Basalt Fibers
For High-Performance Composites

Allan D. Murray
What is Basalt?

- Rock from frozen lava
Typical Basalt Rock
Basalt is 1/3 of Earth’s Crust

- Plentiful in Michigan’s Upper Peninsula
- 9-mile thick deposit in Keweenaw Peninsula
Basalt Strength

- Basalt was readily available in Rome
  - Mt. Vesuvius
- Romans recognized its strength and durability
  - Used in road construction
  - Some still in use
Basalt rock melted and cast into chemical and abrasion resistant pipe liners

- e.g. used in cement slag handling
Fibers from Basalt

- Early fiber manufacturing efforts in US prior to WW2
- Main development effort by Soviets for defense and aerospace applications
- No Soviet effort to commercialize
- Research declassified in 1990's
- Recent efforts to lower cost and commercialize
Continuous Fibers from Basalt
Similar to E-glass forming except:

- Only one material, crushed rock
  - No ‘flux’ like boric oxide added for processing
- Higher melting temperature:
  - 1400 °C+ vs. 1200 °C
- Harder to process, but better properties
Basalt Furnace
The right chemical make-up is essential
Temperature and process control critical
# Basalt Compared to E-glass

<table>
<thead>
<tr>
<th>Compound</th>
<th>w% in E-glass</th>
<th>w% in basalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>52-56</td>
<td>51.6-57.5</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>12-16</td>
<td>16.9-18.2</td>
</tr>
<tr>
<td>CaO</td>
<td>16-25</td>
<td>5.2-7.8</td>
</tr>
<tr>
<td>MgO</td>
<td>0-5</td>
<td>1.3-3.7</td>
</tr>
<tr>
<td>B$_2$O$_3$</td>
<td>5-10</td>
<td>------</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>0.8</td>
<td>2.5-6.4</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.2-0.8</td>
<td>0.8-4.5</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>≤0.3</td>
<td>4.0-9.5</td>
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</table>
High silica and alumina content required to provide glass network
Melt strength must be high and melt viscosity within acceptable range
Other ‘impurities’ help keep mix from crystallizing
Need to obtain an amorphous glass fiber with small or no crystallites
In addition to chemistry, the process conditions are critical:

- Melt temperature
- Melt Temperature uniformity
  - Avoid precipitation in melt
- Fiber draw rate and temperature
  - Avoid crystallization during draw
Basalt Sources for Fiber Production

- Large variation in basalts around world
  - Chemical make-up of the lava source
  - Temperature history and rate of cooling of lava
    - Slow cooling results in segregation and precipitation
    - Weathering and oxidation over time
  - Chemical characteristics and uniformity of basalt quarry are essential for good fibers
Main cost elements:

- Raw material is inexpensive and readily available
- Energy required to melt higher than E-glass, similar to S2-glass
- High platinum-alloy bushing investment
- Low productivity during learning

Thus basalt cost somewhere between E-glass and S-glass but should come down
Fiber Production Sources

- Current sources mainly Eastern Europe
  - Where technology emerged
  - Russia, Ukraine, also now Shanghai, China
- Plans for more production have been announced
  - But these plans haven’t all materialized
- Manufacturing should be close to suitable basalt quarries and inexpensive energy
Thermal Resistance

- 250 to 300 degrees C better than E-Glass
- Similar to S2-Glass
Key Properties of Basalt Fibers

- **Thermal Resistance**
- **Mechanical Strength**
  - Higher stiffness and strength than E-Glass
  - Slightly higher specific gravity
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<th>S2-glass</th>
<th>Aramid</th>
<th>Carbon fiber</th>
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<td>Tensile strength, MPa</td>
<td>3000~4840</td>
<td>3100~3800</td>
<td>4020~4650</td>
<td>2900~3450</td>
<td>3500~4400</td>
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<tr>
<td>Elastic modulus, GPa</td>
<td>93~110</td>
<td>72.5~75.5</td>
<td>83~86</td>
<td>70~179</td>
<td>230~800</td>
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<td>Elongation at break, %</td>
<td>3.1~6</td>
<td>4.7</td>
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<td>2.4~3.6</td>
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<td>Specific gravity</td>
<td>2.65~2.8</td>
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<td>1.44</td>
<td>1.75~1.95</td>
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Key Properties of Basalt Fibers

- Thermal Resistance
- Mechanical Strength
- **Chemical Resistance**
  - Good alkaline resistance
  - Also acid and salt resistance
### Basalt Fiber vs. other Fiber Materials

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% wt. loss after 3 hrs. boiling in:

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<th></th>
<th>H₂O</th>
<th>2N NaOH</th>
<th>2N HCl</th>
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<tr>
<td></td>
<td>0.2</td>
<td>5</td>
<td>2.2</td>
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<td></td>
<td>0.7</td>
<td>6</td>
<td>38.9</td>
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<tr>
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<td>0.05</td>
<td>5</td>
<td>15.7</td>
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Weight loss after 3 hours boiling in saturated cement solution

- CemFil, Saint Gobain: 0.45
- Basalt fibers, Kamenny Vek: 0.35
- E-glass, average: 4.5
Key Properties of Basalt Fibers

- Thermal Resistance
- Mechanical Strength
- Chemical Resistance
- **Ecological Friendliness**
  - Natural and abundant raw material
  - No biological hazard
  - ‘Incinerator friendly’
    - Incineration temperatures around 1100°C
    - E-glass softens and can clog incinerator
Basalt Fiber Application Examples

- Reinforcement of Concrete
Reinforcement of Concrete

- Resistance to alkaline concrete, acids, salt, and water exposure
  - Can even put uncoated chopped fiber in concrete for crack resistance
  - Problems with steel and glass-rebar
- Strength comparable to steel
- Light weight and flexibility makes installation easier
Basalt Fiber Concrete Rebar
Rebar in Concrete
Reinforcement of Concrete

Conveyor Rollers
Basalt-fiber Pultruded Conveyor Rollers
Conveyor Rollers

- Replacing coated steel roller bearings that support heavy coal conveyor belts
- Chemical and abrasion resistance
- Dramatically reduced weight saves energy required to operate conveyor
- Apparently a very short payback period in some applications
Basalt Fiber Application Examples

- Reinforcement of Concrete
- Conveyor Rollers
- Ballistic Protection
Basalt-reinforced composites being evaluated to replace plate steel armor

- High strength and light weight
- High-temperature resistance provides performance where E-glass and other fibers fail
- An early Soviet army application for basalt fiber
Basalt Fiber Ballistic Protection
Basalt Fiber Application Examples

- Reinforcement of Concrete
- Conveyor Rollers
- Ballistic Protection
- Brake Pads
Basalt Fibers in Brake Pads

- Effective replacement for asbestos in brake pads
- High temperature resistance
- Stable high friction coefficient
- Relatively low wear of steel disk or drum compared to ceramic
Basalt Fiber Application Examples

- Reinforcement of Concrete
- Conveyor Rollers
- Ballistic Protection
- Brake Pads
- High-Pressure Pipe
Basalt Reinforced High-Pressure Pipe

- Basalt-fiber wrapped plastic pipes to replace metal pipes
- High strength
- Resistance to high-temperature, moisture, various chemicals
- Sewage, chemical transport, etc.
- Flexibility and easier installation benefits
Reinforcement of Concrete
Conveyor Rollers
Ballistic Protection
Brake Pads
High-Pressure Pipe
Automotive Headliners
2007 Honda Fiberglass-free Headliner
Azdel VolcaLite™ uses basalt fiber to replace E-glass for auto headliners

- Sound absorption and strength/weight reduction benefits claimed
- Primary driver is ‘incinerator-friendliness’
  - Incineration temperatures around 1100°C
  - E-glass softens and can clog incinerator
Basalt fibers have excellent set of properties
  • Thermal, mechanical, chemical, environmental
Cost likely between E-glass and S-glass
Basalt should be of interest in many specialty composite applications