ALLIED COMPOSITE TECHNOLOGIES LLC

# Basalt Fibers For High-Performance Composites

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# Outline

- Basalt Introduction
- Manufacturing Basalt Fibers
- Key Properties
- Application Examples
- Summary

# 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 Chemical Resistance

- Basalt rock melted and cast into chemical and abrasion resistant pipe liners
  - e.g. used in cement slag handling

# Fibers from Basalt

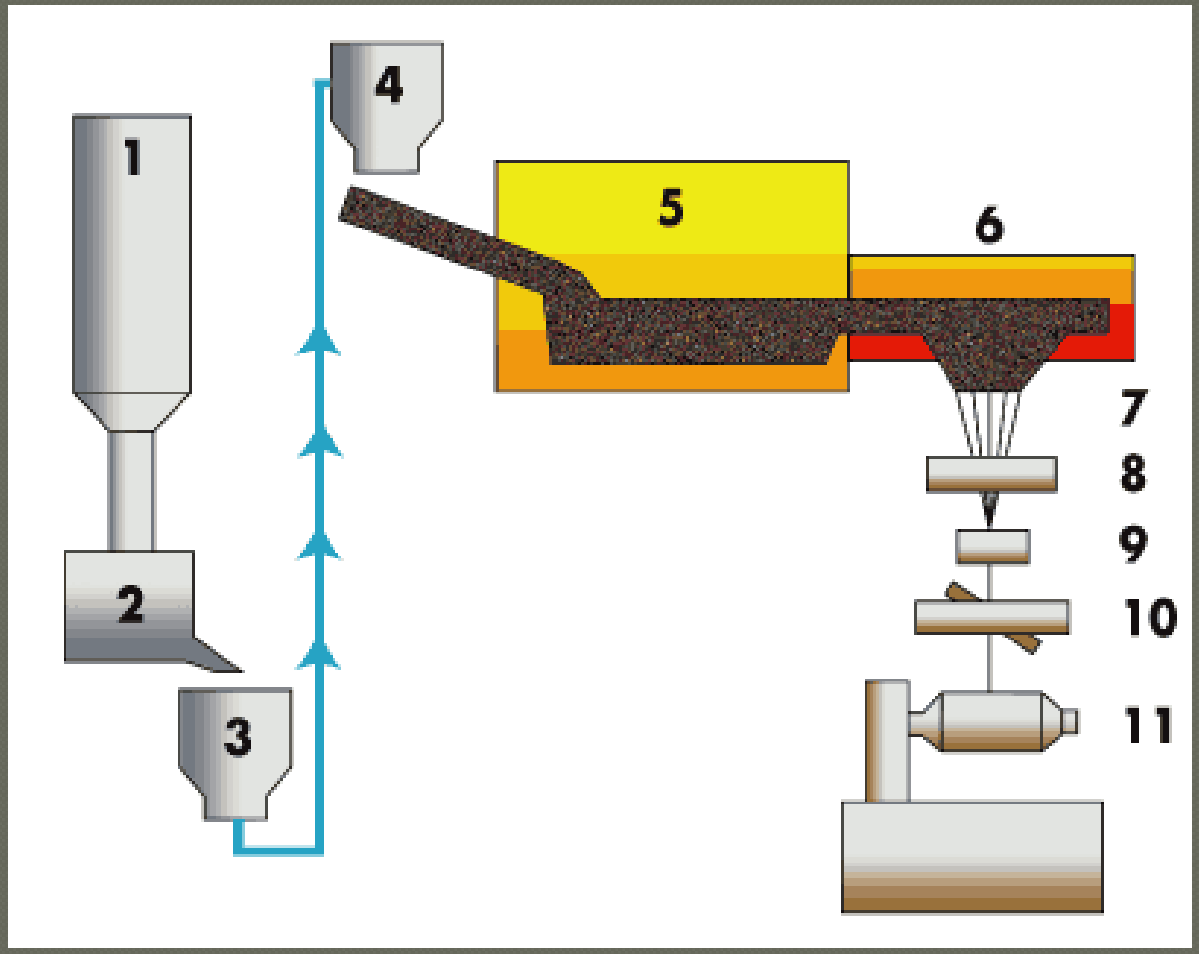
- Early fiber manufacturing efforts in US prior to WW2
- Main development effort by Soviets for defense and aerospace applications
- No Soviet effort to commercialize
- Research declassified in 1990's
- Recent efforts to lower cost and commercialize

# Continuous Fibers from Basalt

# Fiber Forming Process

- 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



# Fiber Forming Process

- The right chemical make-up is essential
- Temperature and process control critical

# Basalt Compared to E-glass

| Compound | w% in E-glass | w% in basalt |
|---|---|---|
| $SiO_2$ | 52-56 | 51.6-57.5 |
| $Al_2O_3$ | 12-16 | 16.9-18.2 |
| CaO | 16-25 | 5.2-7.8 |
| MgO | 0-5 | 1.3-3.7 |
| $B_2O_3$ | 5-10 | ------ |
| $Na_2O$ | 0.8 | 2.5-6.4 |
| $K_2O$ | 0.2-0.8 | 0.8-4.5 |
| $Fe_2O_3$ | ≤0.3 | 4.0-9.5 |

# Basalt Chemistry Required for Fiber Production

- 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

# Fiber Process Conditions

- 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

# Cost of Fiber Production

- 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

# Key Properties of Basalt Fibers

- **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

# Basalt Fiber vs. other Fiber Materials

| | **Basalt** | E-glass | S2-glass | Aramid | Carbon fiber |
|---|---|---|---|---|---|
| **Tensile strength, MPa** | **3000~4840** | 3100~3800 | 4020~4650 | 2900~3450 | 3500~4400 |
| **Elastic modulus, GPa** | **93~110** | 72.5~75.5 | 83~86 | 70~179 | 230~800 |
| **Elongation at break, %** | **3.1~6** | 4.7 | 5.3 | 2.4~3.6 | 0.5~1.5 |
| **Specific gravity** | **2.65~2.8** | 2.5~2.62 | 2.46 | 1.44 | 1.75~1.95 |
| **Max. Temp. of application, °C** | **~650** | ~380 | ~500 | ~250 | ~400 |
| **Melting temp, °C** | **1450** | 1120 | 1550 | NM | NM |

# 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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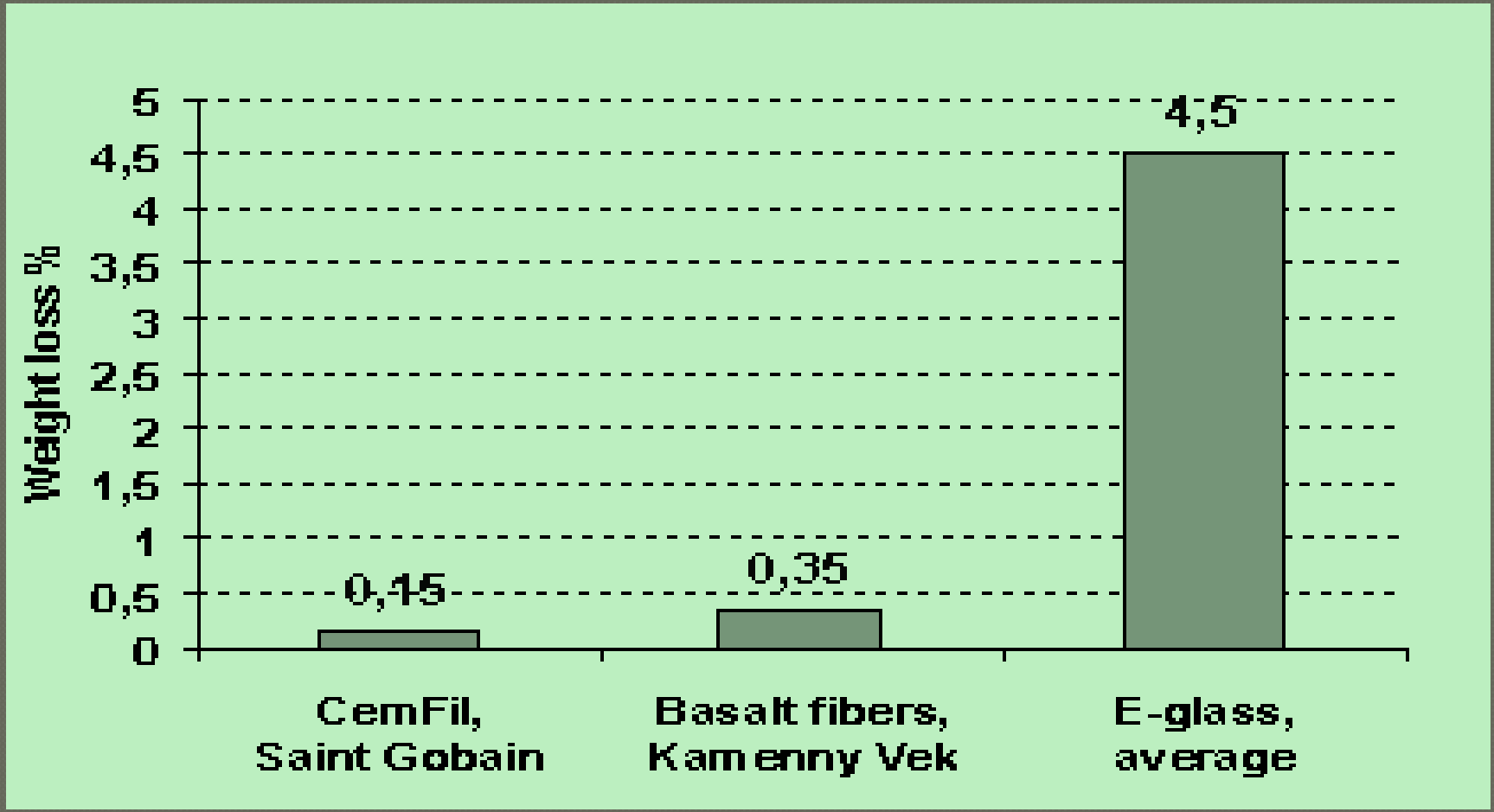
| **Melting temp, °C** | **1450** | 1120 | 1550 | NM | NM |
| **% wt. loss after 3 hrs. boiling in:** | | | | | |
| **$H_2O$** | **0.2** | 0.7 | 0.05 | | |
| **2N NaOH** | **5** | 6 | 5 | | |
| **2N HCl** | **2.2** | 38.9 | 15.7 | | |

# Weight loss after 3 hours boiling in saturated cement solution



# 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

# Basalt Fiber Application Examples

- 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 Composite Ballistic Protection Panels

- 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

# Basalt Fiber High-Pressure Pipe

# Basalt Fiber Application Examples

- Reinforcement of Concrete
- Conveyor Rollers
- Ballistic Protection
- Brake Pads
- High-Pressure Pipe
- **Automotive Headliners**

# Basalt Fiber Automotive Headliners

2007 Honda Fiberglass-free Headliner

# Basalt Fiber Automotive Headliners

- 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

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# Summary

- 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