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BRIGHTER SOLUTIONS TOGETHER

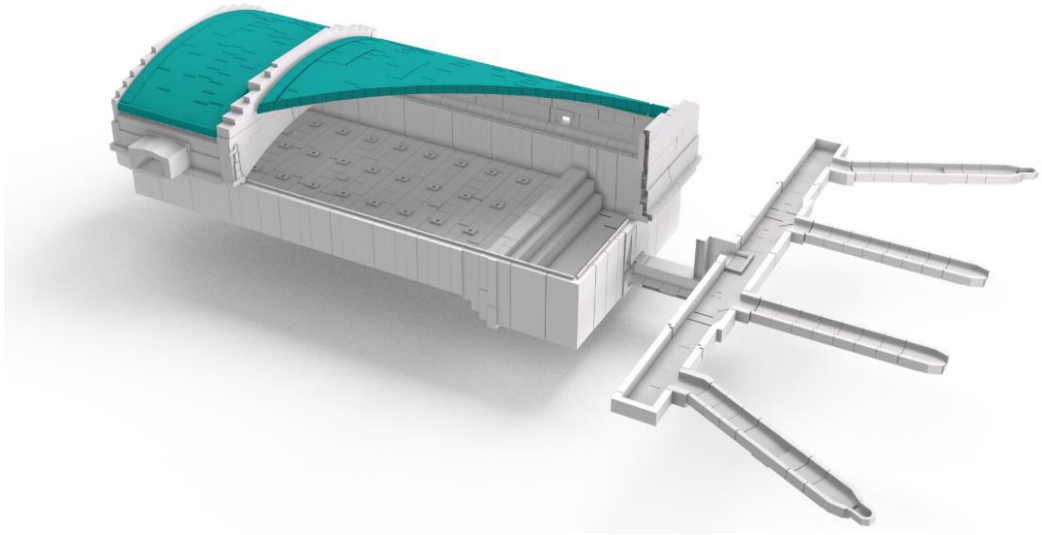
86th Glass Problems Conference and Symposium
October 6-9, 2025, Toledo, Ohio, USA

GMIC

Increasing Melter Throughput, Efficiency and Lifetime through Design of Mullite Refractories for Crowns

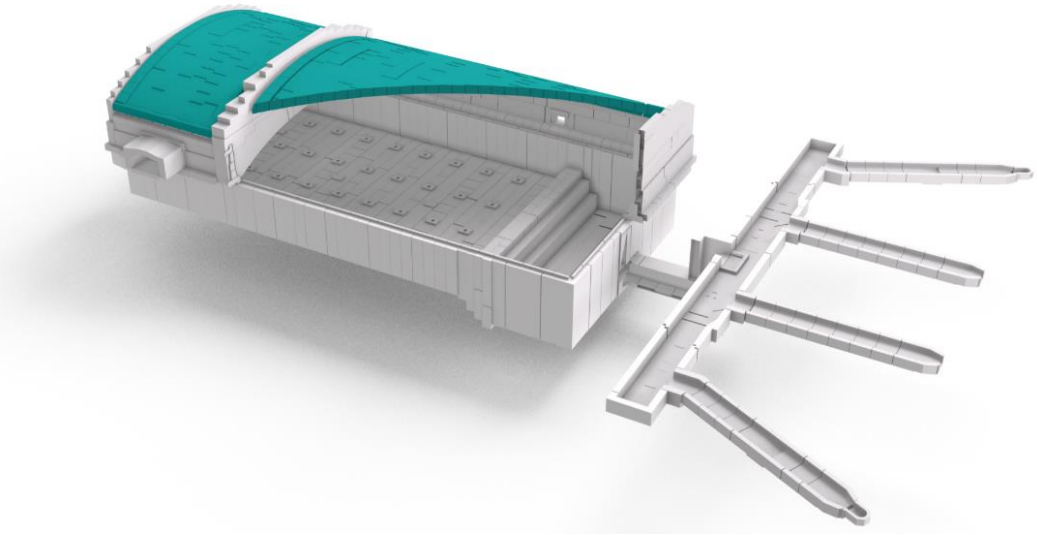
Kristen Pappacena, Krishna Muvvala, Olivier Citti, Damien Bolore, Darren Rogers

REFRACTORY SOLUTIONS THROUGHOUT THE FURNACE'S LIFETIME

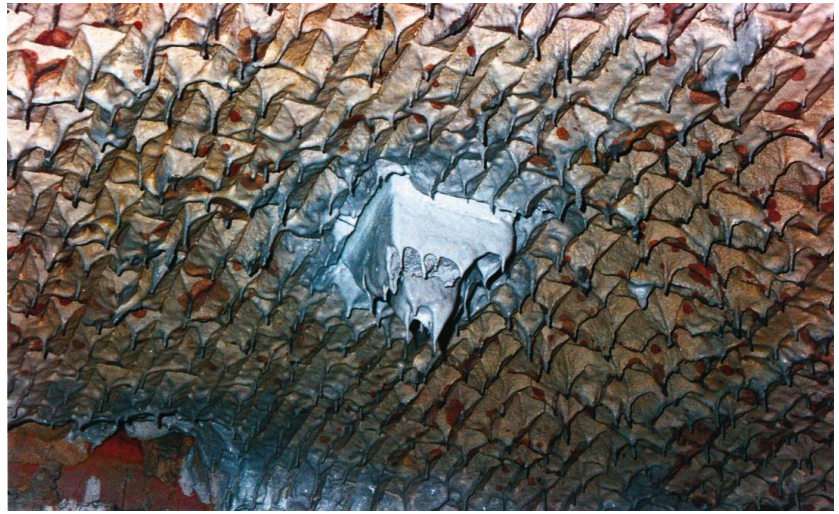


Full Refractory Package

CROWN: HARSH CONDITIONS AND DESIRED PROPERTIES



Silica Crown Example



Harsh Conditions

- **High Temperatures**
  - Creep deformation
  - Heat/energy loss
- **Glass Vapors & Carryovers**
  - Corrosion potential
  - Microstructure changes

Refractory Desired Properties

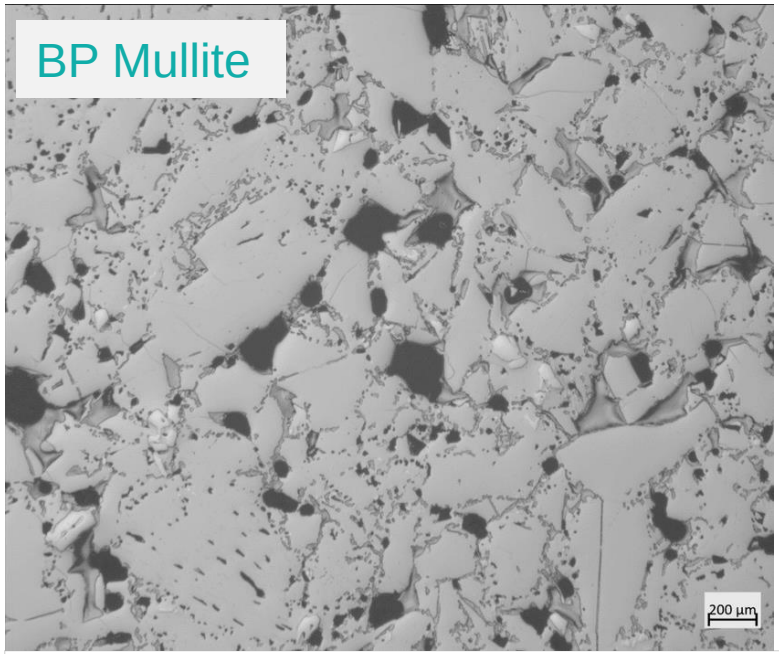
- **High creep resistance**
- **High emissivity**
- **Corrosion resistance & microstructural stability**

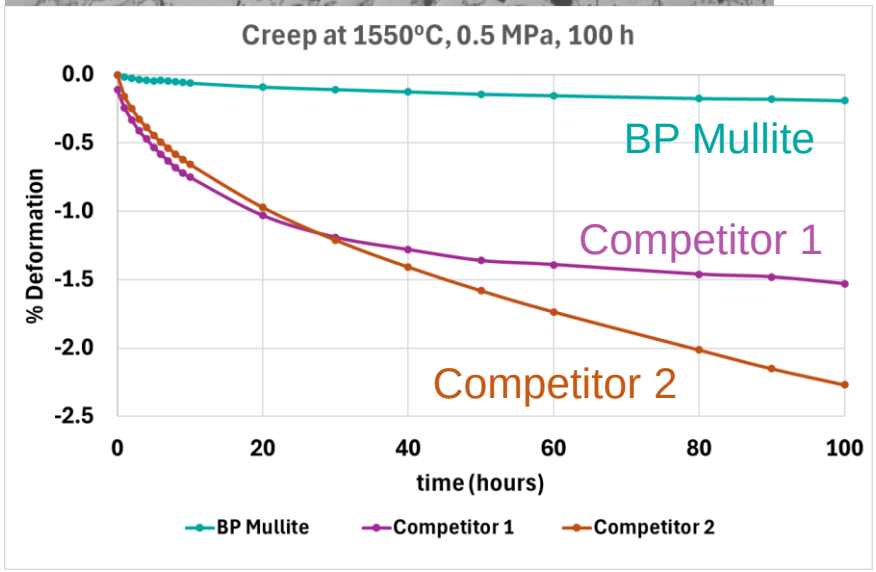
Silica is standard solution but can reach its limit in extreme crown conditions

- **Melting and dripping**
- **High creep rate**

MULLITE

INTRODUCING BP MULLITE

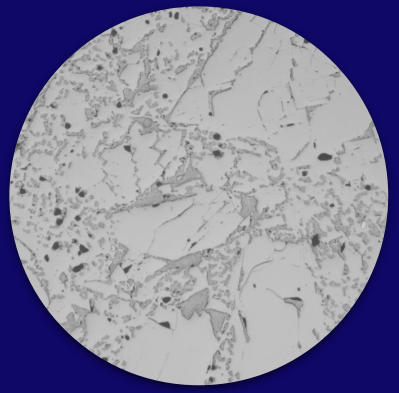




	BP Mullite (Standard Sintered Mullite)
Refractoriness under load (0.2MPa, 0.5%) (°C)	>1700
Cold Crushing Strength (MPa)	100
Coefficient of thermal expansion (x10^{-6}/K)	5.4
Thermal conductivity at 1000°C (W/mK)	2
Creep at 1700°C, 0.4MPa 0-100h (%)	2
Porosity (%)	15
Typical bulk density (g/cm^3)	2.7

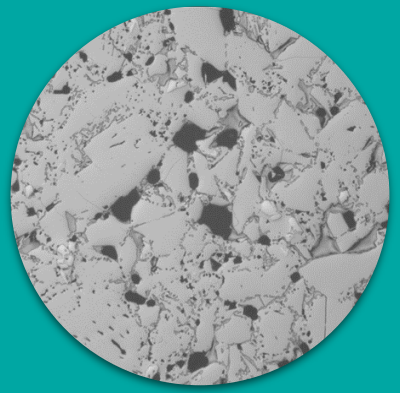
- Used in reinforcement and specialty glass (non-alkali glass) industries
- High vapor corrosion resistance
- Excellent creep resistance

BEYOND BP MULLITE



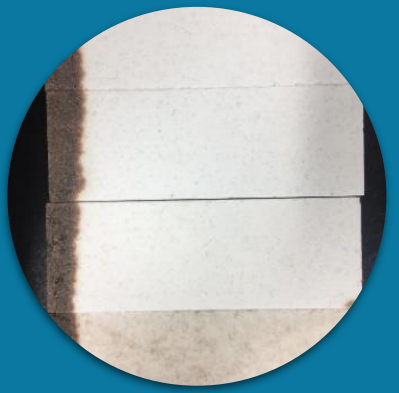
BP Mullite REC:

Improved creep for high temperature performance



BP Mullite:

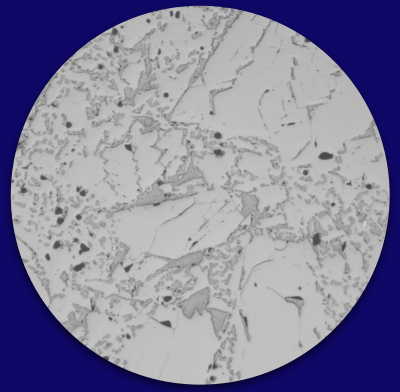
Good creep and emissivity



BP Mullite HE:

Improved emissivity for heat management

BP MULLITE REC



BP Mullite REC:

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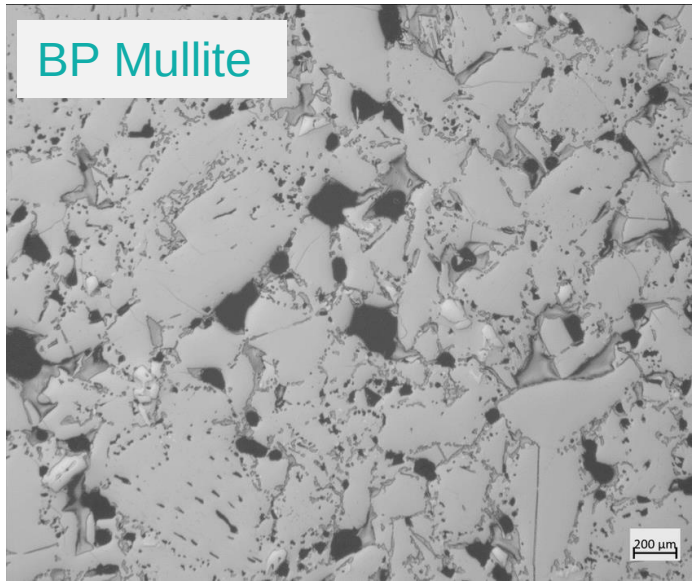
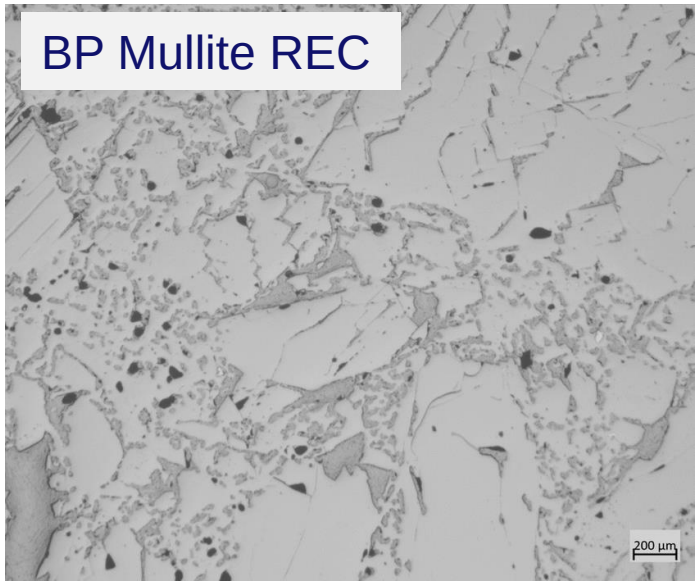
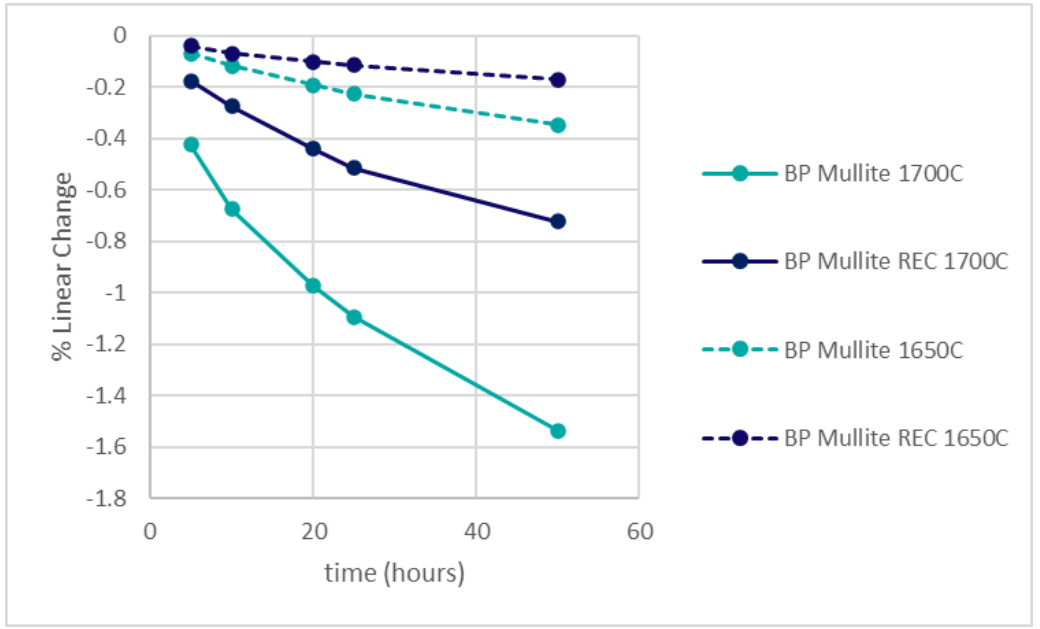
BP MULLITE REC



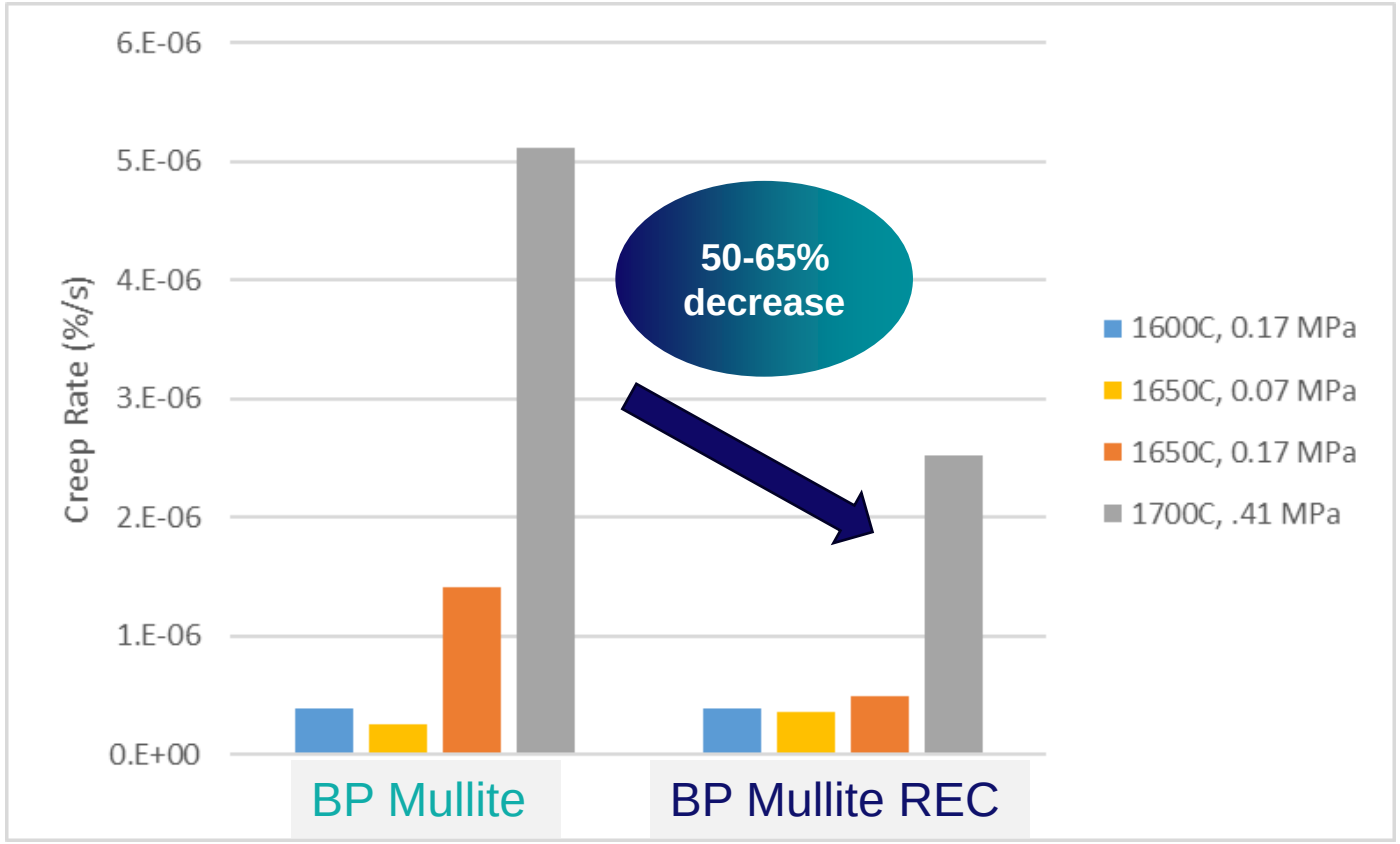


	BP Mullite (Standard Sintered Mullite)	BP Mullite REC (High Creep Resistant Mullite)
Phase Composition	Mullite + corundum + silicate	Mullite
Refractoriness under load (0.2MPa, 0.5%) (°C)	>1700	>1700
Cold Crushing Strength (MPa)	100	130
Coefficient of thermal expansion (x10^{-6}/K)	5.4	5.9
Thermal conductivity at 1000°C W/mK	2.0	2.5
Creep at 1700°C, 0.4MPa 0-100h (%)	2.0	0.5
Porosity (%)	15	13
Typical bulk density (g/cm^3)	2.7	2.67

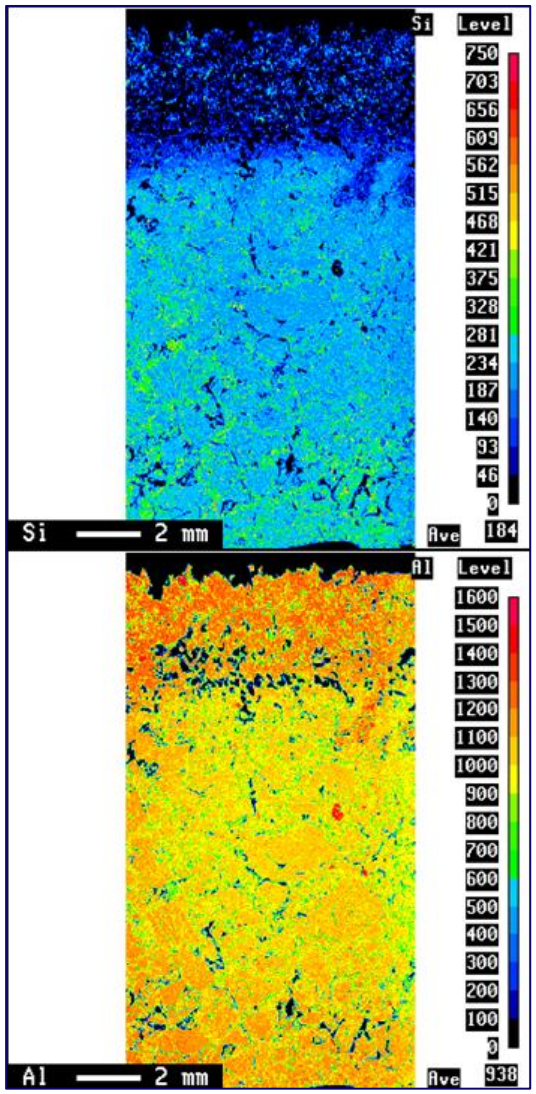


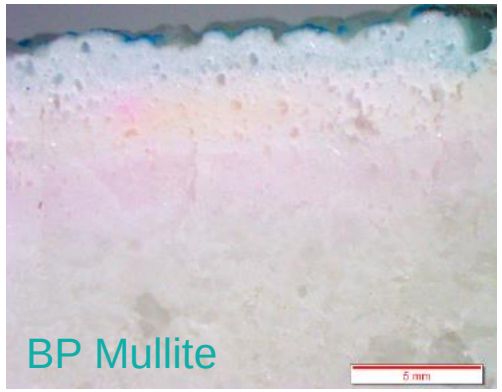
BP MULLITE REC

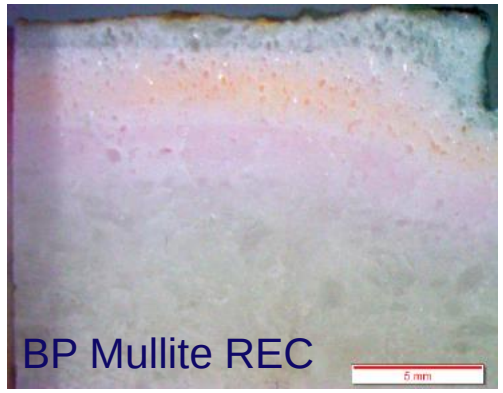
- BP Mullite REC has improved creep performance over BP Mullite
- 50-65% improvement at higher temperatures and loads
- BP Mullite REC creep benefit increases with increasing temperature



VAPOR CORROSION RESISTANCE





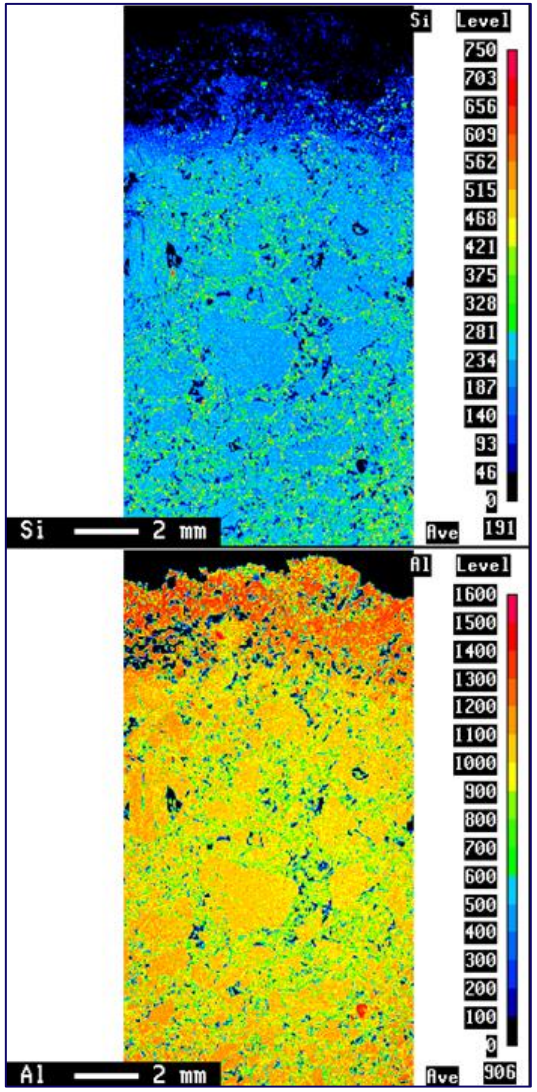


- Vapor corrosion resistance of BP Mullite REC is at least equivalent to BP Mullite
- Good stability in glass vapors and high temperature environment
  - Less free silica in BP Mullite REC

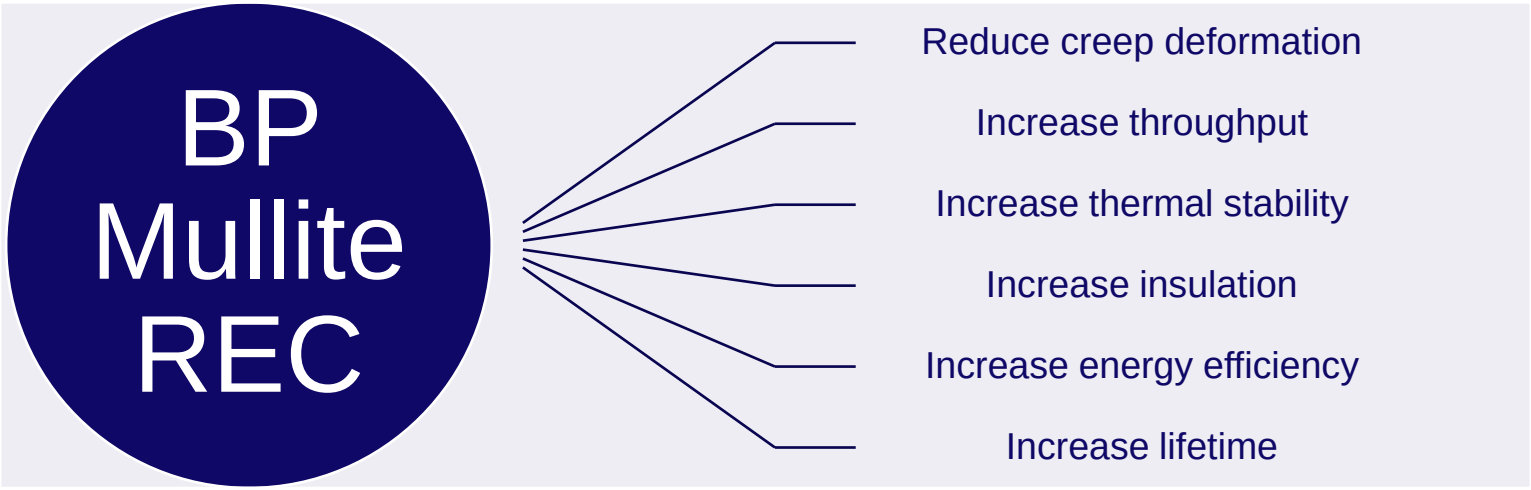
1600 °C – 150 h – 80% colemanite 20% rasorite

($CaB_3O_4(OH)_3$, $3H_2O$ / $Na_2B_4O_6(OH)_2$,3 H_2O)

Infiltration measured on microprobe picture: Mullite to alumina transformation

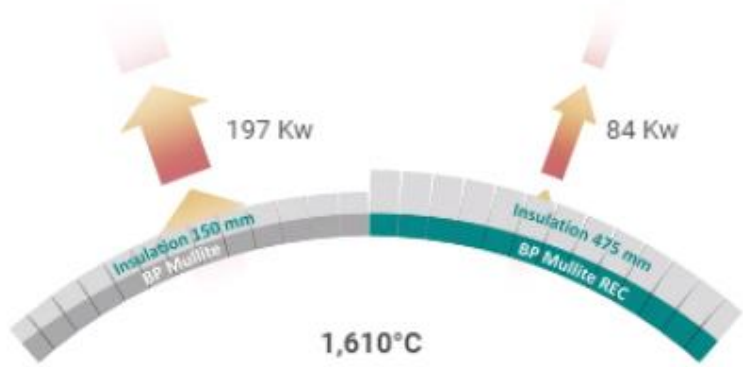


Advantages of using BP Mullite REC

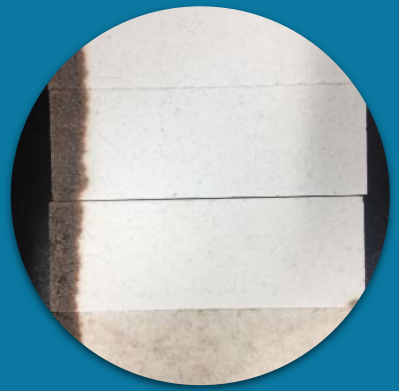


- Potential for ~50°C in operation temperature for same creep deformation
- Potential for increasing insulation
  - Better heat retention at same creep rate
- Overall improvement in throughput, thermal stability, lifetime, and energy efficiency

Add more insulation to prevent heat loss!



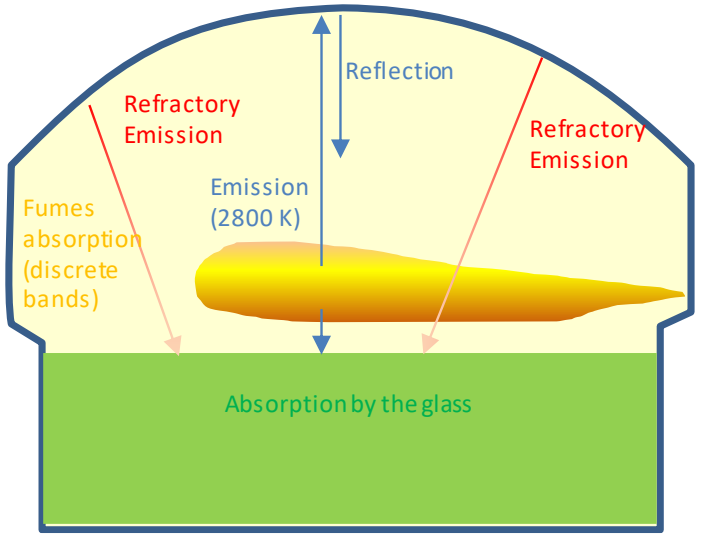
BP Mullite HE



BP Mullite HE:

Improved emissivity for heat management

WHY IS REFRACTORY EMISSIVITY IMPORTANT?



Emissivity of combustion gases

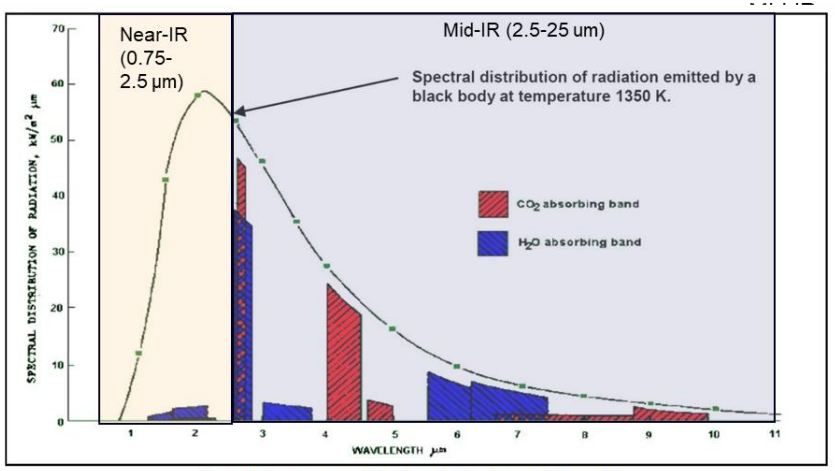
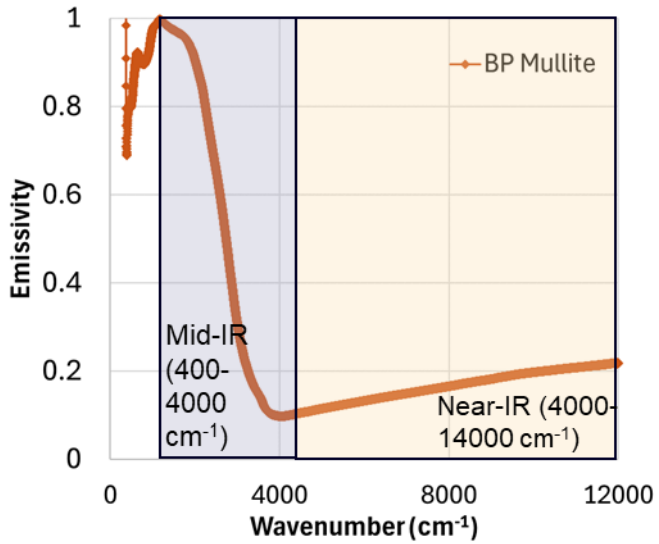


Fig. 1: Energy Spectra of Combustion Products of Natural Gas

https://ammoniaknowhow.com/energy-efficiency-improvements-through-the-application-of-high-emissivity-refractory-coating/

Emissivity of refractories

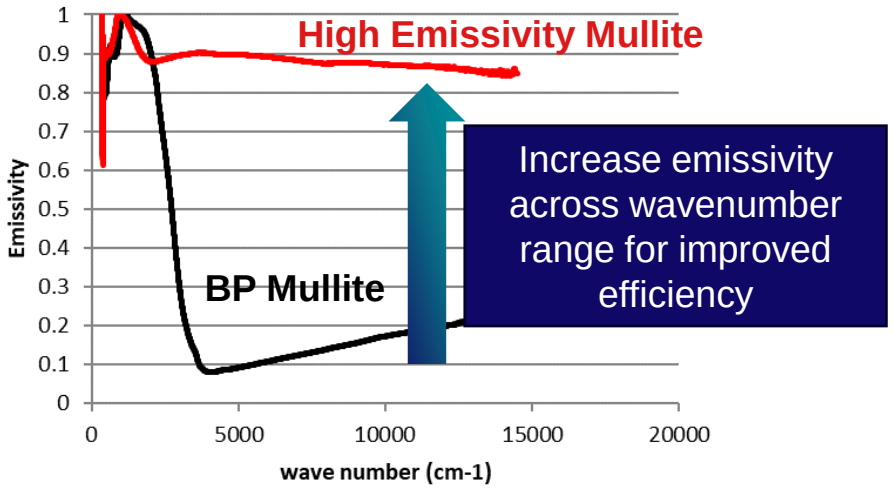


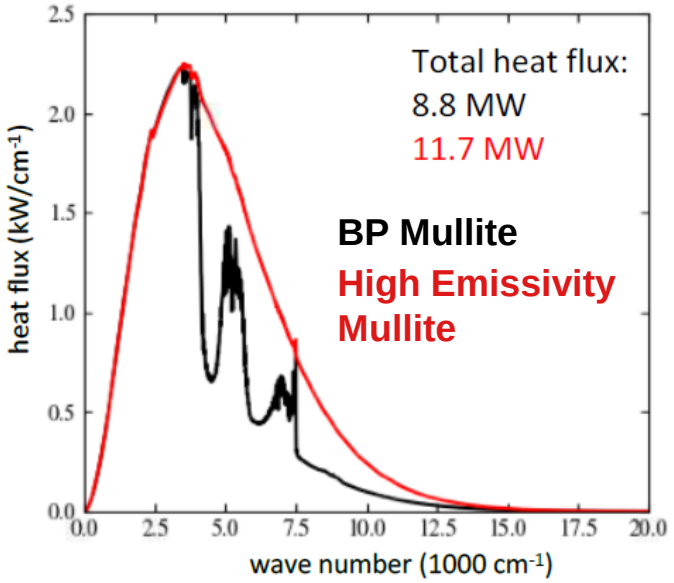
Furnace is heated by radiant heat coming from combustion gases

- Combustion gases have narrow wavenumber windows of emissivity
  - Combustion gases have optically thick regions of high absorption
- Refractories absorb and re-emit thermal energy based on their emissivity
  - >80% of IR radiation is in spectral range where refractories have low emissivity

Need refractory solution with higher emissivity to redirect more heat to the batch melt

MODELING OF HEAT FLUX FOR DIFFERENT EMISSIVITIES





Modeling shows impact of high emissivity

Calculations based on:

- Emissivity and reflectivity of refractory surface
- Absorption coefficient of combustion gases

BP Mullite: Lower emissivity at higher wavenumbers

- The spectral deficits observed are due to regions of low surface emittance and high gas absorption

High Emissivity Mullite: Higher emissivity across the entire range of wavenumbers

- Allows the refractory to absorb and re-emit radiant heat across all wavenumbers

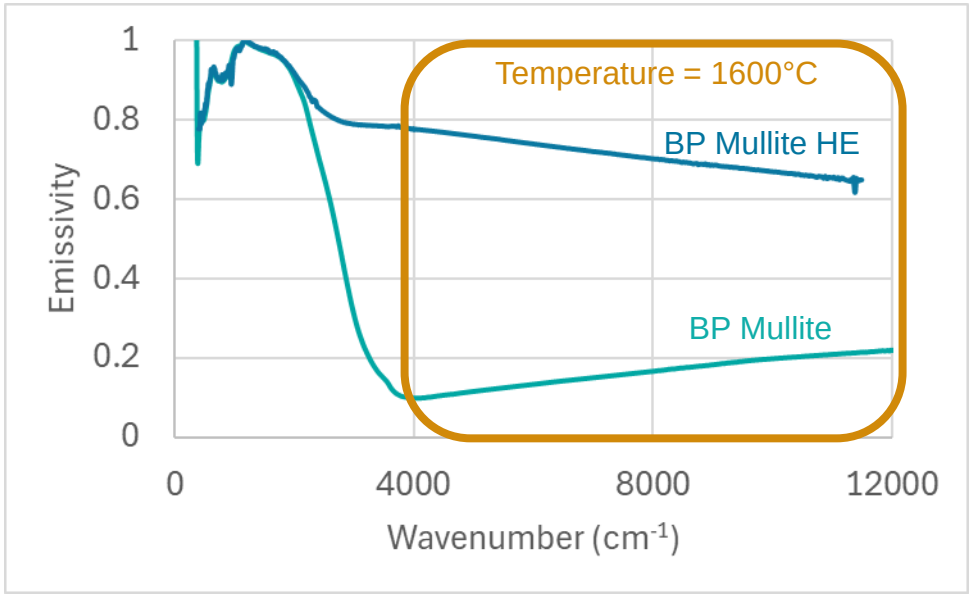
High Emissivity Mullite can offer more up to 33% more heat flux to the glass

→ Better furnace efficiency

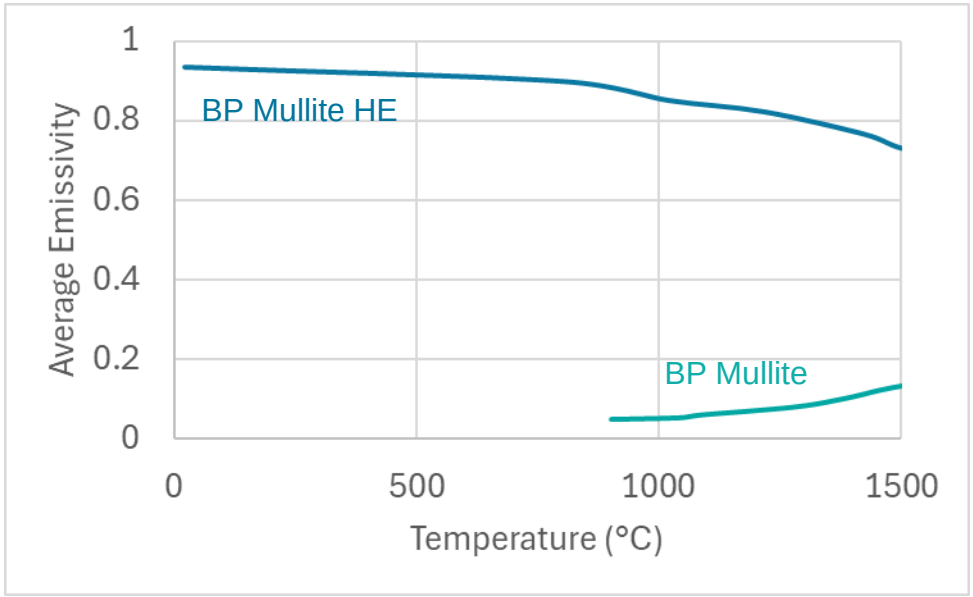
(*) Le, H. P. “Spectral Radiative Modeling of Glass Furnaces” HPC4EI Project SEFPRO/Owens Corning/ Lawrence Livermore National Laboratory 2021

BP MULLITE HE: EMISSIVITY IMPROVEMENT

Emissivity vs wavenumber



Emissivity vs temperature

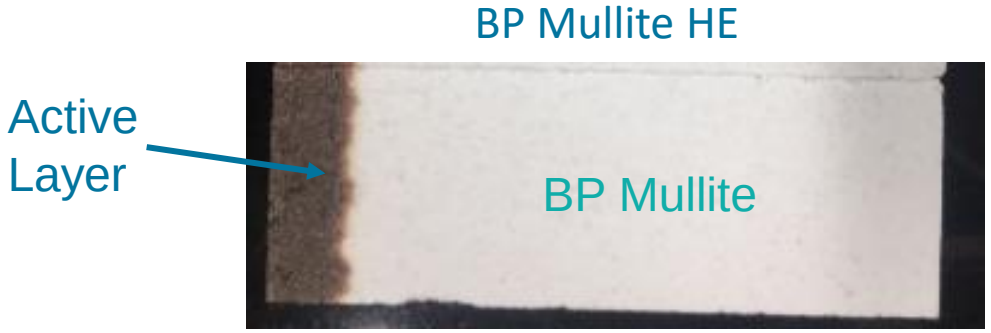


- Emissivity increased over BP Mullite for entire wavelength range
- Thick active layer → enhanced stability over time
- Surface high emissivity, bulk retains excellent creep resistance
  - Active layer does not degrade bulk properties

Emissivity measurements performed at CEMHTI

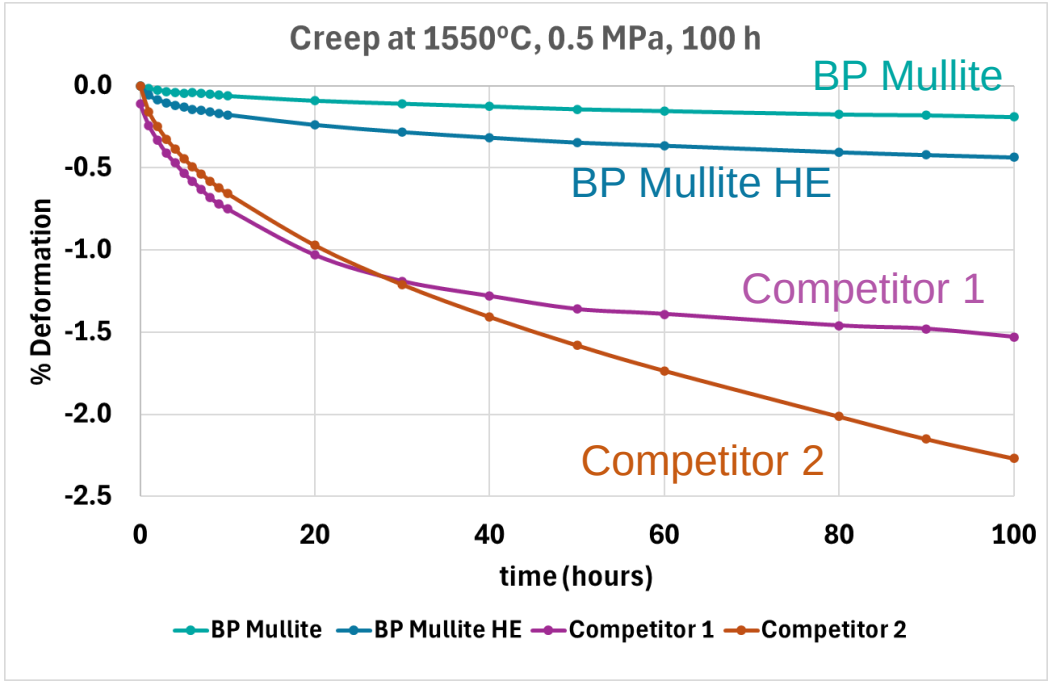
BP MULLITE HE: PROPERTY COMPARISON

BP Mullite HE

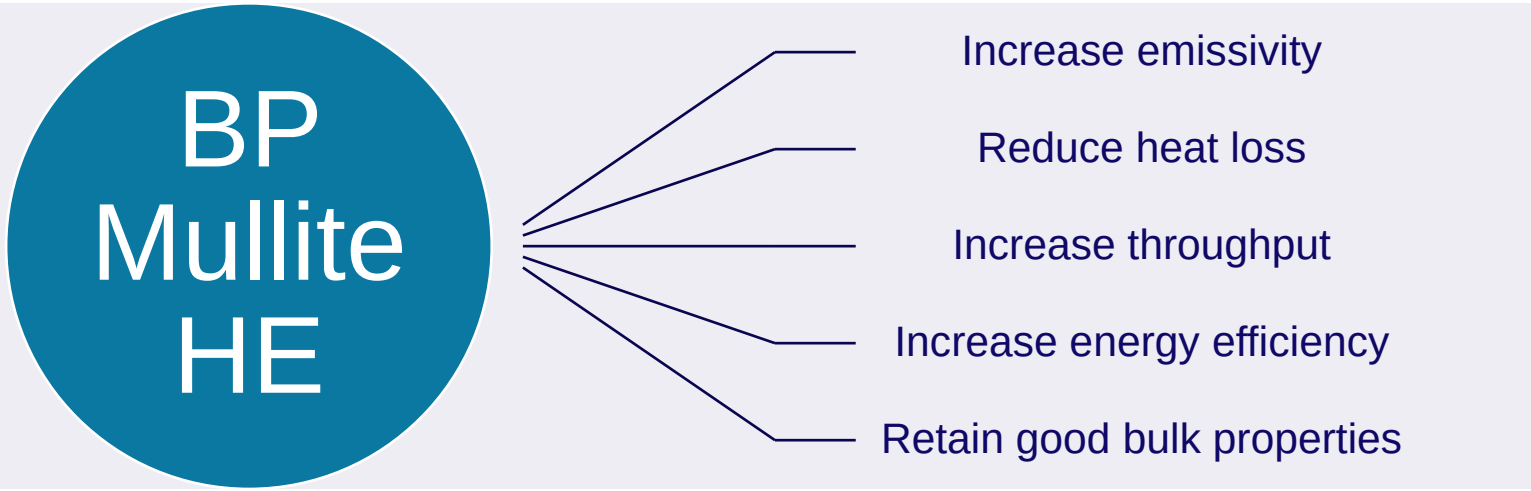


	BP Mullite (Standard Sintered Mullite)	BP Mullite HE (High Emissivity Mullite) Active Layer (~1 inch)
Refractoriness under load (0.2MPa, 0.5%) (°C)	>1700	>1700
Cold Crushing Strength (MPa)	100	80
Coefficient of thermal expansion ($x10^{-6}$/K)	5.4	5.4
Thermal conductivity at 1000°C W/mK	2.0	2.4
Porosity (%)	15	10
Typical bulk density (g/cm^3)	2.70	2.65
Creep at 1550°C and 0.5 MPa, 0 - 100 h (%)	0.19	0.43

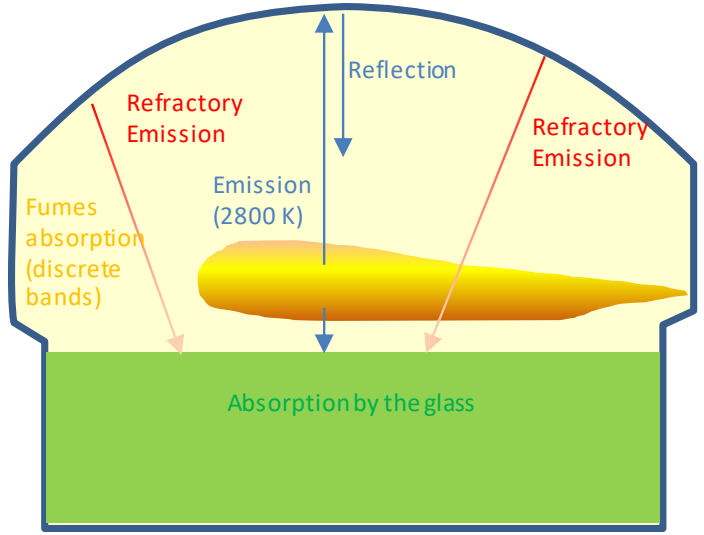
- Active layer on BP Mullite HE is ~ 1 inch
  - Allows total composite to retain properties of BP Mullite
  - Excellent creep resistance, cold crush



ADVANTAGES OF BP MULLITE HE



- Increase emissivity → more heat introduced/retained in glass melt
- Increased throughput and energy efficiency
- Good creep and bulk properties of BP Mullite
- Overall improvement in throughput, thermal stability, lifetime, and energy efficiency



PRODUCT SUMMARY

BP Mullite

- Good creep
- Good emissivity

BP Mullite Rec

- Improved creep by 50-60% at 1700°C
- Higher temperature operating capability (> 50°C)
  - Increased throughput
  - Increased lifetime

BP Mullite HE

- Improved emissivity by 3x above 4000 cm^{-1}
- Reduction of heat loss by 8%
  - Increased throughput
  - Increased energy efficiency

TOTAL CROWN SOLUTIONS

- SEFPRO can provide the most appropriate crown material
- SEFPRO can also help you understand your crown’s performance

CROWN RELATED SERVICE OFFERINGS

How to Better Understand Your Crown

- Scanning and Modeling

3D Scan

- Visualize the furnace, including crown before and after campaign
- Make quantitative assessments of performance

Finite Element Modeling

- Understand temperature distribution and mechanical stresses in crown
- Study performance and improve design

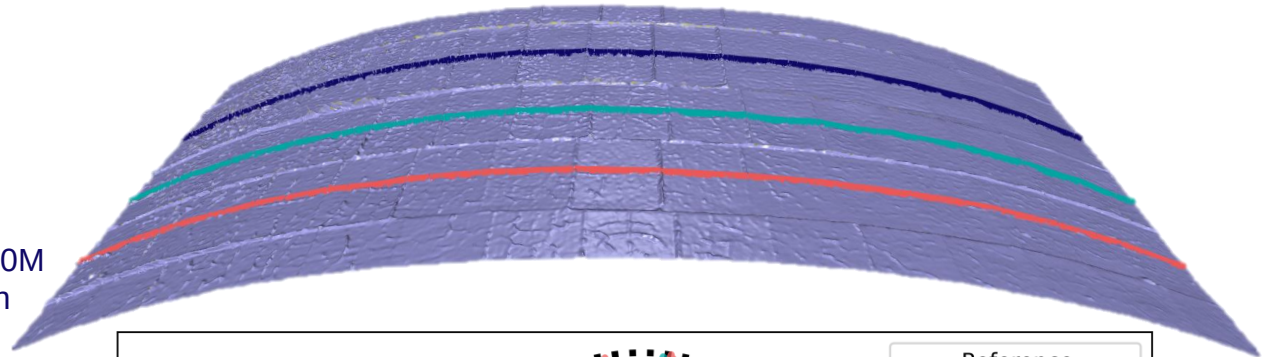
SEFPRO 3D SCAN SERVICE AND CROWN MODELING

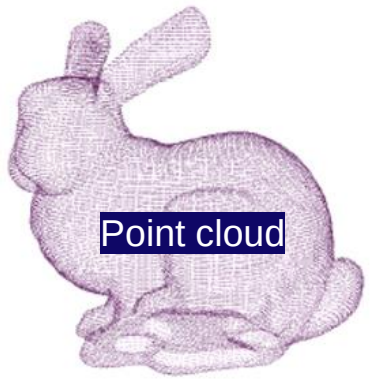
- Offers a highly precise 3D model for full assessment of alignment, corrosion, and sag.

3D laser scanner

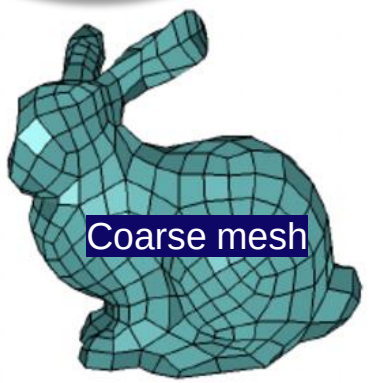
Accuracy: ±2.0 mm
Number of point cloud: +20M
Time: ~5 minutes per scan

Fine mesh of a crown (partial view)



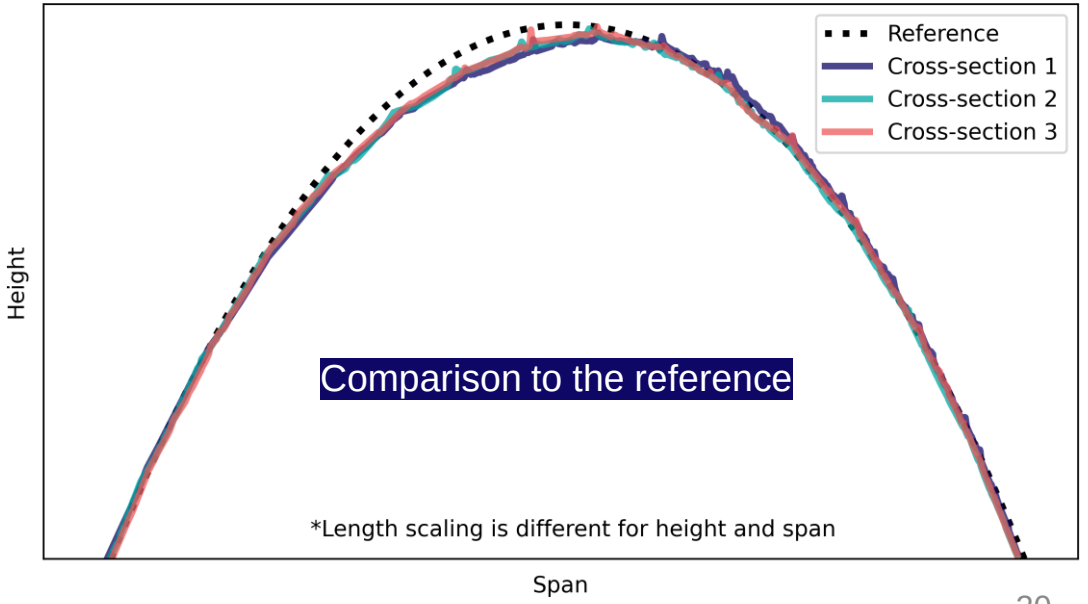


Point cloud



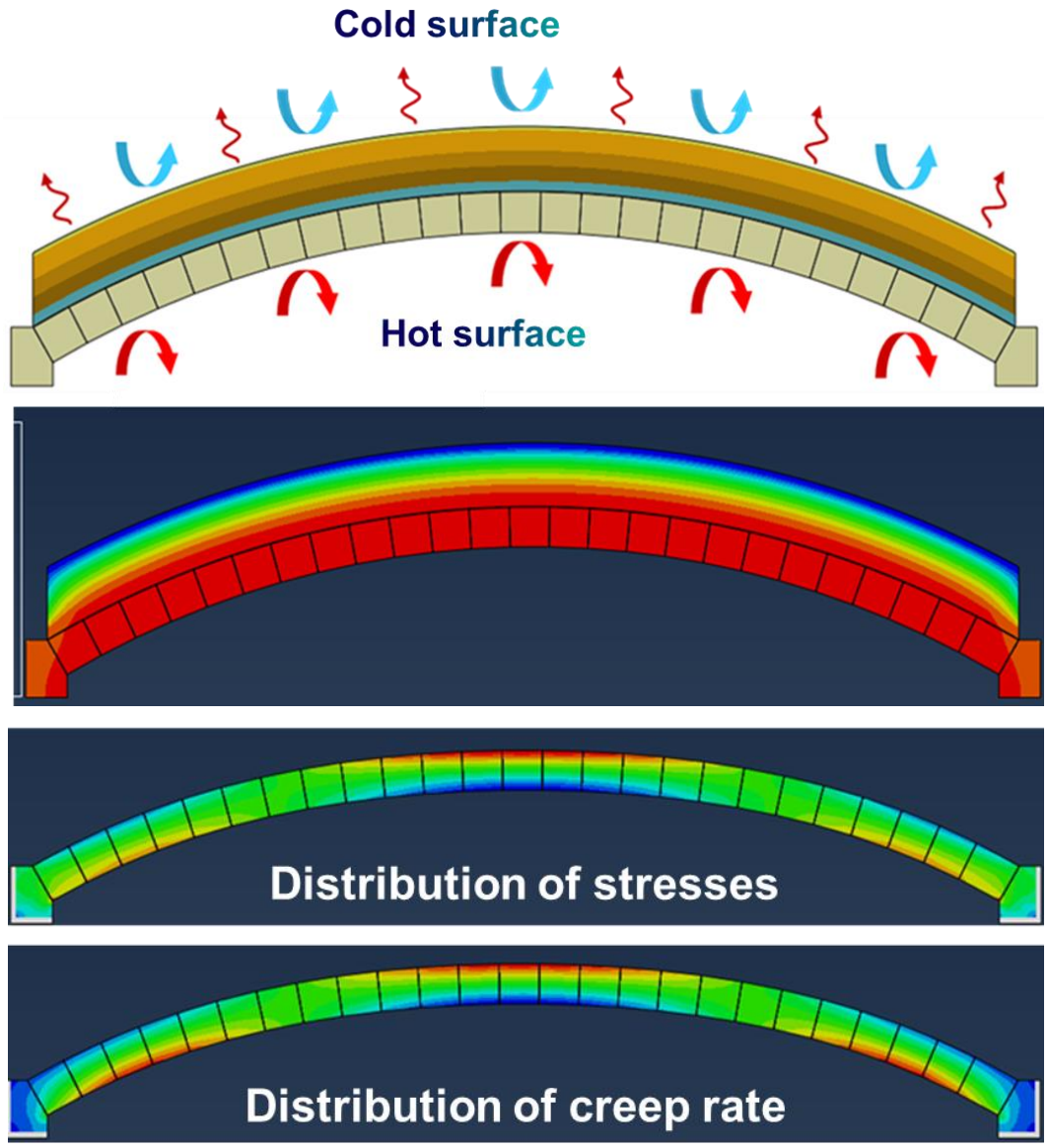
Coarse mesh

Fine mesh



Comparison to the reference

CROWN MODELING – THERMOMECHANICAL MODEL



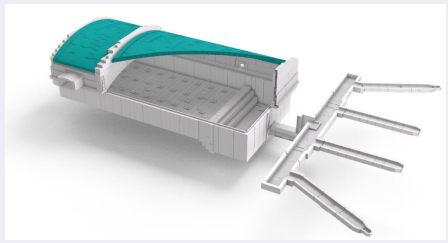
Modeling by Eric Buchovecky, Saint-Gobain Research North America

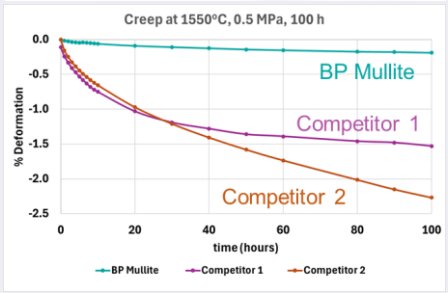
- Crown system considerations
  - Maximum temperature at the hottest location
  - Safety of the structure
  - Minimize heat losses
- SEFPRO Crown Model
  - Dimensions and materials can be specified
  - Temperature profile is calculated based on furnace temperature, crown block properties, and insulation package
- Model capabilities
  - Understand heat flow through the crown blocks.
  - Visualize deformation due to creep and stresses

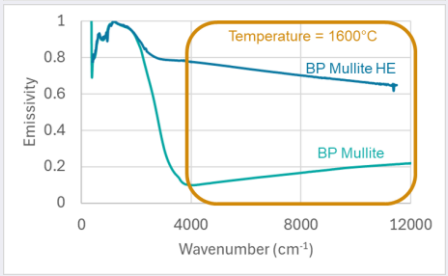
SUMMARY

Critical crown properties

- High creep resistance
- High emissivity







BP Mullite Products provide properties designed to improve furnace operation

→ throughput, lifetime, energy efficiency

BP Mullite

- Good creep
- Good emissivity

BP Mullite Rec

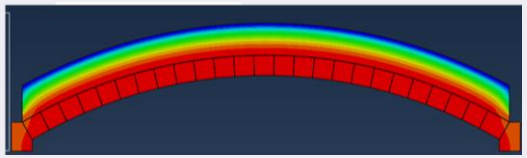
- Improved creep
- Better high T capability

BP Mullite HE

- Improved emissivity
- Better energy efficiency

Crown Services

- 3D Scan –visualize your crown
- Modeling – visualize thermo-mechanical stresses to understand performance



THANK YOU

Question time

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