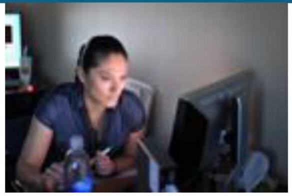
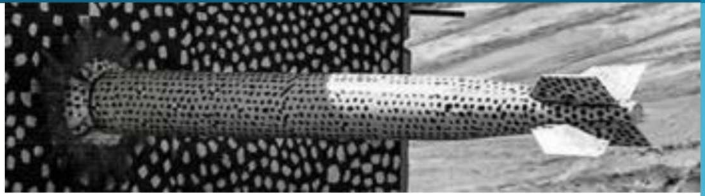
SAND2020-9732C

Minimizing Residual Stress in Brazed Joints by Optimizing the Brazing Thermal Profile





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Overview

Motivation and Objective

Model and Materials

Boundary Value Problem

Optimization

Motivation and Objective

Ceramic to metal brazes are used in many applications:

- Medical devices
- Electronic packaging and connectors
- Hermetically sealed joints
- High power insulators

Brazing temperature profiles cause residual stresses to accumulate in the joint due to coefficient of thermal expansion (CTE) differences. **If we can minimize these residual stresses by optimizing the brazing thermal profile, we can increase the joint strength**.

https://www.friatec-ceramics.com/

https://www.mdcvacuum.com/

https://www.mdcvacuum.com/

Model and Materials

Two alumina ceramic parts are brazed to a Kovar® spacer to create the "ceramic button" test article.

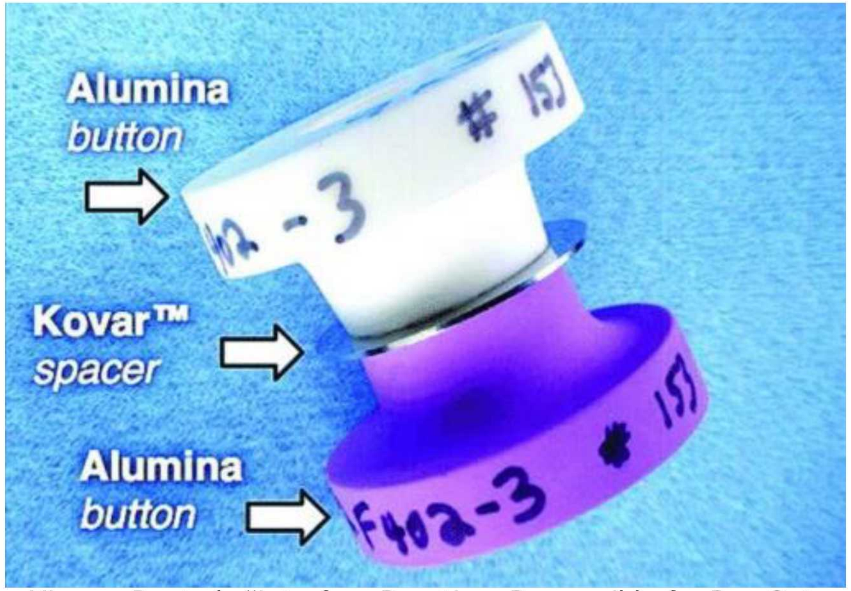
- ASTM F-19 Standard Test Method for Tension and Vacuum Testing Metallized Ceramic Seals[1]

Six braze materials are studied:

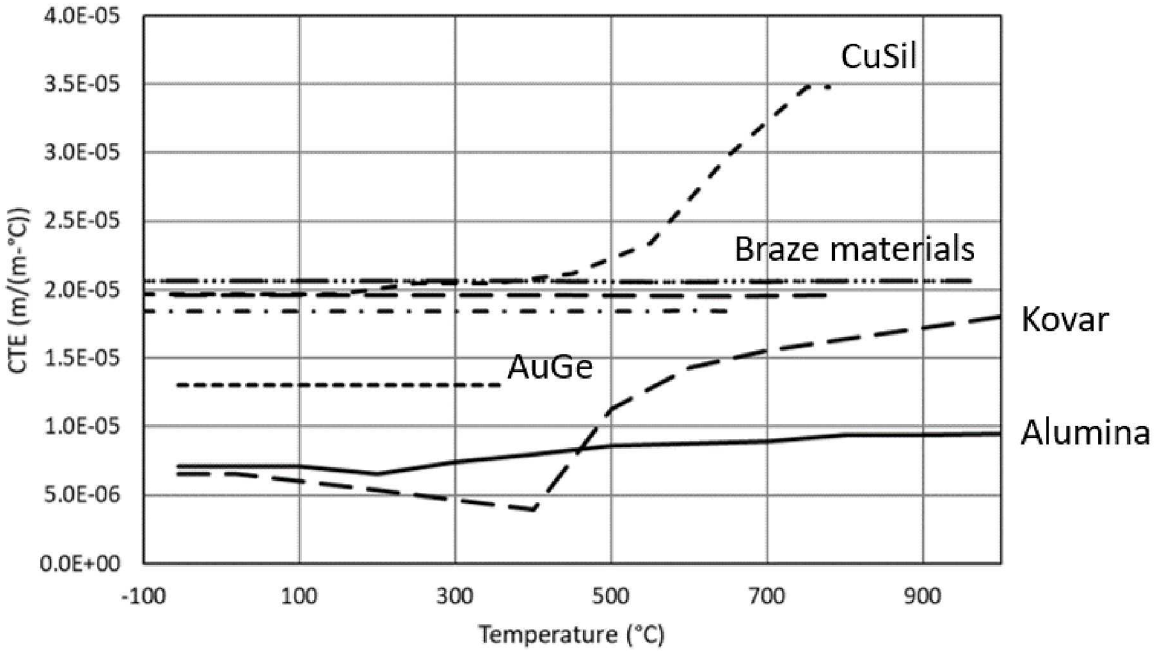
- AgCuZr
- AuGe (Georo)
- CuSil
- InCuSil15
- NiCuSil
- Silver

Braze materials and Kovar are modeled with rate- and temperature-dependent viscoplastic models that capture the creep and plasticity behavior of the material.

Alumina is modeled with a simple thermo-elastic material model.



Vianco, P. et al. "Interface Reactions Responsible for Run-Out in Active Brazing: Part 1." Welding Journal Vol. 97 (2018)



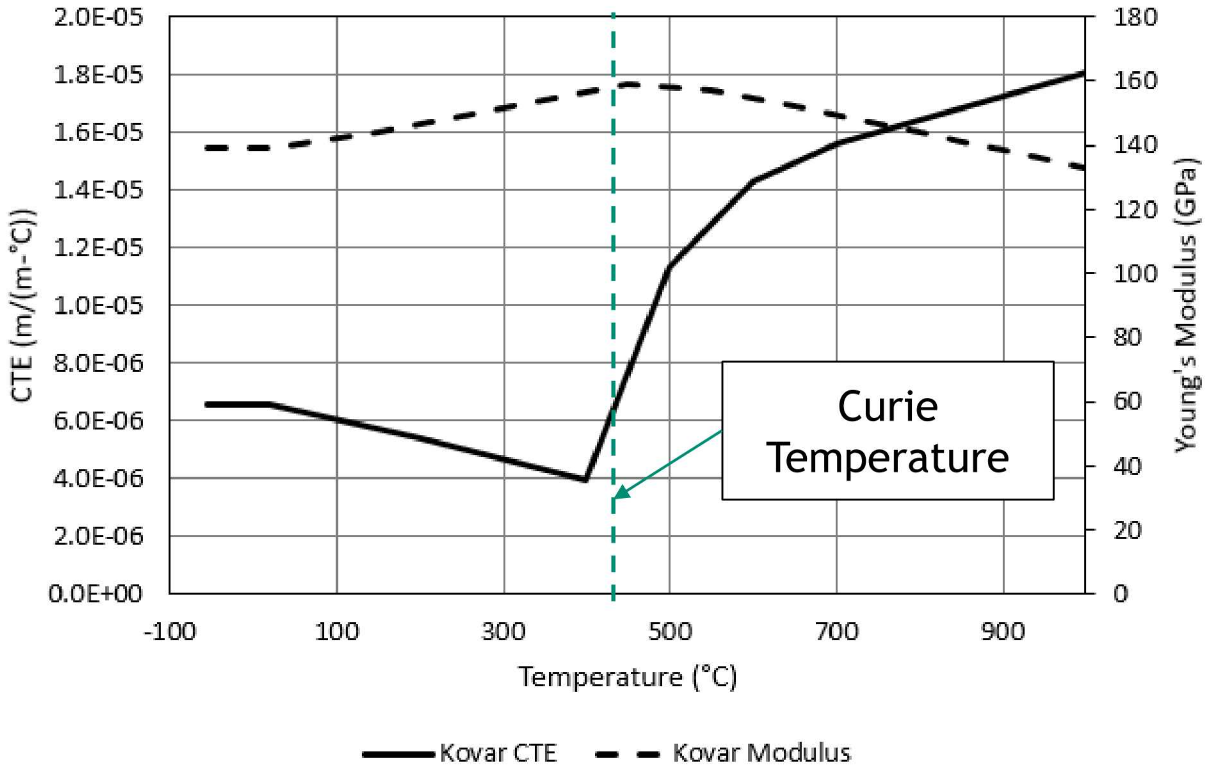
[1] http://www.astm.org/cgi-bin/resolver.cgi?F19-11(2016)

Kovar and its Curie point

Kovar is a low expansion alloy made up of iron, nickel, and cobalt[1]

Kovar has a Curie temperature of 435°C

- Curie temperature represents the temperature above which the material loses its ferromagnetic properties[2]
- This change in magnetic properties also impacts other material properties such as modulus and thermal strain



[1] https://www.carpentertechnology.com/en/product-solutions/cartech-kovar-alloy/

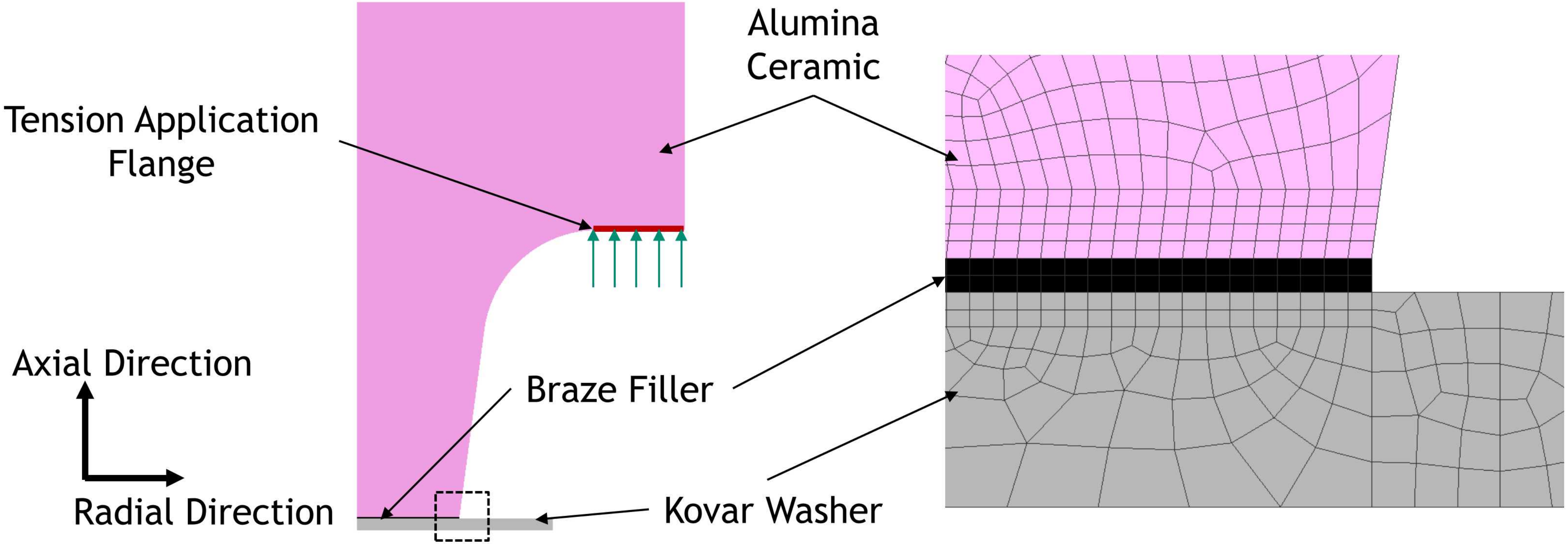
[2] Hofmann, Philip. Solid State Physics: An Introduction. John Wiley & Sons, Berlin (2008).

Finite Element Model

Sierra Solid Mechanics[1] code was used to simulate brazing process and an applied tensile load.

An axisymmetric wedge model was created. Also assumed half symmetry about Kovar washer.

A mesh convergence study was run to ensure two elements through braze thickness can resolve the axial stress in the brazed joint.



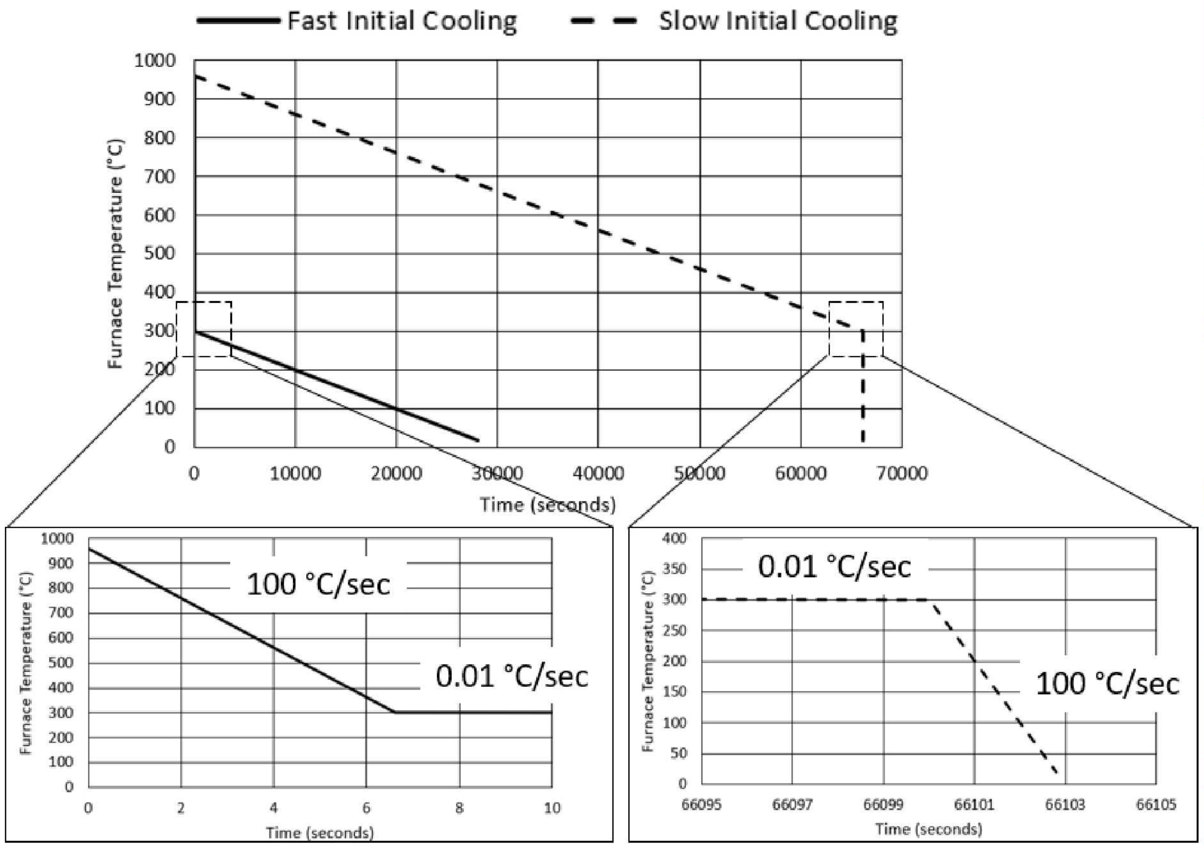
[1]SIERRA Solid Mechanics Team. "Sierra/Solid Mechanics 4.48 User's Guide." Technical Report No. SAND2018-2961, Sandia National Laboratories, Albuquerque, NM. 2018.

Boundary Value Problem

To understand the physics of the problem, four cooling profiles that bound the solution space were developed and studied:

- Fast cooling rate (100°C/sec)
- Slow cooling rate (0.01°C/sec)
- Fast initial cooling, then slow final cooling (FastThenSlow)
- Slow initial cooling, then fast final cooling (SlowThenFast)

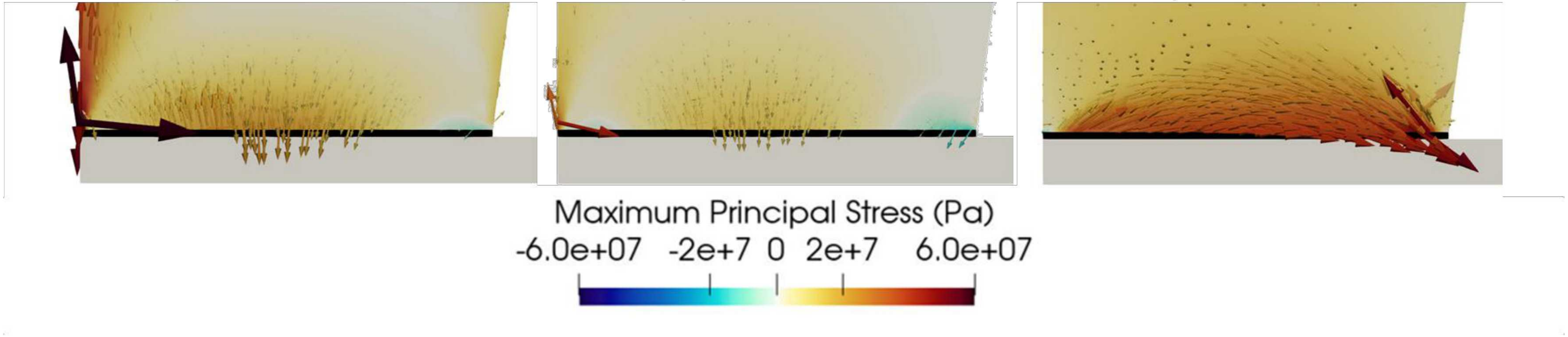
Braze material for boundary value problem is AgCuZr



Contoured stresses show cooling rate impacts

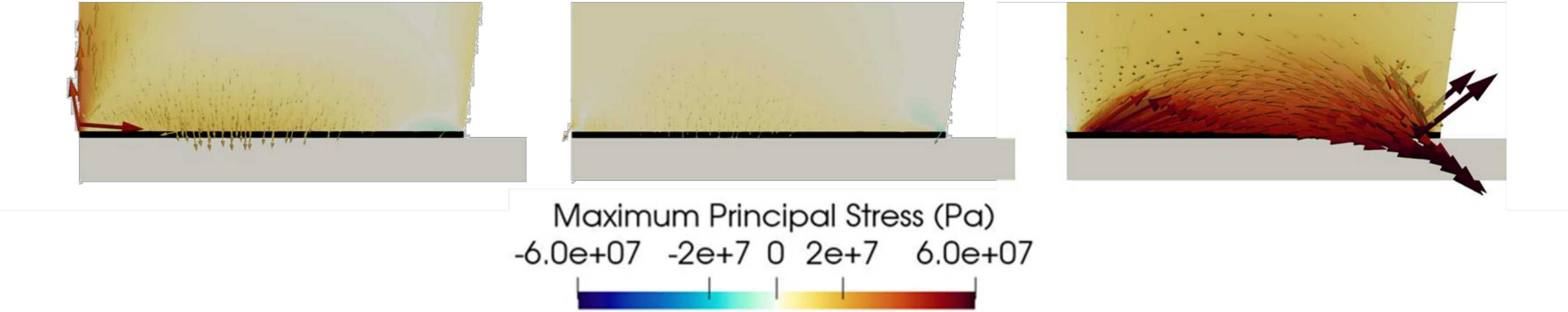
Fast Initial Cooling Rate

Temperature = 400 °C | Temperature = 300 °C | Temperature = 20 °C



Slow Initial Cooling Rate

Temperature = 400°C | Temperature = 300°C | Temperature = 20°C

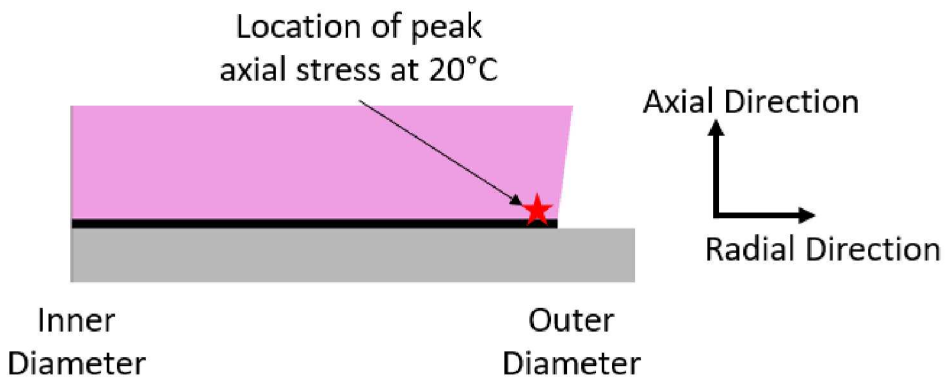


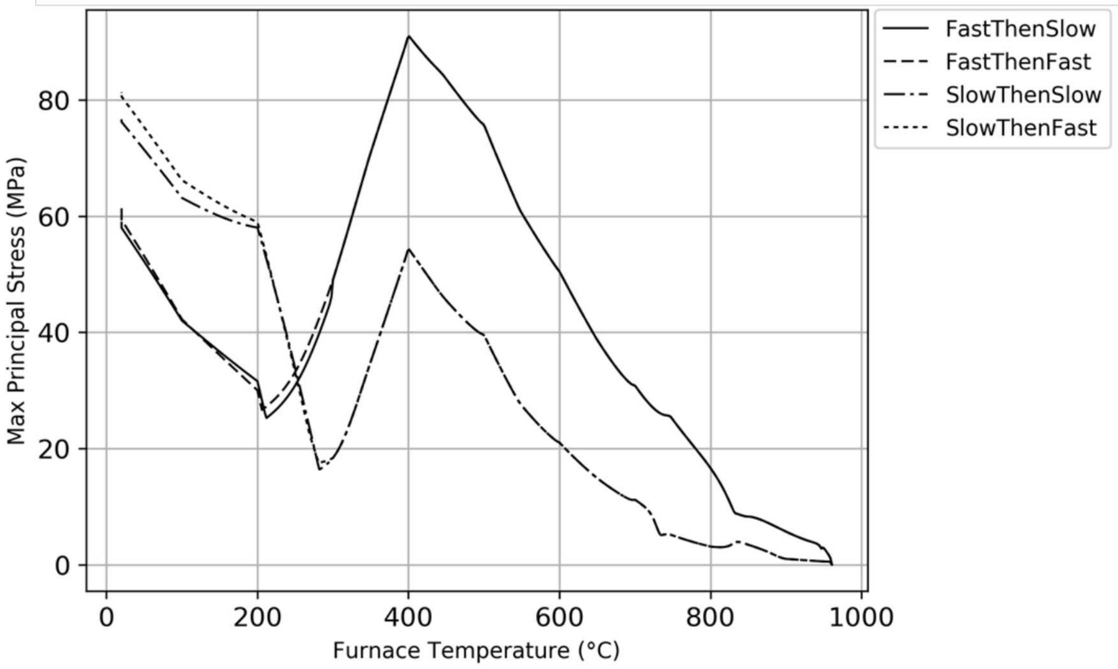
Stresses in ceramic tracked at location near outer diameter

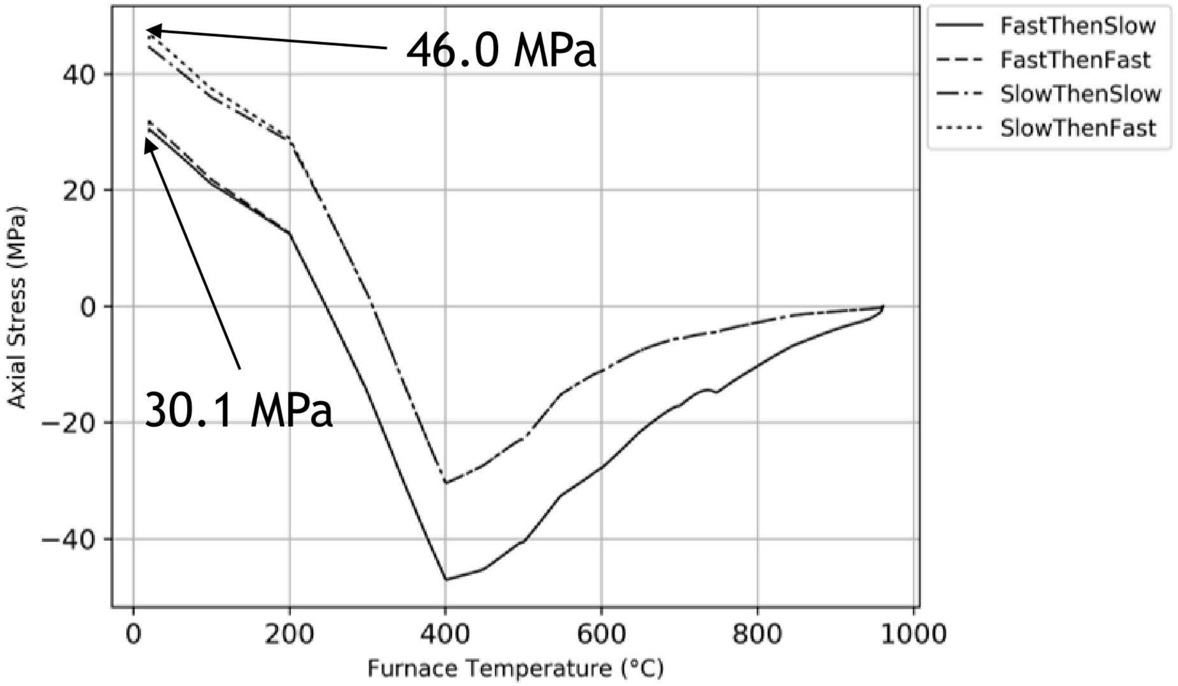
Initial cooling rate has largest impact on stress at 400°C and 20°C

Final cooling rate only has small impact on stress at 20°C

Fast initial cooling rate maximizes stress at 400°C while minimizing stress at 20°C

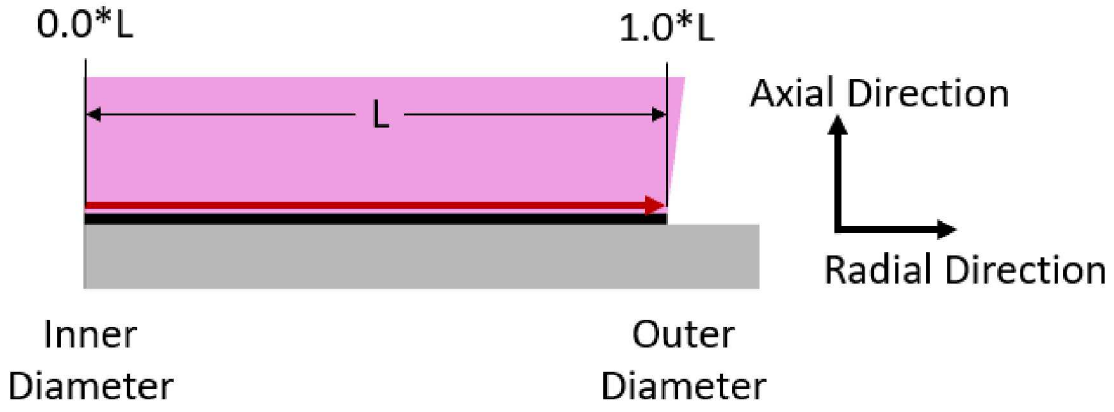


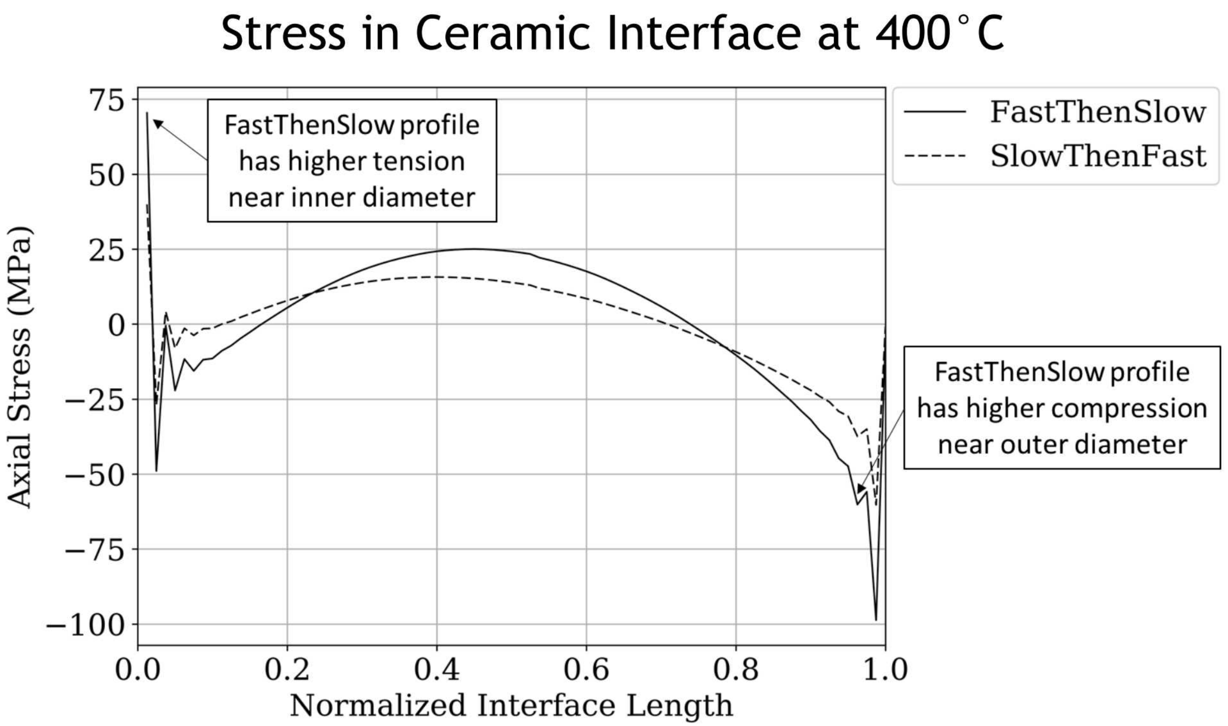


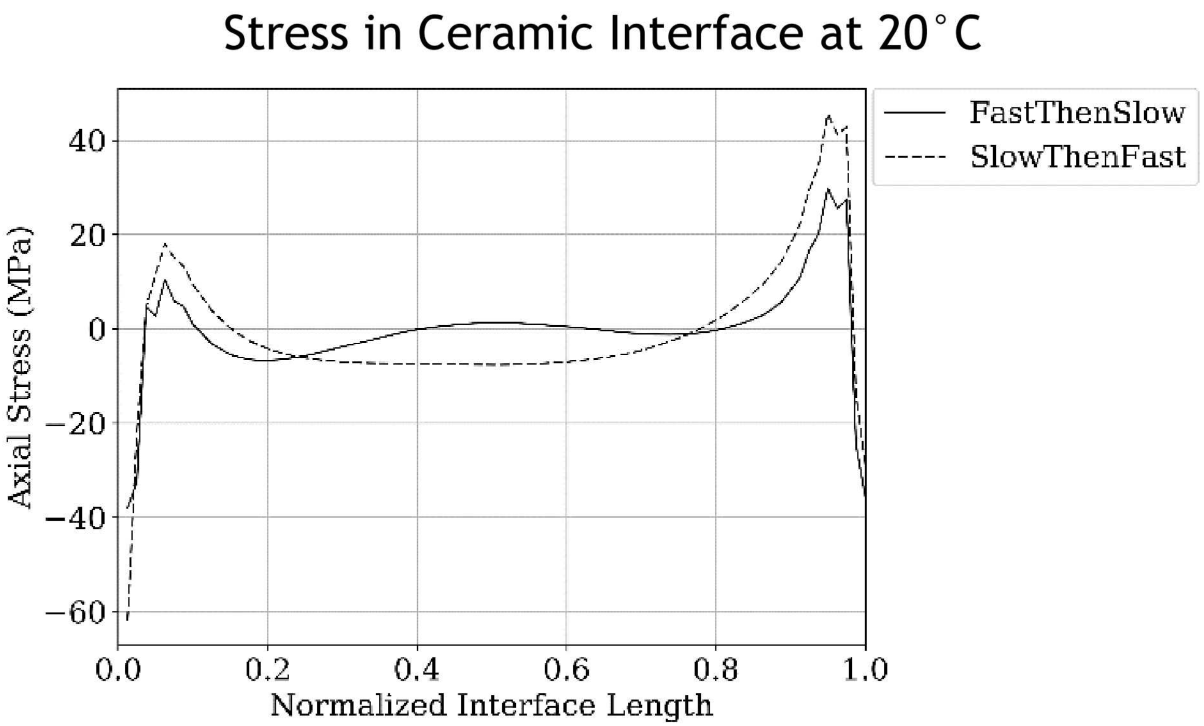


Interface stresses show cooling rate effects

Fast initial cooling rate model sees higher compression stress near the outer diameter at 400°C leading to lower amounts of tensile stress at 20°C







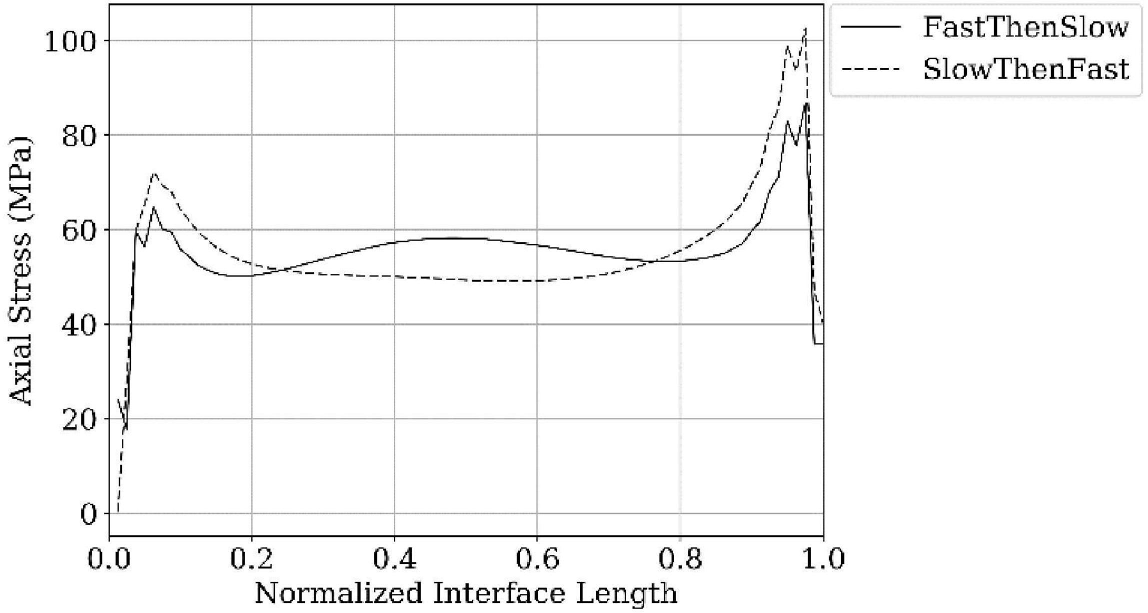
Tensile Load Application on Boundary Value Problem

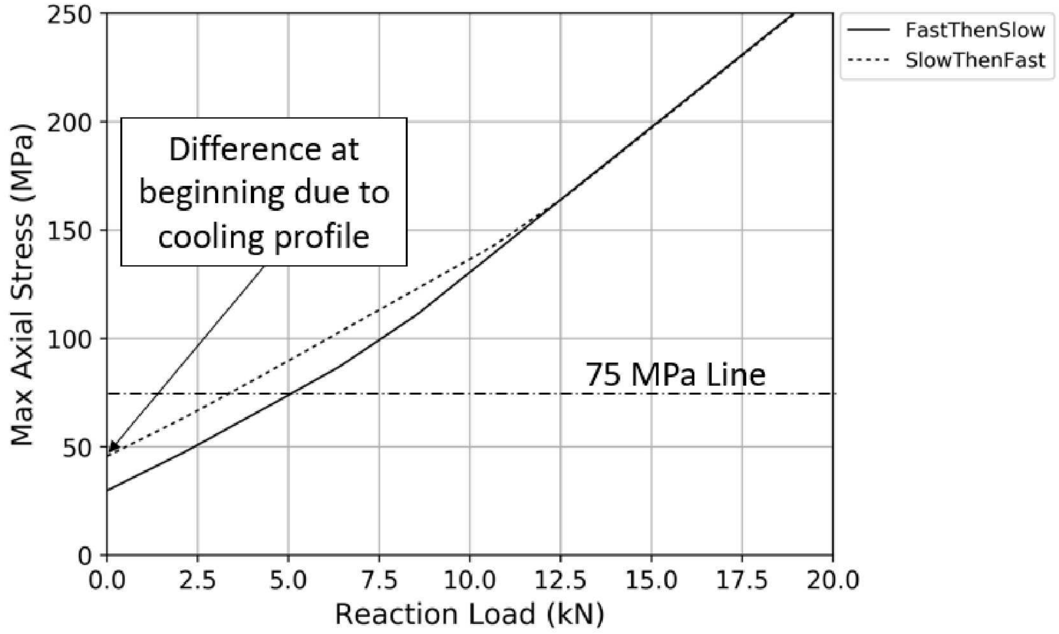
After cooling is completed, the sample is subjected to a tensile load

Residual stress in brazed joint decreases strength during tensile test

~16 MPa difference in residual stress leads to a 2 kN difference in break load if break happens at 75 MPa

Axial stress in ceramic at 6.4 kN of applied tension





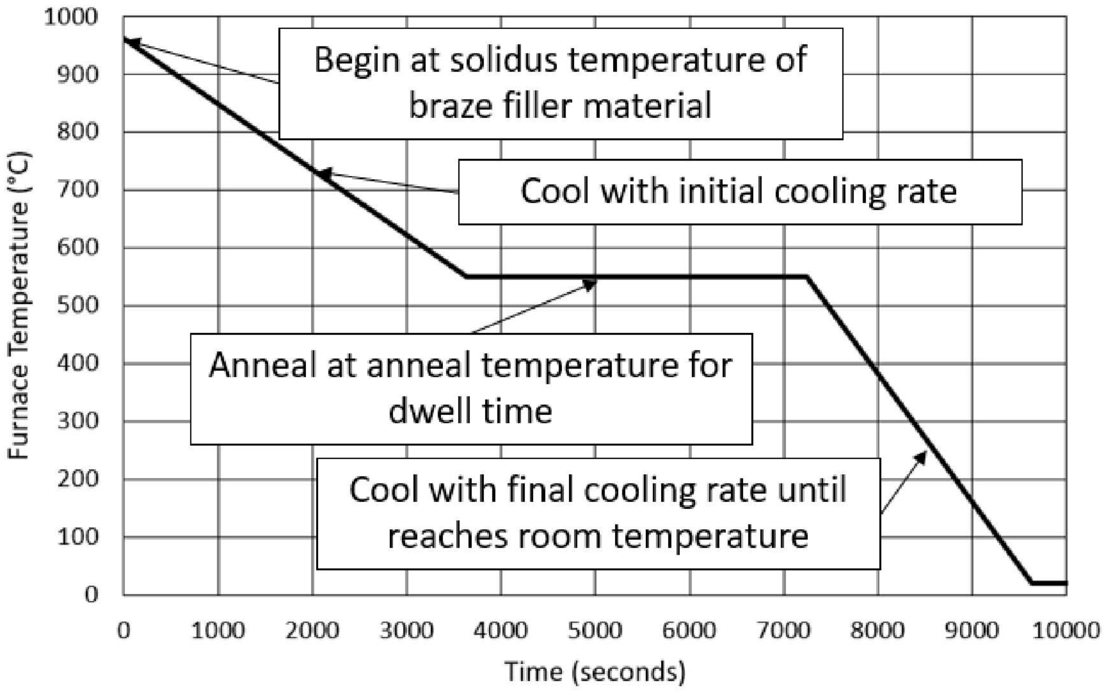
Optimization

Optimization Variables:

- Initial cooling rate
- Anneal temperature
- Dwell time
- Final cooling rate

Dakota, an optimization tool developed by Sandia, was used to vary inputs and minimize stress

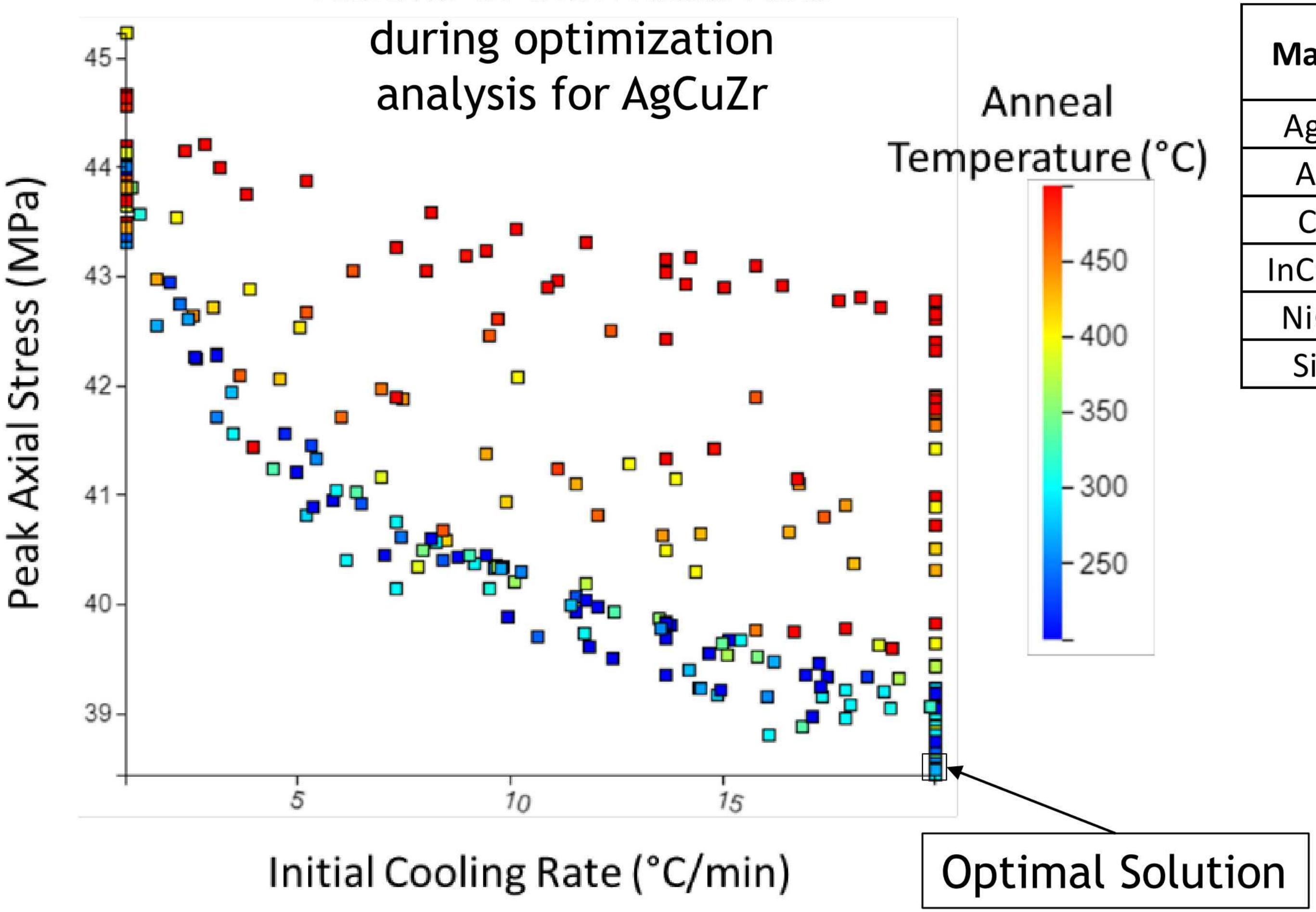
- Objective function – minimize axial and maximum principal stress in ceramic near braze interface



Parameter	Range	
	Low	High
Initial Cooling Rate (°C/min)	1	20
Anneal Temperature (°C)	200	Varies
Dwell Time (hours)	0.1	10
Final Cooling Rate (°C/min)	1	20

Optimization Results

Results of individual runs during optimization analysis for AgCuZr



Material	Initial Cooling Rate (°C/min)	Anneal Temperature (°C)	Dwell Time (hours)	Final Cooling Rate (°C/min)
AgCuZr	20.0	298.2	10.0	1.0
AuGe	1.0	219.9	10.0	5.2
CuSil	18.8	355.5	10.0	1.0
InCuSil15	20.0	200.0	10.0	1.0
NiCuSil	20.0	300.0	7.8	1.0
Silver	20.0	279.2	3.4	1.0

Material	Peak Axial Stress (MPa)		
	Minimum	Maximum	Difference
AgCuZr	38.2	45.0	6.8
AuGe	40.8	53.7	12.9
CuSil	43.6	53.0	9.4
InCuSil15	46.8	60.6	13.9
NiCuSil	36.6	47.7	11.0
Silver	12.4	16.0	3.6

High initial cooling rates and annealing temperatures < 300°C lead to minimized axial stress in the ceramic

Summary

Kovar's Curie temperature has significant impact on material properties during a brazing thermal profile

A fast initial cooling rate maximizes transient tensile stress in ceramic at the Curie temperature but minimizes the residual tensile stress at room temperature.

- A slow cooling rate below the Curie temperature also reduced residual tensile stress a small amount

Less residual stress after the brazing procedure increases strength of brazed joint

Predicted residual stress in the ceramic can be minimized by optimizing the thermal profile for specific braze materials

Acknowledgements

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