Low Weight, High Strength Coal-Based Building Materials for Infrastructure Products

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PROJECT OVERVIEW

Overview

- Funding
  - Federal = $497,688
  - Non-Federal = $126,000
  - Total Project = $623,688
- Period of Performance: 1/1/21-9/30/22
- Team Members
  - University of North Dakota Energy and Environmental Research Center (EERC)
  - Center for Applied Research and Technology (CART)

Project Objectives

1. To develop a process to produce infrastructure components such as structural and face brick and block (55% by weight) of coal-derived “aggregate” material as high strength filler embedded in polymer-derived ceramic matrix to form the brick or block.
2. To produce prototype quantities of coal-based brick (X-BRIX) and coal-based block (X-BLOX): a minimum of 10 full size and representative dimensioned X-BLOX of nominal dimensions 16” × 8” × 8” and a minimum of 20 X-BRIX of nominal dimensions 8” × 4” × 2.5”.
3. To determine if X-BRIX and X-BLOX have better mechanical strength (e.g., three to five times higher flexural strength, two to three times higher compressive strength) and lower weight (30% to 50% lighter) than commercially used and certified Class AA clay brick and high-strength construction grade concrete blocks, and if the amount of toxic elements leaching out of these materials is either negligible or within allowable EPA guidelines.
4. To execute a technology gap analysis to determine work required to scale up infrastructure component production and compare the value per ton of coal in the new process against using the coal as fuel.

TECHNOLOGY OVERVIEW

How are X-MAT Composites unique?

- Our Polymer Derived Ceramic resins are inorganic polymers tuned at the Atomic Level to contain varying amounts of silicon, oxygen and carbon or other elements
- Liquid resins not hazardous, cured resins UL94 V-0
- Use Raw Coal - Resin fully coats and encapsulates the filler particles
- Resin acts as binder between particles - no sintering needed
- X-MAT "Mix and Mold" Process is simple, scalable, and cost-effective - Single Batch Composite
- X-MAT ceramic composites won't burn despite having high coal content
- Low-cost inorganic resins + Coal $0.02-0.05/lb

TECHNICAL APPROACH/PROJECT SCOPE

Process to Produce Ceramic X-BRIX and X-BLOX

- Raw powdered coal was mixed with a customized ceramic forming polymer designed to bond to the coal. The ratio ranges from 65% to 75% coal to produce a “clay-like or damp sand” material
- The mixture was tamped into large trays and cured to 160-200°C in air for 2 hours.
- Once cured, the chunks of plastic-like material were milled down to produce under 5mm particles called “Cured Engineered Aggregate
- The aggregate was mixed with more of the same resin at a 75-80% aggregate to resin mass ratio
- The coated aggregate was then pressed into the appropriate mold to make the part and pyrolyzed in nitrogen to 1000°C for 2-4 hours.
- Cracked parts were recycled by chain milling to produce ceramic carbon ore aggregate for X-MATRIX components

Process to Produce X-Matrix Bricks and Blocks

- The ceramic carbon ore aggregate was mixed with Portland Cement, water, and additives to make a coarse mortar
- The mixture was poured into either an X-BRIX mold or an X-BLOX mold and placed on a vibrating table to settle the material and remove air bubbles
- The panel was allowed to stand for 3 days in the mold and was then de-molded prior to a full cure to form the X-MATRIX Component.

PROGRESS & STATUS OF PROJECT

Project is currently awaiting approval of a 6 month, no cost extension

- Have produced the required number of full-size ceramic X-BRIX
- Producing full size X-BLOX has been problematic
- Have utilized "Engineered Ceramic Aggregate" developed under another NETL program combined with Portland Cement to successfully produce X-MATRIX full size Blocks
- Will utilize the extension to produce 10 full size X-MATRIX blocks
- Engineered Ceramic Aggregate used in place of sand with Portland Cement to produce high strength X-MORTAR

X-BRIX and X-BLOX Formulas

X-MATRIX Coal-based analogs of conventional cement bricks/blocks

- Rock and sand “aggregate” is replaced by coal-based ceramic aggregate

Ceramic like clay bricks – cured aggregate with ceramic forming polymer binder – Fired to 1000°C

- Hard, abrasion resistant, ~ 40% lighter, 3x flexure strength, 2-3X compressive strength

Plastic/Ceramic – ceramic aggregate with inorganic plastic binder – Cured 180°C

- Hard, tough, low porosity, 2-3x flexure strength of commercial bricks and block

Ceramic Bricks

Plastic/Ceramic Brick

X-MATRIX Blocks

Performance Data

Property	X-BRIX	X-BLOX	Comm. Brick	Comm. Block
Compressive Strength	4465 psi	4863 psi	2845 psi	4400 psi
Flexural Strength	1120 psi	2006 psi	712 psi	800 psi
Density	1.57 g/cc	1.55 g/cc	-	2.3 g/cc
Open Porosity	7.57 %	8.14 %	-	-

Comparative Performance Table

EPA Regulatory Limits for RCRA metals from TCLP Extracts

All compositions are well below the EPA Regulatory Limits

Contaminant	Regulatory Level, mg/L	Bituminous Aggregate Brick Core	X-MATRIX Block Formulation	X-MATRIX Mortar Formulation	X-MAT Ceramic Brick	X-MAT X-MATRIX Brick
Arsenic	5	< 0.010	<0.010	<0.010	<0.010	<0.010
Barium	100	0.049	0.312	1.26	0.079	0.310
Cadmium	1	< 0.005	<0.005	<0.005	<0.005	<0.005
Chromium	5	0.212	0.960	0.093	0.259	1.73
Lead	5	< 0.010	<0.010	<0.010	<0.010	<0.010
Mercury	0.2	< 0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Selenium	1	< 0.010	<0.010	<0.010	<0.010	<0.010
Silver	5	< 0.010	<0.010	<0.010	<0.010	<0.010

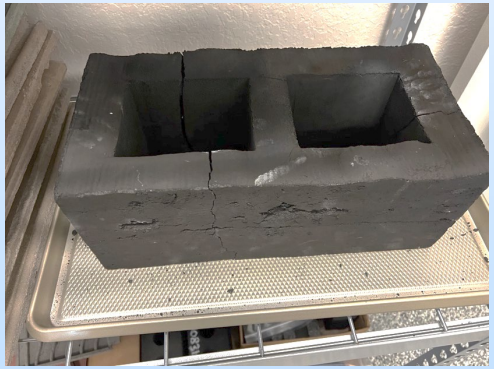
Full Sized Ceramic X-BLOX

CART Cured Ceramic X-BLOX

Cured Ceramic X-BLOX

CART Fired Ceramic X-BLOX

X-BLOX after firing

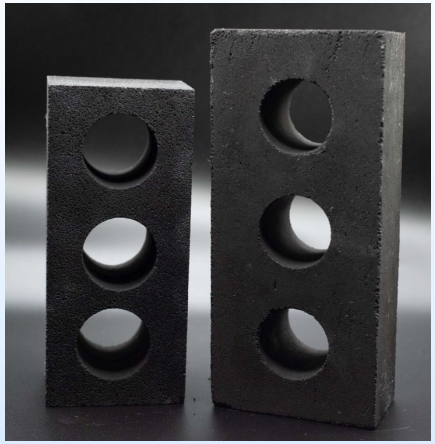


Representative Ceramic Blocks – Cracking during Pyrolysis

Ceramic X-BRIX

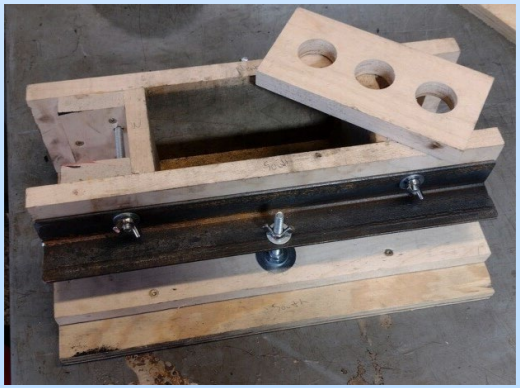
Initial CART Ceramic Bricks

Final CART Ceramic Bricks



Semplastics 3-Hole Ceramic Bricks Bituminous

Semplastics 3-Hole Ceramic X-BRIX Lignite



Mold Used to Produce 3-Holed Bricks

Lightweight X-MATRIX Blocks

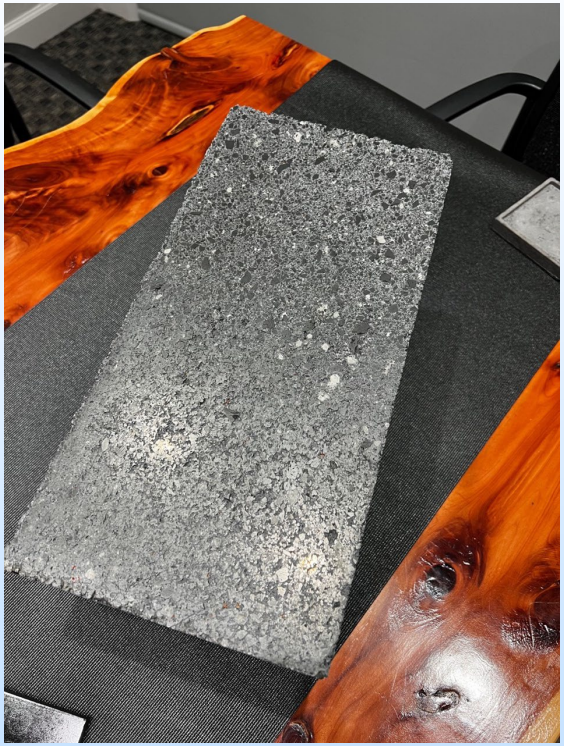
Standard Lightweight Block
14.36kg (31.66lbs)

X-MATRIX Lightweight Block
9.5kg (20.94lbs)

Standard Lightweight Block (Top)
X-MATRIX Lightweight Block
(Bottom)

Standard Lightweight Block (Top)
X-MATRIX Lightweight Block
(Bottom)

Polished Face X-MATRIX Block



X-MATRIX Block
Polished Side – Shows
Exposed Coal Ceramic
Aggregates

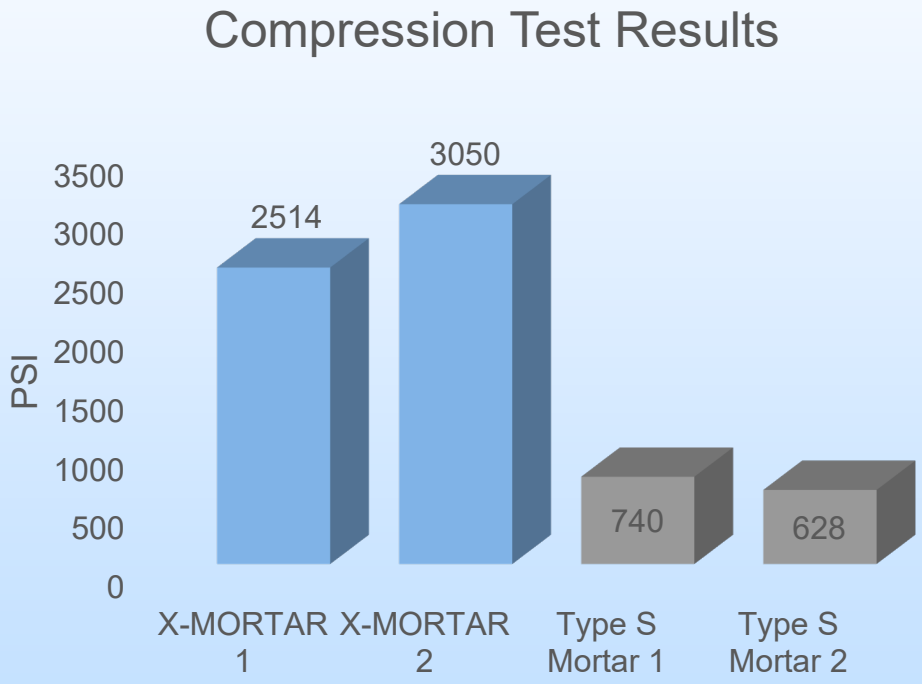
CART Improved
Process for X-MATRIX
Blocks compared with
utilizing a wooden mold

X-MORTAR Compression

X-MORTAR is a specific formulation of X-MATRIX that uses sand sized ceramic coal particles mixed with Portland Cement to mimic the workability of traditional mortar.

X-MORTAR Compression Cubes

Type S Mortar Compression Cubes



X-MORTAR Bonding

X-BRIX w/ X-MORTAR Failure Detail

X-BRIX w/ Type S Mortar Failure Detail

Ceramic X-BRIX Components Bonded with X-MORTAR

Material	Max Load Before Failure
Clay Bricks w/ Type S Mortar	365 lbs
Clay Bricks w/ Coal-Based Mortar	611 lbs

Material	Max Load Before Failure
X-BRIX w/ Type S Mortar	148 lbs
X-BRIX w/ Coal-Based Mortar	653 lbs

We completed a 3-Point Bend Test on clay and ceramic bricks bonded both X-MORTAR and Type S Mortar and found about a significant improvement with the X-MORTAR when looking at the load applied before failure

Scale Up & Future Research

Project Phase	Milestone Targets	
	Technical	Economic
Phase I	Formulation comparisons for X-BRIX and X-BLOX with existing commercial brick and block by flexure testing and compression testing; preliminary abrasion testing and polished sample production	Formulation at $0.65/lb.
	Performance testing with two types of coal (bituminous and lignite)	Pricing analysis
	Development and execution of preliminary testing on a mortar/grout material	
Phase II	Identify formulations, processes and equipment needed for scaling X-BRIX and XBLOX	Formulation at $0.45/lb.
	Comprehensive Prototype testing of X-BRIX and X-BLOX to ASTM C 62-05 and C-90-06 along with accelerated weather & UV Testing	
	Scale-up process	Target customer analysis
Phase III	In-field testing	Market testing

Additional research and market analysis could focus on potentially entering a market for Face Bricks and/or Pavers since they are priced about twice as high on a $$/sq. ft. compared with structural bricks and blocks and wouldn't require the same level of certifications or testing.

SUMMARY

Semplastics has demonstrated a process using greater than 50% Carbon Ore to produce four types of building materials

- High strength ceramic bonded ceramic/carbon ore composite X-BRIX
- Tough inorganic resin bonded ceramic/carbon ore X-BRIX
- Lightweight Portland Cement bonded engineered carbon ore aggregate based X-Matrix Bricks, and X-Matrix Blocks
- Ceramic/carbon ore aggregate - based mortar using finer aggregate

Carbon ore-based infrastructure components with improved properties can be produced, but are only cost/performance competitive in the form of face bricks, façade panels, wall tile, and pavers.

They are not competitive with standard bricks and concrete block on a cost basis.

Acknowledgments

- NETL
  - Technology Manager - Joe Stoffa
  - Federal Project Manager – Mark Render
- CART
  - CEO - Bruce Mutter
- EERC
  - Senior Research Engineer – Dr. Bruce Folkedahl
  - Senior Analytical Chemist – Carolyn Nyberg

APPENDIX

Organization Chart

Semplastics (Prime)

PI leading a team of Engineers & Techs

Primary Technology & Prototype Development
Project Management

CART (SubK)

Prototype Development
Product Design
Assist in Scale-Up Design

EERC (SubK)

Characterization and Analysis including Leach Testing, Particle Size Analysis, etc.

Gantt Chart

Task	Description	Year 1				Year 2	
		Q1	Q2	Q3	Q4	Q1	Q2
1.0	Project Management & Planning						
2.0	Fabrication Process Development and Test Specimen Manufacturing						
M1	Test Samples produced with desired mechanical properties						
M2	Leach testing of test sample and microstructure characterization complete						
3.0	Production and Testing of Prototype Size X-BRIX and X-BLOX						
M3	Full size X-BRIX and X-BLOX Components Produced						
M4	Mortar and Group System Developed & Tested						
M5	Testing of segments from full-size components complete						
4.0	Scale Up Plan, Cost Model, and Plant Cost Estimation						
M6	Market Analysis and Scale Up Plan Complete						

No-Cost Time Extension to utilize alternative process for full size blocks and then updating Market Analysis based on those results.