Microwave Technologies
Key points for manufacture of ceramics

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Outline

- Microwave Benefits- Overview
- Barriers to Technology Uptake
- Overview of Microwave Heating Methods
- Commercial Microwave Systems
- Summary
Why Microwaves?

Benefits

- **Cost savings**
  energy, capital equipment, inventory

- **Property improvements**
  uniformity, nanograins

Microwave heat targets product → Less energy wasted in non-product
Faster ramp rates, shorter dwell times → Time and energy savings, nanogranis
Thermal conduction not as significant → Fast, uniform heating

**Microwave Assist Technology**
850 °C, 35 min, Ds = 150 nm

**Conventional Calcine**
1000 °C, 4 hr, Ds = 500 nm
What are the Problems?

- Benefits of microwave processing dependent on dielectric properties
- Lack of familiarity with microwave systems and processing
- Choice of best microwave system depends on material and process
- Availability of commercial microwave systems for thermal processing > 100 C (binder removal, calcination, sintering)
Microwave Heating

Dielectric Properties

- Indicator of how material will heat
- Tool in developing microwave heating processes

\[ E_r^* = \varepsilon_r' - i\varepsilon_r'' \]

\[ \tan \delta = \frac{\varepsilon_r''}{\varepsilon_r'} \]

Microwave Methods

- **Pure Microwave**
  - Microwave energy only source of heat
  - Pre-heat zone + microwave energy

- **Hybrid Microwave Heating**
  - Microwave Assist Technology
    - Combination microwave and radiant gas or electric
  - Susceptor Assisted Heating
    - Combination microwave and radiant susceptor heating
Pure Microwave System

Dennis Tool Company

- Tungsten carbide cobalt sintering
- Continuous microwave system
- Used in-house for commercial part production
Hybrid Microwave Systems

- Susceptor

- Small systems
- Small products
- Ultra fast radiant heating
- Cannot separate radiant from microwave
Hybrid Microwave systems
Microwave Assist Technology

- Combine microwave w/ gas or electric radiant
- Continuous or batch

MAT electric kiln

Temperature profile across part thickness

MAT gas kiln
MAT vs. Conventional

Blasch Alumina-SiC

Harrop Industries
MAT Elevator Kiln
inert atmosphere, 1620 °C
Temperature and Microwave Absorption

Half-power depth

Heating

- 912 MHz
- 2466 MHz

Temperature (°C)

Half Power Depth (cm)

12 cm

1 cm

1200 °C
MAT Profile – Time is Energy

- MAT ~5x faster firing
- Saved 62 hrs in cycle time
- 16 hrs vs. 78 hrs
- Part quality meets spec
MAT Firing Data
Clay Bricks – Cost Benefit Analysis

- Cost benefit for brick industry
- 13 month payback (2006 prices)
- 46-54% energy savings

- MAT firing
  25 hrs total

- Conventional firing
  70 hrs total
Microwave Kilns and Systems
Currently available in market (MAT or Microwave)

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<th>Location</th>
<th>Frequency (GHz)</th>
<th>Type</th>
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MAT = Microwave Assist Technology  MW = Microwave
Microwave Kilns and Systems

Ceralink MAT Lab Batch Kilns

Ceralink/CM Furnaces

Carbolite Ltd
Microwave Kilns and Systems

CPI Autowave
batch

Takasago
continuous
Microwave Kilns and Systems

MMT batch

Synotherm continuous
Microwave Kilns and Systems

Thermex Thermatron batch

Harrop Industries batch
Microwave Process Considerations

- Microwave processing is dependant on materials properties
- Dielectric Properties are important
  - Microwave absorption, penetration depth
  - Penetration important for size and uniformity
- Re-train thinking on thermal processing
  - Not simply a set time and temperature
  - Process varies with material type and composition
  - Not all materials will see mw benefit
Opportunity to See a Microwave Kiln!

Participants at MAT Kiln Tour
MS&T 2008

Ceralink, Harrop and Thermex Sponsored
MAT Kiln Tour Wednesday 12:30 pm
Leaving from Registration Area