTURE WORK

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Future Work

- Investigate the influence of SCBAs particle size on its performance as an SCM.
- Examine the X-ray diffraction results of SCBA.
- Investigate the influence of w/c ratio on SCBAs performance as an SCM.
- Evaluate the performance of SCBA as an SCM in concrete.
- Perform a life-cycle analysis (LCA) of SCBA as an SCM in concrete.

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Thank You!

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