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A Viscoplastic Constitutive Model for Active Braze Alloys

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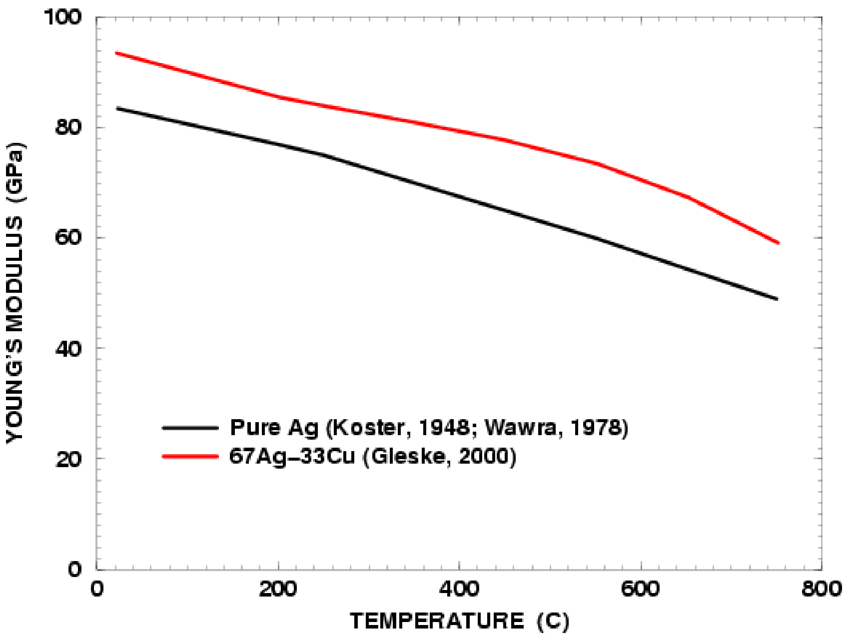
Outline

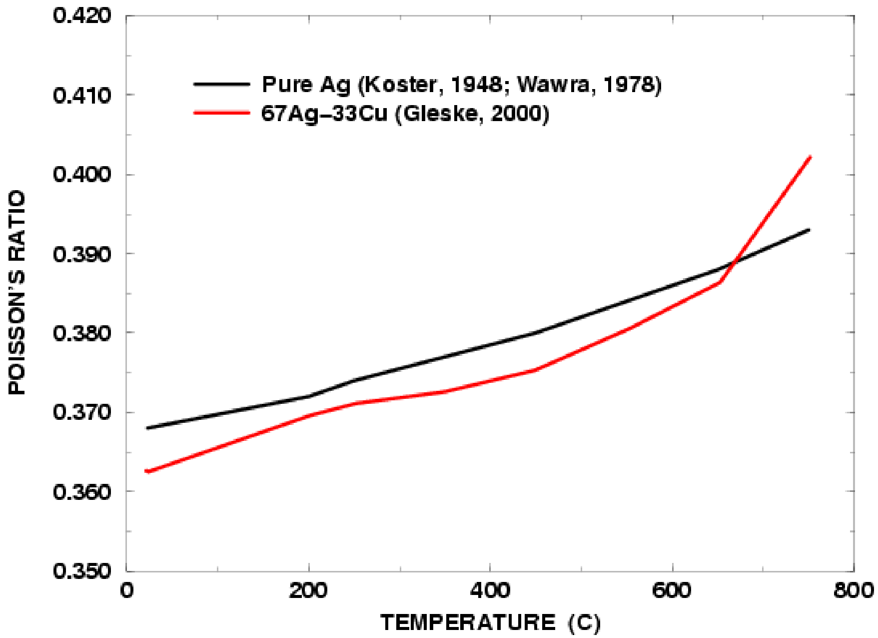
- Mechanical Behavior of Three Active Braze Alloys 63Ag-35.25Cu-1.75Ti, 98Ag-2Zr (wt%), 97Ag-1Cu-2Zr
- Behavior Captured with Existing Models
- Development of Viscoplastic Constitutive Model
- Simulation of Metal-to-Ceramic Brazing

Elastic Moduli for Pure Ag and 67Ag-33Cu

Young's Modulus



Poisson's Ratio



References:

Koster, W., *Z. Metallk.,* **39**, pp. 145, 1948.

Wawra, H., *Z. Metallk.,* **69**, pp. 518-523, 1978

Gieske, J., internal memo, Sandia National Labs, 2000.

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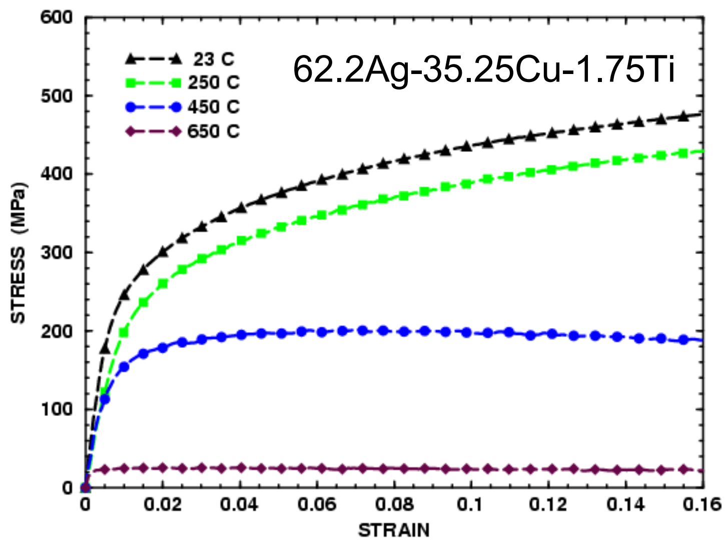
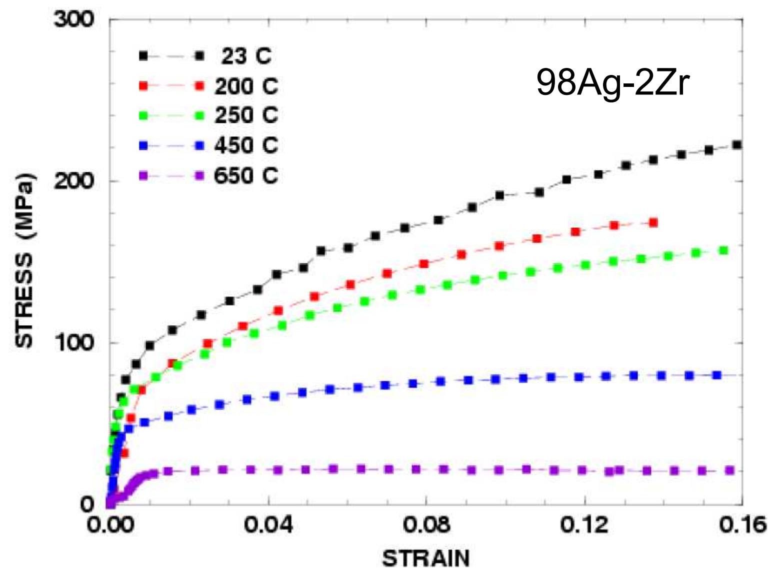
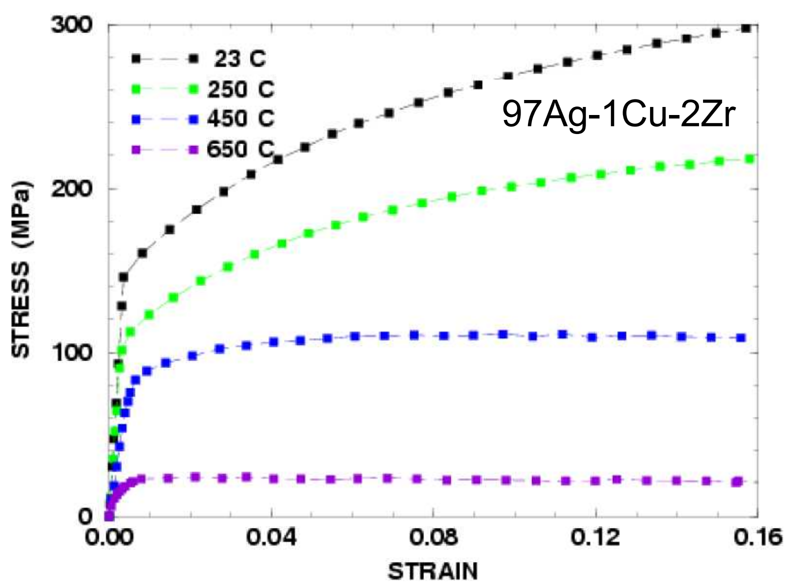
Isothermal Uniaxial Compression Experiments
(constant true strain rate of 1.67 x 10^{-4} per sec.)







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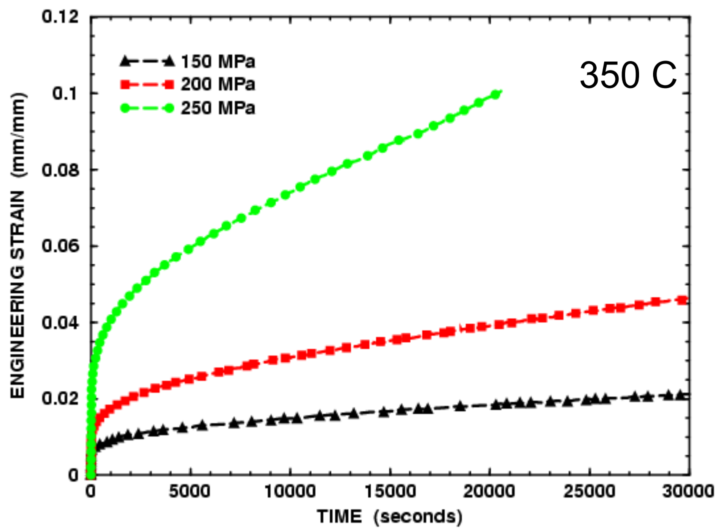
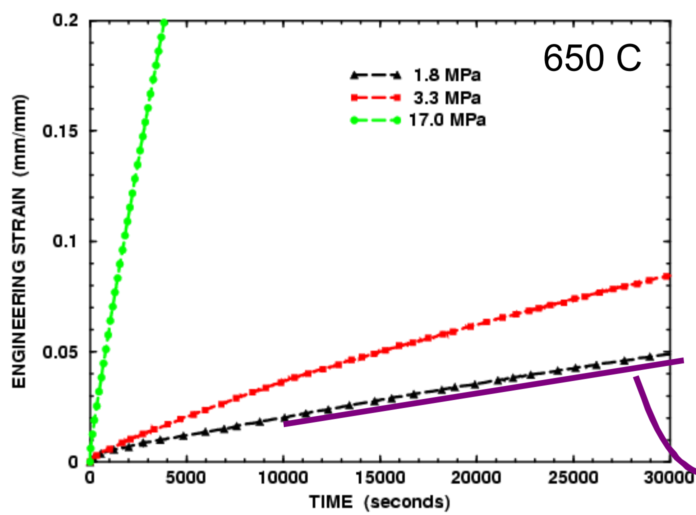
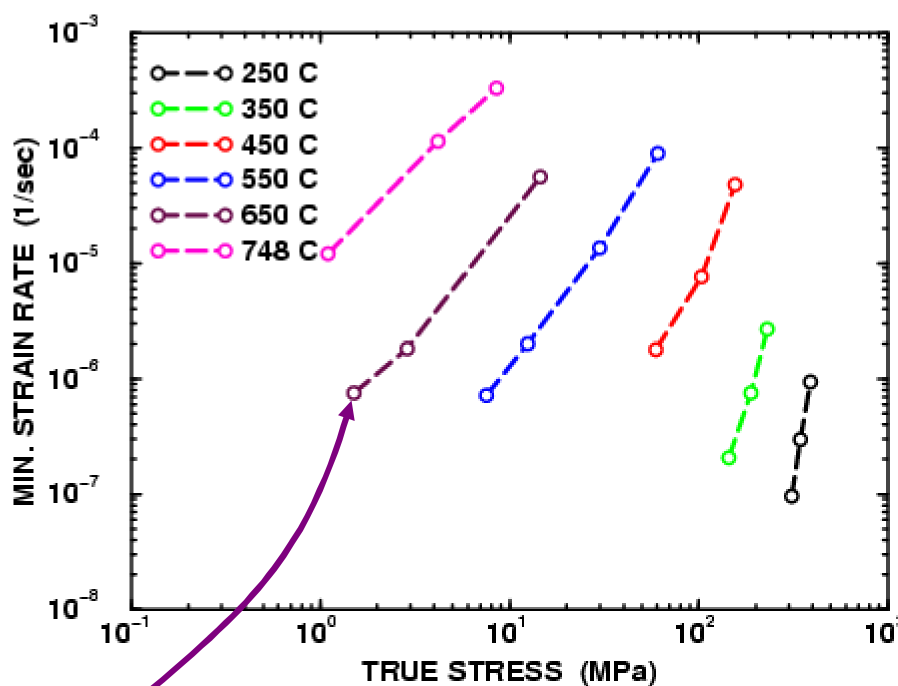
Creep Compression Experiments
(constant engineering stress)



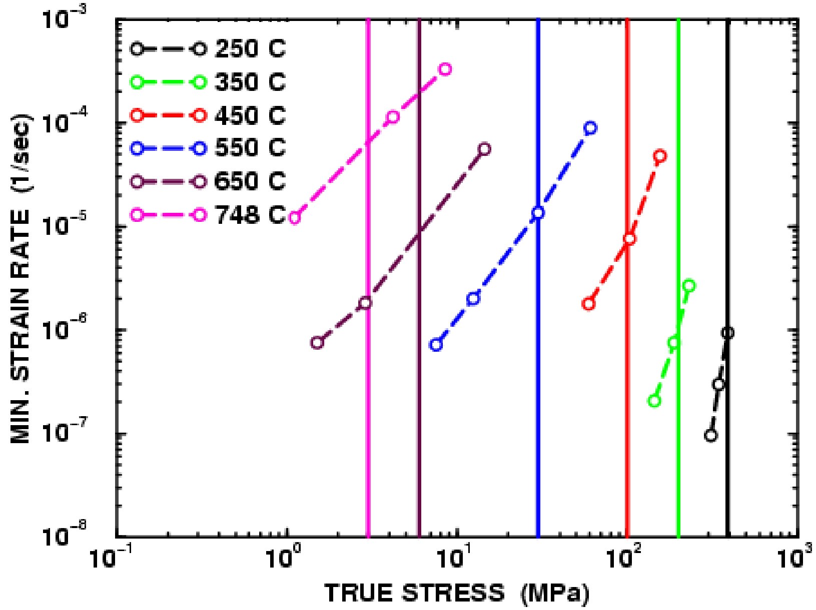


62.2Ag-35.25Cu-1.75Ti

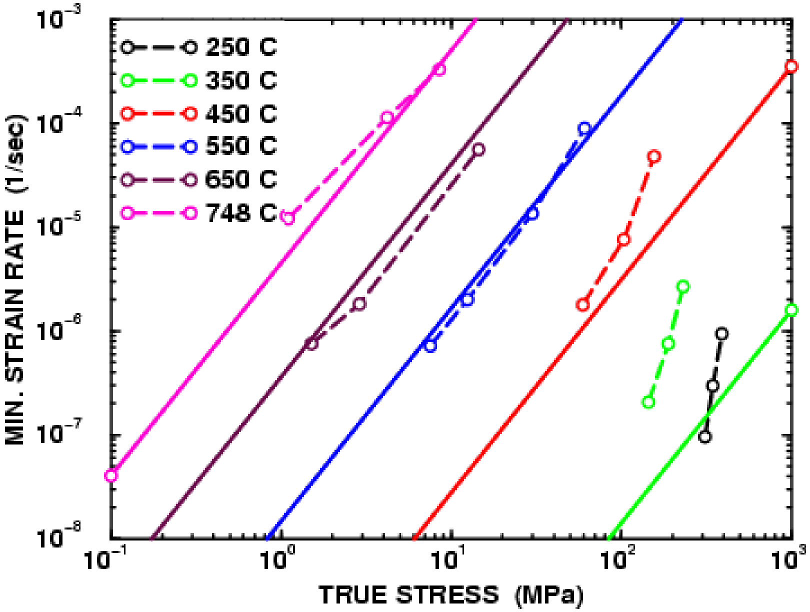


Minimum or Steady-State Creep Rate

Steady-State Creep vs. Stress



vonMises Plasticity Model

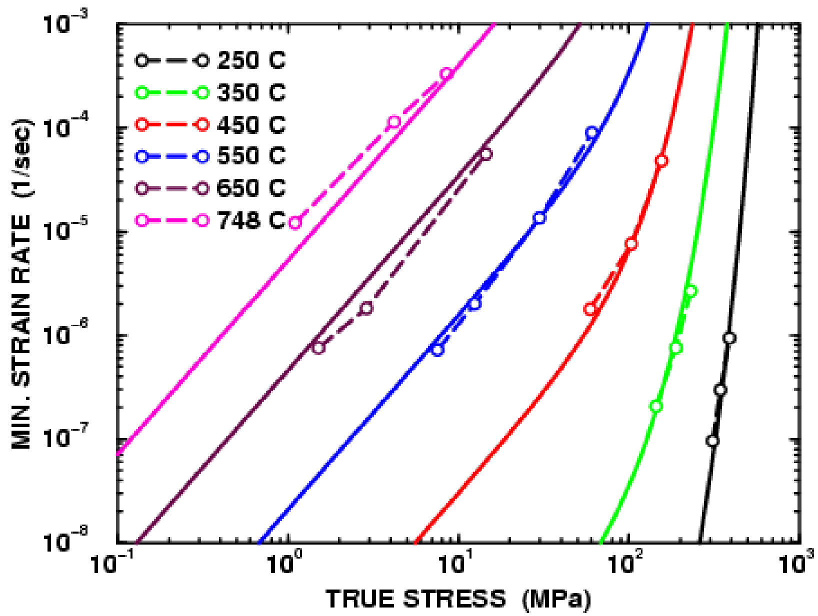


Power-Law Secondary Creep Model

$$\varepsilon^{ss} = 9.9388x10^4 (\sigma)^{2.05} \, exp\left(\frac{-48{,}300}{R\theta}\right)$$

R is the gas constant (1.987 cal/mole/Kelvin)

Steady-State Creep vs. Stress



Hyperbolic Sine Secondary Creep Model

$$\dot{\varepsilon}^{ss} = 8.13 \times 10^{7} \, sinh^{1.87}\left(\frac{\sigma}{50.66}\right) exp\left(\frac{-46{,}706}{R\theta}\right)$$

Ref: Garofalo, F. **Fundamentals of Creep and Creep Rupture in Metals**, MacMillan Company (1965)

A Viscoplastic (UCP) Model

Total strain rate = elastic + inelastic

$$\dot{\boldsymbol{\varepsilon}} = \dot{\boldsymbol{\varepsilon}}^e + \dot{\boldsymbol{\varepsilon}}^{in}$$

Isotropic, linear elastic

$$\boldsymbol{\sigma} = \mathbf{E} : \boldsymbol{\varepsilon}^e$$

Inelastic strain rate

$$\dot{\boldsymbol{\varepsilon}}^{in} = \frac{3}{2}\gamma\mathbf{n} = \frac{3}{2} f \, \sinh^p\left(\frac{\tau}{D}\right)\mathbf{n}$$

Normalized stress difference tensor
s is the stress deviator, **B** is state tensor

$$\mathbf{n} = \frac{\mathbf{s} - \frac{2}{3}\mathbf{B}}{\tau}$$

Effective Stress: scalar measure of stress difference magnitude

$$\tau = \sqrt{\frac{3}{2}\left(\mathbf{s} - \frac{2}{3}\mathbf{B}\right) : \left(\mathbf{s} - \frac{2}{3}\mathbf{B}\right)}$$

References:

Miller, A.K., **Unified Constitutive Equations for Creep and Plasticity**, Elsevier, 1987.
Neilsen, M.K. et al., SAND96-0984, Sandia National Labs, 1996.
Johnson, G.C. and Bammann, D.J., *Intl. J. Solids Structures*, **20**, 725-737, 1984.
Flanagan, D.P., and Taylor, L.M., *Comp. Mth. Appl. Mech. Engr.,* **62**, 305-320, 1987.

A Viscoplastic (UCP) Model (cont.)

Evolution Eq. for State Variable D

$$\dot{D} = \frac{A_1 \gamma}{(D - D_0)^{A_3}} - A_2 (D - D_0)^2$$

Evolution Eq. for State Tensor $\mathbf{B}$

$$\dot{\mathbf{B}} = \frac{A_4 \, \mathbf{d}^{in}}{b^{A_6}} - A_5 b \mathbf{B}$$

Magnitude of **B**

$$b = \sqrt{\frac{2}{3} \mathbf{B} : \mathbf{B}}$$

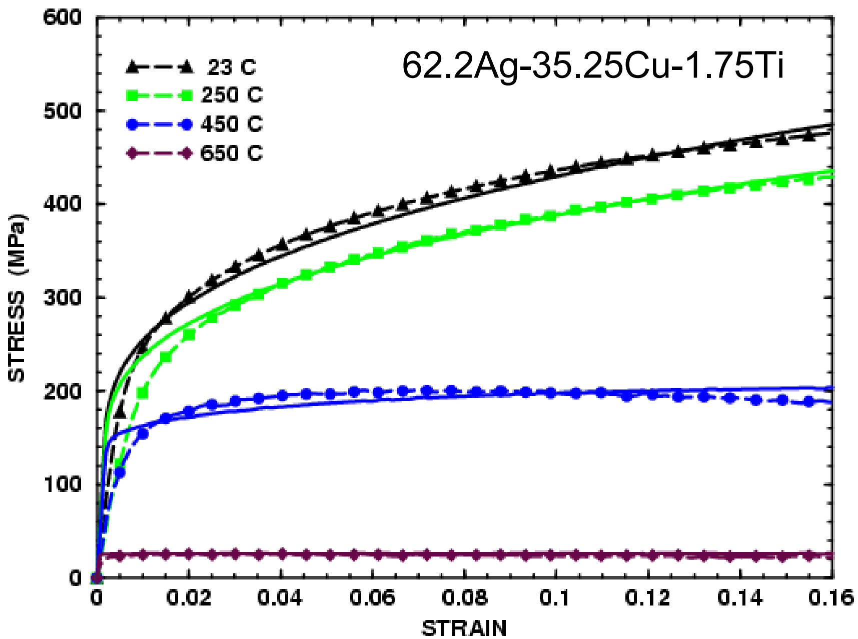
Material Parameters for UCP Model

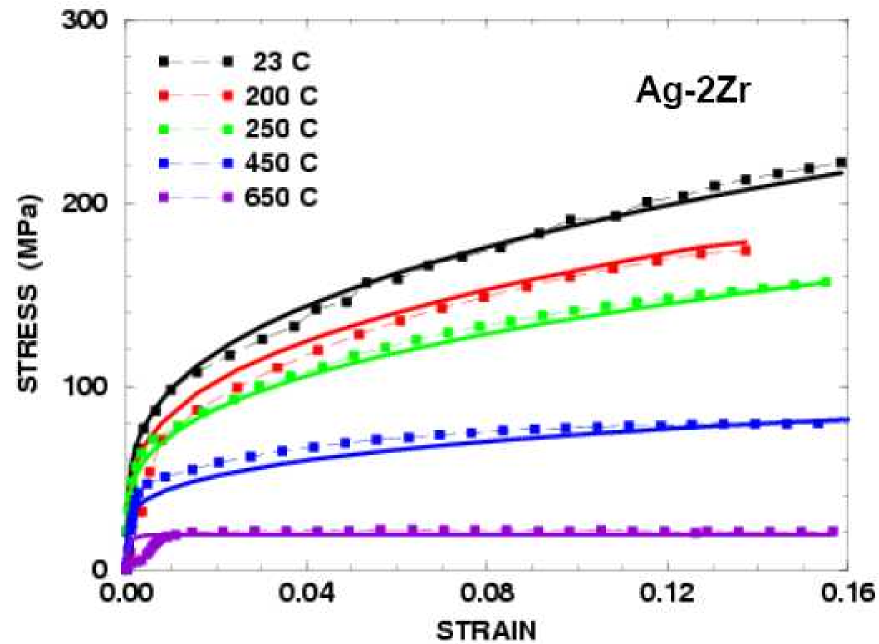
Table 3. 98Ag-2Zr Material Parameters.

Temp. (°C)	Flow Rate ln(f)	Sinh Expo. p	Isotropic Hardening, A_1 (MPa^{A3+1})	Isotropic Recov., A_2 1/(MPa-sec)
23	-86.29	12.0	15840.	2.117e-11
200	-71.11	11.4	12300.	2.000e-10
250	-64.10	11.26	12290.	8.469e-8
350	-37.15	5.81	3933.	3.191e-7
450	-30.36	5.81	3245.	9.641e-6
550	-24.59	5.81	3100.	2.541e-4
650	-18.12	5.81	3087.	6.457e-3
750	-10.67	5.81	3000.	7.116e-3

Iso. Exponent, A_3	1.7278
Kin. Harden., A_4 (MPa^{A6+1})	0.0
Kin. Rec., A_5 1/(MPa-sec)	0.0
Kin. Exponent, A_6	1.7278
Flow Stress, D_0 (MPa)	5.00

Simulations of Uniaxial Compression Experiments with Viscoplastic Model Show Good Agreement with Data





- solid lines show model predictions
- symbols show experimental results

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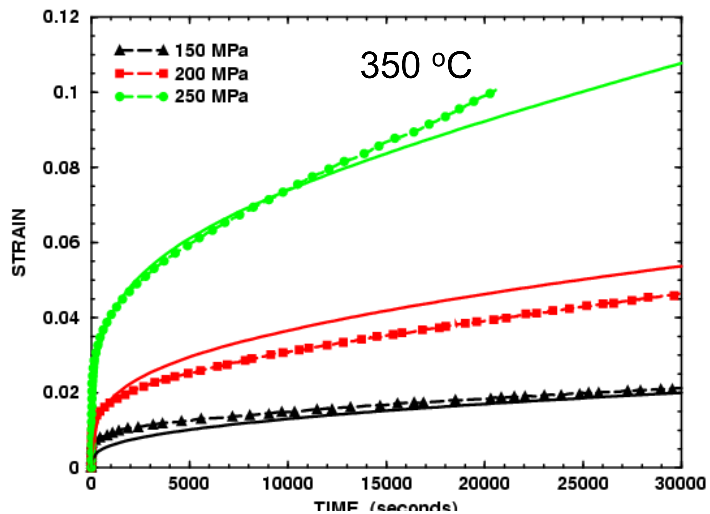
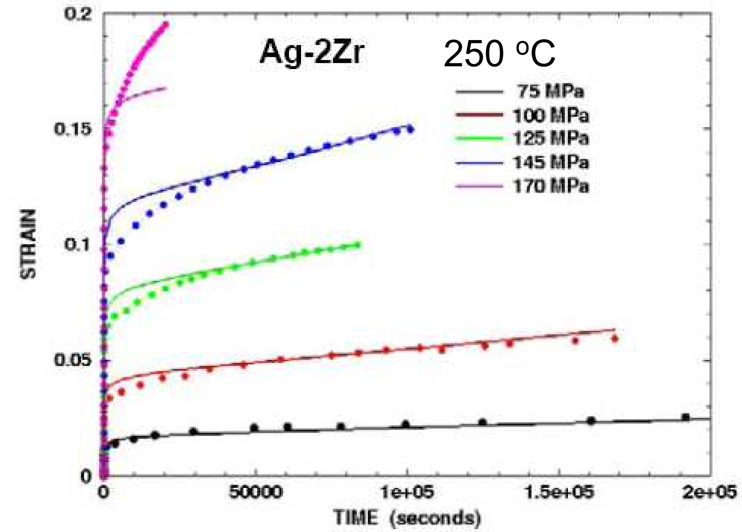
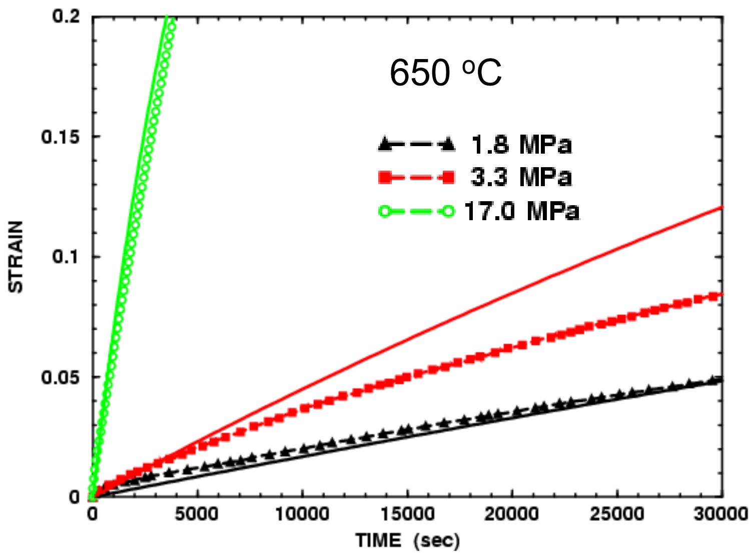
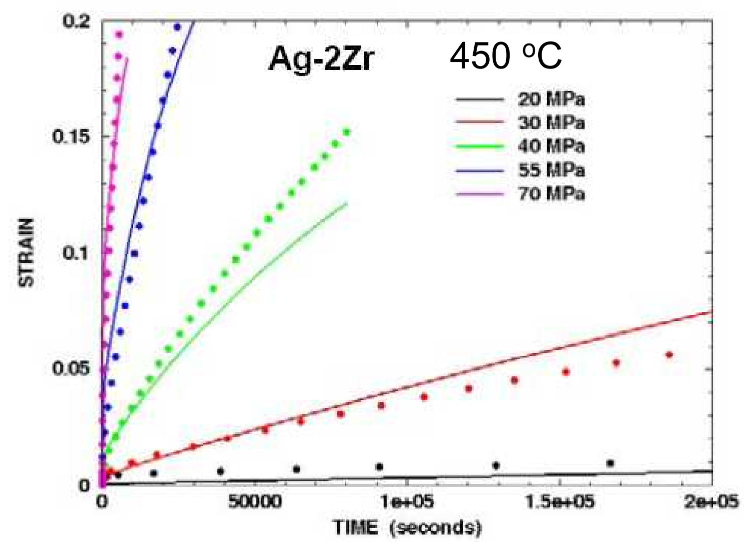
Simulation of Creep Compression Experiments





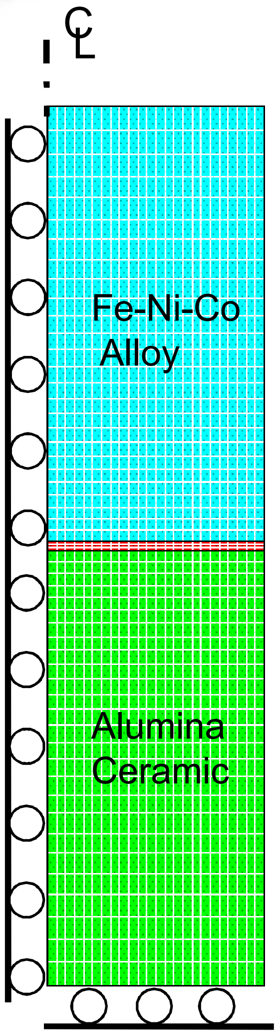


62.2Ag-35.25Cu-1.75Ti

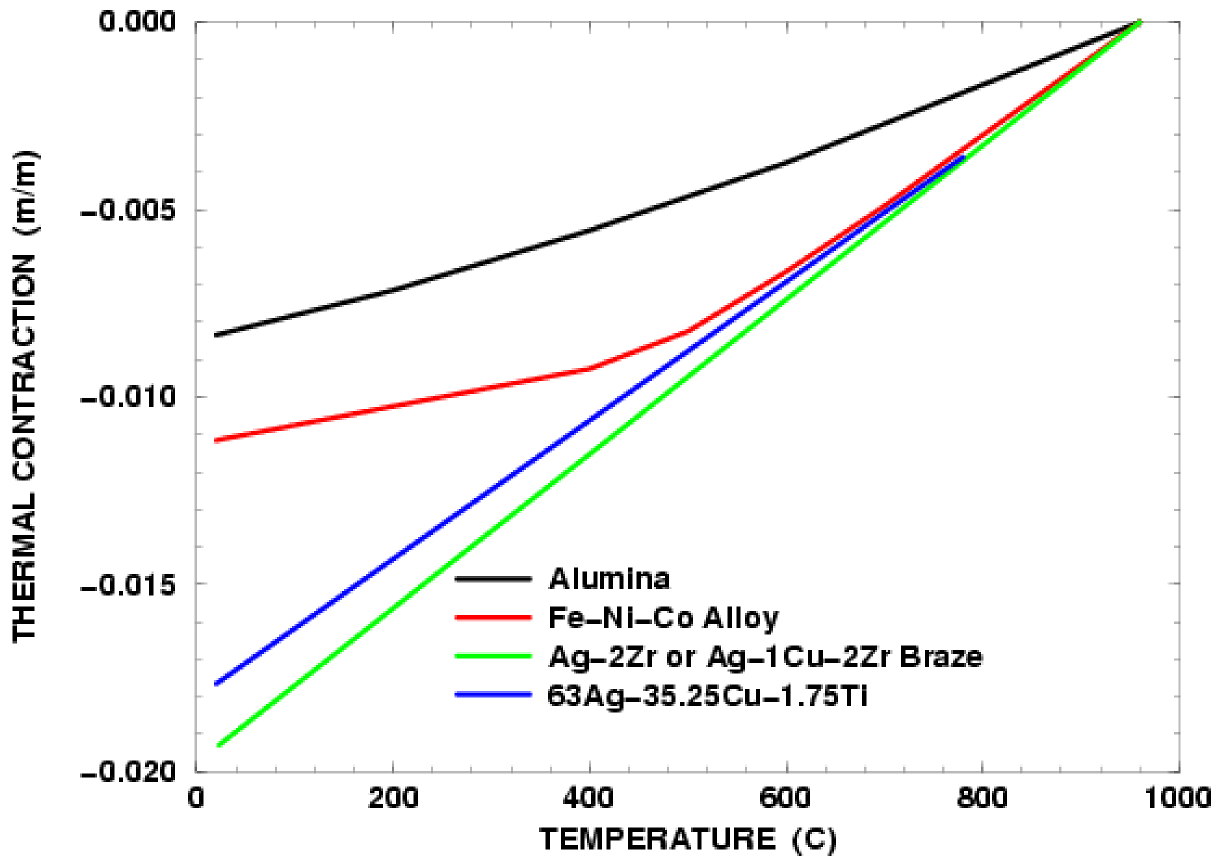


- solid lines show model predictions
- symbols show experimental results

Simulation of Metal-to-Ceramic Brazing

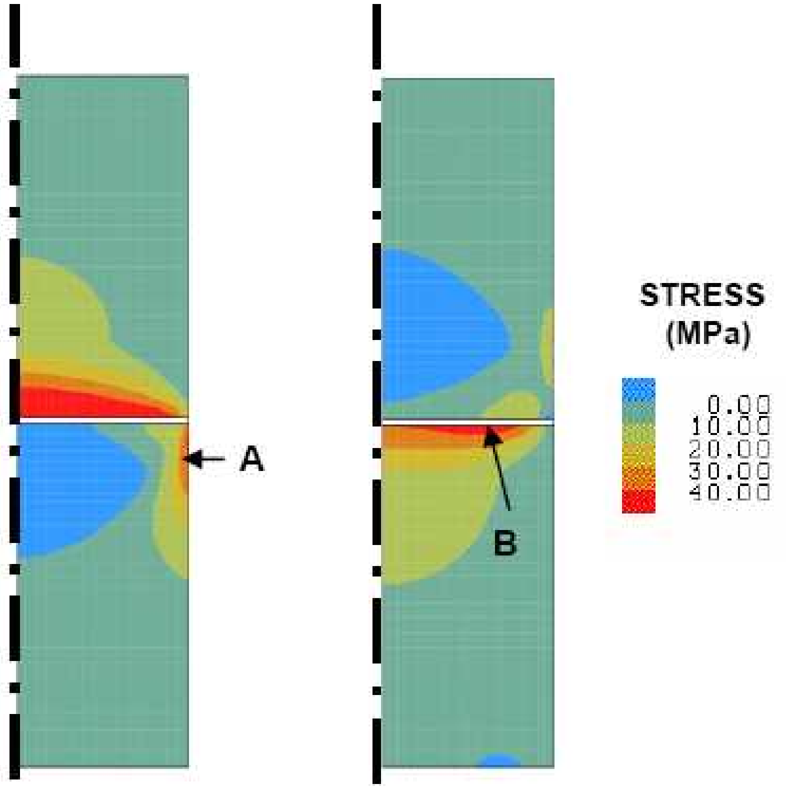


Axisymmetric finite element model



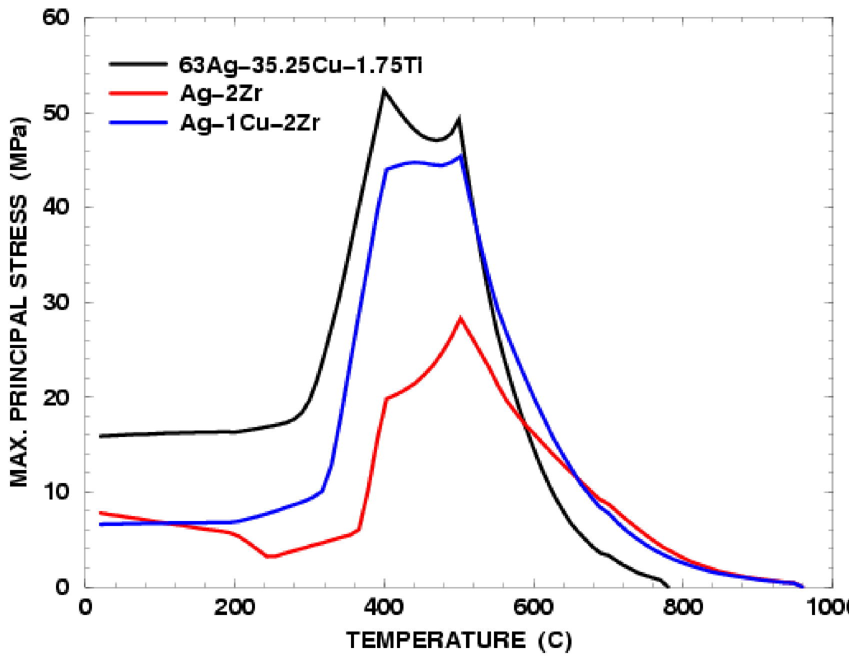
Thermal expansion of braze joint materials

Simulation of Metal-to-Ceramic Brazing



a. 1800 seconds
(490.0 °C)

b. 3600 seconds
(20.0 °C)



Max. Tensile Stress History
at Point A

Maximum tensile stress distribution in alumina ceramic during post-braze cooldown cycle, 97Ag-1Cu-2Zr

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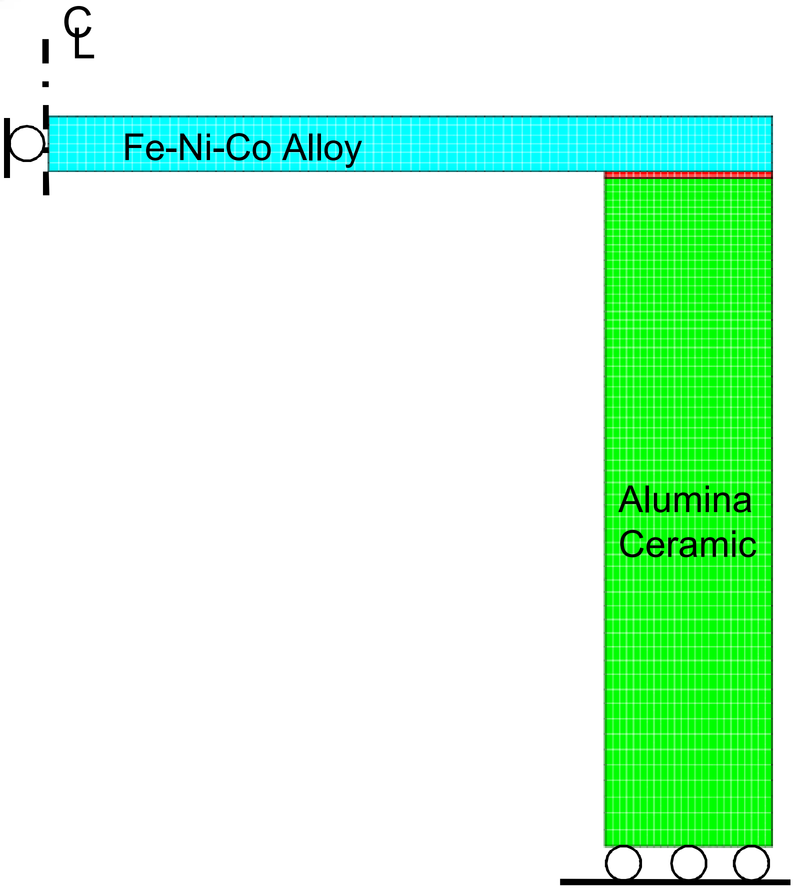
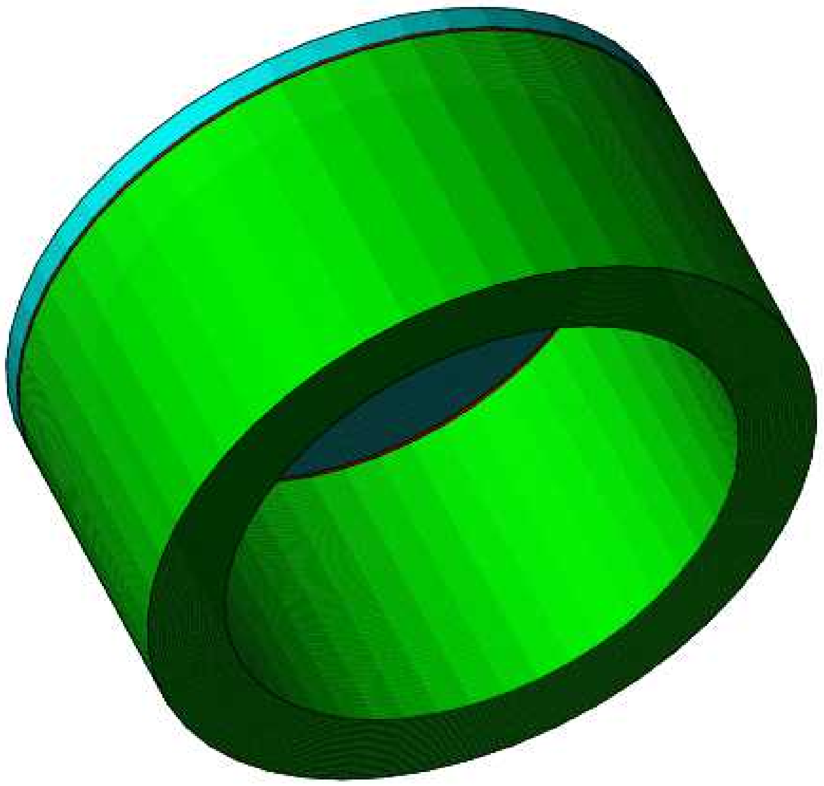
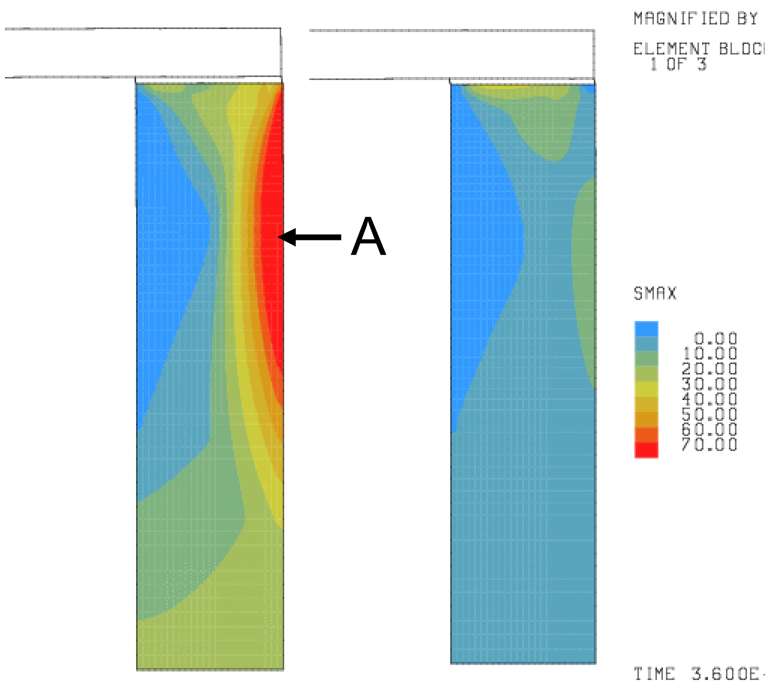
Simulation of Metal-to-Ceramic Brazing





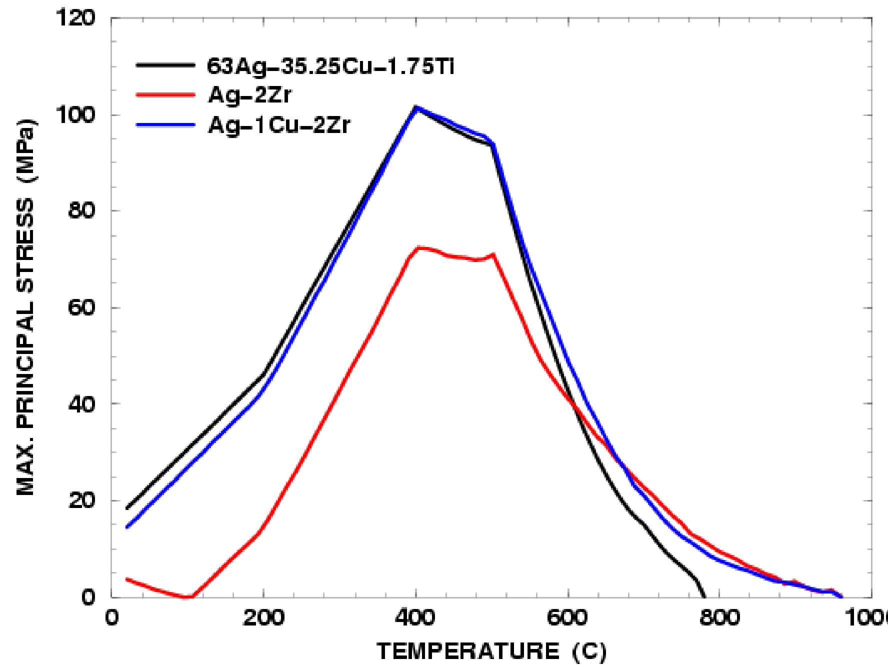
Axisymmetric finite element model
20.0 mm I.D. 26.0 mm O.D, 1.0 mm thick washer

Simulation of Metal-to-Ceramic Brazing



a. 2132 seconds (403.0 °C)

b. 3600 seconds (20.0 °C)



Maximum Tensile Stress History at Point A

Maximum tensile stress generated in alumina ceramic during post-braze cooldown cycle, 97Ag-1Cu-2Zr

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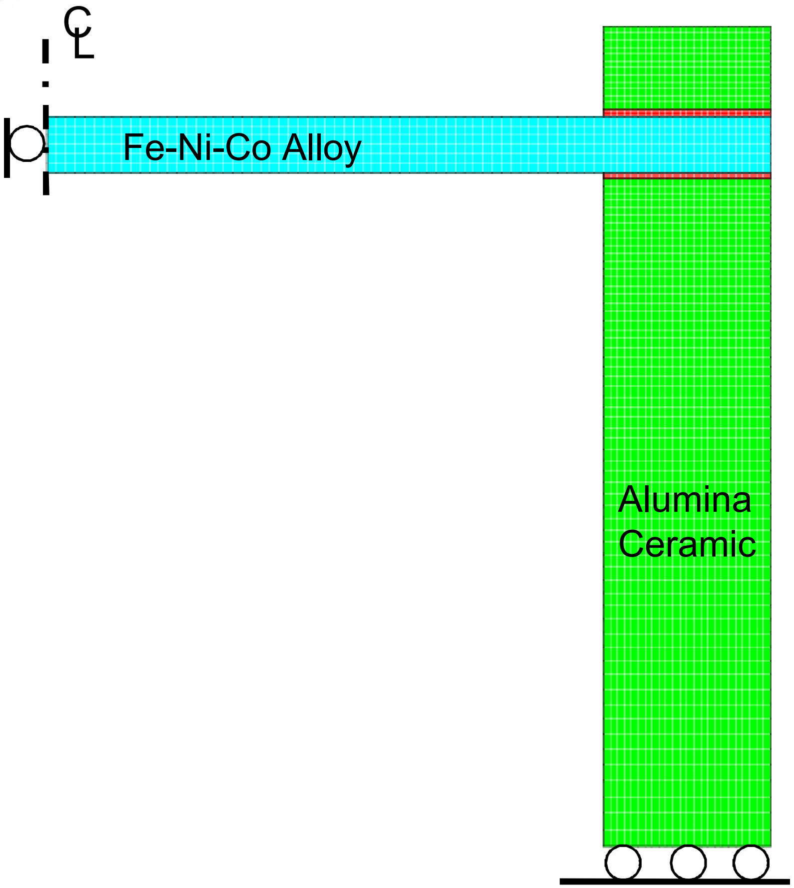
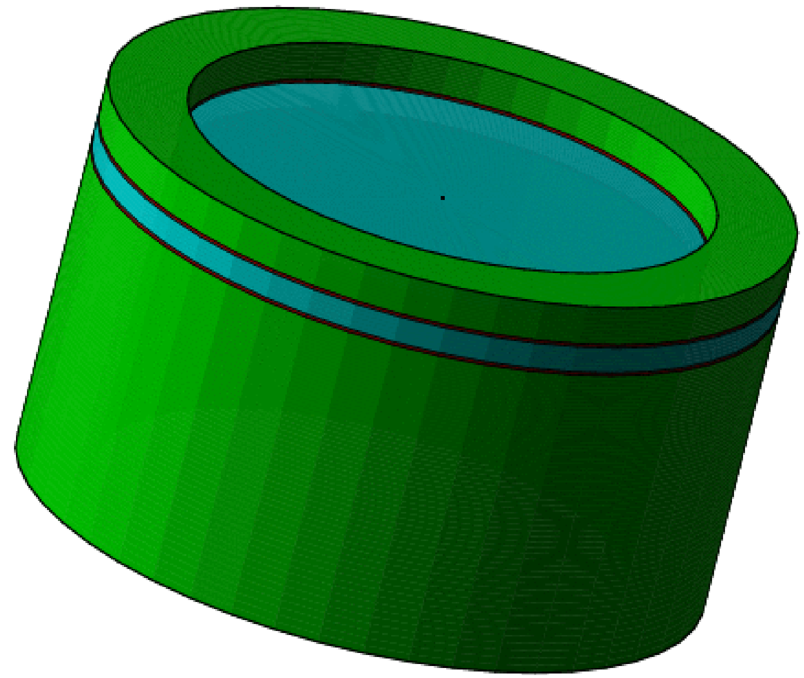
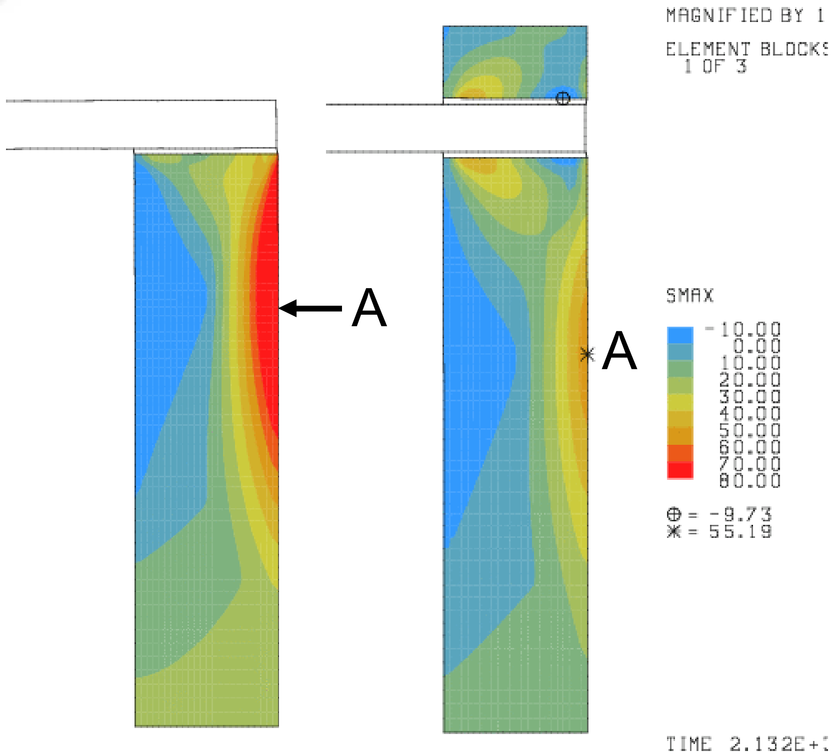
Simulation of Metal-to-Ceramic Brazing



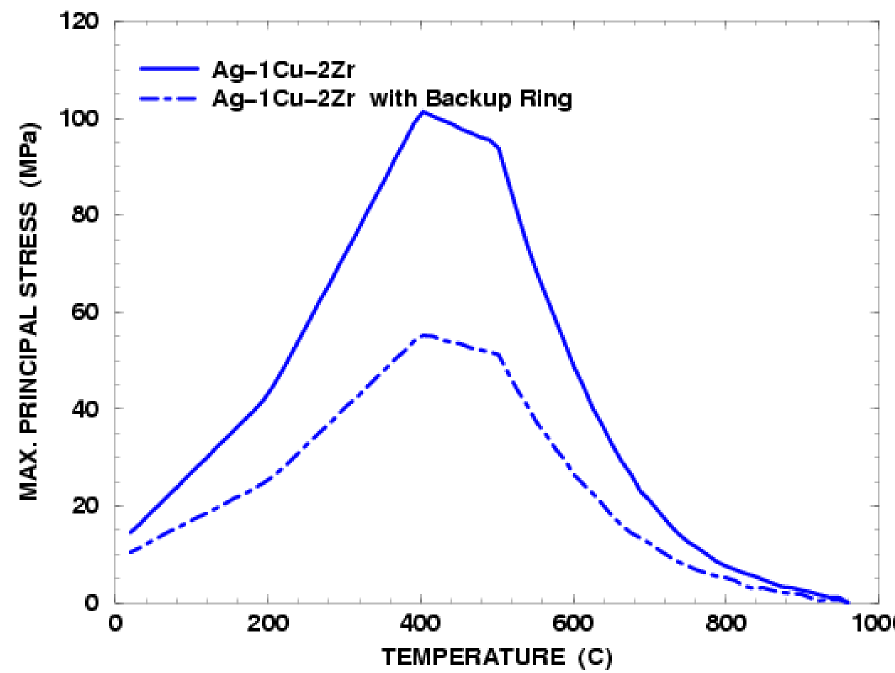


Axisymmetric finite element model
20.0 mm I.D. 26.0 mm O.D, 1.0 mm thick washer

Simulation of Metal-to-Ceramic Brazing



w/o backup ring (403.0 °C) with backup ring (403.0 °C)



Maximum Tensile Stress History at Point A

Maximum tensile stress generated in alumina ceramic during post-braze cooldown cycle, 97Ag-1Cu-2Zr

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Summary

- Viscoplastic models were developed for 3 active braze alloys: 63Ag-35.25Cu-1.75Ti, 98Ag-2Zr, 97Ag-1Cu-2Zr
- Parameters for the models were obtained from a combination of uniaxial compression and creep compression experiments
- Cyclic loading experiments are needed to identify both isotropic and kinematic hardening/recovery parameters.
- The models were used to investigate stress generated during metal-to-ceramic brazing.
- The peak ceramic stress generated during brazing of a Fe-Ni-Co alloy rod to alumina ceramic rod was highest when the lower temperature 63Ag-35.25Cu-1.75Ti braze alloy was used.
- Backup rings were shown to be effective in reducing both transient and residual tensile stress levels in the ceramic.

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