Sandia Brazing Research and Modeling Capabilities*

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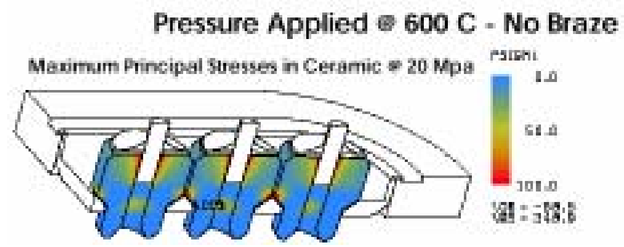
Brazing is widely used to join metals and ceramics to each other for a variety of high reliability components

- **headers**
- **connectors**
- **feedthroughs**
- **thermal batteries**
- **high voltage tubes**
- **electromechanical devices**
- **storage containers**



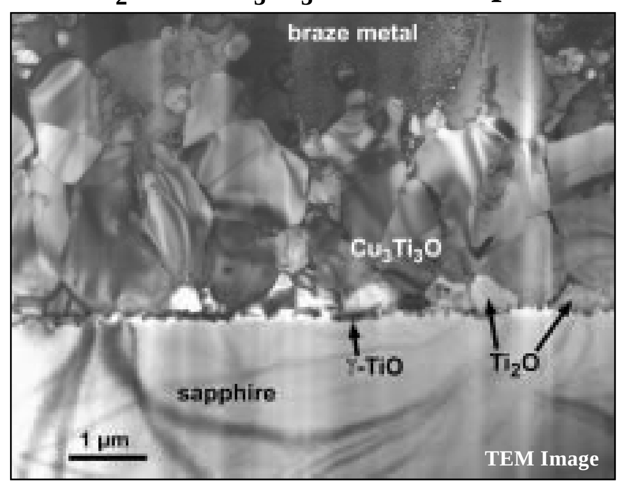
New active brazing alloys simplify hermetic joining issues

Basis: **Oxide-forming additives to filler metal (e.g., V, Ti, Zr, Hf) promote direct wetting and adhesion to the ceramic materials (Al_2O_3, Si_3N_4, cermet, …)**

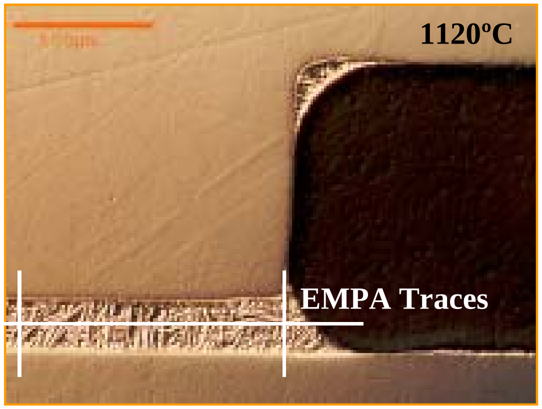
Payoff: **Eliminate complex Mo-Mn metallize / Ni-plate & related processing for conventional alloys**

Issue: **Complex reactions between active braze elements and ceramic/metal base materials need to be understood to control and optimize process**

TiO, Ti_2O & Cu_3Ti_3O reaction products

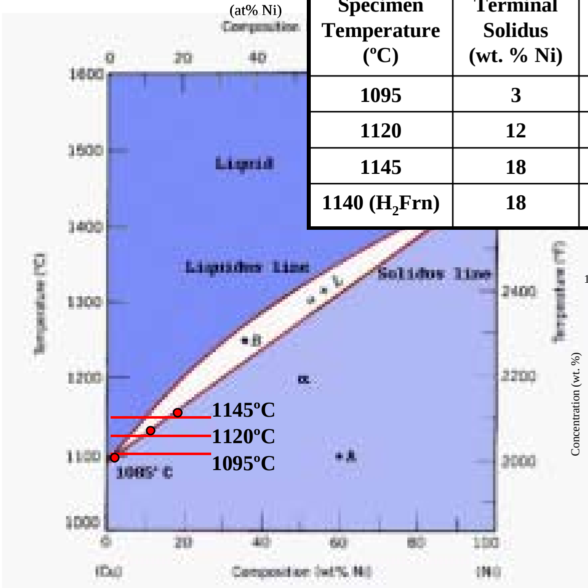


Braze flow visualization and dissolution reactions are important components in understanding the braze process

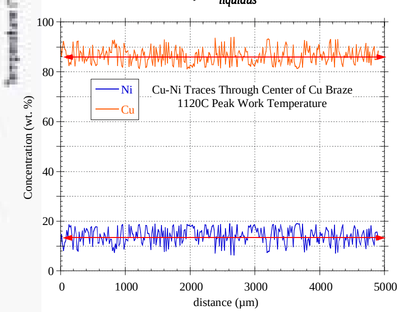


Cu-Ni binary braze flow & dissolution experiments

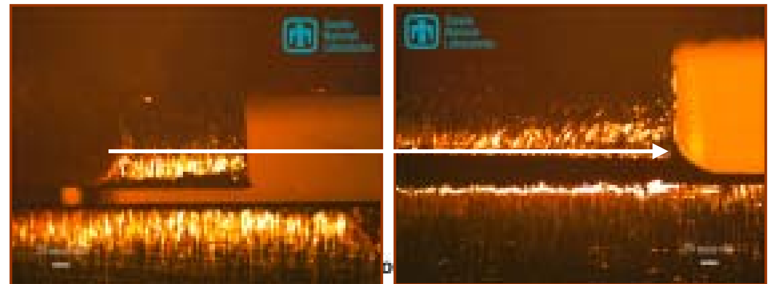
Specimen Temperature (°C)	Terminal Solidus (wt. % Ni)	EMPA Ni Content (wt. %)	Joint Thickness (μm)	Resident Time Above 1085°C
1095	3	6	175	0.5
1120	12	14	195	1.5
1145	18	20	210	3
1140 (H_2Frn)	18	10	190	660

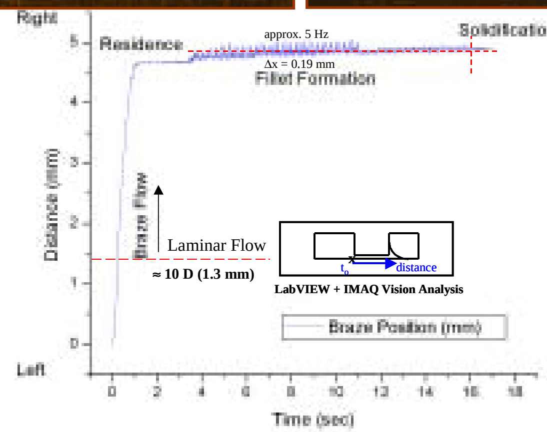


Note: At 1145°C, $C_{liquidus}$ ~ 10 wt. % Ni



Braze Capillary Flow Visualization



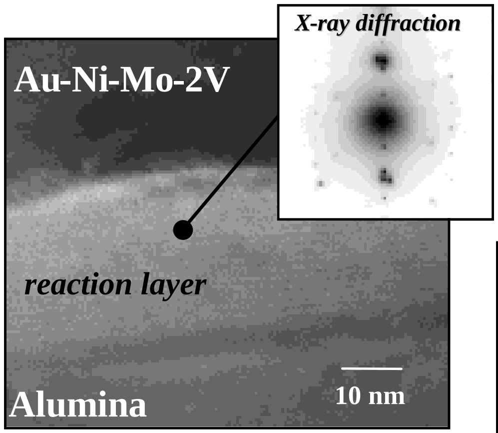


Recent Accomplishments

- Conference paper / presentations (IBSC'03; CSM Materials Science Seminar; C6 ASCI Solidification Working Group)
- *S&T of Welding & Joining* journal paper
- In-Situ Visualization of Braze Flow patent

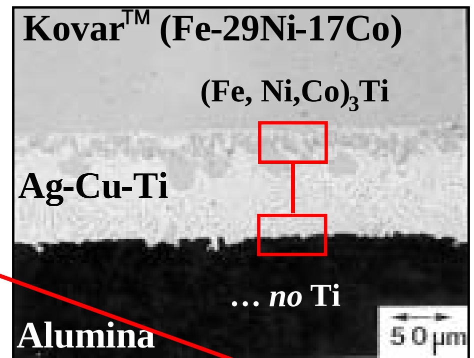
Active brazing technology is bridging a wide range of needs because of the fundamental knowledge being developed

Alumina ceramic / braze interface reactions vary significantly with active element



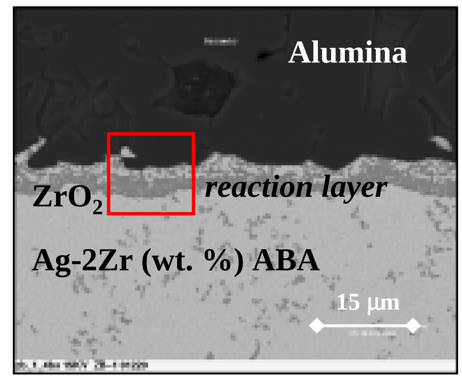
V activation

Competing reactions between dissimilar base materials can introduce unwanted results

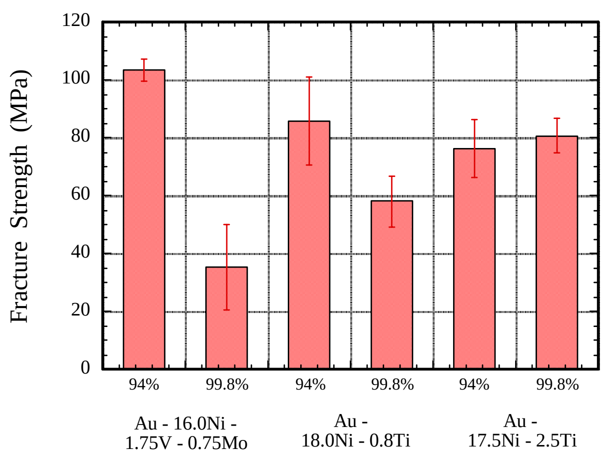


Ti activation

… compatibility issues



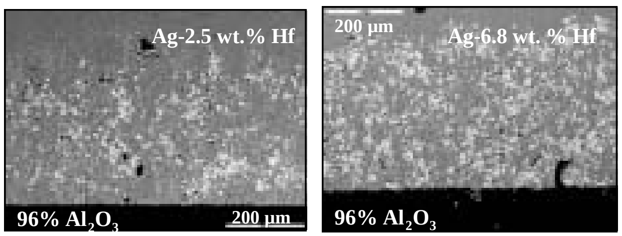
Zr activation

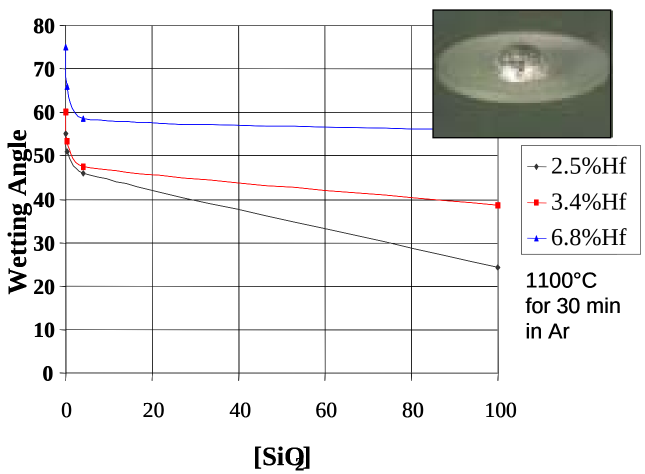


Fracture strengths for 94 & 99.8% alumina brazed with Ti & V-bearing Au-Ni filler metals exhibit dependency on glassy phase and more stable TiO_x reaction product

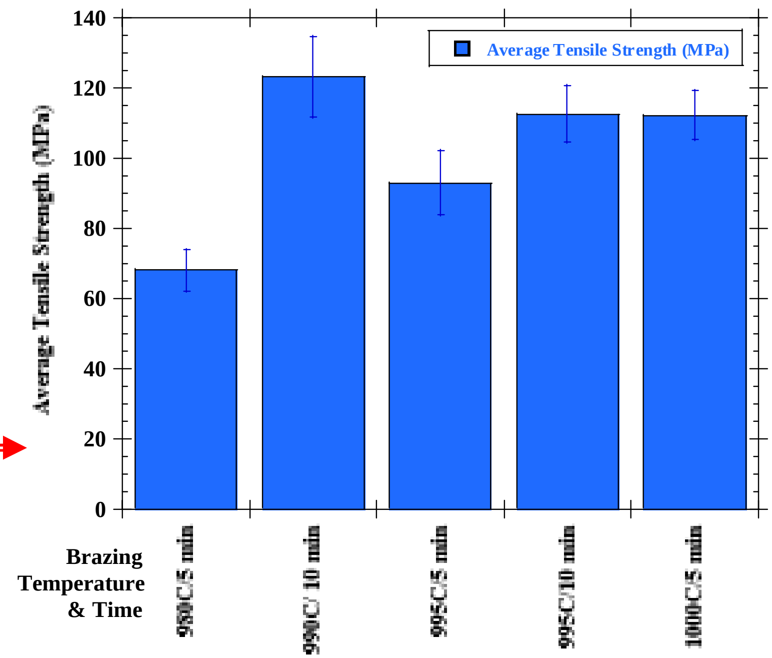
A multidisciplinary approach to characterizing the different brazing reactions and properties is necessary for success

Determining effects of reaction products & microstructures on properties (hermeticity & strength) as a function of active element (thermodynamics / kinetics), base material (adhesion / dissolution), brazing conditions (temperature, time, atmosphere, heating cycle & gradients, orientation), surface preparation (ceramic air-firing).

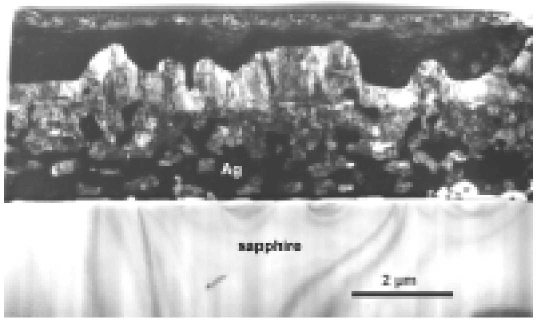




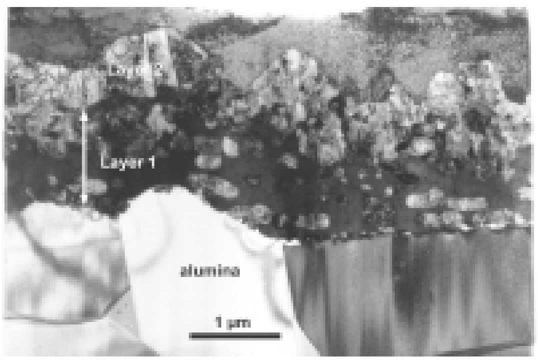
Al-500 alumina brazed with Ag-3.4Hf & 0.25 mm Kovar™



Ability to correlate braze interface reactions with desired properties will yield more producible & reliable joints

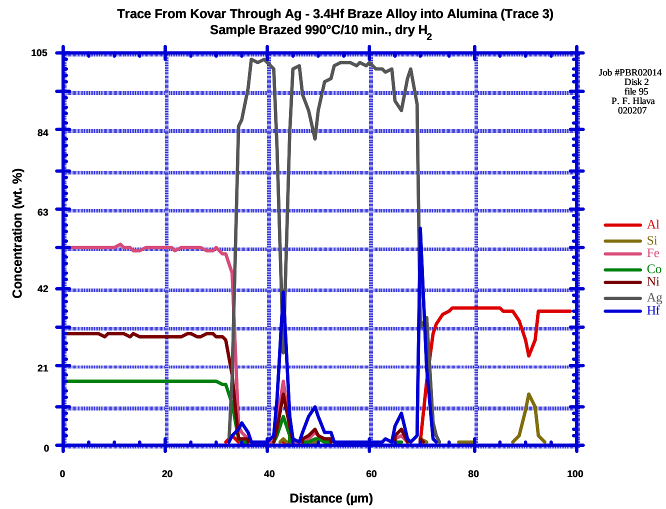


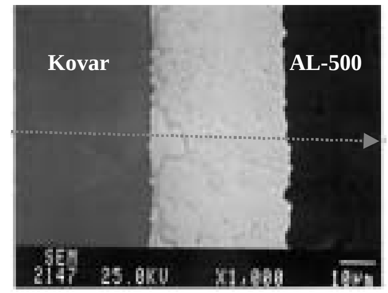
Single crystal sapphire & polycrystalline alumina brazed with Ag-2Zr

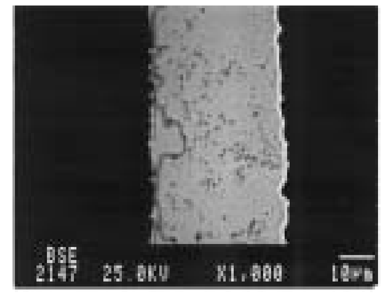


94% alumina brazed with Ag-2Zr is hermetic, fails in the bulk ceramic and has 130 MPa tensile strength

BSE image shows continuous HfO_2 reaction layer at ceramic interface







Ag-3.4Hf ceramic braze joints also demonstrate similar excellent properties (hermetic & 125 MPa)

Recent Accomplishments

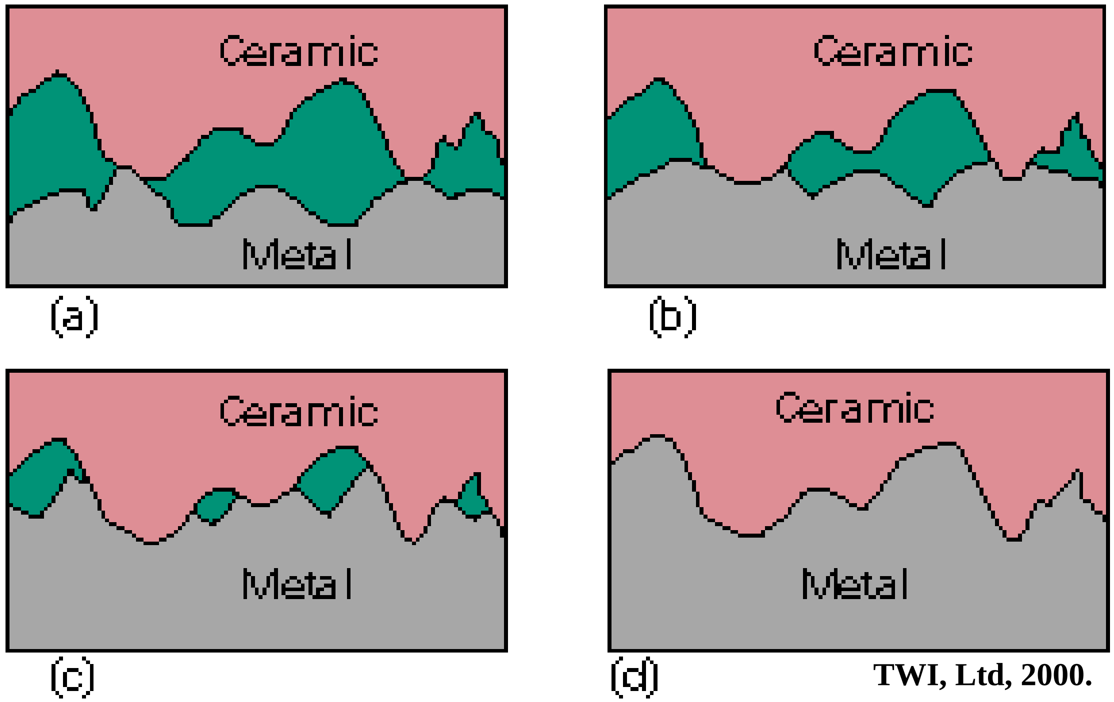
- **Implementation of active brazing in production**
- **Conference paper / presentations (ASM Materials Solutions 2002; AWS IBSC'03; ACerS 2003)**
- ***Metallurgical Transactions A* paper (in publication)**
- **Coating System for Direct Ceramic Brazing patents**

Sandia National Laboratories

NNSA

Diffusion bonding offers an alternative joining process

Ceramic-metal and metal-metal joints are possible



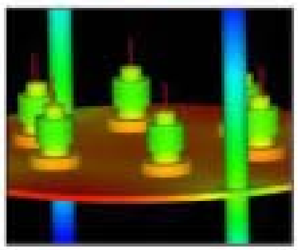
TWI, Ltd, 2000.

a) Hard ceramic and comparatively soft metal surfaces come in contact (T, t, P)
b) Metal surface yields under high local stresses
c) Deformation continues mainly in the metal, leading to interface diffusion & void shrinkage
d) Metallurgical bond is formed

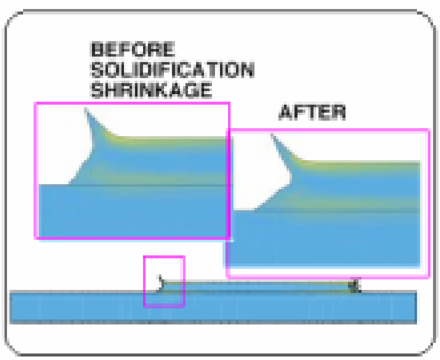
FEA Brazing Model Development & Validation

Thermal Responses

Fixtured Assembly



Fluid Flow Responses



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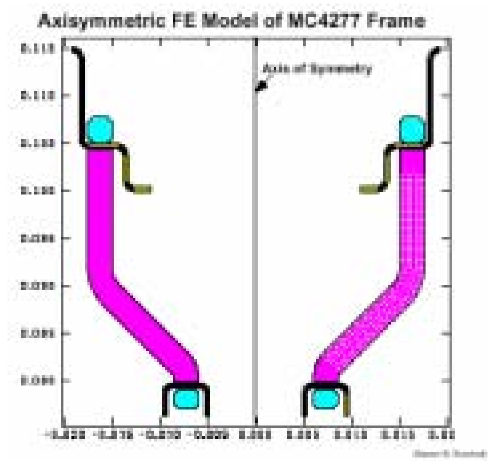
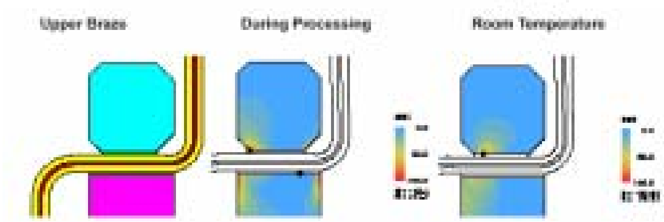
Stress & Failure Predictions





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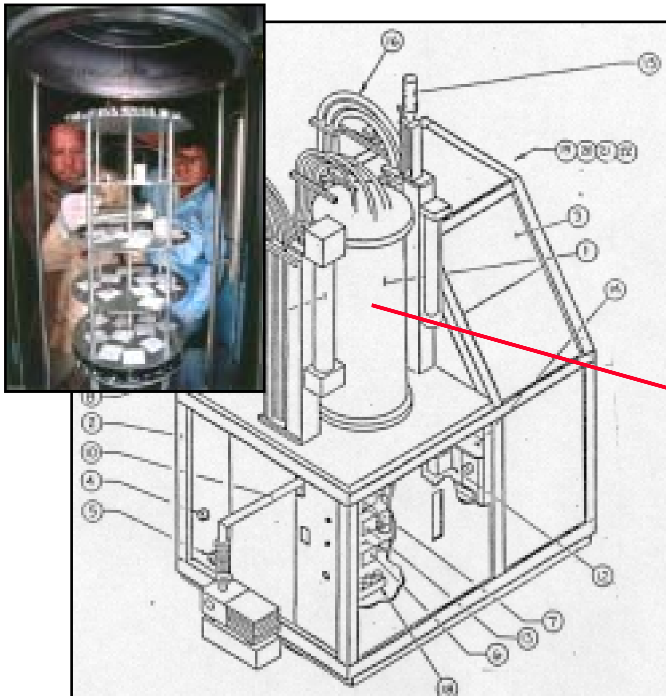
Design & Production

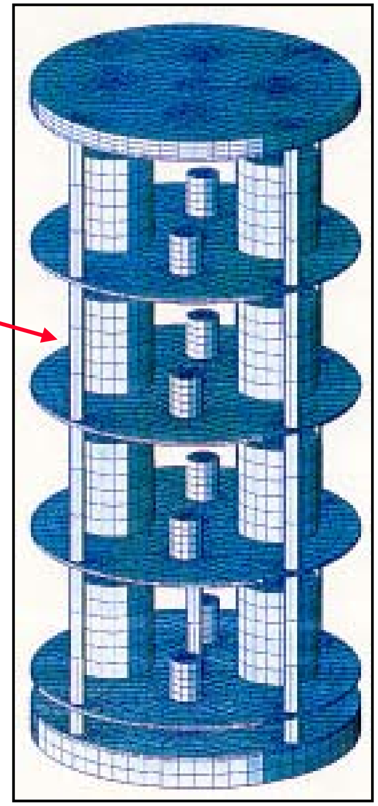
Engineering Sciences Center Simulations

FEA Thermal Modeling of Furnace Brazing



- convective heating by hydrogen gas is assumed negligible
- heating driven by radiation from furnace elements & conduction from Mo shelves to work piece

Work Rack & Parts



- Nonlinear, 3-D transient thermal finite element code
- Ability to mesh very fine details (large node and surface radiation enclosure)

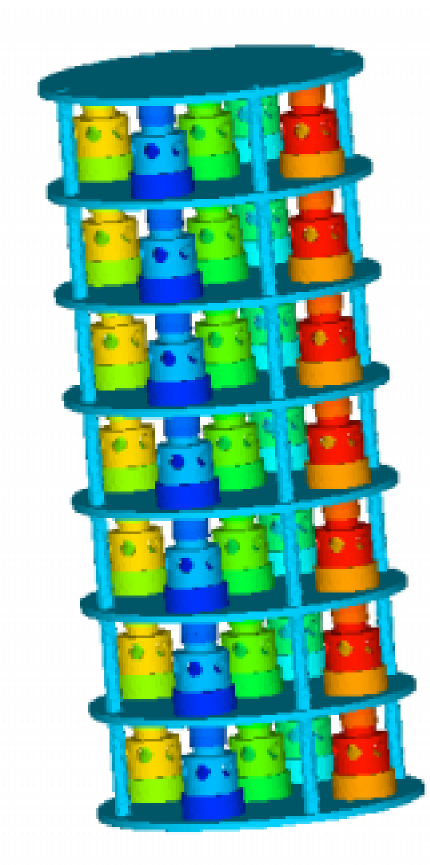
Typical Model Inputs

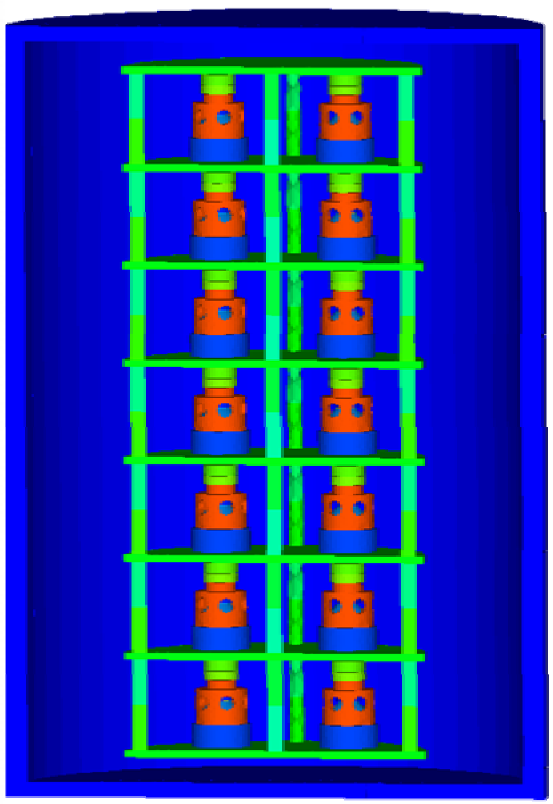
- materials density
- thermal conductivity
- specific heat
- emissivity
- thermal boundary conditions

Simulations processed on massively parallel teraflop compute server

Example: Two-Step, Cu + 50Au-50Cu Braze Assembly Process Characterization

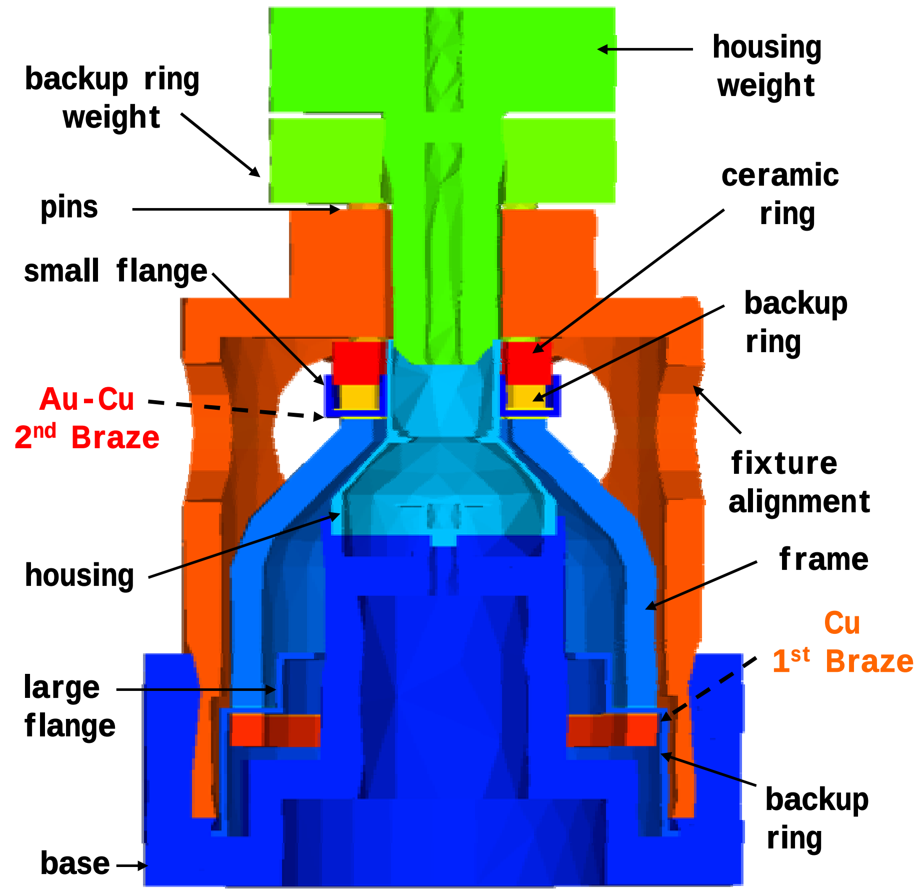
FEA Thermal Model





Oven - 1/2 section

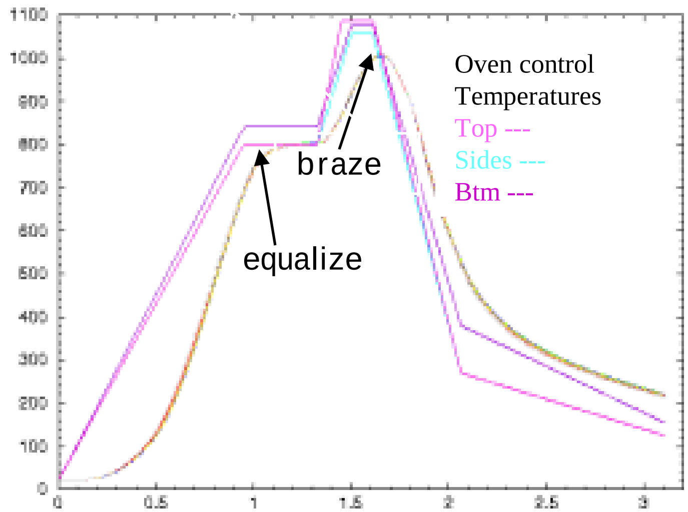
Braze Fixture



Process Space Simulations

Process Space:

- Thermal boundary conditions:
  - 1st ramp rate (10, 40°C/min)
  - 1st hold time (5, 25 min)
  - 1st hold temp (930, 960°C)
  - 2nd ramp rate (10, 40°C/min)
  - peak temp (1000, 1030°C)
  - time @ peak temp (0, 10 min)
  - cooling rate (10, 40°C/min)
- Number of shelves (4, 7)
- Number of fixtures/shelf (2, 5)
- Shelf type (solid, perforated)
- Fixture material (Mo, Kovar®)
- Emissivity (low, high)

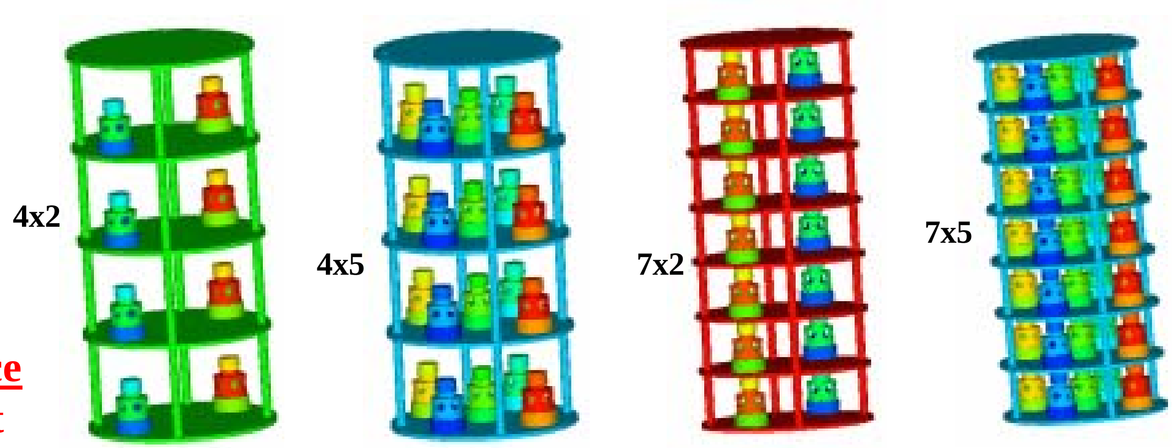


Trends at Peak Temperature:

- Top and bottom shelves are hottest (trim heater settings)
- Middle shelf most uniform
- Center unit of five on each shelf is coolest (~ 5°C lower)
- 10 min. hold at set temp. gives uniform heating, but increases time above melting
- Brazing temperature is uniform within individual units

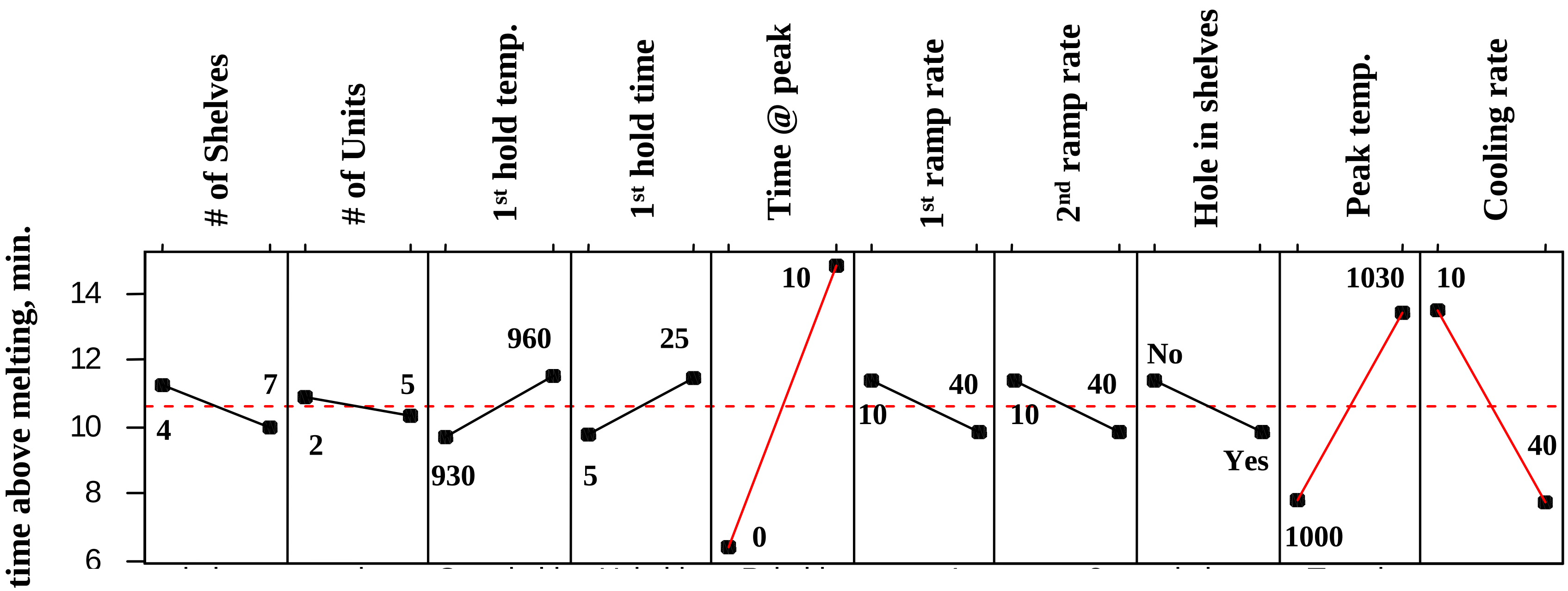
Data acquired:

- Peak brazing temperature
- Time braze is melted
- Temperature uniformity
- Determine optimization parameters in <u>process space</u> versus experimental “point solutions”



Two-level fractional factorial design for 12 factors in 16 unique trials

Example: DoE$_x$ Screening Sensitivities for Thermal Characterization of Brazing Process



Factor sensitivities to the brazing conditions on the central shelf

—— main effect factor significance