Precision Epoxy-Cast Ceramics by Conventional and Microwave Processing

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Roadmap

- Epoxy cast ceramic applications in MEMS
- Xray Lithography (LIGA process)
- Epoxy casting process
- Micropart burnout/sintering
- Epoxy casting “scale-up”

Ceramic MEMS Applications

<u>Miniature power supplies e.g. Microengines</u>

- Miniature Stirling heat engine
  at Sandia National Laboratories

- Both micro and mesoscale components

Stirling Engine Concept

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Stirling Engine Concept


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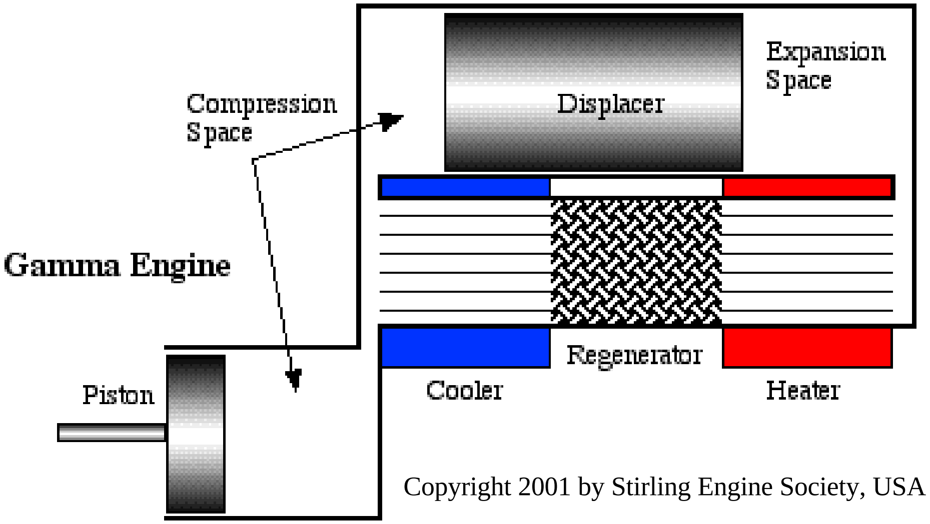

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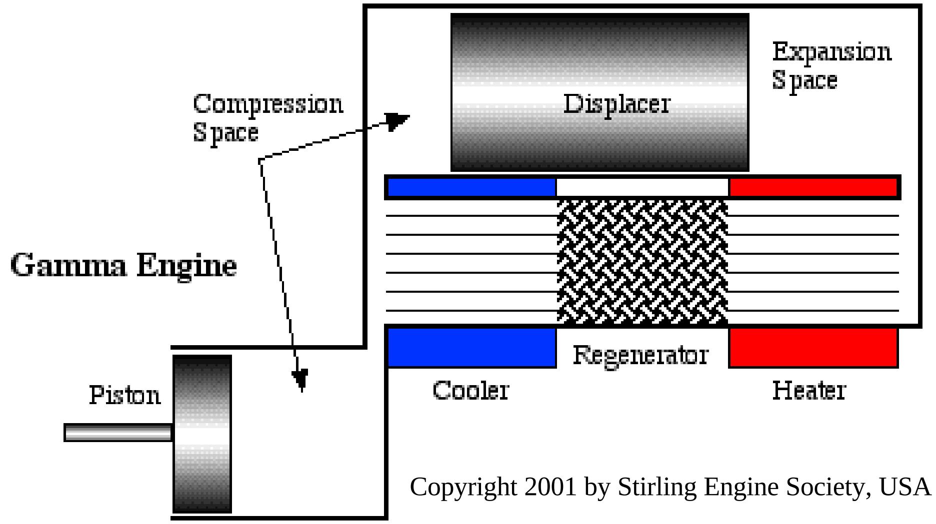

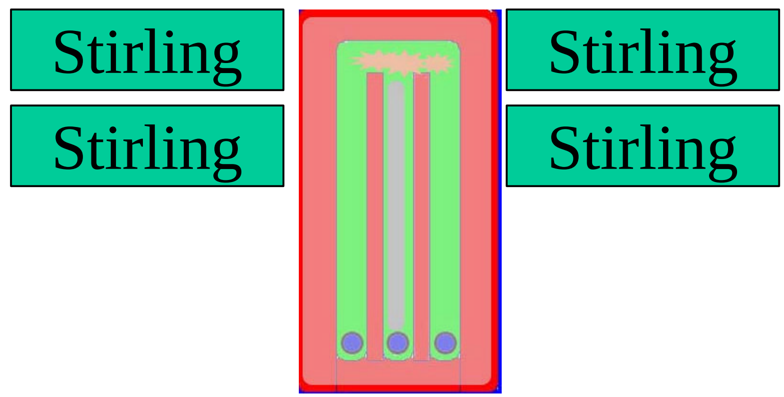

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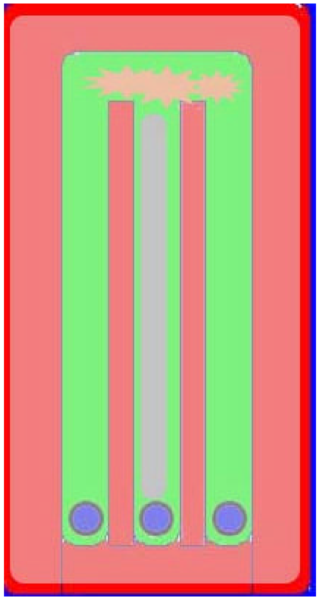
Materials selection for components

Combustor

- Thermal shock resistance
- Thermal cycling fatigue resistance
- High toughness
- CTE compatibility



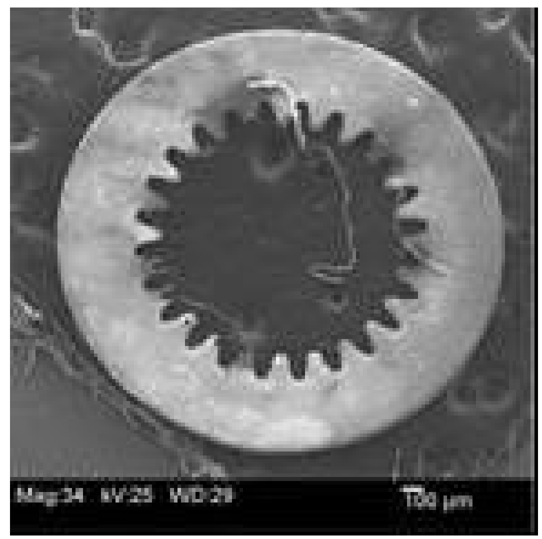
Materials selection for components

Combustor

- Thermal shock resistance
- Thermal cycling fatigue resistance
- High toughness
- CTE compatibility

Gears

- Wear resistance



Materials for this Study

- Alumina AKP-53 (Sumitomo)
  - Similar CTE as precious metal catalyst
  - Poor thermal shock resistance
- ZTA using Tosoh 3YS Zirconia
  - Improved thermal shock resistance

How LIGA Fits

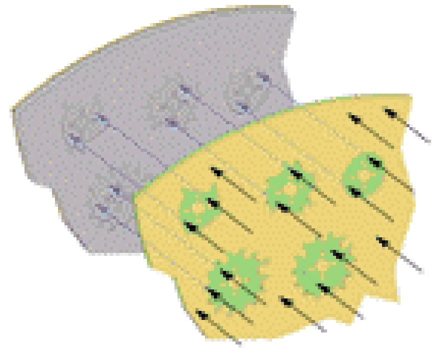
Ability to create high resolution components on the micro and mesoscale

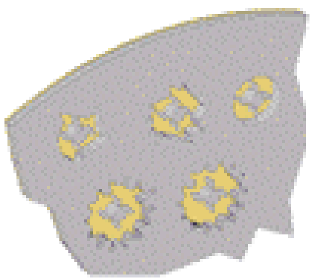
– Microparts, e.g. fine gears

– Mesoscale devices, e.g. 4 x 1 cm combustors with sub-millimeter features

LIGA Process

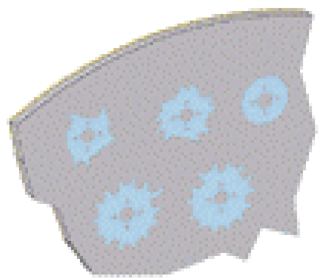
- X-rays from a synchrotron are incident on a mask patterned with high Z absorbers. X-rays are used to expose a pattern in PMMA, normally supported on a metalized substrate.

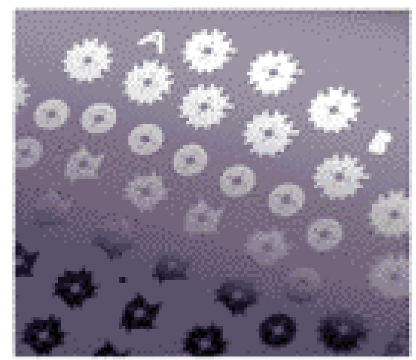




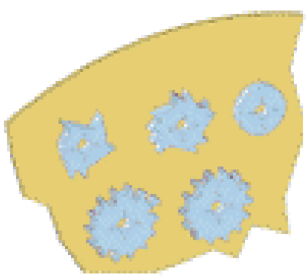
- The PMMA is chemically developed to create a high aspect ratio, parallel wall mold.

- A metal or alloy is electroplated in the PMMA mold to create a metal micropart.





photograph of chrome mask



- The PMMA is dissolved leaving a three dimensional metal micropart. Individual microparts can be separated from the base plate if desired.

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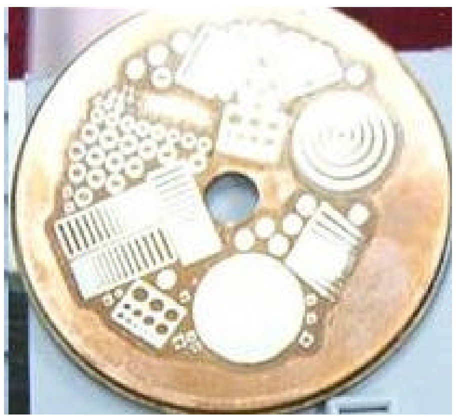
Molding Process for Mass Producing Parts

Injection molding stamp

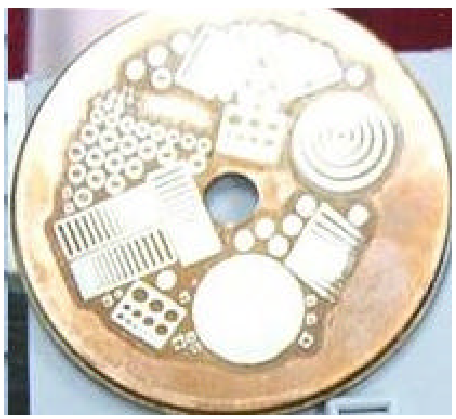


Nickel features electroplated on tool steel base

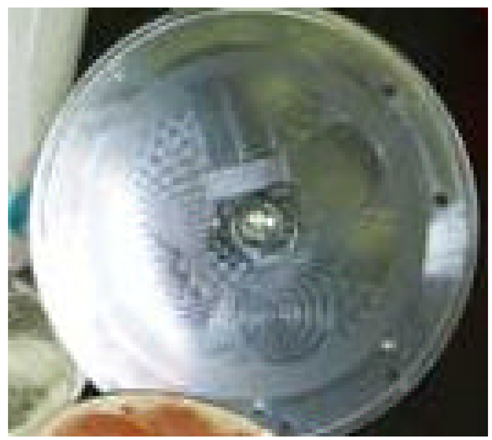
Used as master mold in injection molding process

Molding Process for Mass Producing Parts

Injection molding stamp



PMMA micromold

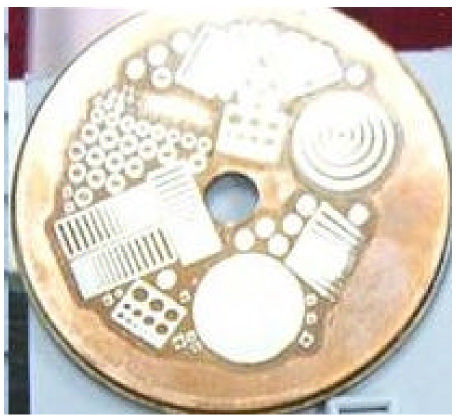


1000's of low cost
PMMA micromolds
Made from one stamp

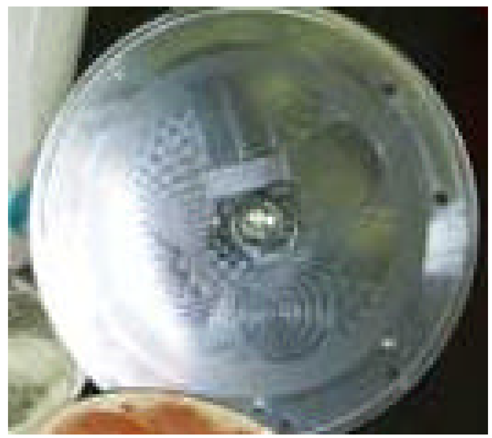
Solubility of PMMA
in acetone allows
for easy demolding

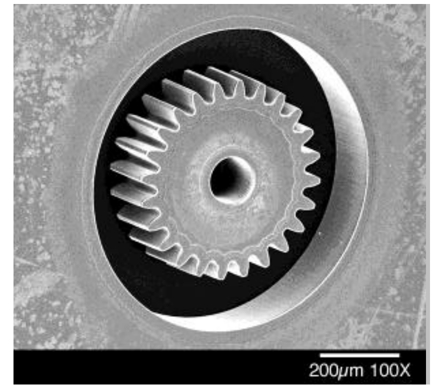
Molding Process for Mass Producing Parts

Injection molding stamp

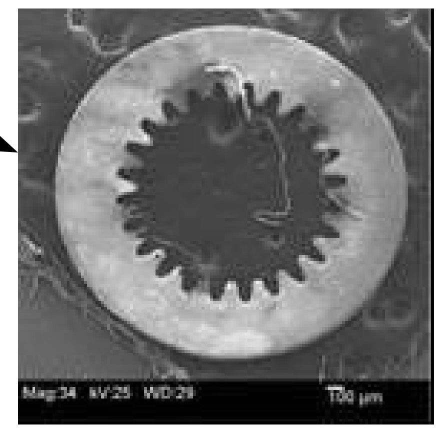


PMMA micromold





micrograph of gear mold



micrograph of MW sintered gear

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Epoxy Casting Process Steps

- Slurry prep in organic solvent
- Epoxy resin addition
- Solvent removal
- Blending with curing agent
- Casting
- Demolding - soxhlet

Debinding and Sintering

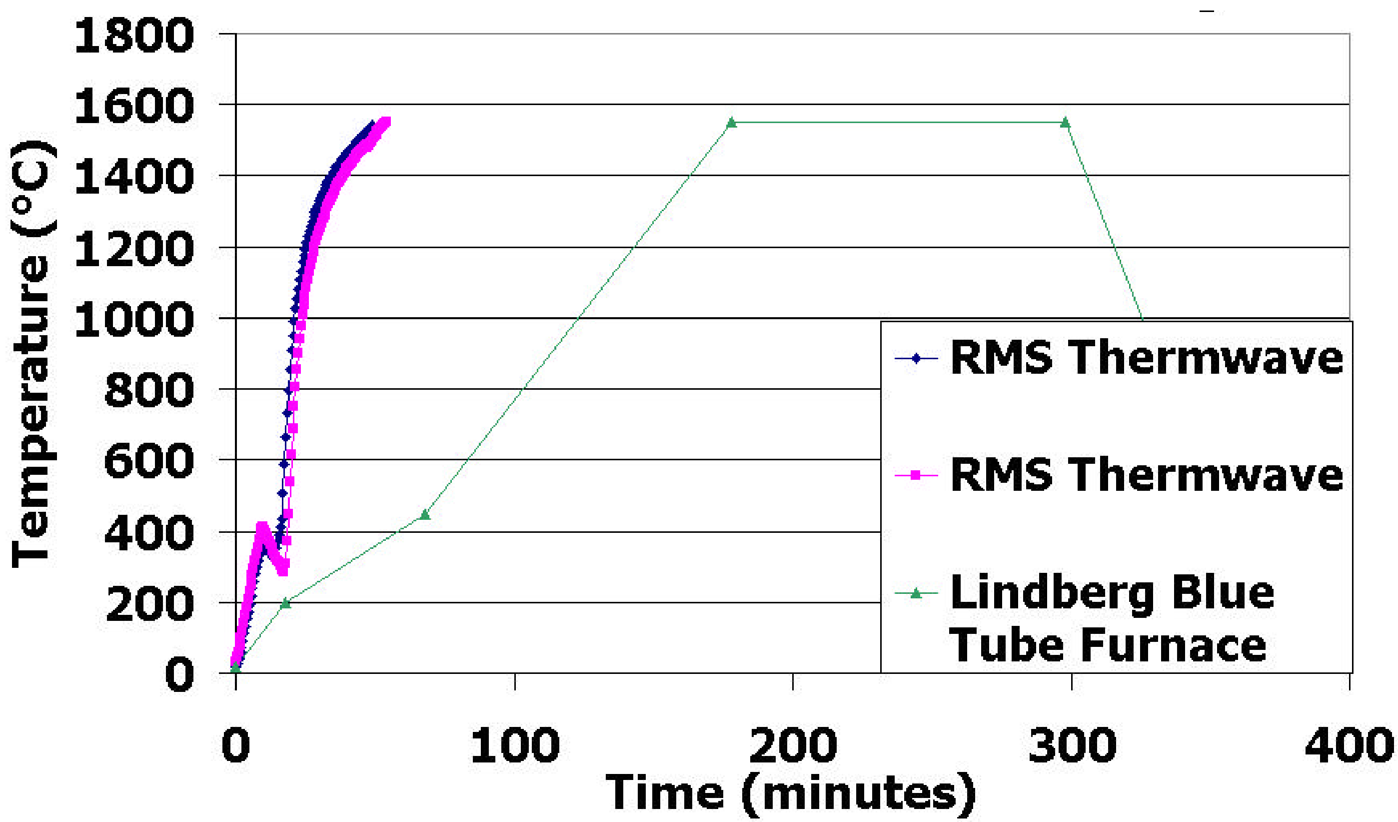
Challenges

- Thermoset binder system
- No open porosity
- High volume fraction binder

Microwave offers

- Fast materials and process development
- Fast manufacture
- Dense nanostructures

Microgears: Debinding and Sintering



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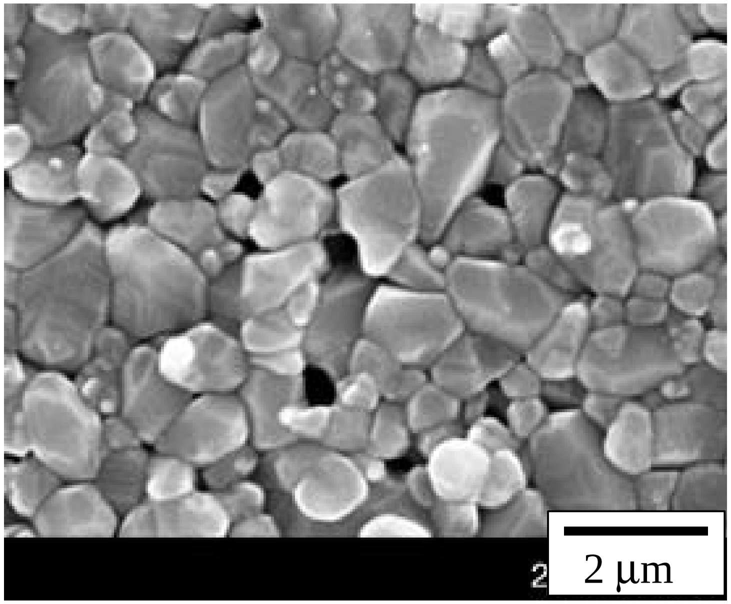
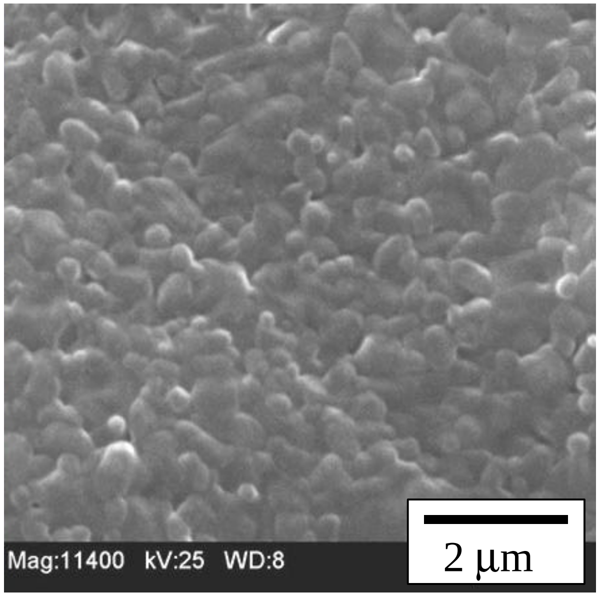
Microgears

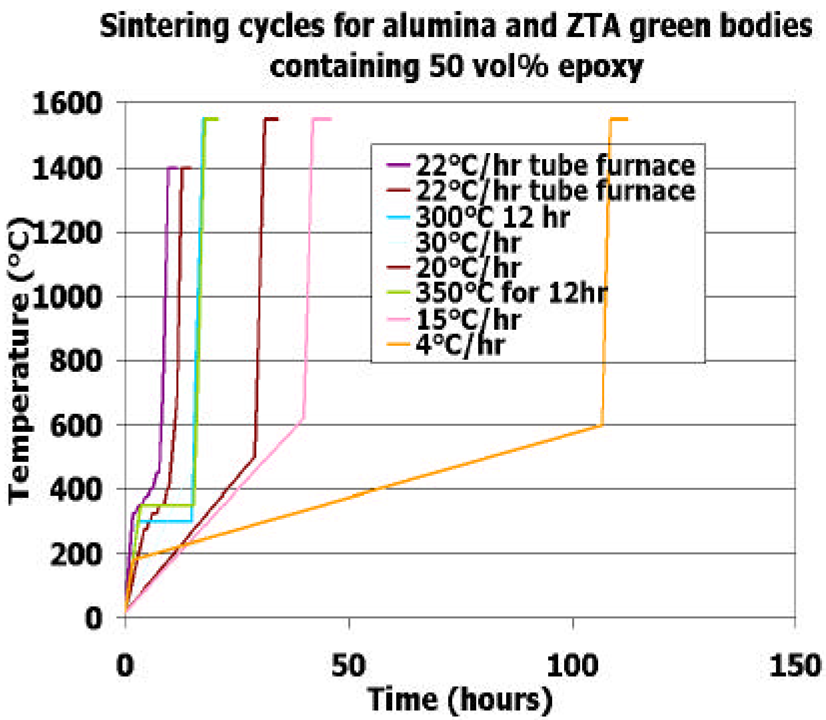


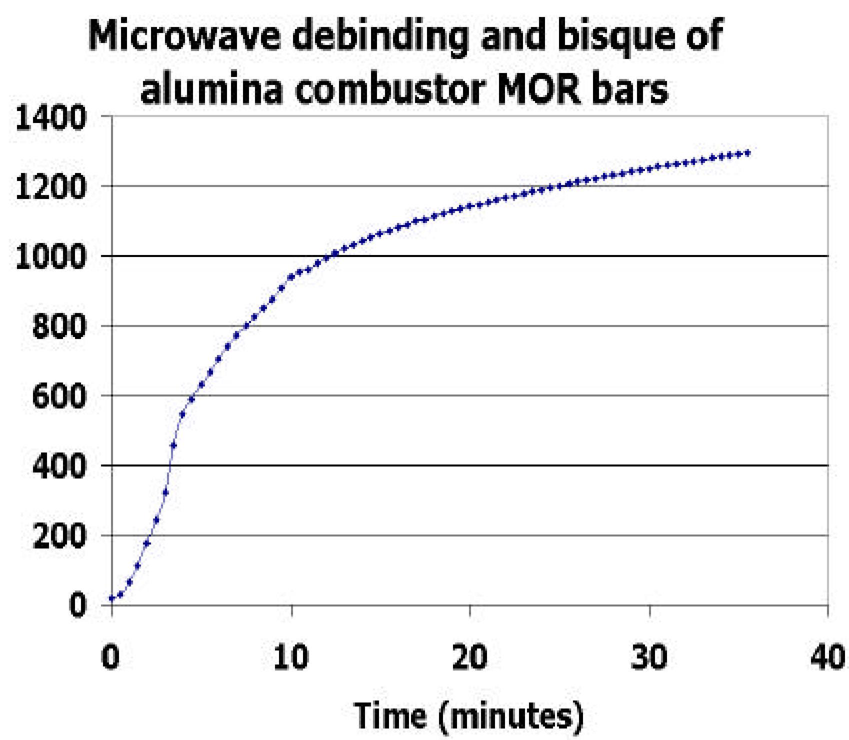
Conventional Sinter
1550°C



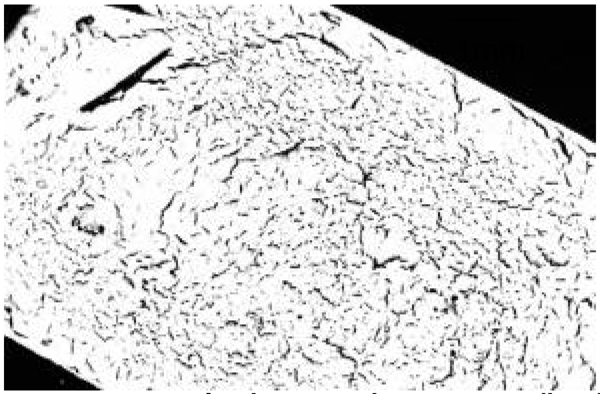
Microwave Sinter
1550°C

Combustor: Debinding and Sintering

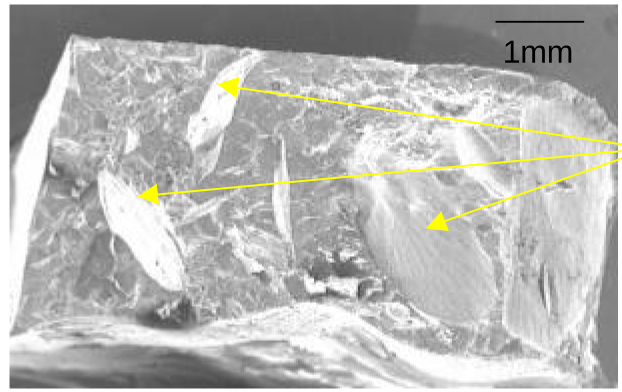




50 v% epoxy bars burned out conventionally



ZTA sample heated at 22°C/hr in tube furnace with constant air flow



Alumina fracture surface

- Conventional sintering resulted in flexural strength of only **10 MPa**
- Microwave burnout at 150°C/min improved strength to **40 MPa**

Conclusions

LIGA + epoxy → ceramic microcomponents for miniature power supply

Microwave → fast, tiny, high value parts
→ nanograin structures

LIGA + epoxy feasible for mesoscale components with adjusted composition

Microwave rapid binder burnout may offer best solution

Thank You!

QUESTIONS??