

Coal-Derived Alternatives to Fibre-Cementitious Building Materials (DFF E0031981)

Wednesday, October 26th, 2022

U.S. DOE-NETL Resource Sustainability Project Review Meeting

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Ohio University

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ISEE Overview

- Institute Facts
 - Faculty: 4
 - Staff: 4
 - Students: 16 Graduate; 14 Undergraduate
 - Space: 14,000 ft²
 - Over \$25M in external research since 2008
- Research Capabilities
 - Thermocatalytic and Electrochemical Processes
 - Atomic and Process Simulations
 - Materials R&D
 - Techno-economic and Lifecycle Analyses

Areas of Research



Energy

- CO₂ Capture/Utilization
- Shale Gas Conversion
- H₂ Production



Wastes

- Building Materials
- Critical Materials
- Plastic Recycling



Water

- Nutrient Recovery
- Produced Water
- Critical Materials

Project Overview

Project Specifics

- DOE/NETL Cooperative Agreement No. DE-FE-003981
- DOE Project Manager: Michael Fasouletos
- Principal Investigator (PI): Jason Trembly
- Participants: CONSOL Energy and CFOAM (CONSOL Innovations)

Project Budget

- Federal: \$500,000
- Non-Federal: \$125,000

Project Duration

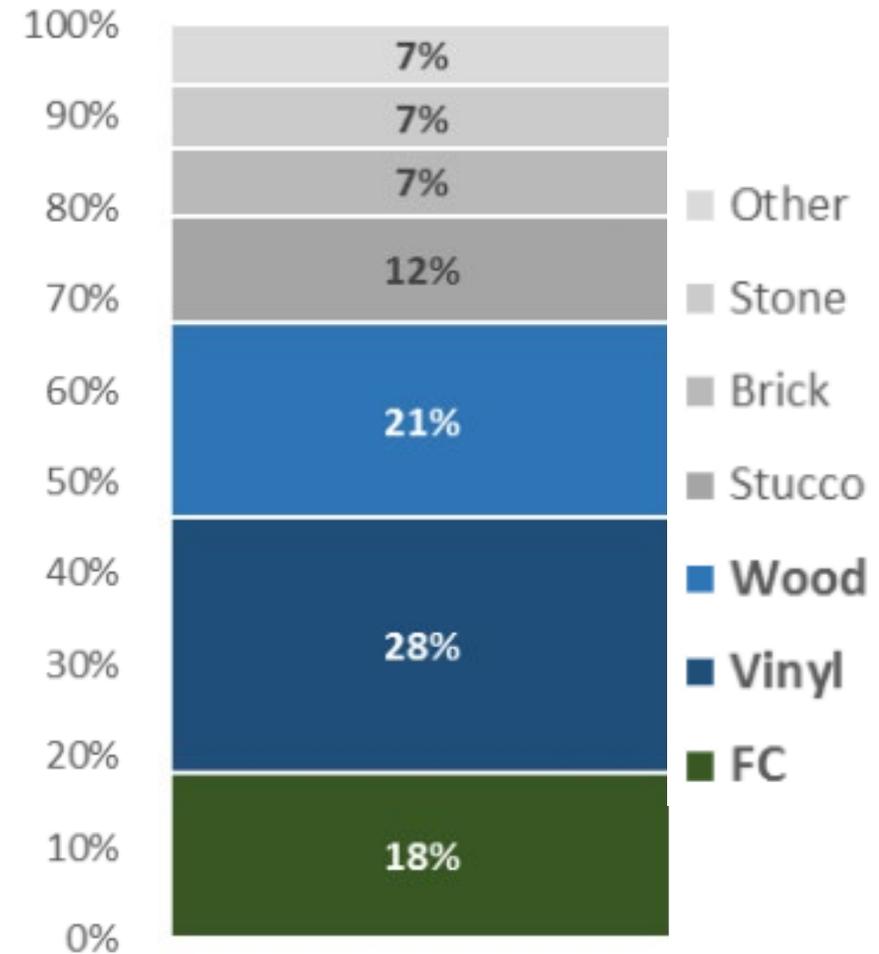
- January 1, 2021– December 31, 2022



DOE-NETL Carbon Ore Processing Program

Cladding Materials

- Vinyl and fiber cement (FC) siding products dominate the U.S. market, with 2.6 and 2.1 billion square feet installed in 2018.
- The FC siding market is valued at \$13.2 billion and is expected to reach \$20.3 billion by the end of 2025.
- FC siding is a composite material consisting of three primary components:
 - Cement (40-60 wt.%), filler (typically fly ash or sand, 20-50 wt.%), wood fiber (8-10%) with additional additives (<1 wt.%)
- Advantages of FC siding include
 - Durability and Style versatility
 - Ability to emulate wood
 - Resistance to fire, weather, and insects
- Disadvantages of FC siding include
 - High emissions compared to Vinyl siding
 - High purchase and installation costs (2-3 times higher than vinyl siding)
 - Deleterious health effects to construction workers
 - High surface density (lb/ft²)



North American siding market share

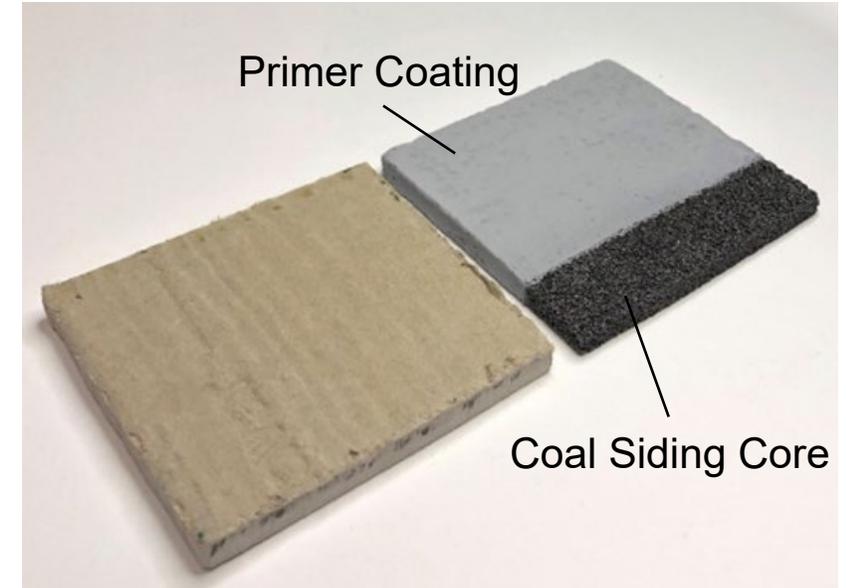
Coal-Derived Siding

Benefits of coal-based foam siding

- Lower-cost siding product with equivalent or better performance
- Lower density
- Safer and more environmentally friendly product due to minimal silica content and cement-free formulation
- Utilization of commercial extrusion technology, minimizing manufacturing costs and commercialization timeline
- High thermal stability and fire resistance

Merits

- High-value building product market, creating 0.5-1.0 million tons/yr of new coal demand
- The manufacturing of coal-based siding would support new manufacturing jobs.



Cross-sectional views of (left) commercial FC siding and (right) prototype coal foam siding product

Project Objectives

Overall: Develop coal-based siding materials used in residential and commercial cladding applications.

- Consist of ≥ 51 wt.% coal and > 70 wt.% carbon
- Offer performance, cost, and environmental benefits

Phase I Objectives

- Develop continuous bench-scale carbon foam manufacturing process
- Assess carbon foam properties for cladding applications
- Develop molecular dynamic simulations to predict carbon foam properties
- Conduct techno-economic and technology gap analyses



Project Scope

Project Milestones

Description	Planned Completion Date	Actual Completion Date
Coal Siding Material Performance Report	January 31, 2022	January 31, 2022
Techno-economic and Market Analyses	August 31, 2022	August 31, 2022
Technology-gap Analysis	December 31, 2022	

Project Success Criteria

- Establish the ability to produce coal siding core containing greater than 80 wt.% coal using continuous methodologies.
- Experimentally validate coal siding meets ASTM C1186 specifications.
- Establish coal siding manufacturing costs of <\$0.55/ft (20% less than FC siding)

Current Project Status

Material R&D

- Carbon foam (CF) cladding materials
 - Meet ASTM cladding specifications
 - Have lower density than existing cladding materials
 - Maintain significant oxidation and fire resistance
- CF-enhanced fiber cement claddings
 - Meet ASTM cladding specifications
 - Reduce in cladding density by up to 30%

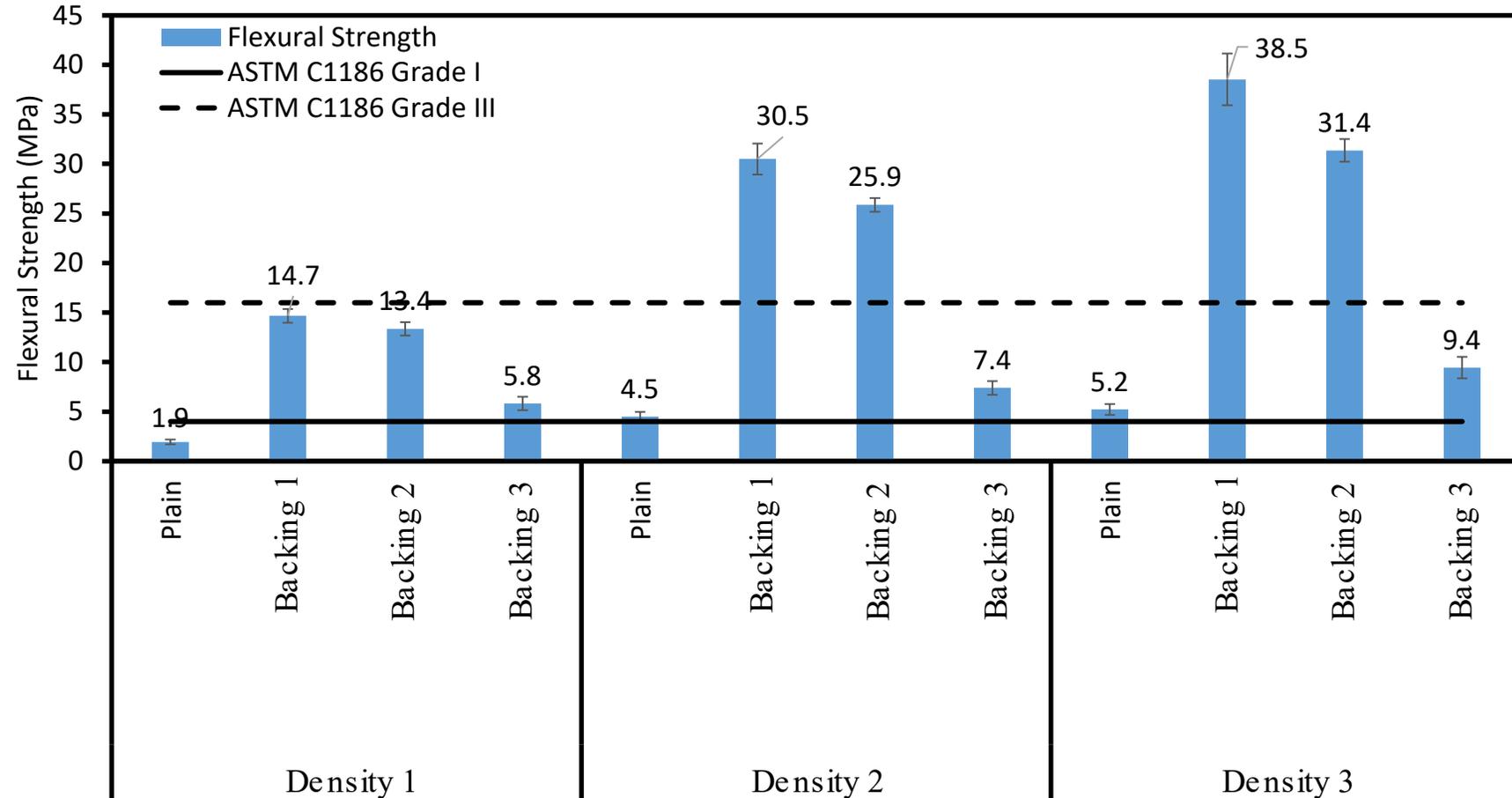
Process R&D

- Continuous coal-to-CF manufacturing matured to TRL5
- Preliminary cost analyses indicate CF-based materials have significant market potential

Carbon Foam: Flexural Properties

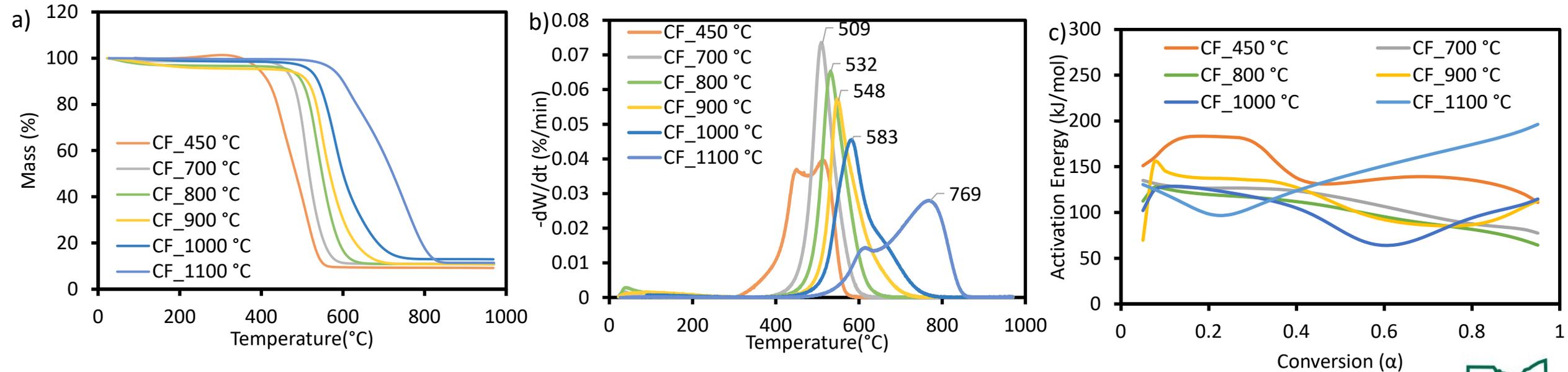
Flexural Strength (FS)

- Carbon foams (CFs) with different densities and fiber backing materials were tested per ASTM C1186
- CFs with higher densities and no fiber backing meet ASTM requirements for Grade I
- Fiber backing significantly improved FS
- CFs with higher densities exceed ASTM requirements for Grade III



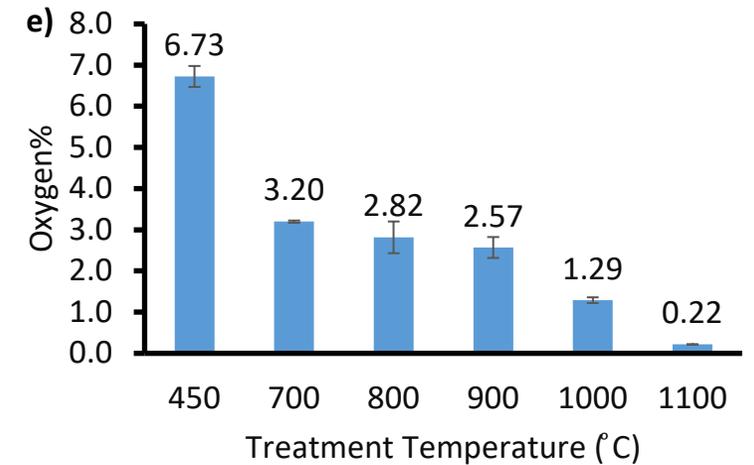
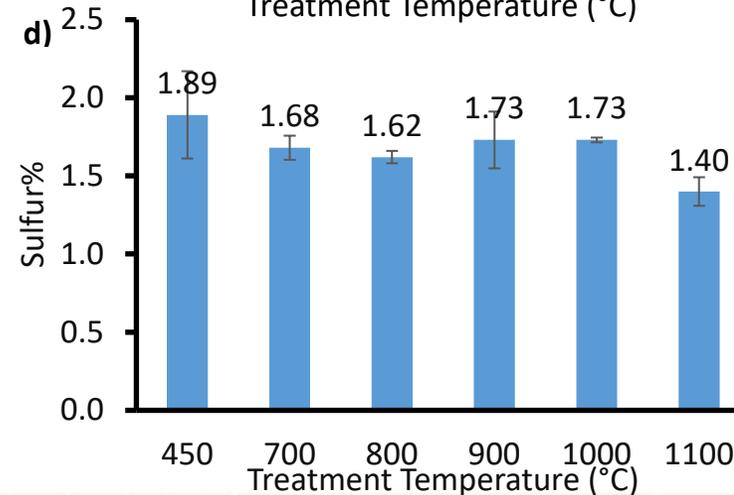
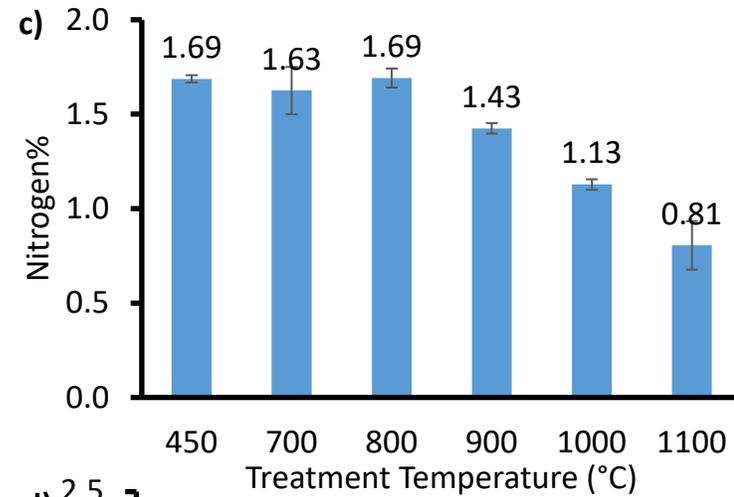
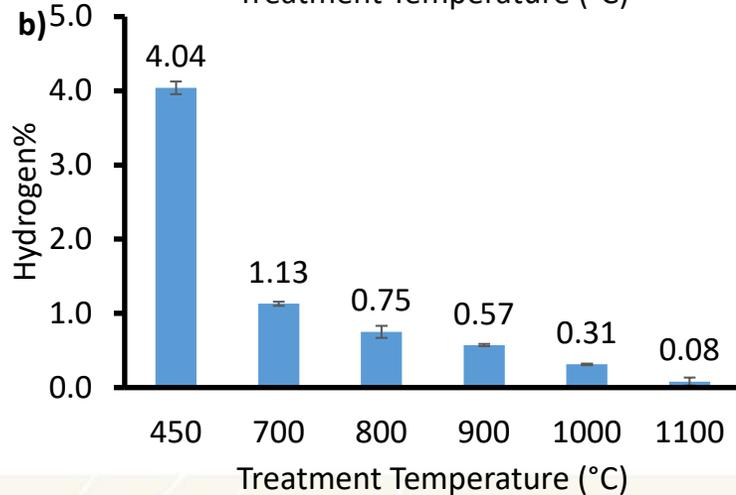
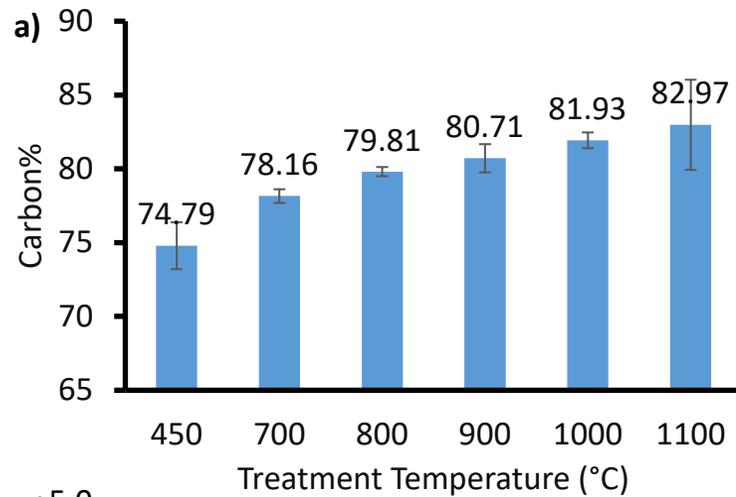
Carbon Foam: Thermal Stability and Flammability

- Thermo-oxidative stability increased with the treatment temperature increase
- CF self-extinguished after removal of the flame when tested per ASTM D635



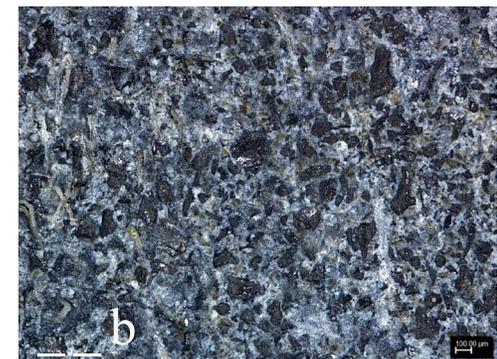
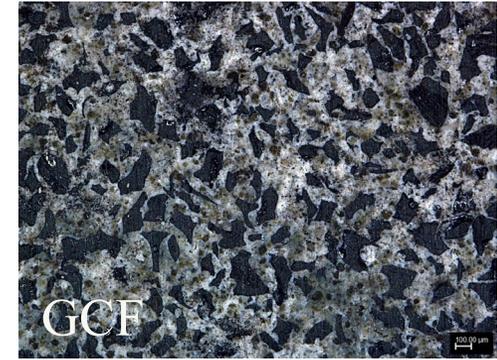
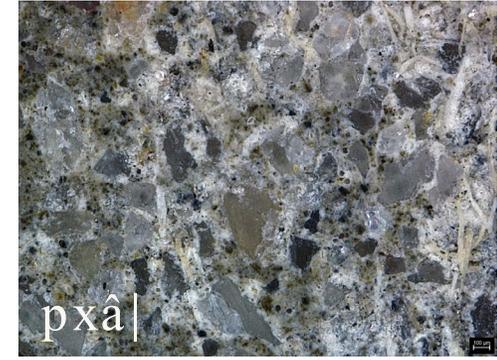
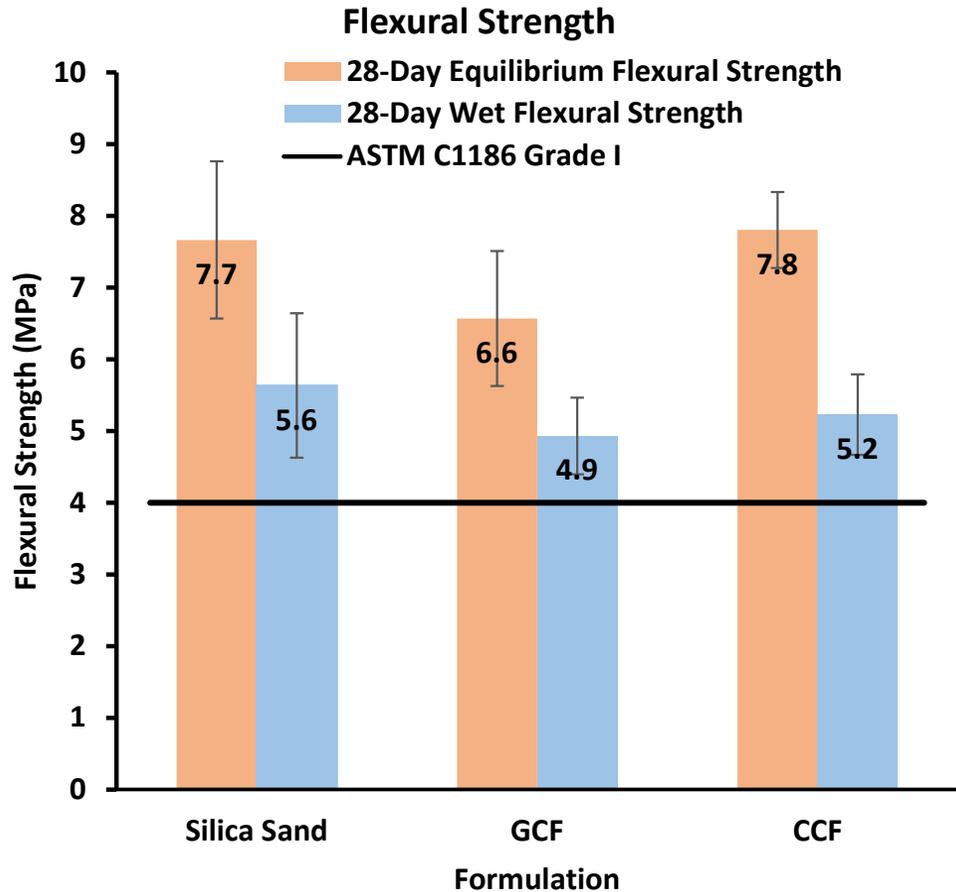
Carbon Foam: Composition

- Elemental analyses indicated carbon content to increase with treatment temperature



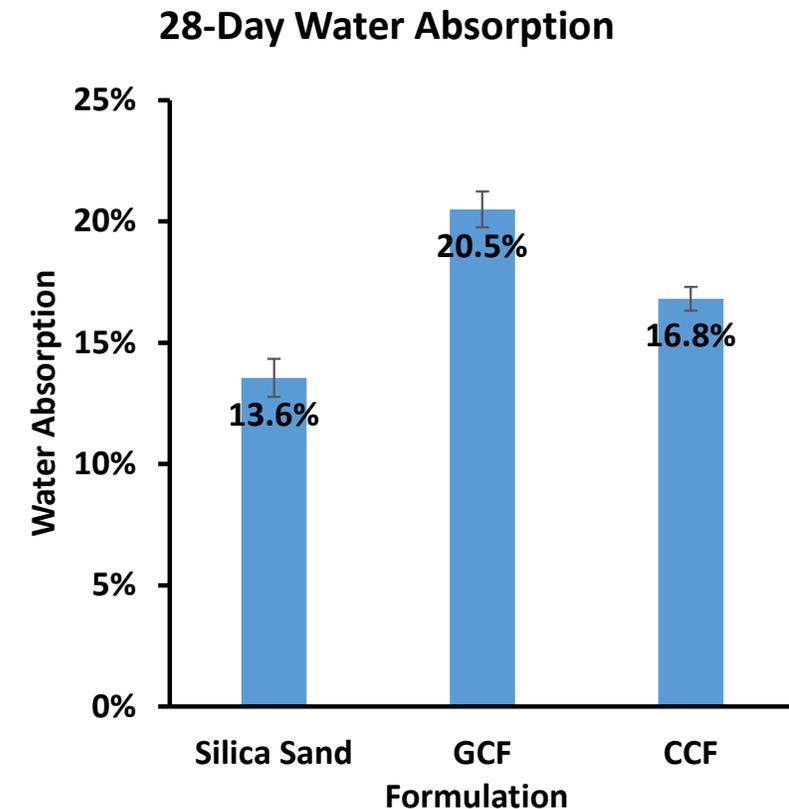
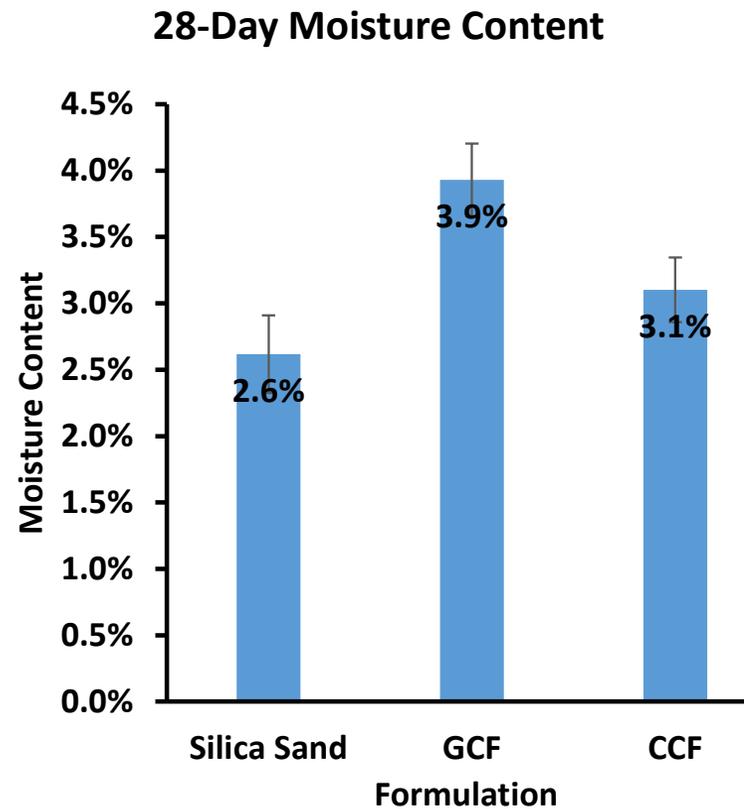
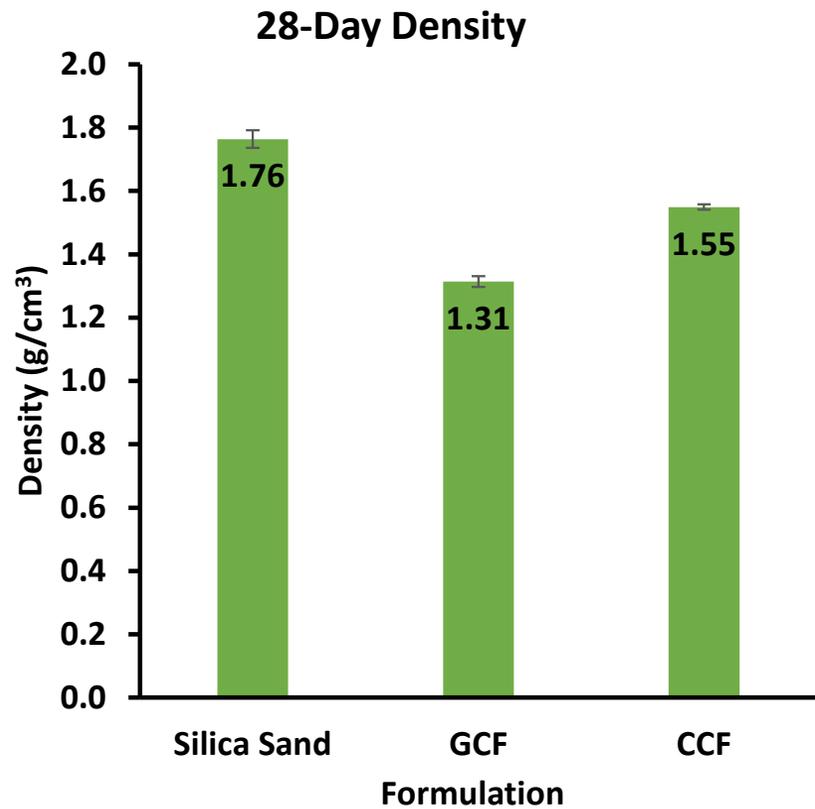
CF-Enhanced Fiber Cement: Flexural Strength

- Meets the 4 MPa flexural strength requirement for Grade I Type A siding – ASTM 1186
 - Statistically equivalent flexural strength to the traditional sand composite



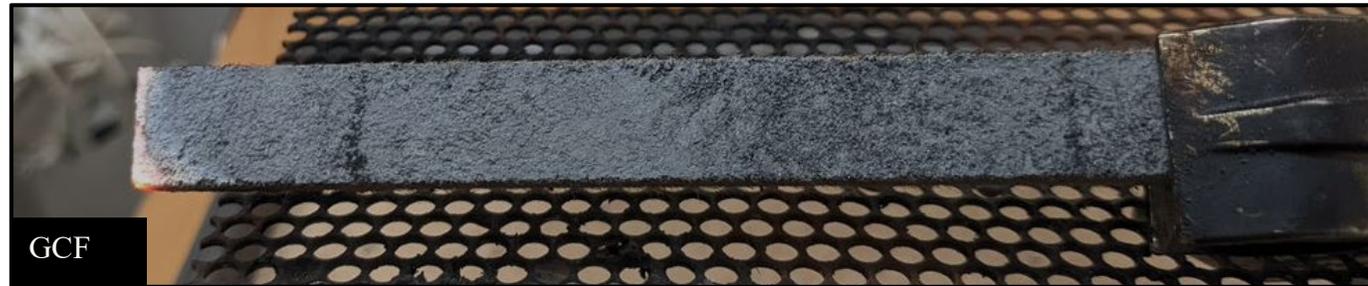
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- Reduction in composite density up to 30.0%
- Greater moisture content and water absorption due to higher mass fraction of cement



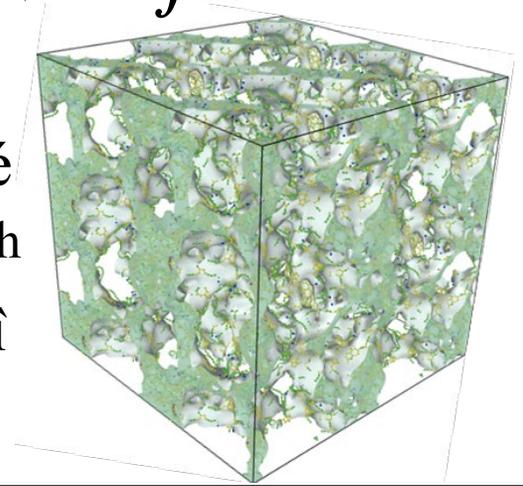
CF-Enhanced Fiber Cement: Flammability Resistance

- Failure to ignite and immediate extinguish upon removal of test flame
 - ASTM D635

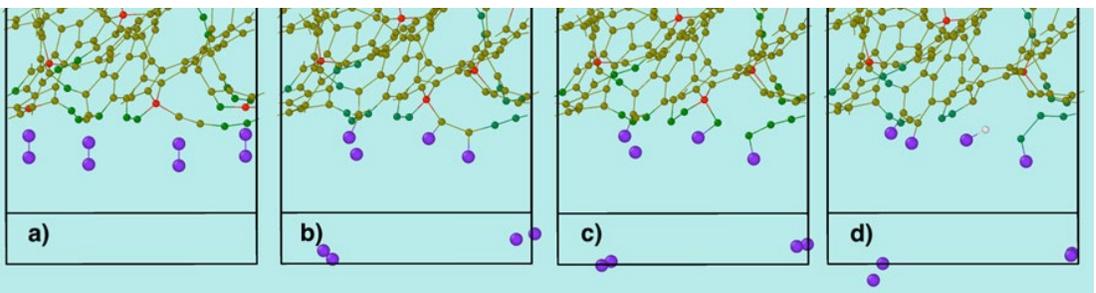


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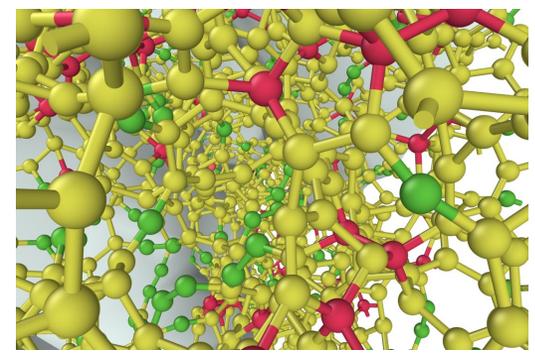
8000 atom C-foam model



Mechanism of O₂ reaction at the surface of a -C material at 1000K. The O₂ molecules stick to active C sites on the surface (b), break the O-O bond (c), and then come off as CO molecule (d).

Site	Adsorbent	E _{ads} (eV)
long sp	O ₂	-3.41
bent sp	O ₂	-6.28
long sp	N ₂	6.02
bent sp	N ₂	2.64
sp ²	O ₂	-2.29
sp ²	N ₂	6.93

Adsorption energies of the O₂ and N₂ molecules on different sites of the a-C surfaces.



Internal structure of C-foam matrix. Red, yellow, green, and blue atoms represent 4-fold, 3-fold, 2-fold, and 1-fold coordinated C atoms.

Future Development & Summary

Future Development

- Refine formulations for end-user applications
- Identify a facility to conduct pilot-scale manufacturing trials

Summary

- Coal-derived materials meet ASTM specifications for cladding applications
 - Equivalent strength, lighter weight, better oxidation resistance, tunable properties
- New continuous carbon foam manufacturing process developed
 - Reduces processing time from days to minutes
- Coal-derived carbon foam manufacturing technology matured to TRL4/5

Acknowledgements

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Questions

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