U.S. Department of Energy
Energy Efficiency and Renewable Energy

HIGH-STRENGTH / ALKALINE RESISTANT IRON-PHOSPHATE GLASS FIBERS AS CONCRETE REINFORCEMENT

OIT/DOE Award DE-FC36-04GO14046
Assigned to Mo-Sci Corp.

Ted Day
3 June, 2005

mo•sci CORPORATION

Participants

MO-SCI Corp. – Lead Organization
Rolla, MO

University of Missouri-Rolla – Sub-contractor
Graduate Center for Materials Research
Rolla, MO

Advanced Glass Yarns – Sub-contractor
Aiken, SC

HTR-Group - Partner
Lake Ozark, MO

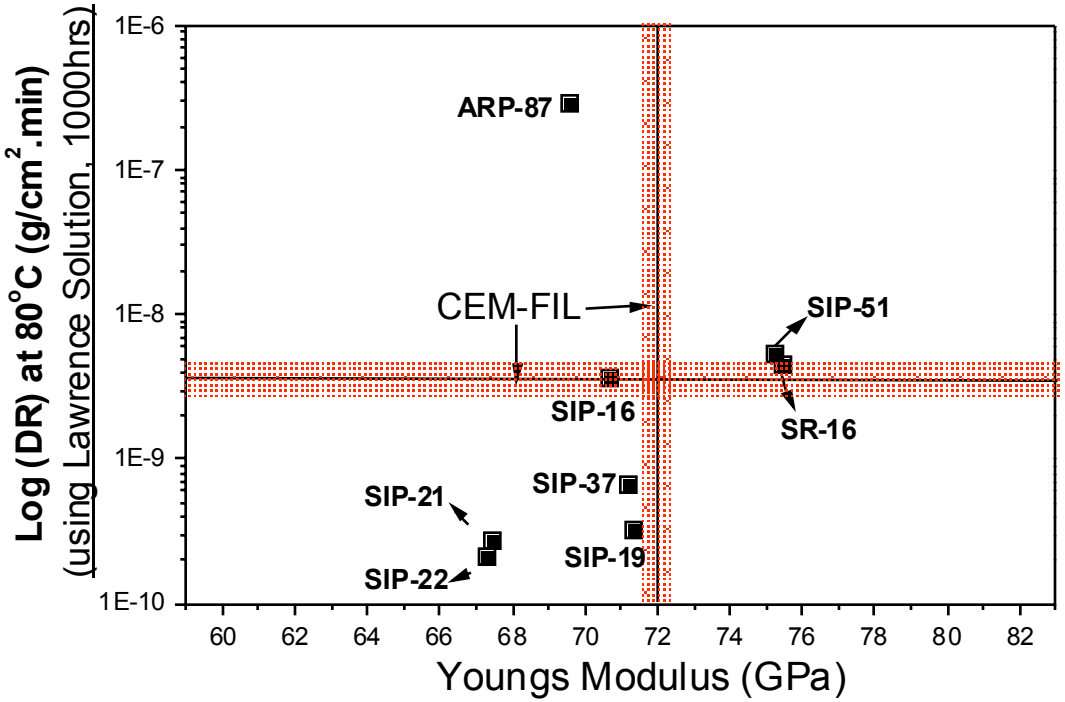
- **Goal:** Develop Iron-phosphate glass fibers for concrete reinforcement.
- **Challenge:** Iron-phosphate glass fibers show promise for high-chemical durability in alkaline environments and lower manufacturing costs but have not been produced industrially.
- **Benefits:** Energy savings in manufacturing Iron-phosphate compared to manufacturing silica-based glasses:
  - **~ 6.5 million BTU's/ton glass**.
- **Potential End-User Applications:** Generate low cost glass fibers for reinforcing concrete for the construction industry.
- **FY06 Activities:** Evaluate waste materials from the automobile industry; escalate glass melting and glass fiber manufacturing and demonstrate pilot production in industry.

Goals

Develop Iron Phosphate glass fibers with a chemical durability and mechanical strength suitable for reinforcing concrete materials (GRFC)

Iron Phosphate fiber after nine months in a neat Portland cement

Comparison of dissolution rate (chemical durability) and elastic modulus of Iron Phosphate glasses and a commercial (Cem-FIL) silicate glass used in Cement products



Challenges

- Iron-phosphate glass fibers show promise for high-chemical durability in alkaline environments and lower manufacturing costs (energy and raw materials).
  - Optimize composition of Iron Phosphate glasses for concrete applications
  - Measure and evaluate critical properties of Iron Phosphate glasses: chemical durability, tensile strength, viscosity, Tg, density, and sizing parameters
  - Determine industrial manufacturing parameters: bushing materials, melting time and temperature, and refractory materials
  - Test GFRC (glass fiber reinforced concrete) mixes

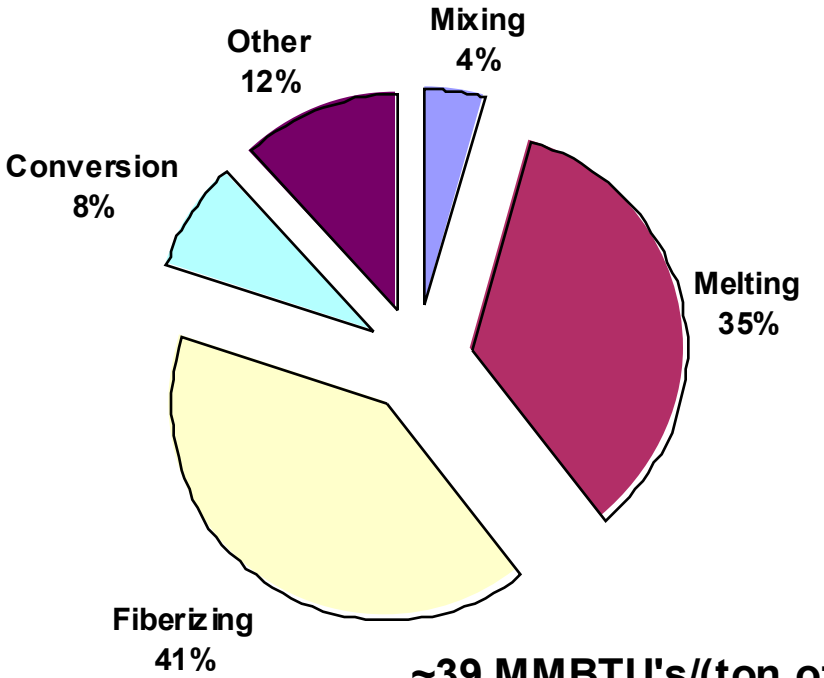
Benefits

- The potential benefits of these new fibers compared to silicate-based fibers are
  - Energy savings,
  - Environmental and Technical advantages, and
  - Cost savings.

Energy Benefits

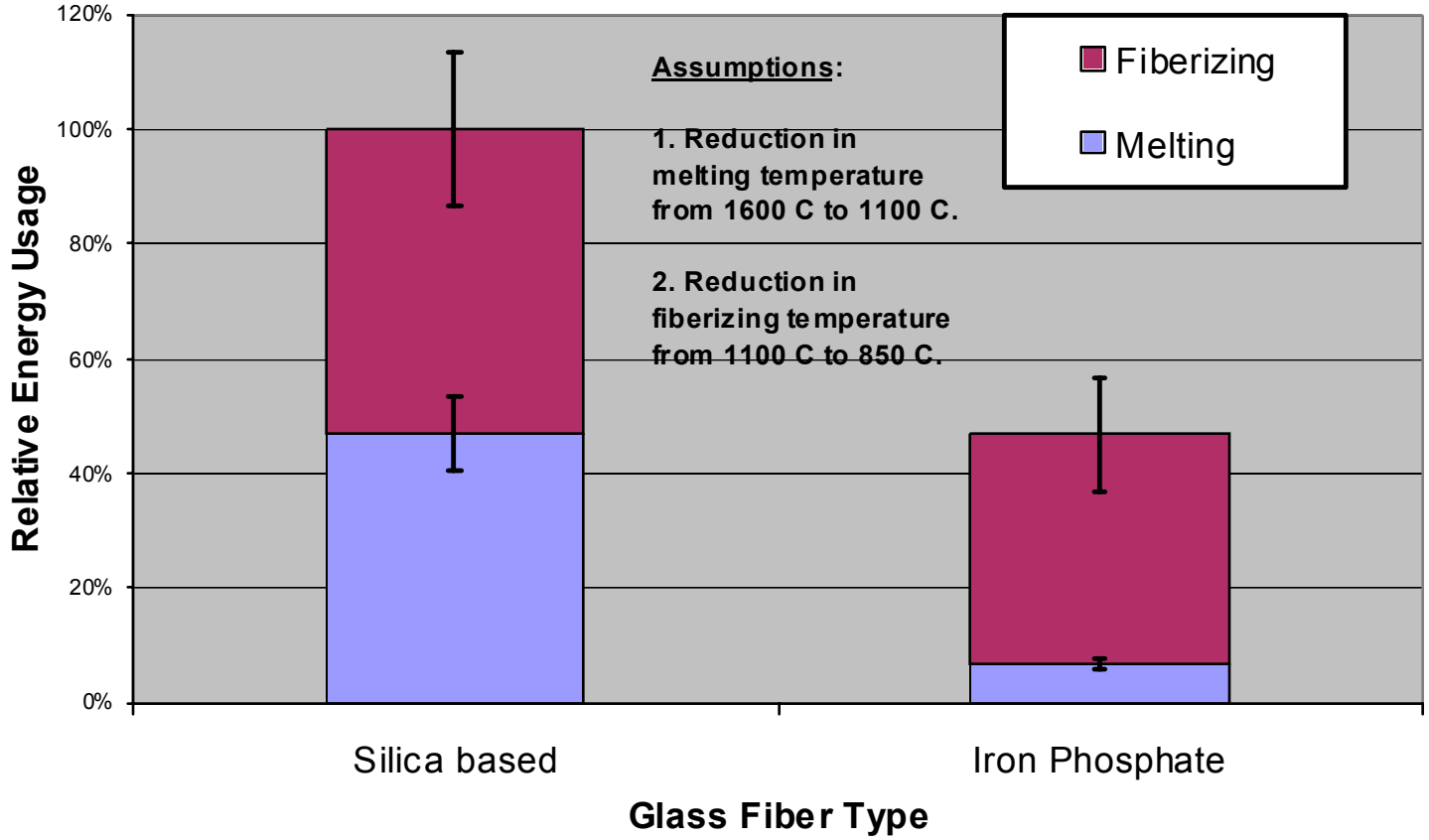
- Potential for 40-60% lower energy usage (glass melting and fiber manufacturing) compared to the higher melting silica-based fibers in current use
- Extended life of refractories in melting, which would give fewer stones and defects in the fibers
- Can produce fibers at lower temperatures compared to higher melting silicate-based glasses

Energy Usage for Producing Silica-based Insulation Fiber



~39 MMBTU's/(ton of glass)

Comparison of the Energy Needed to Manufacture Silica and Iron Phosphate Based Fibers



Environmental Advantages

- Extension of furnace life through lower melting temperatures and shorter melting times, which will generate less refractory waste
- Ability to use commercially available alumino-silicate refractories as opposed to more expensive or potentially hazardous refractories (i.e., chromia-based refractories for E-glass)
- Avoid health related issues associated with silica-based fibers and particulates
- Potential use of phosphate wastes from the metal finishing industry and from recycling of fluorescent light bulbs, as raw materials (source of Fe_2O_3, CaO, and phosphate)

Cost Benefits

- Comparable or lower cost raw materials
- Lower melting temperature and shorter melting time that should extend furnace life
- Potential for developing glass fibers with properties similar or better performance compared to commercial silica-based fibers
- Reduce foreign imports

Raw Materials for Production

T.M. Neidt, Recycling of Industrial Phosphate Waste for Iron Phosphate Glass Fibers, Final Report Phase I SBIR US EPA, 2003

- The market for Iron Phosphate fibers would create a market for phosphate-based waste as a raw material for production
- Estimated that $12/(ton of glass) cost savings is possible for each 10% weight of phosphate waste used

Potential End-User Applications

- Exterior building façade panels
  - 80% of all components manufactured in the US
  - 60 million ft^2 of GRFC cladding panels produced from 1977 to 1993
- Surface bonding
- Electrical utility products
- Building restoration

Specific Applications

- Architectural components and cladding
- Asbestos replacement
- Fire protective systems
- General building components
  - Low-cost housing
  - Small buildings and enclosures
- Marine applications
- Reparations
- Street furniture
- Water applications
  - Low pressure pipes
  - Sewer linings
  - Tanks

Projected Milestones

- **June 2005**
- Manufacture Iron Phosphate glass fibers with chemical durability to alkaline environments and with elastic modulus equal or better to commercial silica-based fibers - **COMPLETED**
- **June 2006**
- Produce Iron Phosphate glass fibers using less expensive metal bushings and/or melt at reduced temperatures (~1,000°C).
- Demonstrate use of inexpensive waste or recycled materials as raw materials for Iron Phosphate glass formulation.
- **June 2007**
- Incorporate Iron Phosphate glass fibers in concrete mixes
- Manufacture Iron Phosphate glass fibers in industry in pilot-scale operation

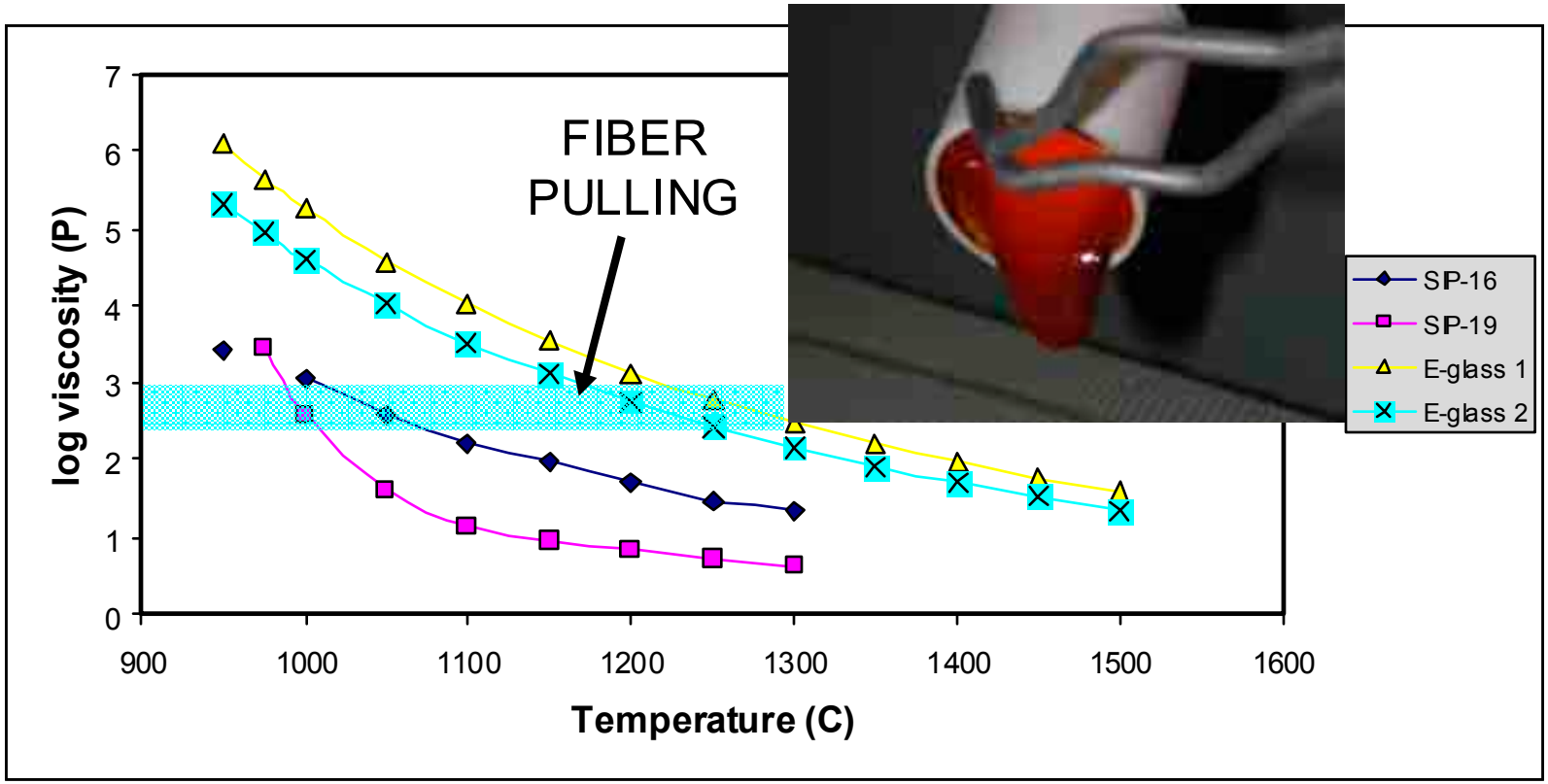
FY06 Activities

- Manufacture Iron-phosphate glass fibers in platinum bushings at relatively low temperatures (~1,000 °C)
- Produce Iron Phosphate glass fibers using less expensive metal bushings.
- Use inexpensive waste or recycled materials in Iron Phosphate glass formulation.
- Partner with the Illinois Waste Management & Research Center, Champaign, Illinois to test waste sludges from industry as potential raw materials
- Investigate procedures for melting dark Iron-phosphate glasses other than radiation – as with silica-based glasses

Glass melting

Simulated waste glass cylinder, 8 liters, melted at 1200ºC

Viscosity Comparison of Iron-Phosphate Glasses Compared to Silicate Glasses



Iron Phosphate Glass Fibers

Barrier-Pathway Approach

Barriers

- Lower tensile strength of Iron-phosphate glasses compared to silicate glasses
- Determine best way to melt dark glasses in industrial furnaces

Pathways

- Optimize chemical composition of Iron-phosphate glasses
- Develop glasses with higher chemical durability and high elastic modulus
- Melt Iron-phosphate glasses by induction heating

Critical Metrics

- Savings of ~40% in melting compared to silicate glasses
- Savings of ~15% in fiberizing compared to silicate glasses
- Beneficial use of current industrial wastes (~10-20% wt. of batch)

Benefits (estimated)	2003	2020
Energy Savings	1.1 trillion Btu	2 trillion Btu
Cost Savings	$ 78 million	$ 130 million

T.M. Neidt, Final report Phase I SBIR: Recycling of Industrial Phosphate Waste as Raw Material for Innovative Iron Phosphate Glass Fibers, September 30, 2003.

Estimated savings of 6.5 million BTU's/ton glass

Estimate conversion of 10% of total silica-based market to iron phosphate fibers

Estimate 3% growth to 2020

Conclusions

- Iron phosphate glass compositions can be melted in only 4 to 6 hr at temperatures below 1250°C, which is at least 300°C lower than commercial silicate-based glasses. Commercially available refractories have been used.
- Iron phosphate glasses have been prepared whose chemical durability (in Lawrence solution, pH = 13 and 80°C) and elastic modulus equals or exceeds that of the higher melting silicate glasses now used in cement products.
- Continuous glass fibers (10 to 30 microns in diameter) have been successfully pulled from several iron phosphate melts at temperatures as low as 850°C which is significantly below the temperature now used for silicate-based glass fibers.
- Results to date are promising and iron phosphate glasses with even better properties (chemical durability, viscosity, strength) are expected as the glass compositions are optimized.