Surface Treatment of Refractories Using High Density Infrared Heating

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June 2003
IMF Program Review Meeting

Refractories Play Crucial Role in IOF Industries

- Cross-cutting technology since they are used by all IOF industries
- Major degradation mechanism has been penetration and corrosion by molten metals or glass
- Methods to reduce penetration, wetting, and corrosive chemistry would improve refractory life

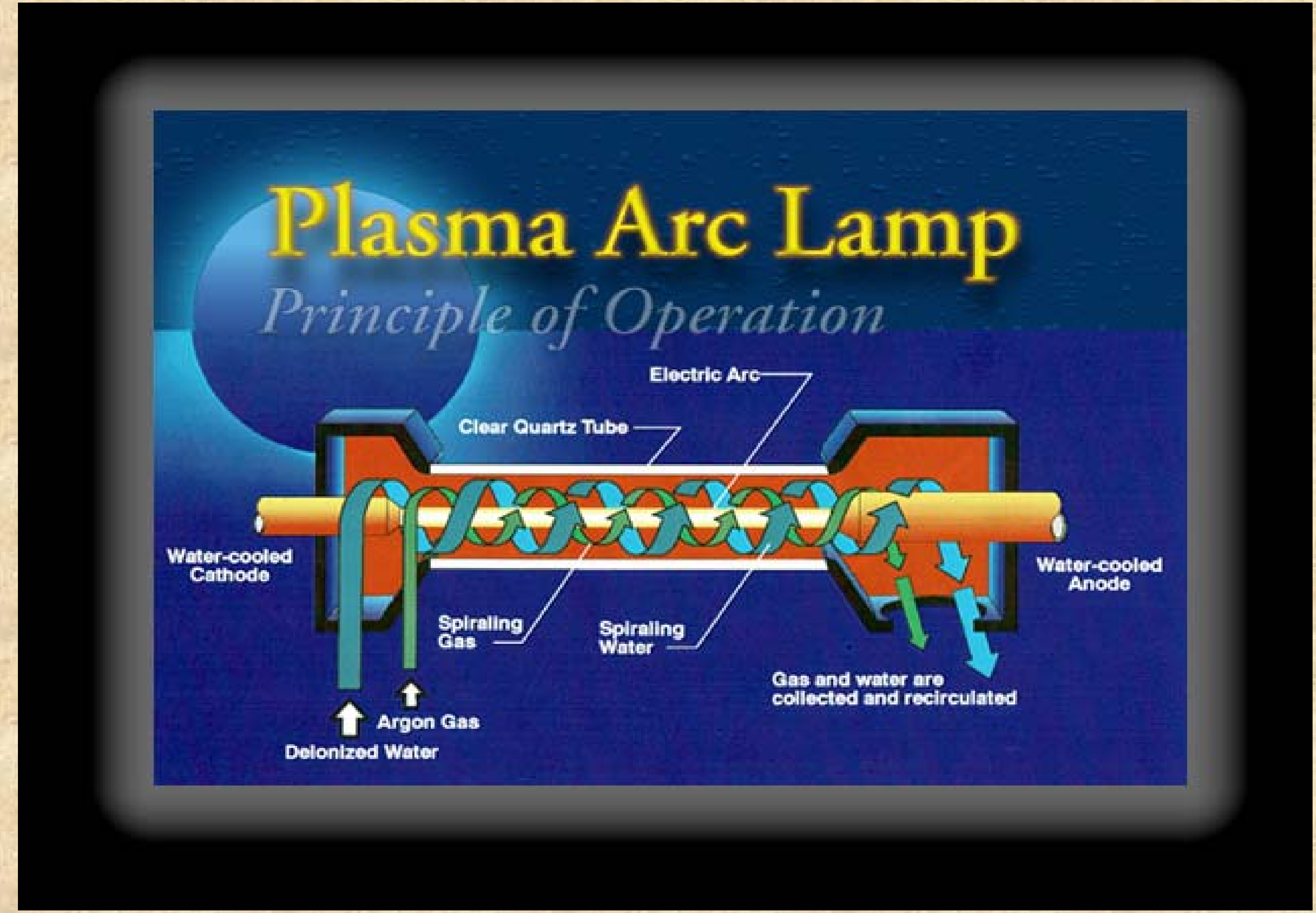
Project Background

- Laboratory project started in October 2001
- Funding Level
  - $200K/year total
  - $160K to ORNL, $40K to UMR
  - Contributions from companies in form of materials

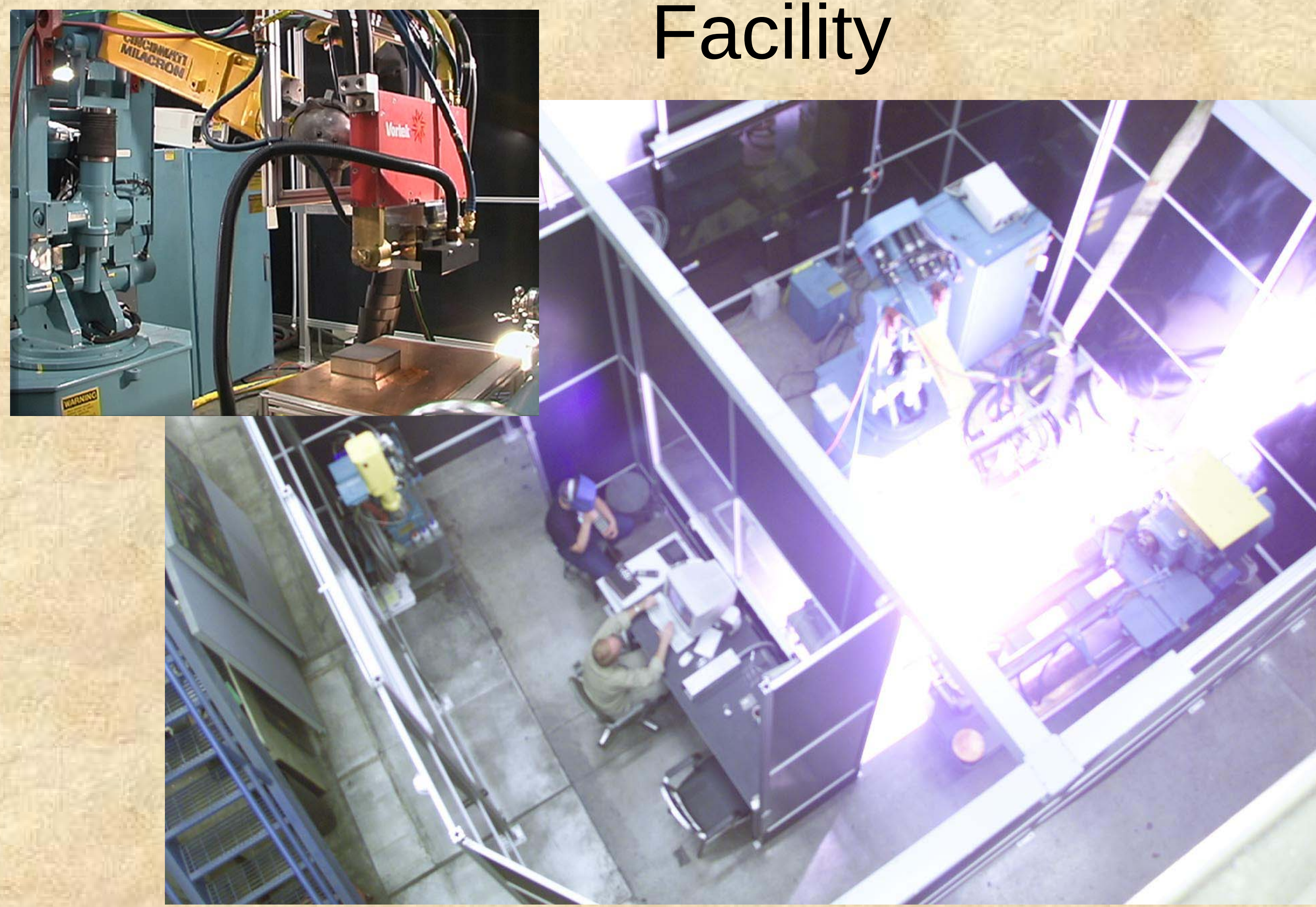
HDI of Refractories Project Partners

- Mariano Velez and Bob Moore - University of Missouri-Rolla
- Companies
  - Emhart Glass
  - Allied-Mineral
  - Magneco-Metrel
- Albany Research Center

The Technology Utilizes the Radiant Energy from a Contained Stabilized Plasma



ORNL Plasma Infrared Processing Facility



ornl

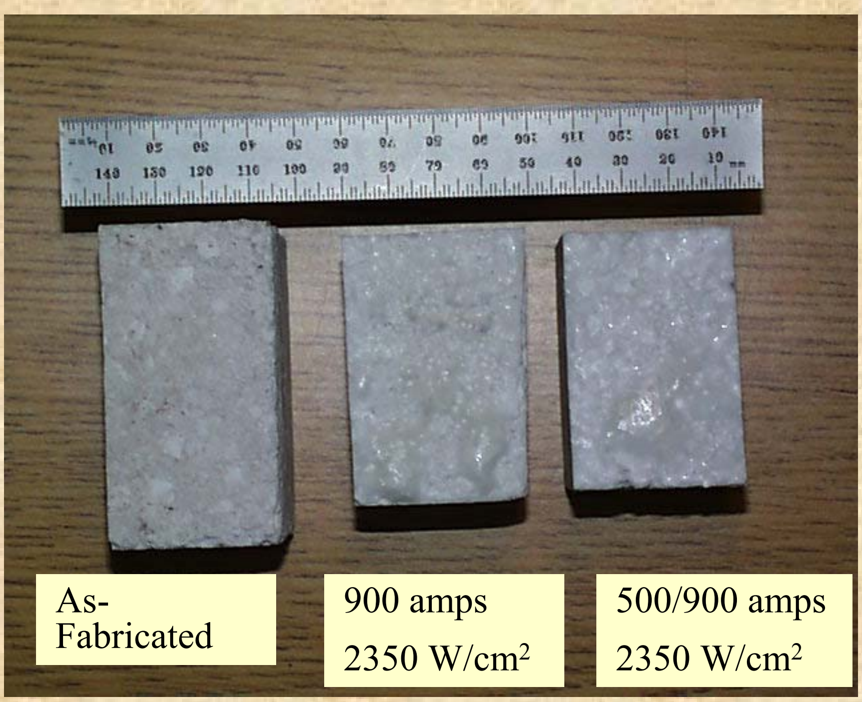
Approach and Objectives for HDI of Refractories Project

- Reduce surface porosity to improve penetration resistance (FY 2002)
- Change surface chemistry by coatings to improve corrosion resistance (FY 2003)
- Future activities will look at increasing surface emissivity (FY 2004)

Several Refractories Used in Initial Study to Reduce Surface Porosity

- Numerous commercial materials used
  - Results published in three papers
- Two examples to be shown
  - Aluminosilicate
    - 88% Al_2O_3-12% SiO_2
    - 2.9 g/cm^3 with ~16% porosity
  - High alumina castable
    - 88% Al_2O_3-4% SiO_2-4% Calcium aluminate-4% MgO
    - 3.2 g/cm^3 with ~12% porosity
- All were fired to ≥800°C prior to IR treatment
- Non-IR treated materials fired to 1500°C for one hour

Visual Appearance of Aluminosilicate Refractory



As-Fabricated

900 amps
2350 W/cm^2

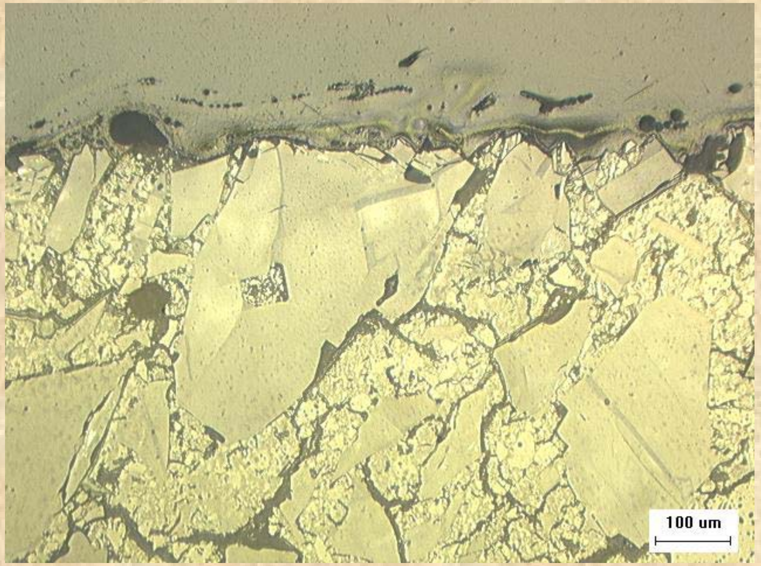
500/900 amps
2350 W/cm^2

900 amps
2350 W/cm^2

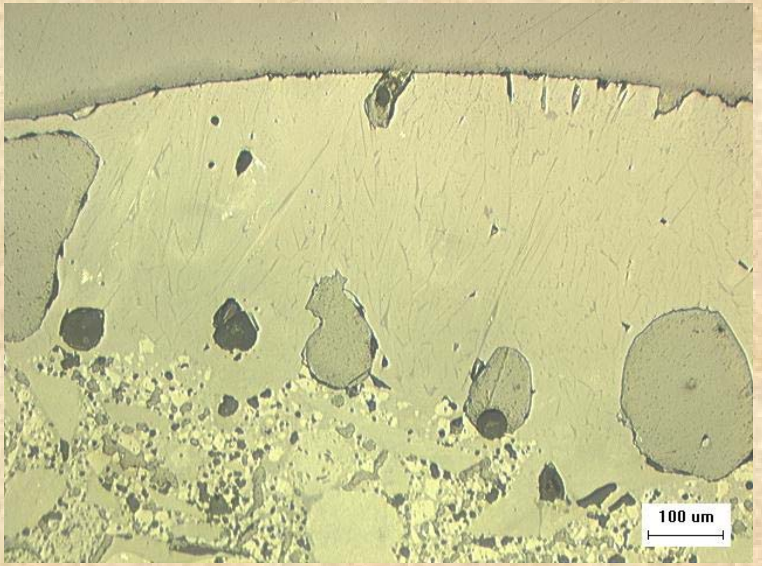
5 mm

- Scan rate of 1 cm/sec
- Surface shows some bubbles

Surfaces of Aluminosilicate

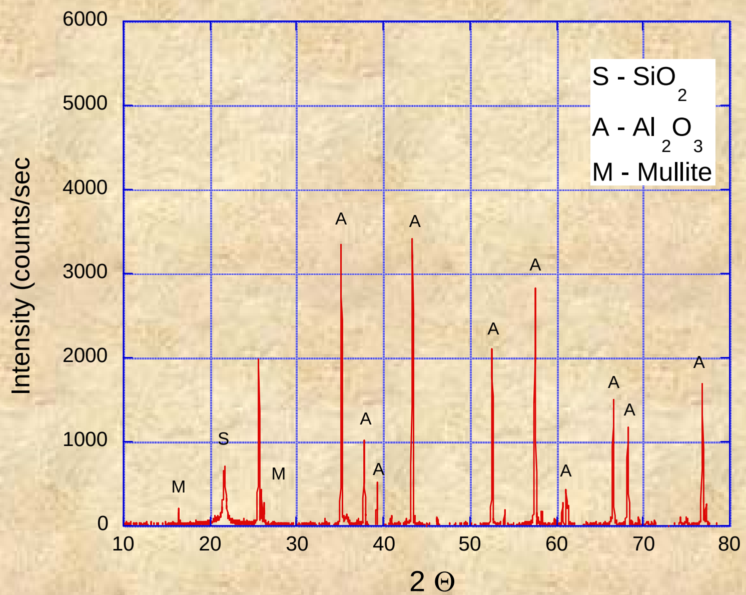


Conventional heating 1500°C for 1 hour



IR heating at 2350 w/cm^2

X-ray Diffraction Identified Phases in Aluminosilicate



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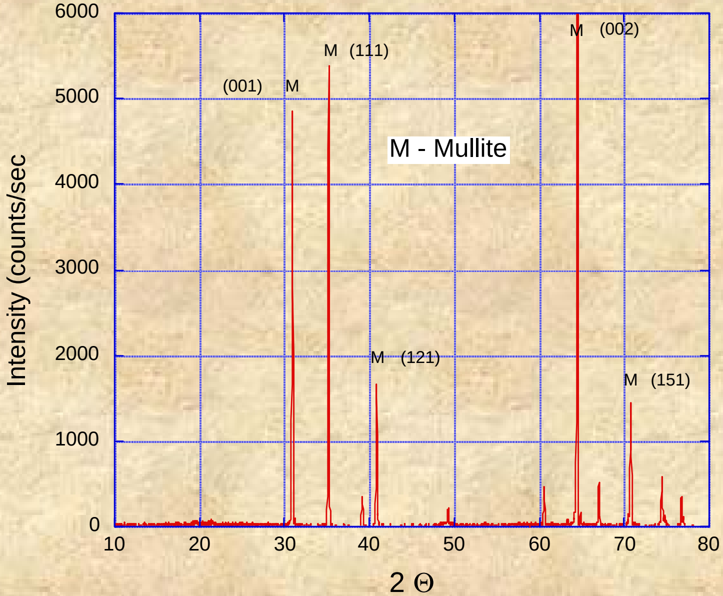
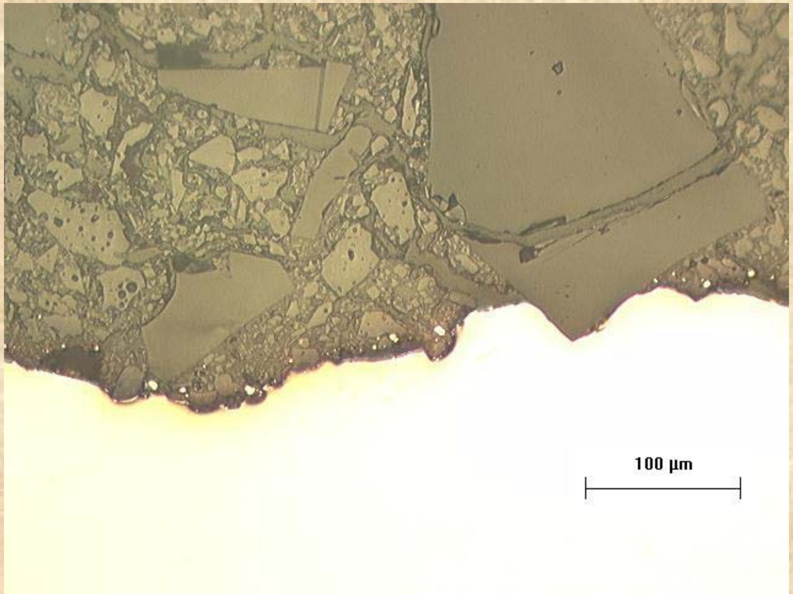
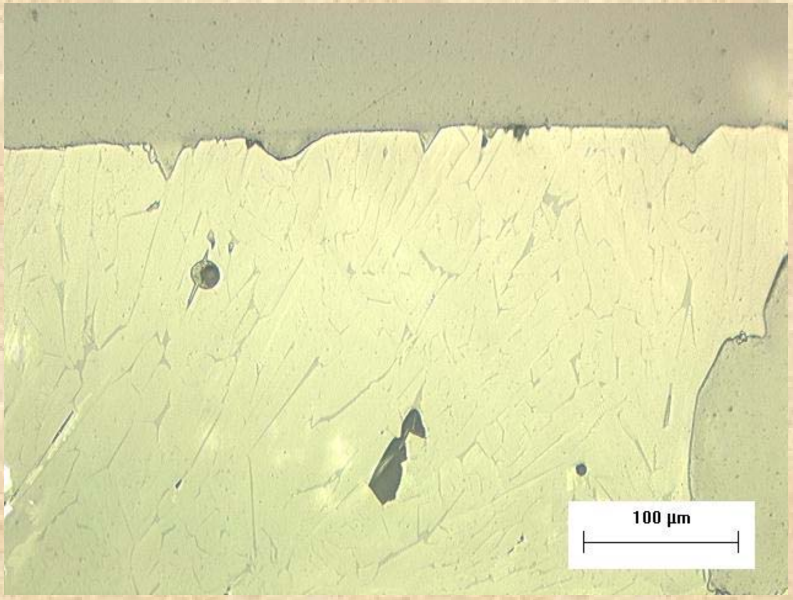


IR heating at 2350 w/cm^2

- Conventional heating shows formation of mullite and residual raw materials
- IR heating shows formation of highly oriented mullite

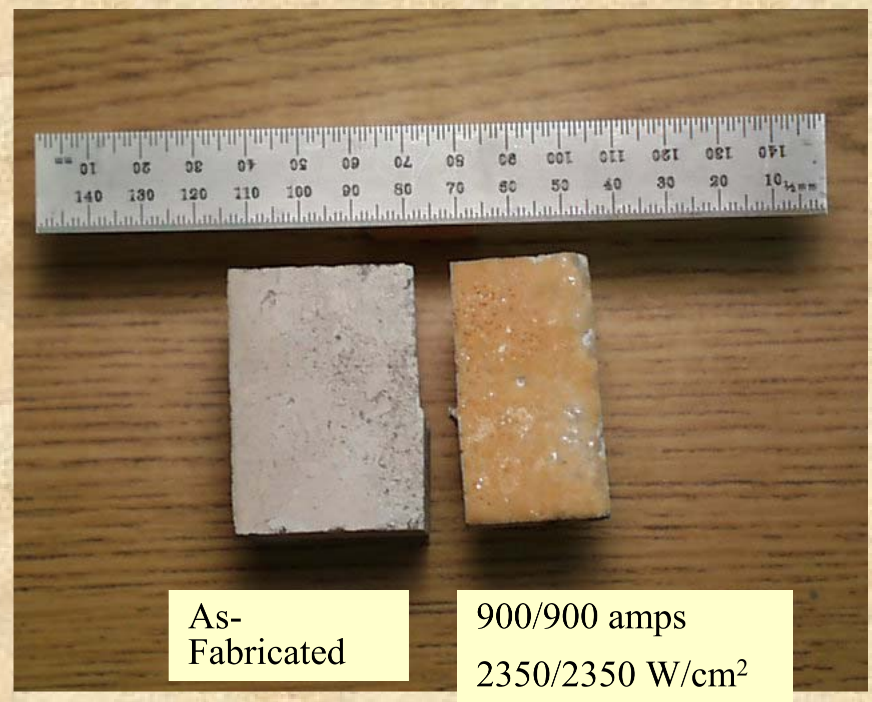
Interface Between Aluminosilicate and Molten Copper





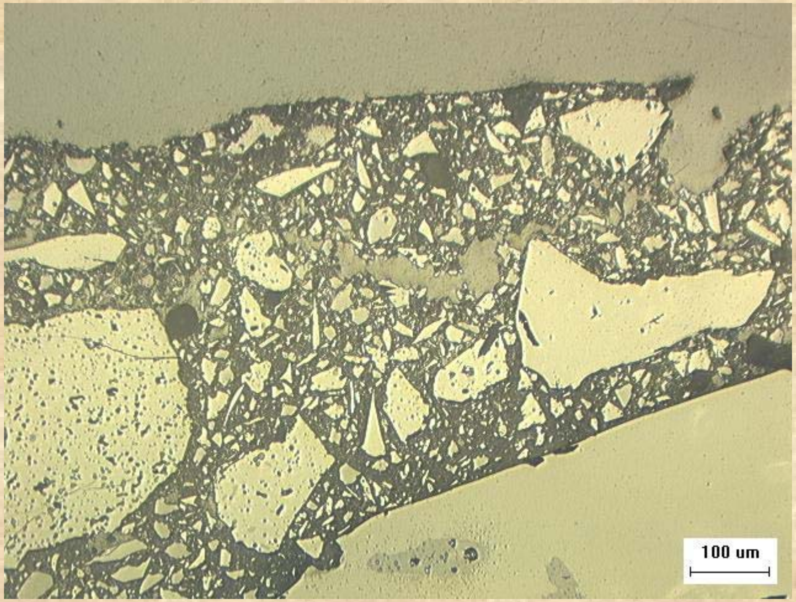
- Cu contact 1200°C for 100 hours
- Copper did not adhere to IR treated surface

Visual Appearance of High Alumina Castable

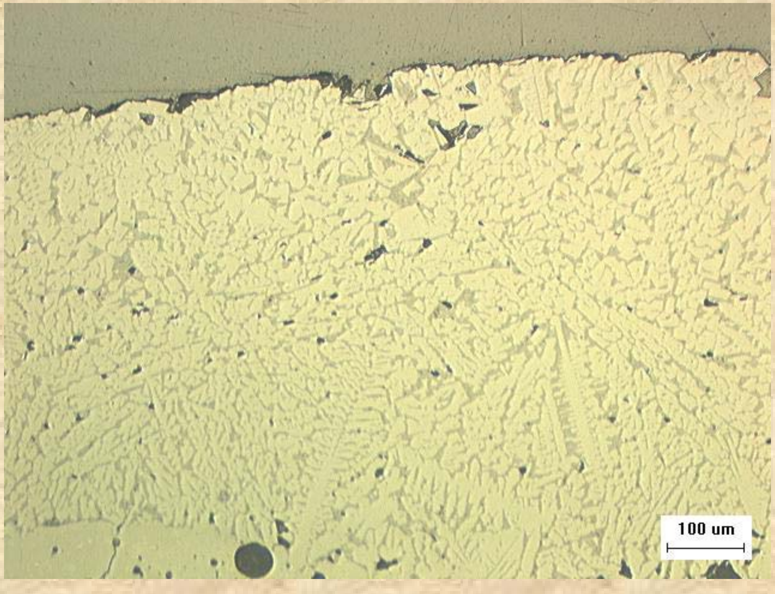


- Scan rate of 1 cm/sec

Surfaces of High Alumina Castable

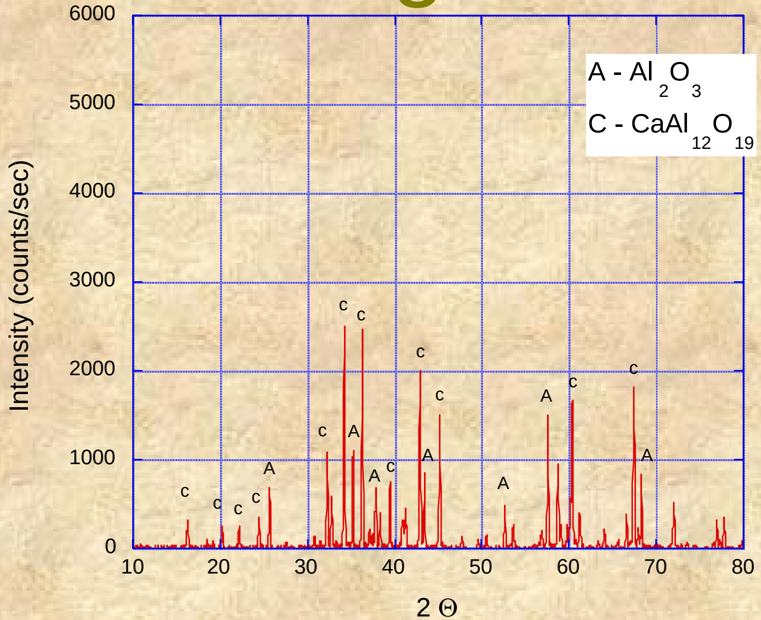


Conventional heating 1500°C for 1 hour

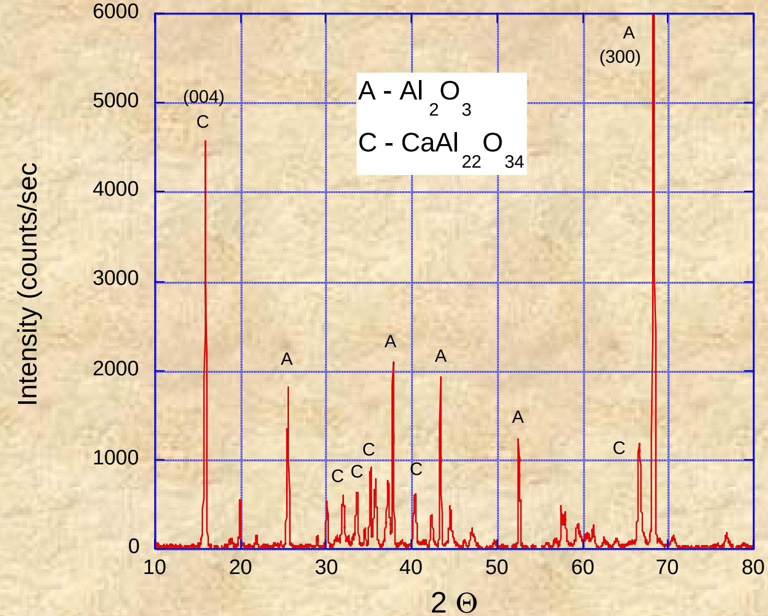


IR heating at 2350 w/cm^2 (Dual Scan)

X-ray Diffraction Identified Phases in High Alumina Castable



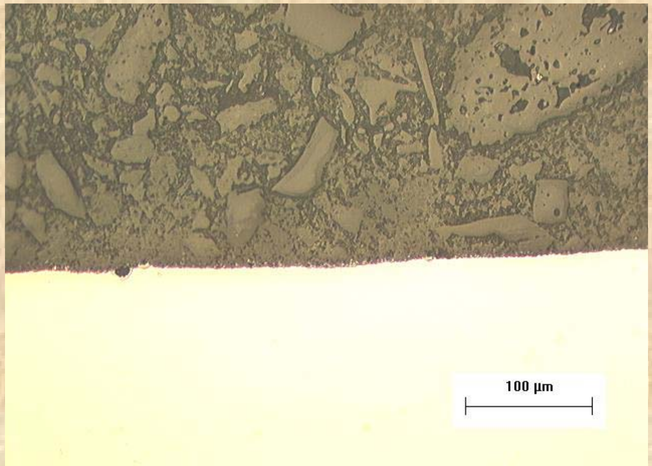
Conventional heating 1500°C for 1 hour



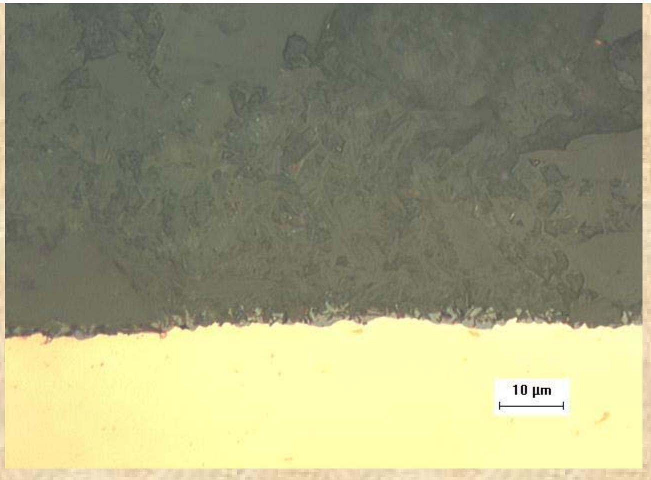
IR heating at 2350 w/cm^2

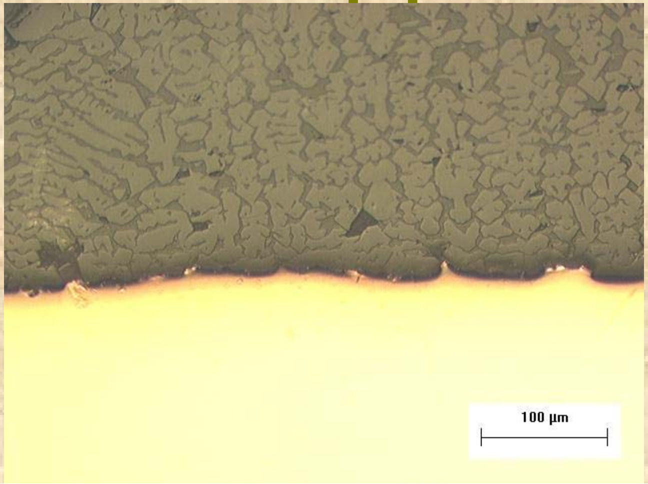
- Conventional heating shows formation of alumina and calcium aluminate materials
- IR heating shows formation of highly oriented phases

Interface Between High Alumina Castable and Molten Copper



Conventional heating 1500°C for 1 hour





IR heating at 2350 w/cm^2 (Dual Scan)

- Cu contact 1200°C for 100 hours

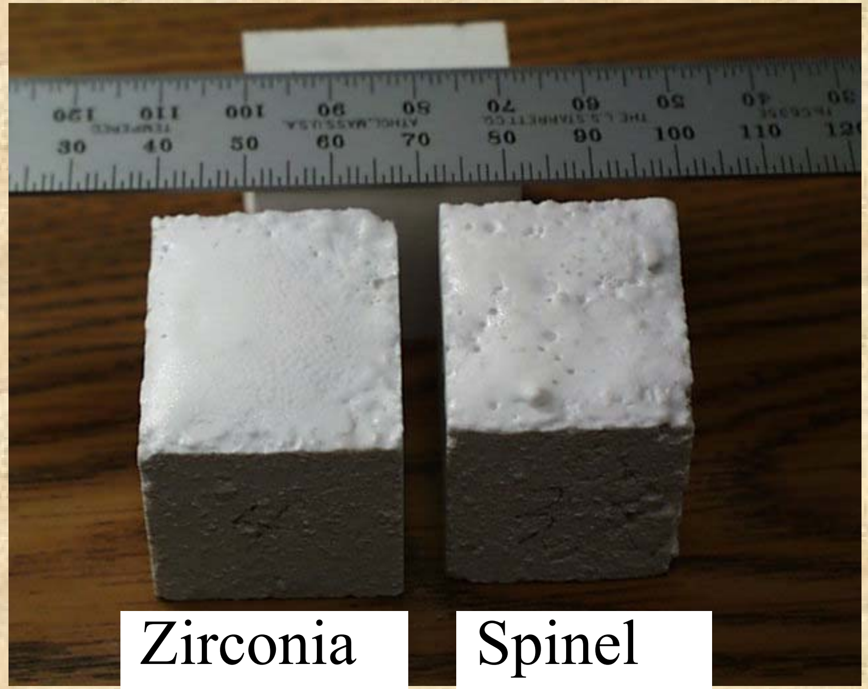
Surface Chemistry Modification and Coatings on Refractories

- Coatings can reduce porosity and improve corrosion resistance
- Capability to put corrosion resistant surface on less expensive or more environmentally safer refractories
- Work currently in progress

Coating Systems on Refractories Being Investigated

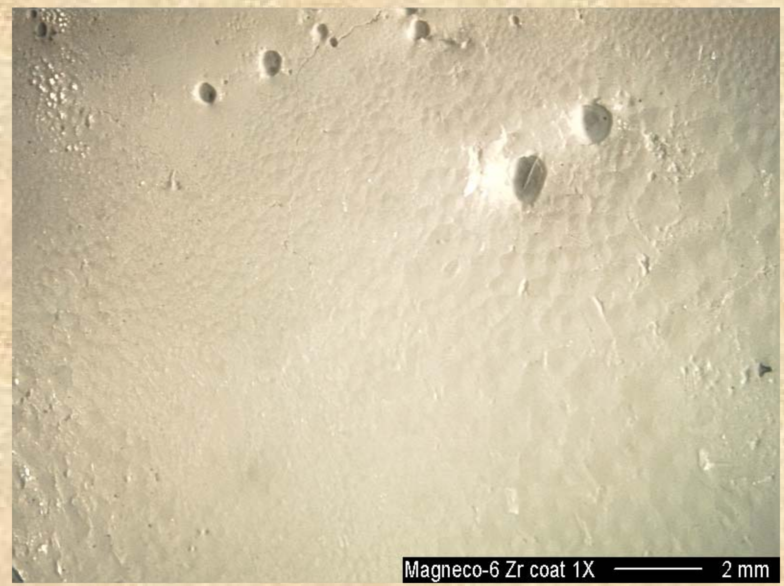
- Zirconia and spinel coatings on aluminosilicates for glass applications
- Zirconia and spinel coatings on silica for molten aluminum contact
- Zirconia coatings on AZS for glass contact
- Alumina, zirconia and spinel coatings on MgO for molten metal applications
  - MgO also used in cement industry

HDI-Bonded Coatings on Refractories



- Coatings on aluminosilicate refractory

Surfaces of Ceramic Coatings



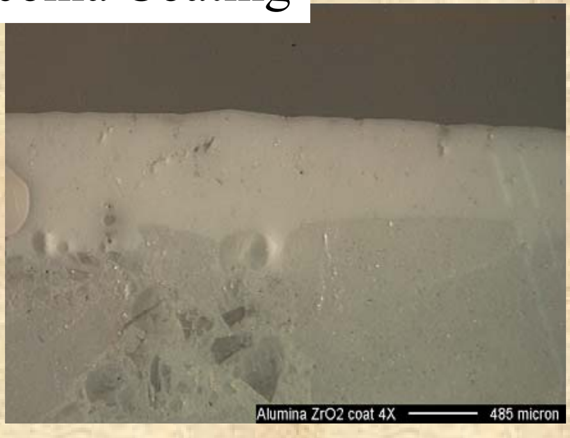
Zirconia coating

Spinel coating

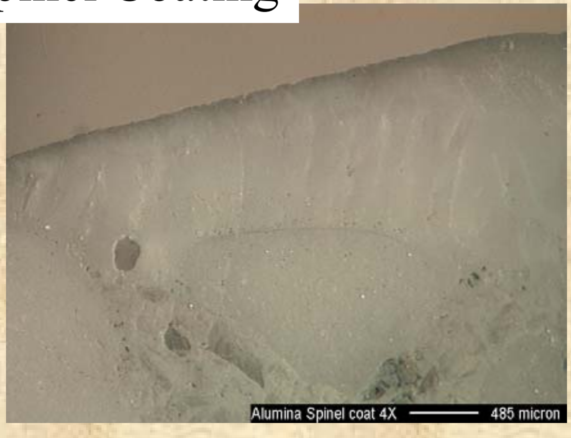
- Coatings on aluminosilicate refractory
- X-ray diffraction shows either zirconia or spinel on surface that is oriented

Cross-Section of Coatings on Aluminosilicate Refractory

Zirconia Coating



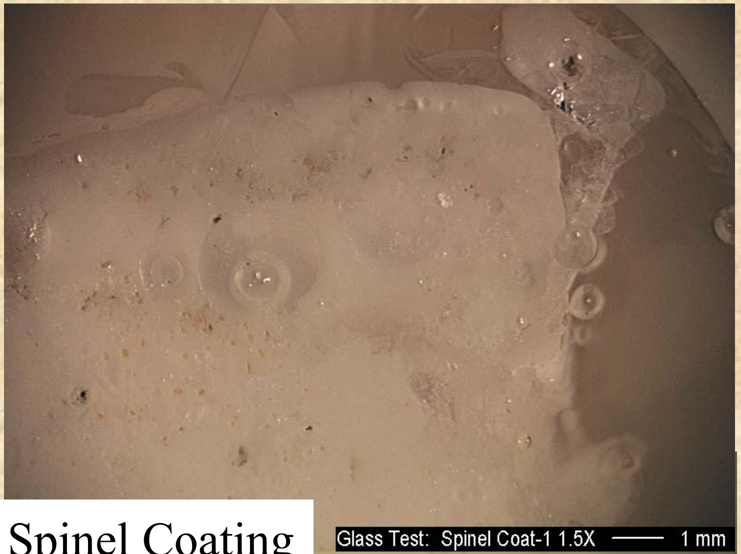
Spinel Coating



- Coatings appear to be well bonded to underlying refractory
- In general, coatings are high density

Cursory Glass Corrosion Test of Spinel Coated Aluminosilicate

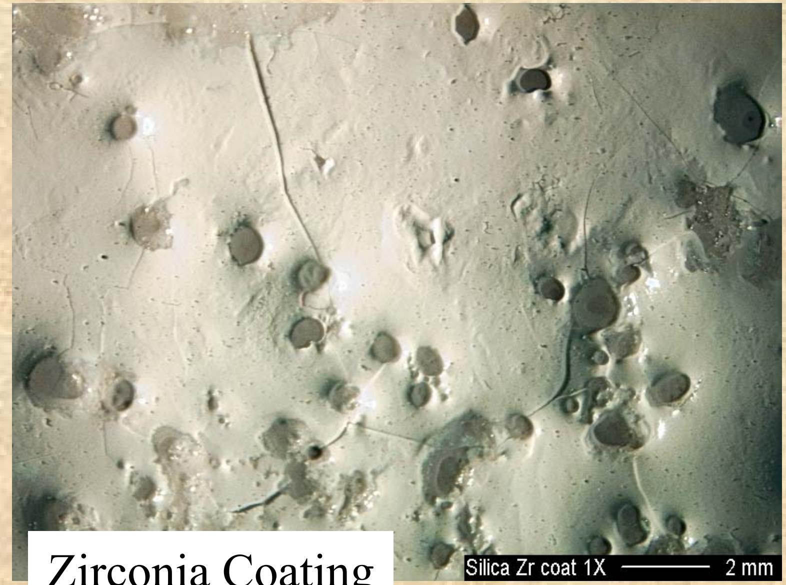
No Coating



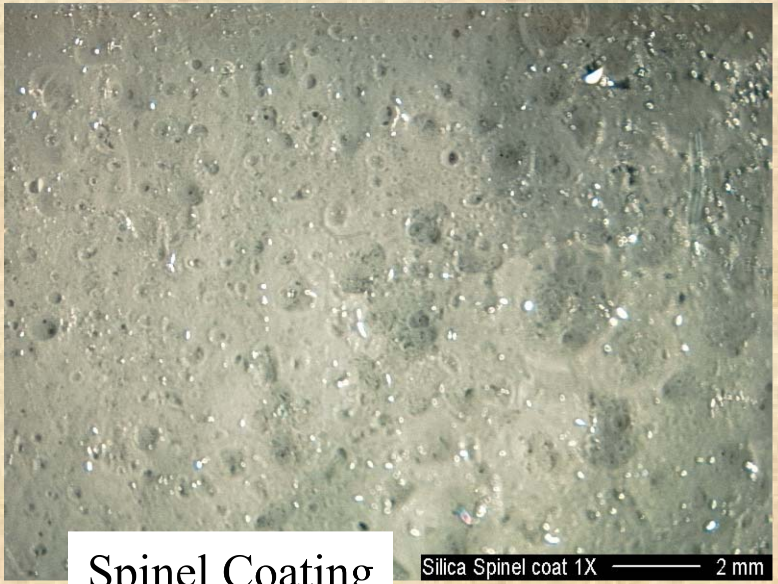
Spinel Coating

- Soda-lime-silica container glass
- 1400°C for 100 hours
- Spinel coating provided significant improvement in corrosion resistance

Surfaces of Coated Silica Refractory



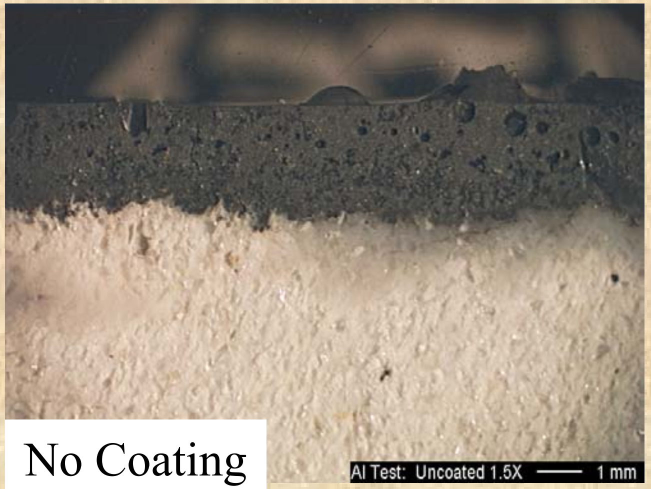
Zirconia Coating



Spinel Coating

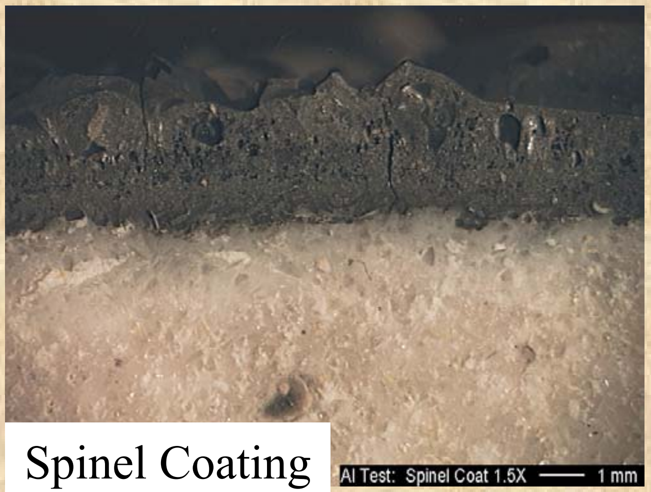
- Zirconia coating had both zircon and zirconia on the surface
- Spinel coating was amorphous and had significant amount of trapped porosity

Corrosion Testing of Coated Silica in Molten Al



No Coating

Zirconia Coating



Spinel Coating

- In contact with molten aluminum
- 800°C for 100 hours
- Displacement reaction between molten Al and refractory

Industrial Interaction on HDI Treatment of Refractories

- Materials supplied by several refractory companies
- Interest in testing zirconia coated aluminosilicate
- Coating and testing of aluminosilicate plunger for glass contact application

- Industrial Issues
  - Refractory industry very sensitive to cost
  - Interested in ability to transport equipment and use in field

Cost Estimates for IR Surface Treatments

- Capital Cost Uncertain
    - ~$250 K for equipment
    - Amortization over lifetime unknown
- Operating Costs
  - Tube life ~1200 hours at $500/tube
  - Electricity (assuming 5¢/kw-h using full power and scan speed of 1 cm/sec)
    - 0.3¢/square inch (0.05¢/square centimeter)
    - 43¢/square foot

High Density IR Surface Treatments of Refractories

- HDI exposures sufficient to melt surfaces of refractories and reduce porosity
  - Power levels required dependent on composition
  - Some gas bubbles developed from trapped porosity
  - Grain orientation during crystallization of melted regions
  - IR treated materials showed less penetration by molten copper
- Ceramic coatings can be applied to refractories to change the surface chemistry
  - Coatings appear to be high density and adherent
  - Initial corrosion tests show potential for improved resistance
  - Further testing in progress