Technology for Producing Small Holes in Advanced Materials

Stephen D. Nunn
Oak Ridge National Laboratory
May 22, 2003

Project Overview

- Industry roadmap identified needs for fuel injectors
  - Smaller spray holes
  - Variable orifice geometry
  - Improved durability
- Project success will result in improved fuel economy and reduced emissions
- Initiated in March 2002; expected completion in FY2005

Objectives

- Demonstrate feasibility of producing holes 50μm or smaller in ceramic and cermet materials
  - High strength
  - High temperature capability
  - Erosion and corrosion resistant
- Explore methods to fabricate precision arrays of fine holes
- Fabricate fuel injector nozzle shapes with fine holes

Technical Approach

- Produce holes *in situ* - no drilling or EDM
- Use metal inserts and capillary forces to produce voids in powder compacts of cermet material
- Gelcast ceramic material around removable wire inserts or fugitive pore formers
- Use thermal plastic coextrusion to form complex arrays of holes in ceramic material

Technical Accomplishment Summary

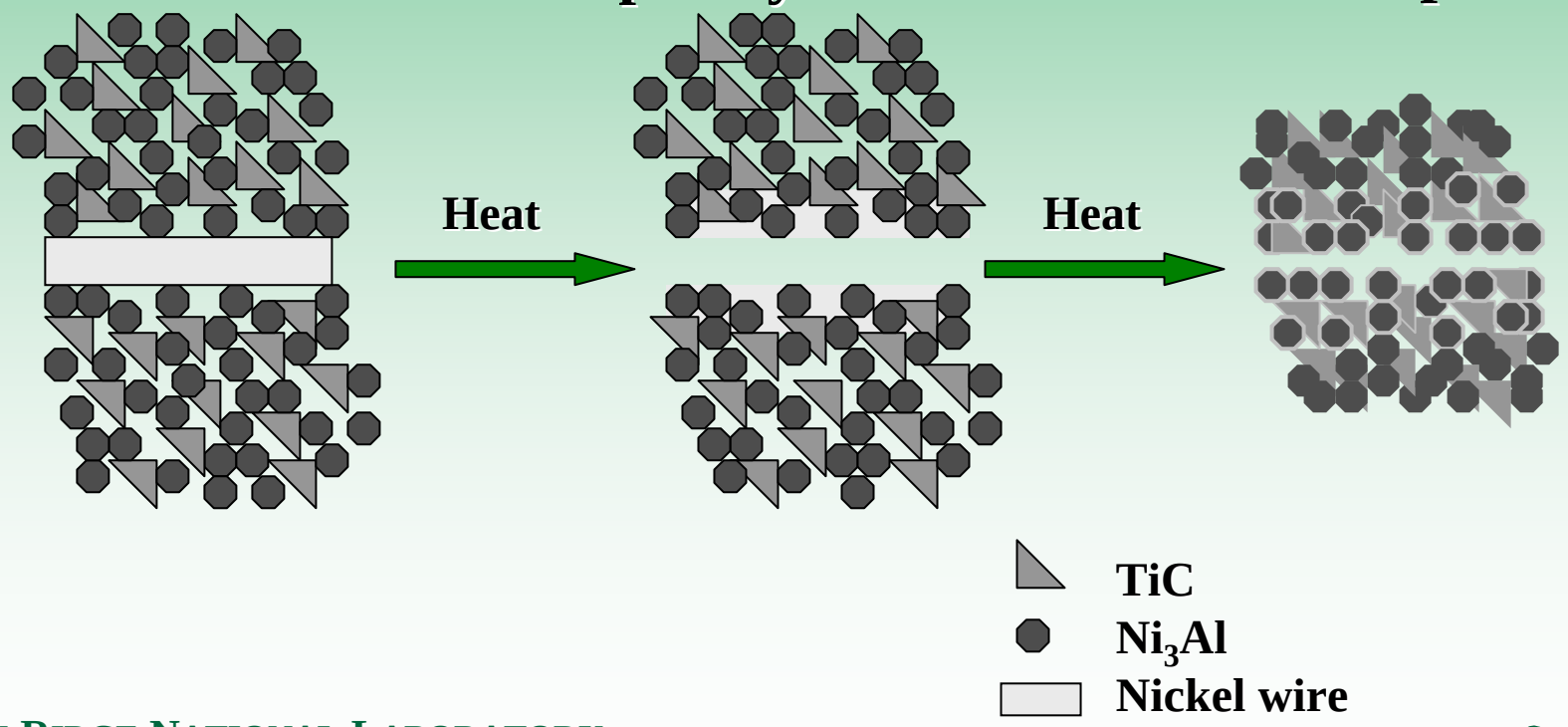
- Demonstrated 30μm hole formation in TiC/Ni_3Al cermet material
- Demonstrated 30μm hole formation in Al_2O_3 and ZrO_2 ceramic materials
- Produced arrays of holes in gelcast ceramic
- Fabricated injector nozzle shapes by gelcasting
- Produced arrays of holes in coextruded ceramic

Forming Holes in Cermets

Powder compact with embedded Ni wire

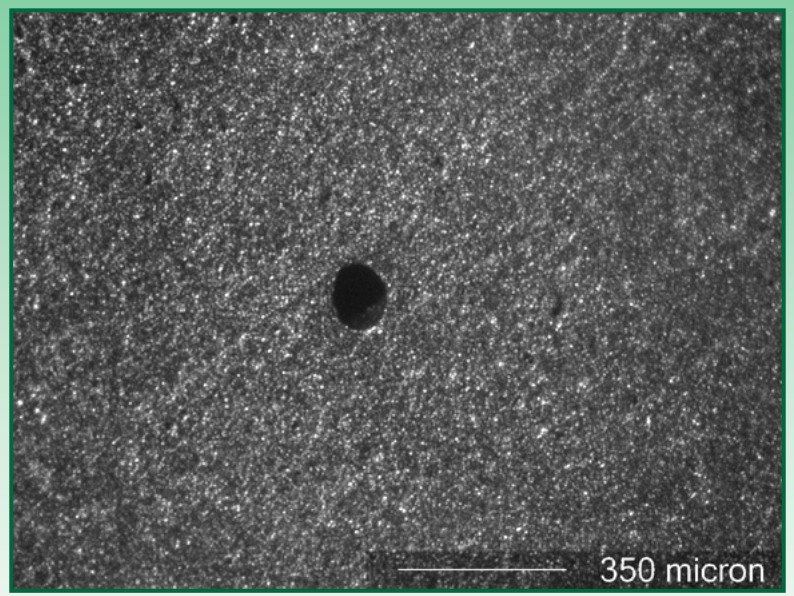
Melted wire drawn into powder by capillary action

Compact sinters while reaction layer forms on particles

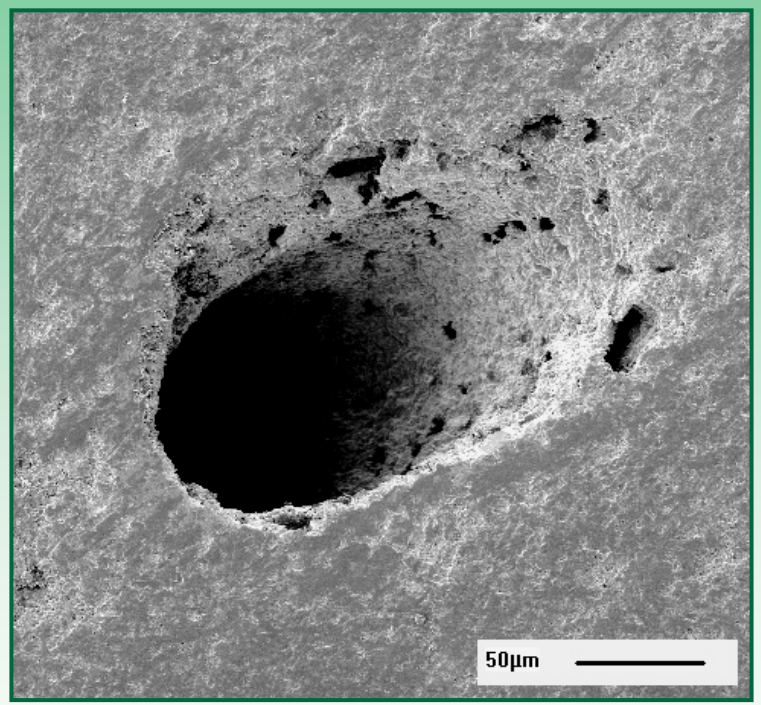


Forming Holes in Cermets

Holes in TiC / Ni_3Al Cermet



Optical micrograph



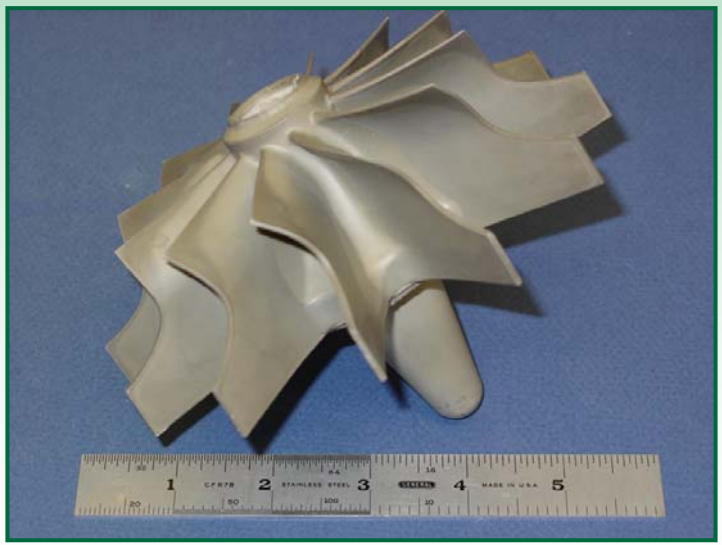
SEM micrograph

Forming Holes in Gelcast Ceramics

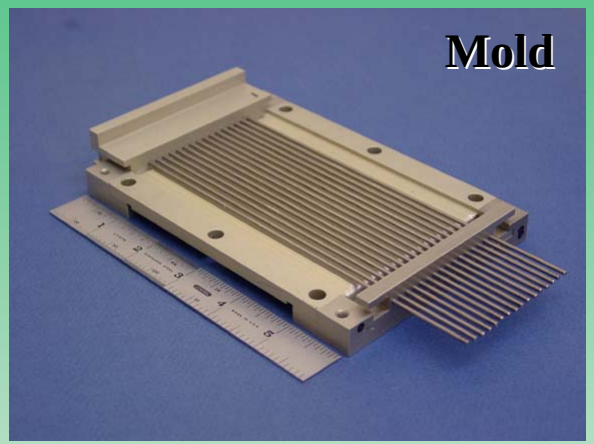
Gelcasting: complex shape forming process that eliminates most machining

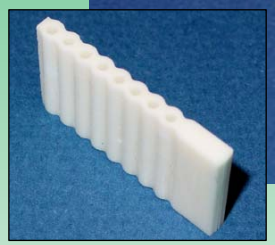
Ceramic slurry is cast in a mold and gelled

Dried part is heated to sinter to high density



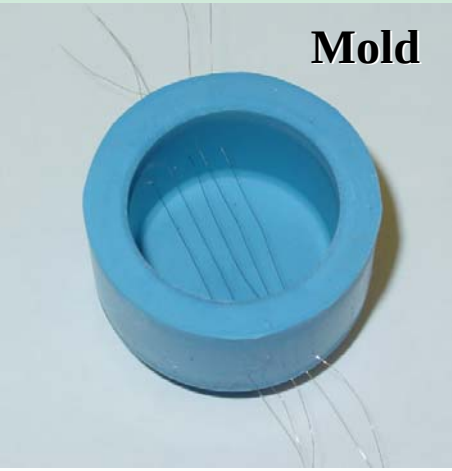
Forming Holes in Gelcast Ceramics





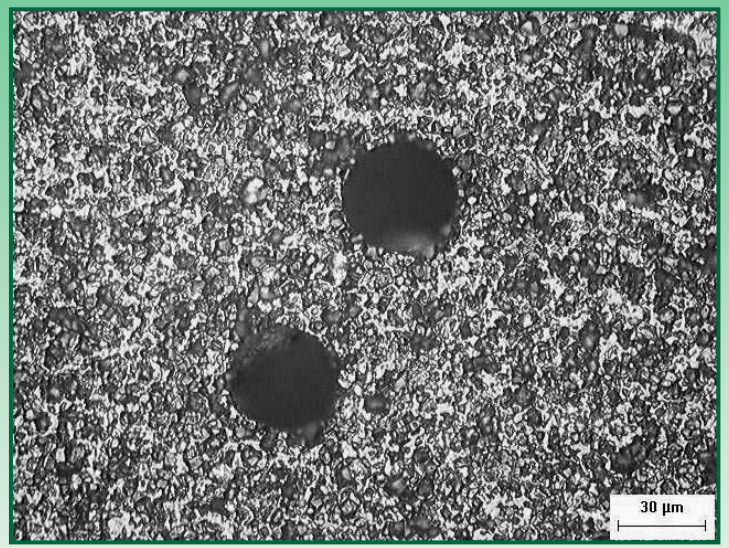
Using removable rods to form long holes in a ceramic plate

Small wires or fibers can be used to make fine holes in gelcast ceramics

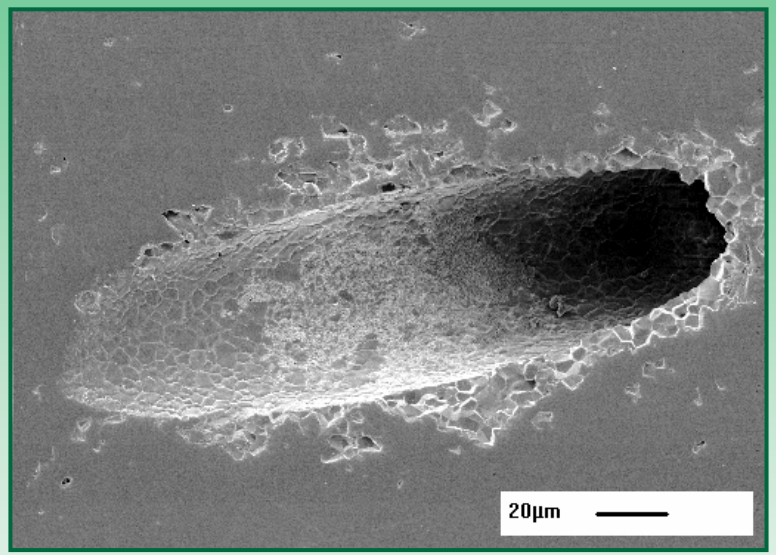


Forming Holes in Gelcast Ceramics

Holes in sintered Al_2O_3



Optical micrograph

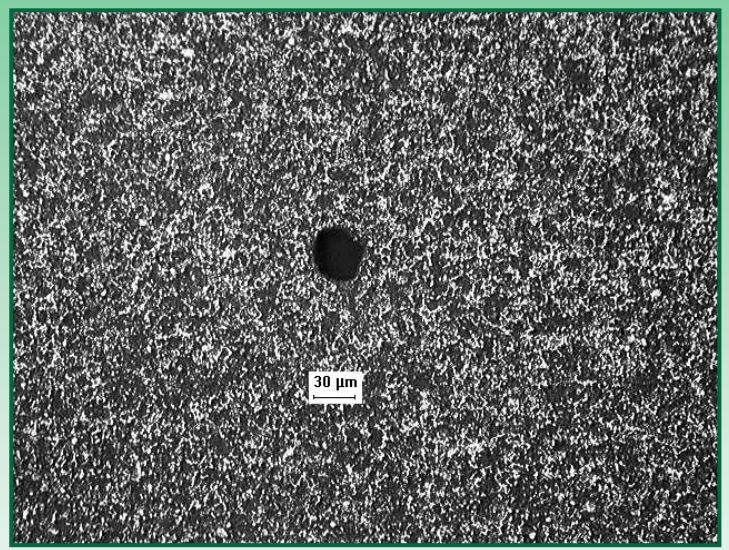


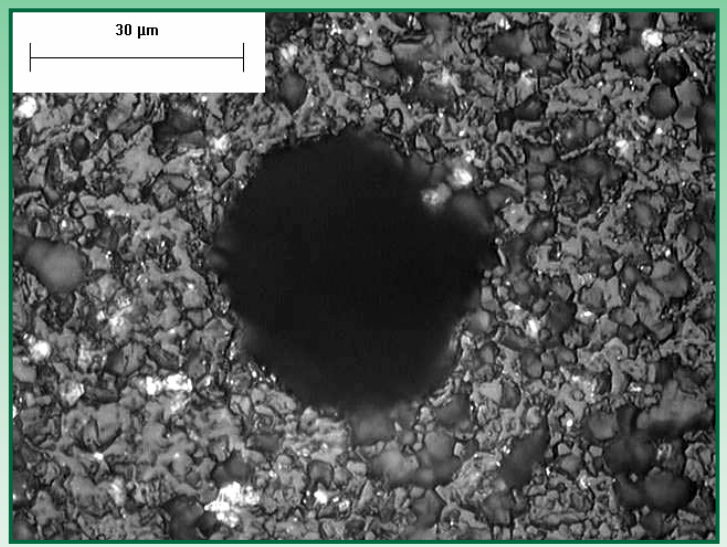
SEM micrograph

The gelcasting slurry contained organic fibers which were burned out during the sintering process. Holes over 20mm long were formed using this method.

Forming Holes in Gelcast Ceramics

Holes in sintered Al_2O_3



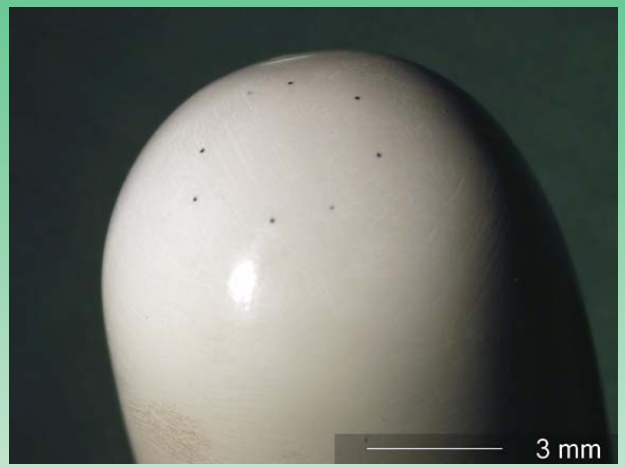


The alumina slurry was gelcast around embedded wires which were removed prior to sintering.

Gelcast Nozzle Shapes

Crude nozzle casting with wires

After hand shaping

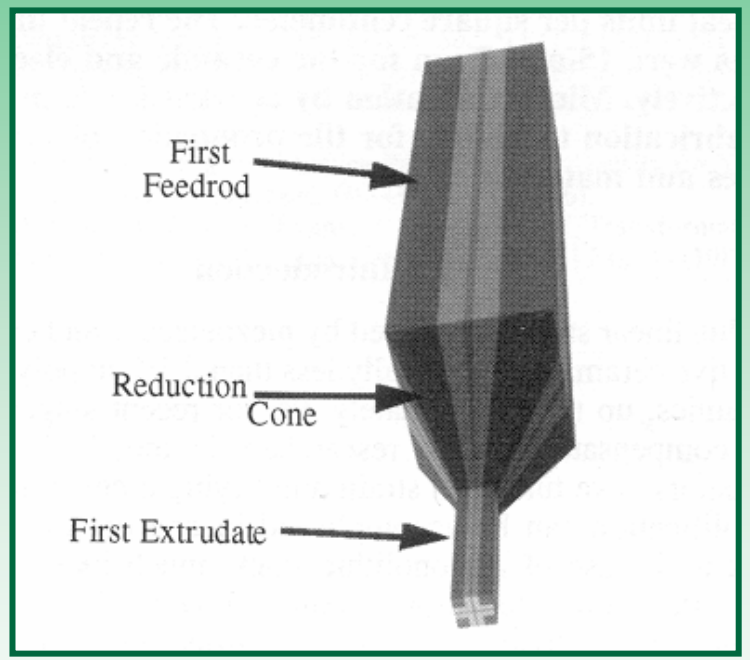


Gelcast nozzle tip with embedded wires

Gelcast ceramic nozzle shape after sintering (shown with steel nozzle)

Thermal Plastic Coextrusion

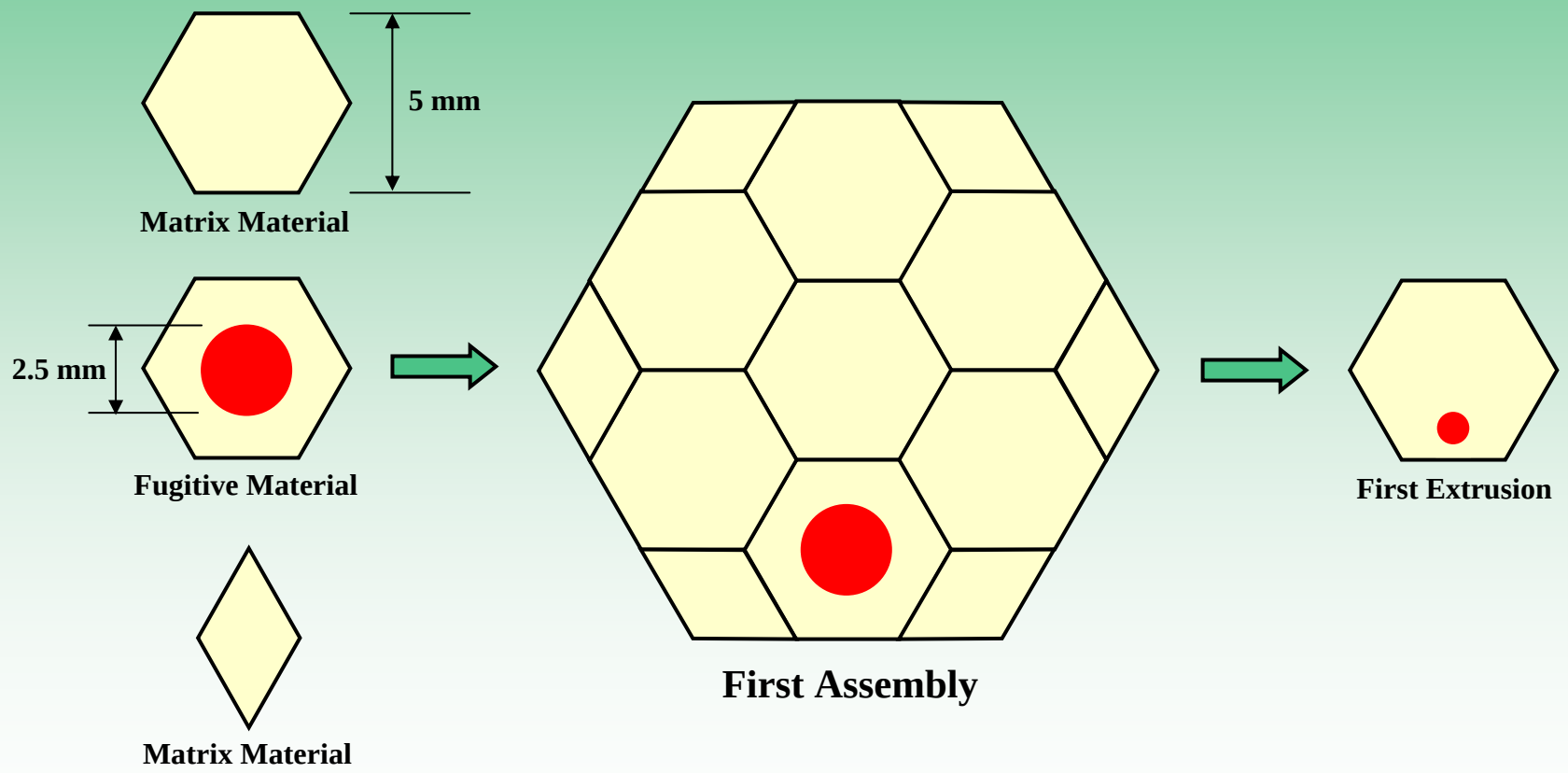
- Powder in thermal plastic resin (ceramic, metal, carbon, etc.)
- Formulated to have uniform flow properties
- Segments assembled to form a complex pattern
- Extruded under pressure and heat to reduce the cross-section



Crumm and Halloran, *J. Am. Ceram. Soc.*, **81** [4] 1053-57 (1998).

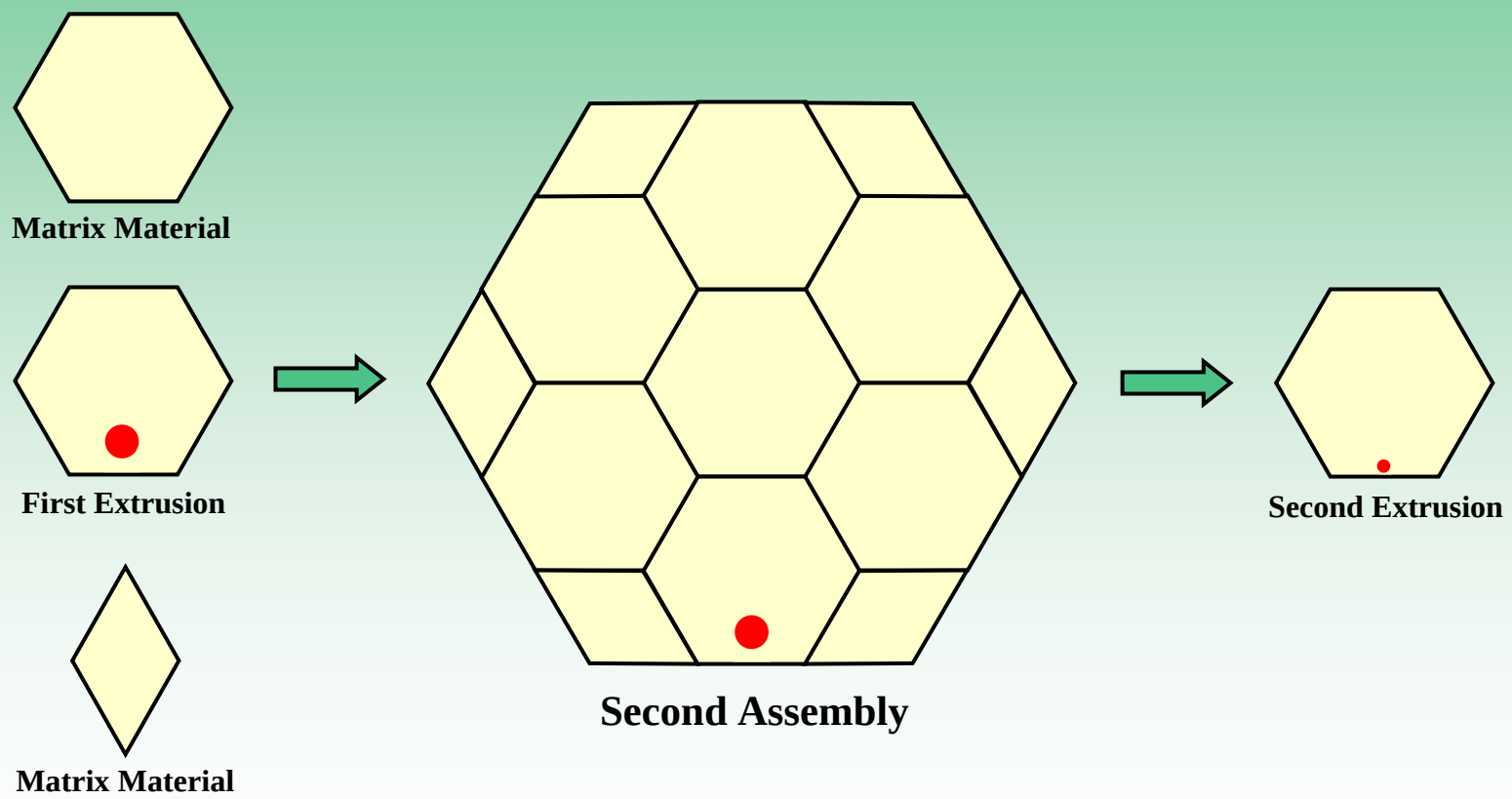
Coextrusion Forming

3 components are assembled to form the hexagonal feed rod.



Coextrusion Forming

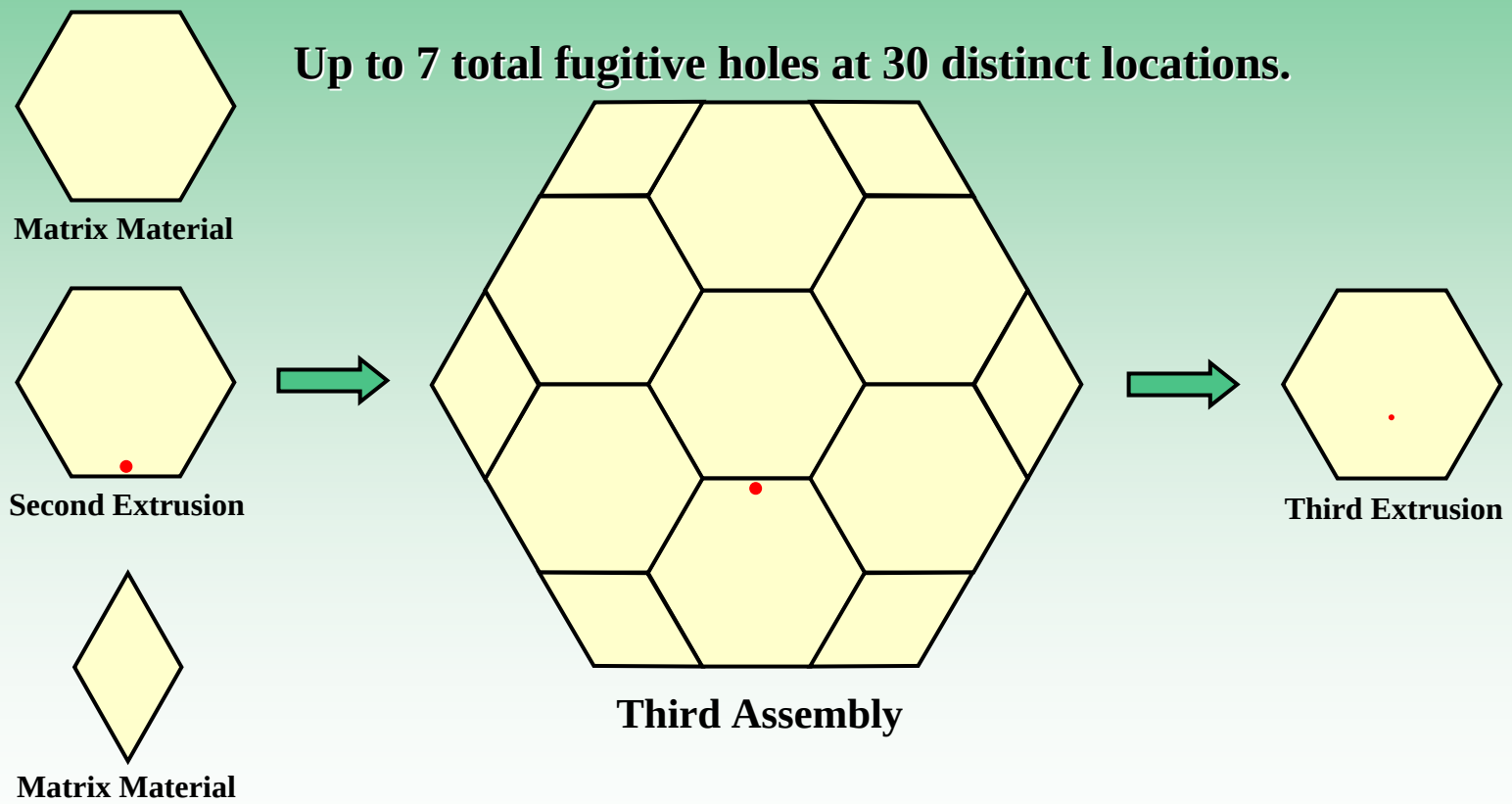
3:1 reduction allows repeated assembly of feed rod.



Coextrusion Forming

For the third extrusion, the pore former is moved to an internal location.

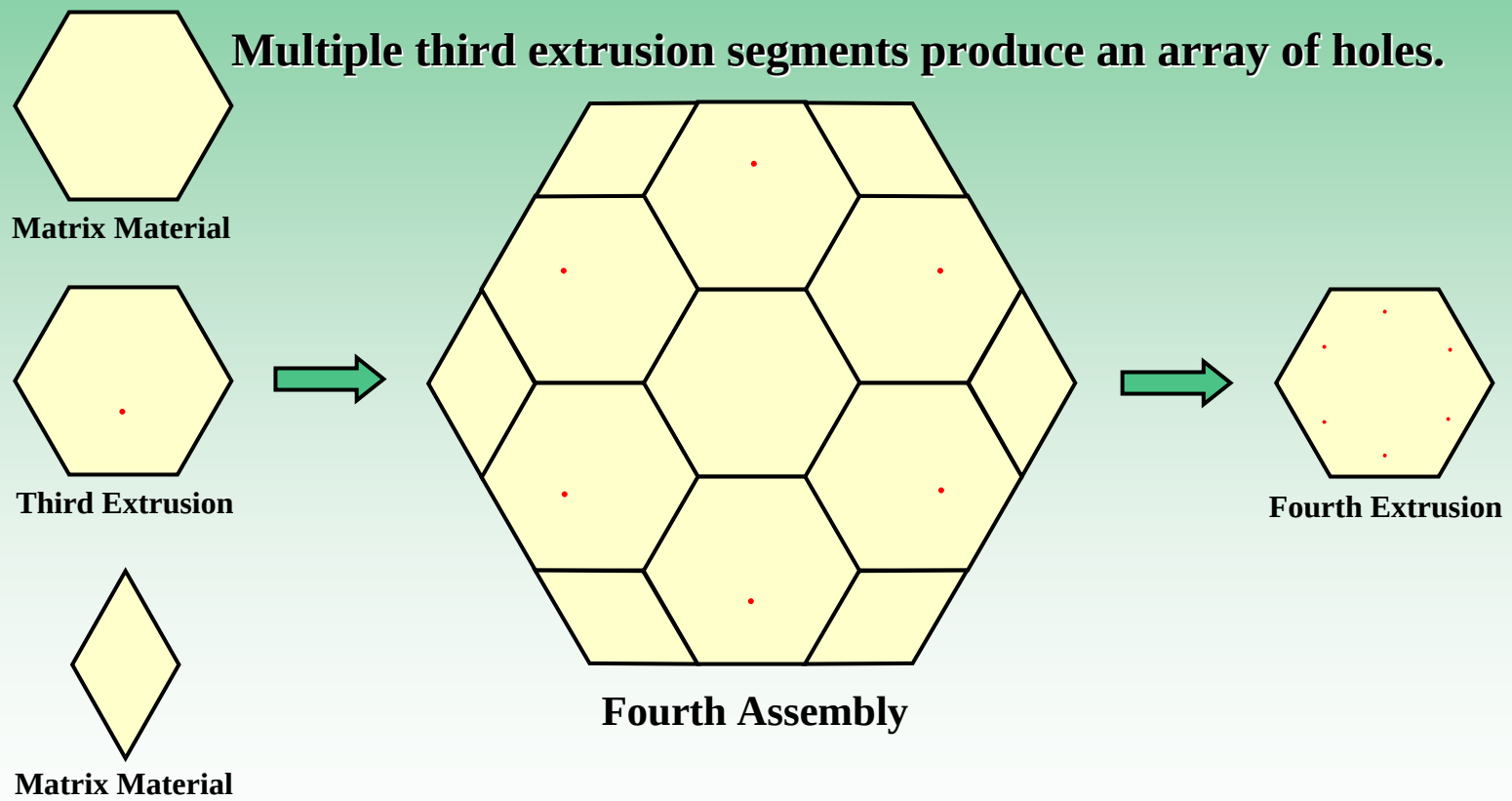
Up to 7 total fugitive holes at 30 distinct locations.



Coextrusion Forming

Final extrusion: Four 3:1 reductions take fugitive core from 2.5mm to 31μm.

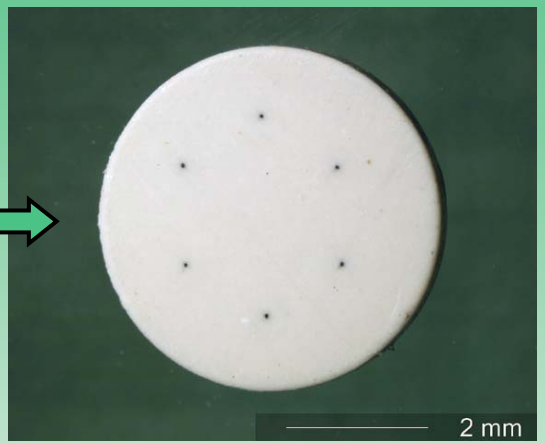
Multiple third extrusion segments produce an array of holes.



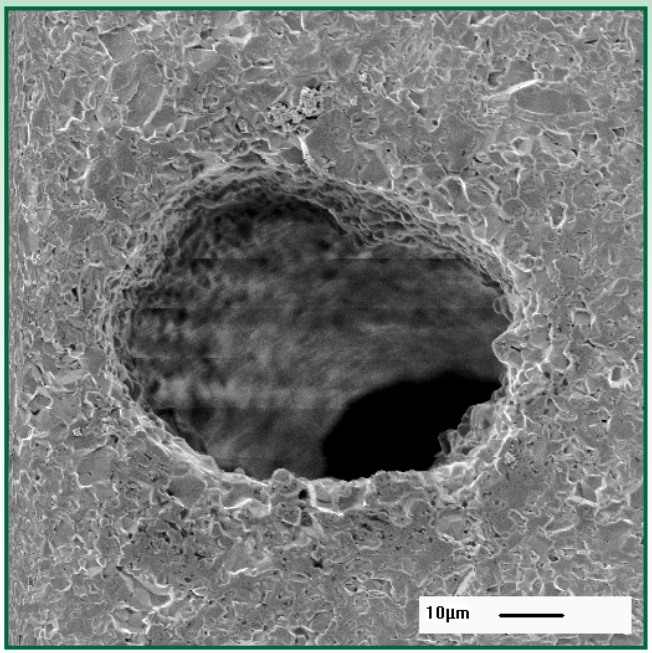
Coextrusion Products

Extruded alumina rods with carbon-filled hole pattern - 5mm x 50mm

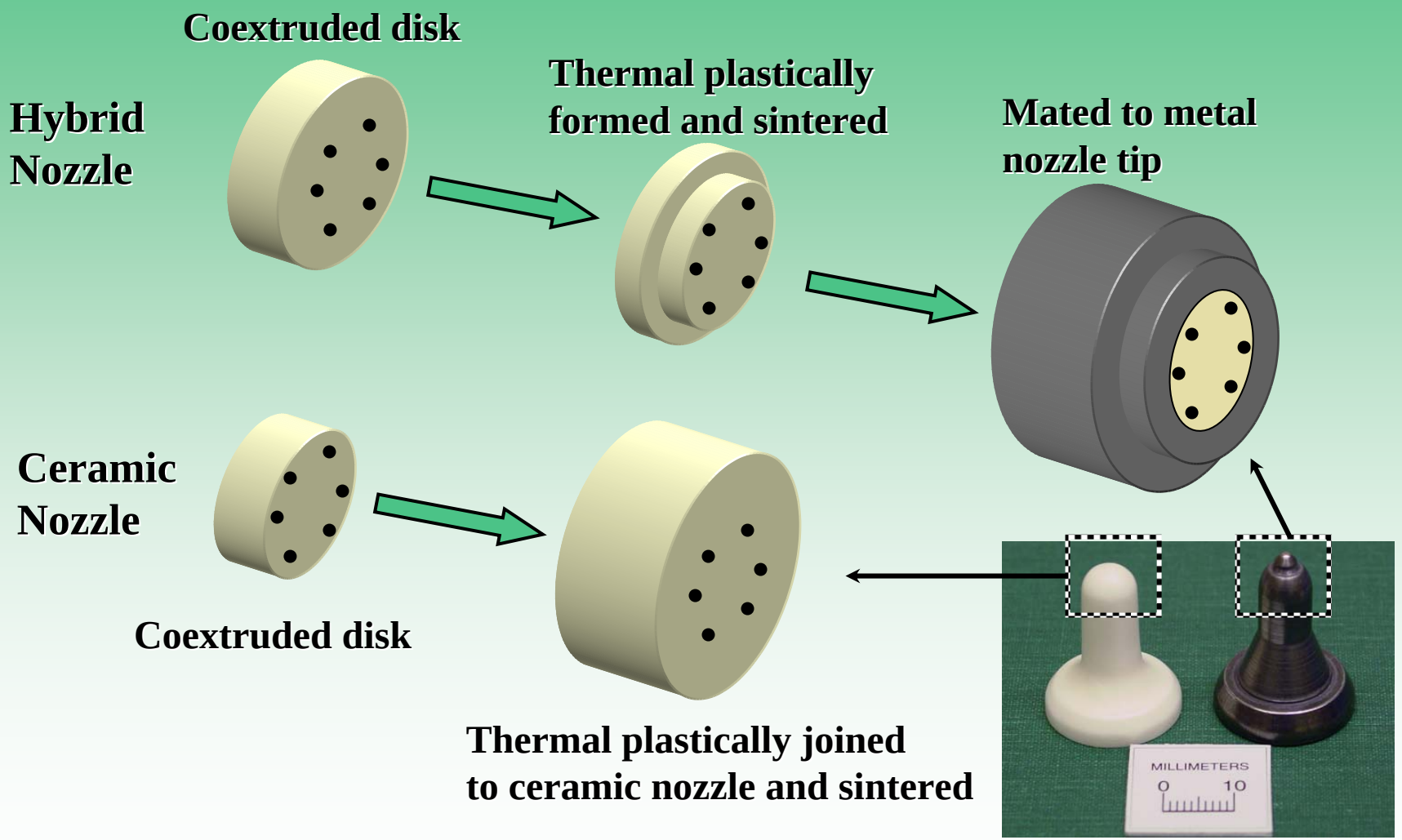
Cross-section of extruded alumina rod - 5mm diam.



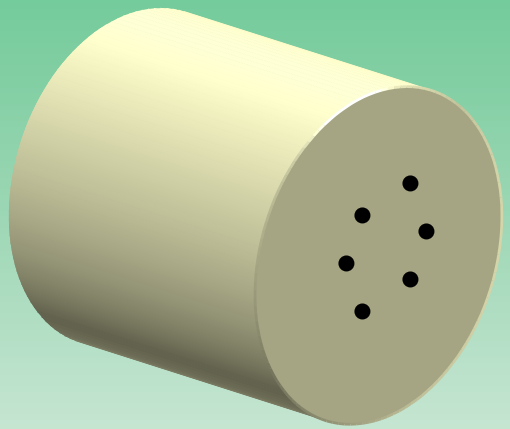
SEM micrograph of hole after carbon burn-out



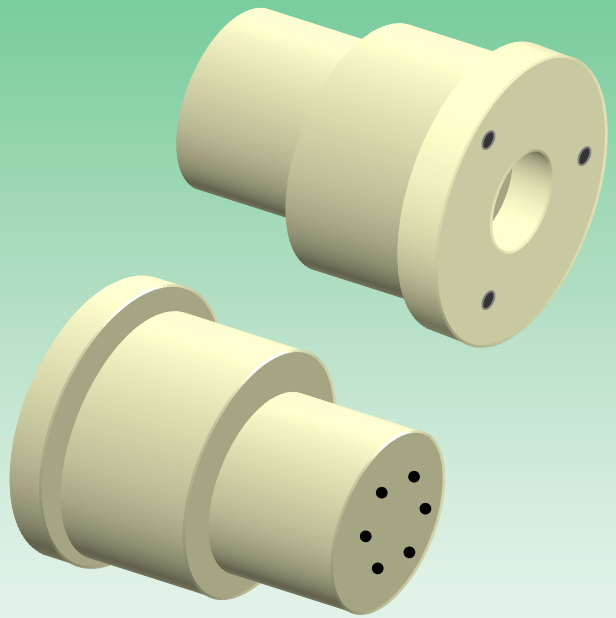
Coextruded Nozzle Assembly



Monolithic Coextruded Nozzle

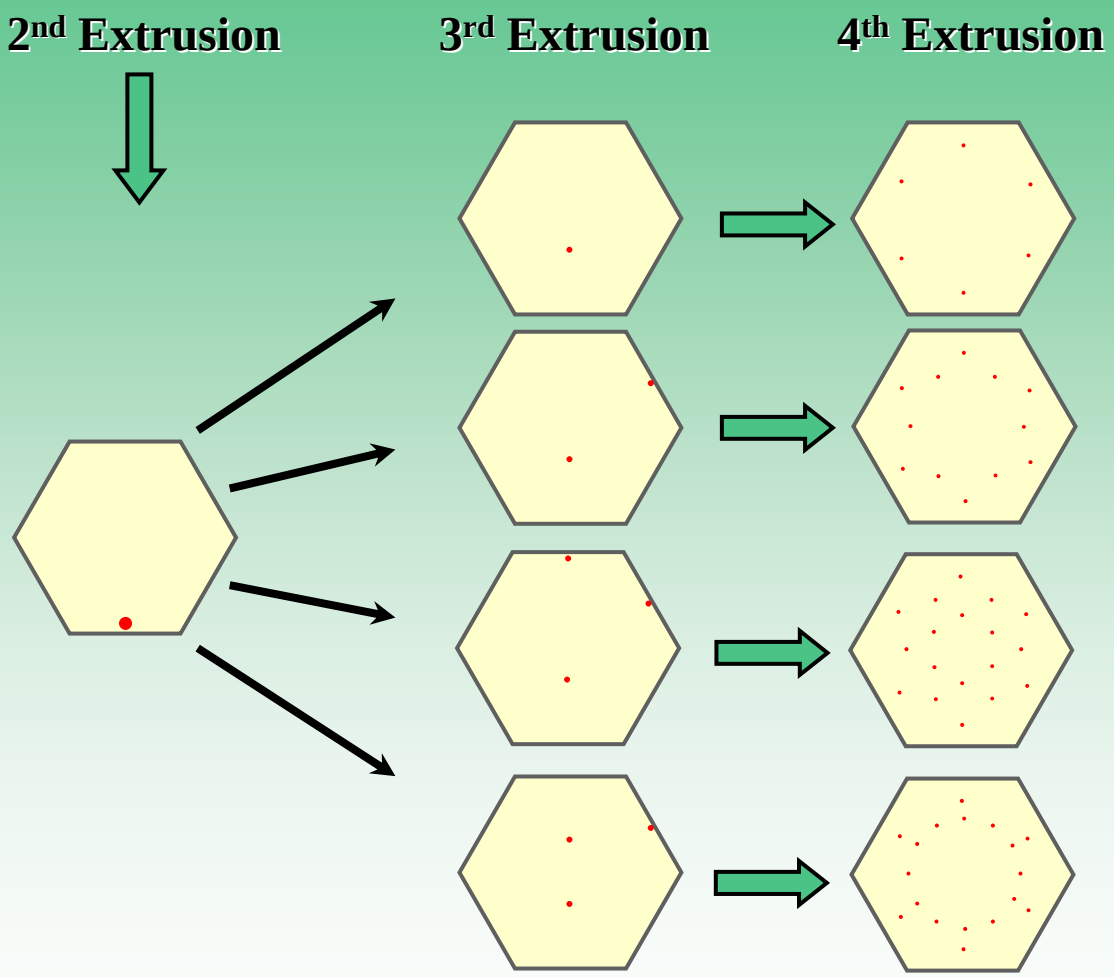


Coextruded cylinder



Green machine to final shape and sinter to full density

Hole Pattern Geometry

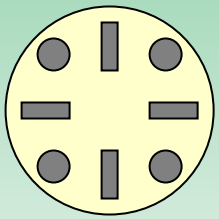


- A nearly infinite variety of hole patterns is possible
- Up to 7^4 = 2,401 total holes after 4 extrusions

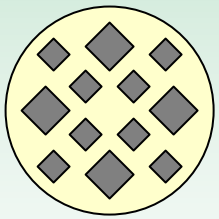
Hole Shapes and Sizes

- Holes can be of any arbitrary shape

- Hole shapes can be mixed in a single nozzle tip



- Hole sizes can be varied in a single nozzle tip



Coextrusion Summary

- Utilizes many different materials: ceramics and powder metals
- Coextruded material can be thermal plastically shaped and machined
- Complex hole arrays can be produced
- A very large number of holes is possible
- The hole size and shape can be varied

Project Summary

- Demonstrated 30μm hole formation in TiC/Ni_3Al cermet material
- Demonstrated 30μm hole formation in Al_2O_3 and ZrO_2 ceramic materials
- Produced arrays of holes in gelcast ceramic
- Fabricated injector nozzle shapes by gelcasting
- Produced arrays of holes in coextruded ceramic

Plans for Future Work

- Design and fabricate precision gelcasting molds
- Produce ceramic fuel injector nozzles by gelcasting
- Demonstrate thermal plastic shaping of coextruded disk inserts
- Evaluate joining methods for fabricating hybrid fuel injector nozzles
- Evaluate thermal plastic joining and shaping of ceramic fuel injector nozzles
- Study green machining of complex shapes from coextruded stock