Coal Core Composites for Low Cost, Light Weight Fire Resistant Panels and Roofing Materials

Annual Project Review
Award #DE-SC0018794

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Purpose of Project and Fossil Energy Objectives

Purpose of Project

• To utilize coal as a low-cost filler in low-cost polymer-derived ceramics to produce commercially viable high-volume use of coal for roof tiles

Alignment with Fossil Energy Objectives

• Commercial applications would use large volumes of coal – roof tiles contain more than 70% coal
• Raw coal is used – little or no pre-processing is needed
• Production to be sited near or at coal source – will provide high-value jobs

Driving Question that was answered:

Can a laboratory process be scaled up to produce full-size roof tiles with two different form-factors and target markets? – confirmed
## Technology Benchmarking

### Comparison of Semplastics Roof Tiles to Commercial Products

<table>
<thead>
<tr>
<th>Property or Attribute</th>
<th>Semplastics X-tiles (pressed) (psi)</th>
<th>Semplastics X-tiles (molded) (psi)</th>
<th>Clay Roof Tiles (high-end tiles) (psi)</th>
<th>Vermont Slate (high-end slate) (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexure Strength</td>
<td>5715</td>
<td>3250</td>
<td>1460</td>
<td>3680</td>
</tr>
<tr>
<td>Density</td>
<td>1.65</td>
<td>1.45</td>
<td>2.08</td>
<td>2.51</td>
</tr>
<tr>
<td>Impact Resist (normalized)</td>
<td>1.80</td>
<td>1.40</td>
<td>1.00</td>
<td>3.50</td>
</tr>
<tr>
<td>Porosity (% by volume)</td>
<td>4.5</td>
<td>8.5</td>
<td>15.3</td>
<td>0.50</td>
</tr>
<tr>
<td>Cost/Square ($/100 sq ft)</td>
<td>$250-$550 (est.)</td>
<td>$200-$400 (est.)</td>
<td>$350-$450</td>
<td>$900-$1,200</td>
</tr>
</tbody>
</table>
Current Status of Project

**SEMPLESTICS**

- Beginning the first round of new coal-clay barrel tiles (clay tile replacement) – have demonstrated ability to produce full size (16" × 12" × 0.5") tiles
- Have installed mixer, press, curing oven and larger kiln/retort to process up to 32 tiles per run
- Initial runs have demonstrated the heating cycle does not induce cracks in the tiles
- Full-size tiles demonstrate comparable properties to baseline small pressed test plates

**CART**

(Center for Advanced Research and Technology, Bluefield, WV)

- CART has begun producing the first flat tiles made with their new mold design and press
- CART will mix the resin with coal, press the tiles, and cure the tiles
- Due to issues with their kiln, CART will ship the cured tiles to Semplastics for pyrolysis at least for the next few months
Current Status of Project (cont.)

COVID-19 has caused delays

• Kiln ordered by Semplastics delayed more than 6 weeks then came in damaged, adding another 2 weeks to setup; finally installed and tested in February

• Kiln retort delayed 6 weeks due to metal supply delays and the welder himself contracting COVID-19

• The first firing of the kiln and retort with parts was completed March 29, 2021

• CART attempted to order a kiln in early January and found there was a 12-16 week lead time for a new kiln; sourced a used kiln but it arrived severely damaged and would need to be completely rebuilt

• CART will rely on Semplastics to fire their flat roof tiles for the next few months

• Semplastics re-activated the furnace used to make the Phase I and early Phase II pressed tiles – capable of firing 4 tiles per run (as for the kiln, a run takes 5 days)
CART has begun Prototype Flat, Pressed Tile Production

- CART has installed a 100-ton hydraulic press for prototype production (shown on left)
- Set up a prototype line to use 25 lbs of coal per batch
- Can make 5-6 cured roof tiles per batch
- Approximately 18 batches per square
- New design will minimize tile overlap
- CART will do the prototype scale-up of pressed tiles demonstrating feasibility of producing a 10 ft × 10 ft square of cured tiles
More Prototype Production Equipment at CART

Hobart 50-quart Planetary Mixer for mixing resin and polymer

Mechanical Convection Oven for curing pressed tiles
Tile Mold at CART

New Tile Mold for pressed tiles
Semplastics Coal-Clay Tile Program

• Developed resin emulsification process to create “black clay” or coal coated with a water resin emulsion
  • Material behaves just like regular clay used for roof tiles but is 68-70% coal when dried
  • Demonstrated a baseline formulation to make coal-clay for either extrusion or low-pressure molding

• Designed and built a barrel tile mold

• Used 50 lb. per hour clay mixer to mix the emulsified polymer with the raw coal powder to make the coal-clay

• Used our “pug mill” – a mixer/extruder – to extrude short 4” diameter rods that are then pressed in a low-pressure mold

• Demonstrated that coal-clay can be molded into full-size barrel tiles using a 30-ton hydraulic press with the mold
Barrel Tiles

As-molded Barrel Tile

2 Tiles after Pyrolysis/firing
Coal-Clay Tile Processing

50 lb. per hour Clay Mixer

200 lb. per hour Pug Mill Extruder
Coal-Clay Tile Processing

Mold Inserts to Produce a Barrel Tile

30 Ton Platen Press
Coal-Clay Tile Processing

Fiberglass Drying/Curing Support

Drying/Curing Oven
Coal-Clay Tile Processing

Kiln with Retort and Support Furniture

Kiln Ready for a Pyrolysis Run
Coal-Clay Tile Processing

- Semplastics has leased and built out a prototype demonstration facility (shown below) adjacent to our Oviedo, Florida site to produce full-size barrel tiles and to produce the 10 ft × 10 ft square of tiles
Scale-Up Challenges

• **COVID-19 Supply Chain Issues**
  • Delivery times for Semplastics’ kiln and retort more than doubled

• **Scaling up Polymer Production**
  • Produced 2nd 30-gallon scale batch at toll producer with refined synthesis procedure – QA analysis indicates properties comparable to midrange of lab-scale batches

• **Barrel Tile Processing**
  • Semplastics is working to improve the drying/curing process for the barrel tiles to eliminate cracking during drying/curing – *modifying drying cycle to produce uniform drying on both sides*
  • Developing fiberglass mold inserts and steel support forms to keep the soft coal-clay tile shape during drying and curing
  • Current production rate is 2 tiles/day without inserts, need to make 6-7 tiles/day to meet program goals – *feasible with mold inserts*
Scale-Up Challenges (cont.)

• **CART must improve mold design for increased throughput**
  • CART has developed a process based on 25 lb. batches (one bag of coal) to produce 5-6 tiles per batch
  • Need to streamline tile removal from the mold – Curing oven capable of handling up to 10 tiles/day

• **Pressed Tile Firing Bottleneck**
  • Due to COVID-19 supply chain issues, CART does not have a working kiln on site to pyrolyze/fire the cured tiles
  • CART will have to ship the cured tiles to Semplastics for pyrolysis essentially doubling the number of tiles that have to be processed at Semplastics – Looking to utilize extra Semplastics furnace for pyrolysis, currently limited to 4 tiles for each 5-day cycle
Next Steps at Semplastics

Semplastics new prototype fabrication facility contains pilot scale equipment for coal-based products

• Semplastics’ facility is expected to begin producing the square of molded barrel tiles by April 30, 2021
  • Plan to make low-pressure molded coal-clay barrel tiles
  • Developing fiberglass mold inserts and steel supports to hold the shape while drying and curing which will greatly improve throughput to the 6 tiles/day target rate
  • Still optimizing the drying/curing cycle and the pyrolysis cycle established that minimizes/prevents cracking – designed for up to 32 tiles per 5-6 day run cycle. Will optimize the curing/heat cycle to accommodate large numbers of tiles

• Some tiles will be sent to an accredited testing laboratory for qualification testing according to ASTM 1167
Next Steps at CART

• CART has set up the prototype production line in Bluefield, WV, which contains:
  • A large mixer to catalyze the pre-ceramic polymer
  • A planetary mixer to mix the coal powder with the polymer
  • A CNC milling system and a CNC router to produce tile molds
  • A hydraulic platen press to produce the pressed tiles
  • A large curing oven to cure the pressed tiles

• CART is using this equipment to:
  • Optimize the mold designs
  • Develop the curing schedules
  • Produce a square of cured pressed tiles
  • Produce tiles for ASTM 1167 testing
Expected Outcome by End of Phase II

• CART plans to demonstrate the ability to produce a full “square” (10’ × 10’) of full-size flat tiles in 20 working days and will produce a minimum of 20 cured tiles (at least 10 to be fired at Semplastics)

• CART will also produce up to 30 flat tiles to support testing at an accredited roof tile testing laboratory to confirm the tiles meet commercial performance specifications

• Semplastics will produce a full “square” of barrel tiles

• Semplastics will produce up to 30 full-size barrel-shaped tiles to support testing at an accredited testing laboratory

• Both CART and Semplastics will provide suggested improvements based on the Phase II work including:
  • Techniques to streamline production processes
  • Cost reduction routes
  • Further improvements in design for both tile types
Expected Outcome by End of Phase II (cont.)

- CART will also demonstrate a new type of low-cost roof tile based on new coal-based aggregate filled cement
  - The technique was developed by Semplastics and will be transferred to CART for scale-up
  - These cement tiles would have the same form-factor as the pressed ceramic tiles
  - CART plans to produce a full square of combined cement and ceramic roof tiles by the end of the program
New Technologies and Process Improvements

• Recently developed an “Aggregate Process” that offers significant improvement over the pressed tile and extrusion technique
  – Decreases pressing pressure from current 1000 psi to as low as 75 psi
  – Decreases part shrinkage so lower stresses during pyrolysis – allows larger parts
  – Control over % porosity and pore size
  – Pore size and % porosity independent of pressing pressure
  – Parts up to 3” thick can be produced with no cracks after pyrolysis
  – Expected to increase production tile yield by more than 15% over the current process
  – Expected to decrease tile production costs when implemented
  – Being developed to produce other coal-filled ceramic parts such as coal bricks
Ceramic coated-coal based aggregate/filler developed for concrete

- A recent invention by Semplastics that has the potential to use millions of tons of coal
- Coal-based ceramic aggregate or filler is a composite of coal powder and ceramic binder
- The aggregate is 60-70% coal by mass, the rest is Semplastics’ low-cost ceramic forming polymer
- The mixture is simply deposited onto a tray or carrier and pyrolyzed in a reducing atmosphere to produce a rock-like material
- The chunks of coal ceramic composite are then chain-milled to form 20 micron to 5 mm size aggregate particles
- All scrap from other roof tile manufacturing techniques can be used as aggregate – zero waste process
- The aggregate is mixed with Portland cement and water, then cast just like regular concrete
Ceramic coated-coal based aggregate/filler-based concrete has superior properties when compared to standard concrete:

- Compressive Strength 6000-7500 psi – 2X or more standard concrete tiles
- Flexure Strength 1500-2000 psi - 2X-3X concrete tiles
- Density 1.65 g/cc ~ 35% less than of concrete
- Cost between standard concrete and ultra-high strength concrete
- Price competitive with “precast concrete” and standard concrete roof tiles
- Market for standard concrete roof tiles much larger than the total market for both ceramic roof tiles and slate
Total Available Market and Targets

High End Roof Tiles: $7.2 Billion in 2020

<table>
<thead>
<tr>
<th>Product Type</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>CAGR % 2018–2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Tile</td>
<td>$3,793.6</td>
<td>$3,947.1</td>
<td>$4,100.5</td>
<td>4.0%</td>
</tr>
<tr>
<td>Metal</td>
<td>$1,043.0</td>
<td>$1,122.0</td>
<td>$1,201.0</td>
<td>7.3%</td>
</tr>
<tr>
<td>Clay</td>
<td>$248.0</td>
<td>$327.0</td>
<td>$406.0</td>
<td>27.9%</td>
</tr>
<tr>
<td>Polymer composite</td>
<td>$590.2</td>
<td>$657.6</td>
<td>$724.9</td>
<td>10.8%</td>
</tr>
<tr>
<td>Slate</td>
<td>$379.2</td>
<td>$568.8</td>
<td>$758.4</td>
<td>41.4%</td>
</tr>
<tr>
<td>Total Available Market</td>
<td>$6,054.1</td>
<td>$6,622.4</td>
<td>$7,190.8</td>
<td>9.0%</td>
</tr>
</tbody>
</table>

Distribution by Volume in 2018

- Concrete Tile (62%)
- Metal (16%)
- Clay (5%)
- Polymer composite (14%)
- Slate (3%)

Initial Product Replacement Target!

Target Distribution Region

5 of the top 10 states with rooftop solar capacity are in the same region as the planned roof tile plant.
Commercial Products

Design Drivers

- Immediate Use: 10%
- Stocked @ Distributor: 10%
- Demand: 10%
- Aesthetics: 10%
- Availability: 9%
- Longevity: 9%
- Weight per Tile: 9%
- Price: 33%

Stage 1
- Slate style (pressed)
- Target price: $700/sq.

Stage 2
- Villa style (extruded)
- Target price: $500/sq.
### Commercial Value Proposition

<table>
<thead>
<tr>
<th>Features</th>
<th>Value</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>End-users (Resident Roof Owners)</td>
<td>Fireproof and non-combustible</td>
<td>Greater safety</td>
</tr>
<tr>
<td></td>
<td>High tensile and flexural strength</td>
<td>Low maintenance</td>
</tr>
<tr>
<td></td>
<td>Great impact resistance</td>
<td>Good load distribution</td>
</tr>
<tr>
<td></td>
<td>Low porosity</td>
<td>Low water absorption rate</td>
</tr>
<tr>
<td></td>
<td>High wind resistance</td>
<td>Low damage from extreme weather</td>
</tr>
<tr>
<td></td>
<td>High sound dampening</td>
<td>Greater environmental buffer</td>
</tr>
</tbody>
</table>

| Roof Contractors | Light weight | Ergonomic | Easy to install |
| Direct from manufacturer | Classification as “Environmental Product Declaration” | LEED credits can be used for new construction projects |
| Distributors | Light weight | Lower price for comparable product | Greater product margins |
| Coal-based composition | Potential for earning CO₂ credits | Opportunity for greater product margins |

- **Domestic option** for manufacturing ceramic roof tiles
- **Supports jobs** in the coal sector
- **Beneficial use application** for coal with technology that can move into new sectors (such as new building materials, batteries, proppants)
Commercial Strategy and Revenues

Manufacturing and direct distribution to end-customers in the roofing industry

Value Chain Position

Channels

Manufacturing Representatives
- Joe Hall Roofing
- Mad Sky

Online Contractor Applications
- iRoofing “app”
- Acculynx

Online Web and Digital Marketing
- http://www.x-tiles.com
- Other online building retailer websites (e.g., https://www.buildzit.com/)

- Cumulative revenues up to 2030 reach $320 Million
- Expected first commercial sales in 2022
Concluding Remarks

• The project has demonstrated the ability of coal-based roof tile materials to meet at least one the Strategic Fossil Energy Objectives
  • Size of addressable roof tiles market including slate, ceramic tiles and the new cement-based tiles being developed was estimated to be $5.26 Billion in 2020
  • At roughly 2.8 lbs of coal per tile the total market potential would be 9.8 billion lbs of coal per year
  • This helps address a key challenge for coal/fossil energy: how to use large amounts of coal but not rely on power generation
Concluding Remarks (cont.)

- **The Project Next Steps would include:**
  - Completing the tasks remaining in the Phase II program as discussed previously
  - Further streamlining (increasing throughput) of both the pressed tiles and the barrel tiles as the high and intermediate end of our target markets
  - Continue optimizing the ceramic-coated coal based concrete tiles as the higher volume, lower cost alternative in the larger cement tile market
  - Apply for a Phase IIB award to continue with the above as well as address roof tile market needs including:
    - Coloring the roof tiles – simplifying the process
    - Developing textured surfaces – demonstrating good replication of textures
    - Providing ways to seal/provide glossy/semi-gloss surfaces like clay tiles
    - Producing other components needed for roofs such as soffits, caps and endcaps
Questions / Discussion