Welding Residual Stress Models
Material Properties

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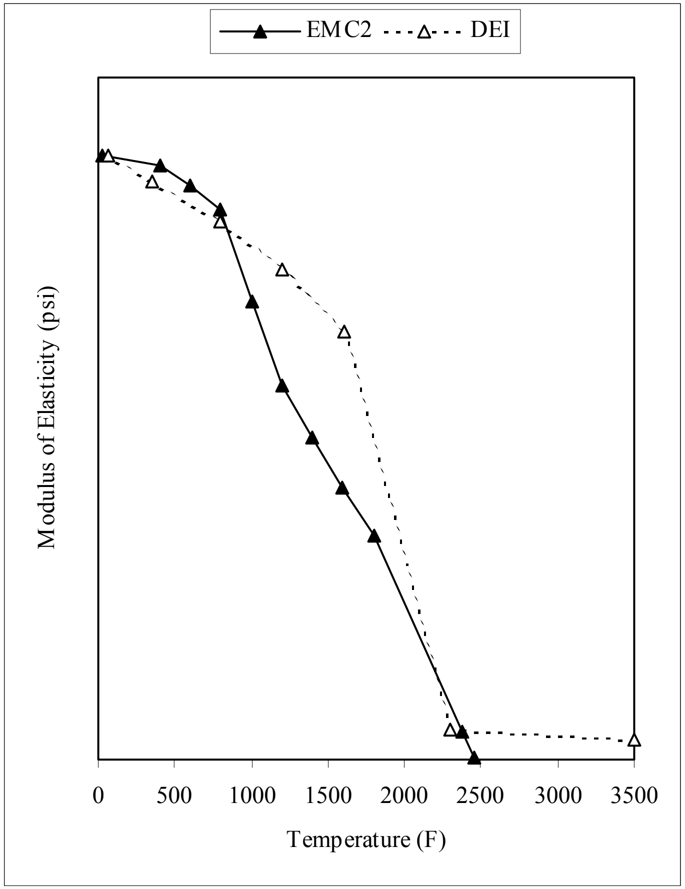
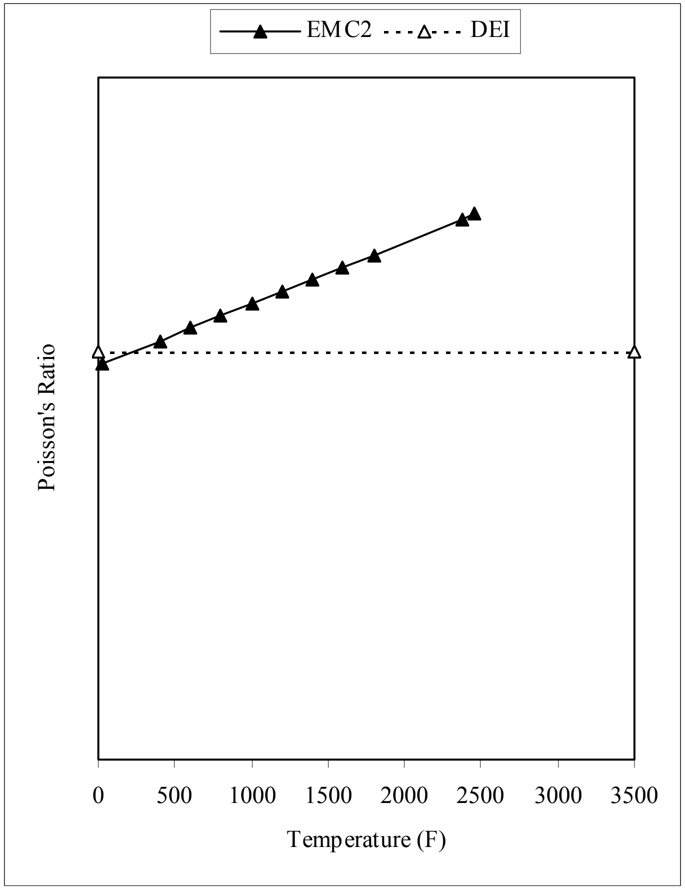
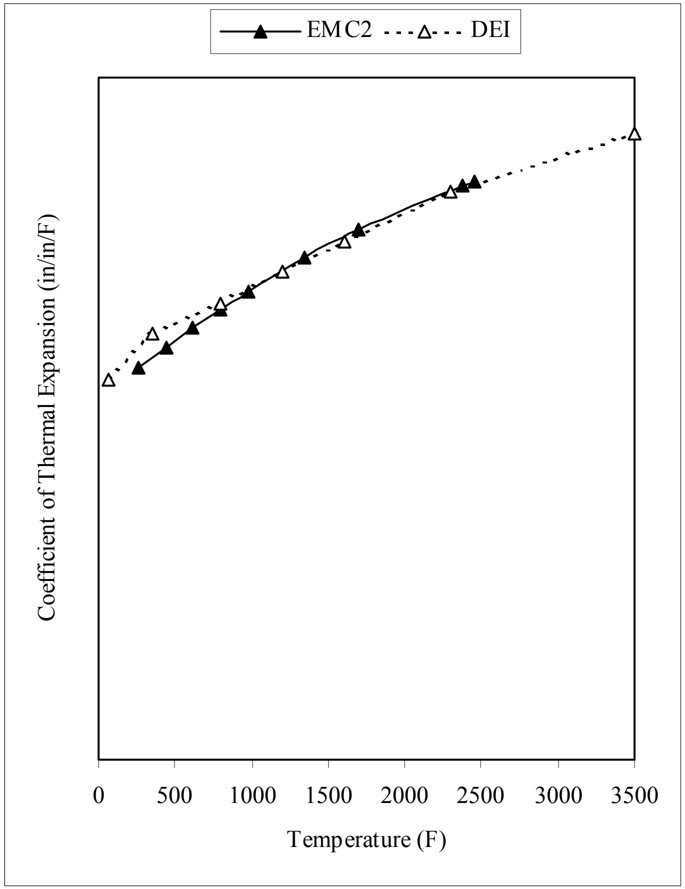
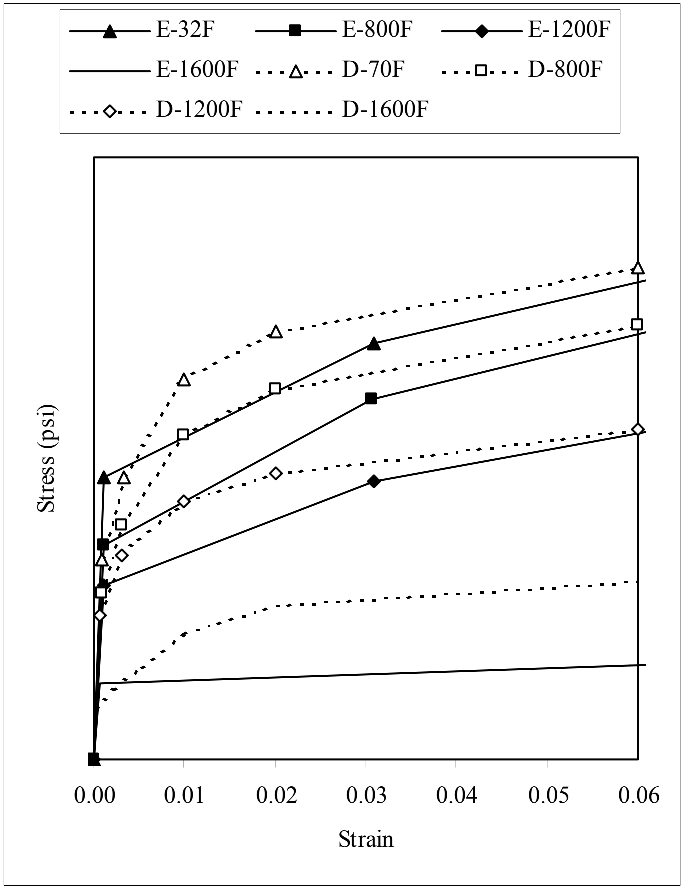
Comparison of DEI and EMC^2 Material Properties
Alloy 600 - Modulus and Poisson's Ratio





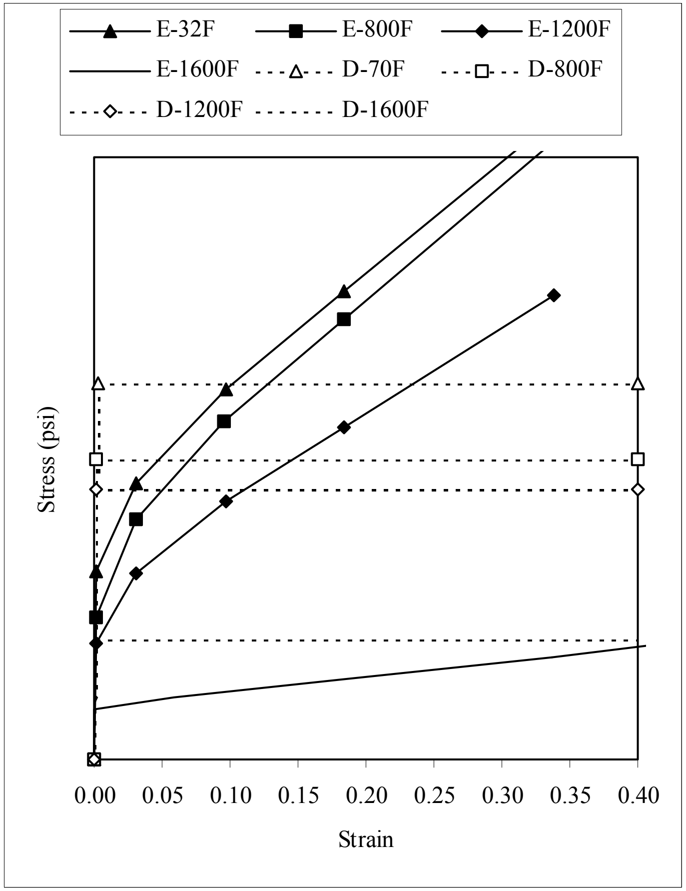
Comparison of DEI and EMC^2 Material Properties
Alloy 600 - Thermal Expansion and Stress-Strain



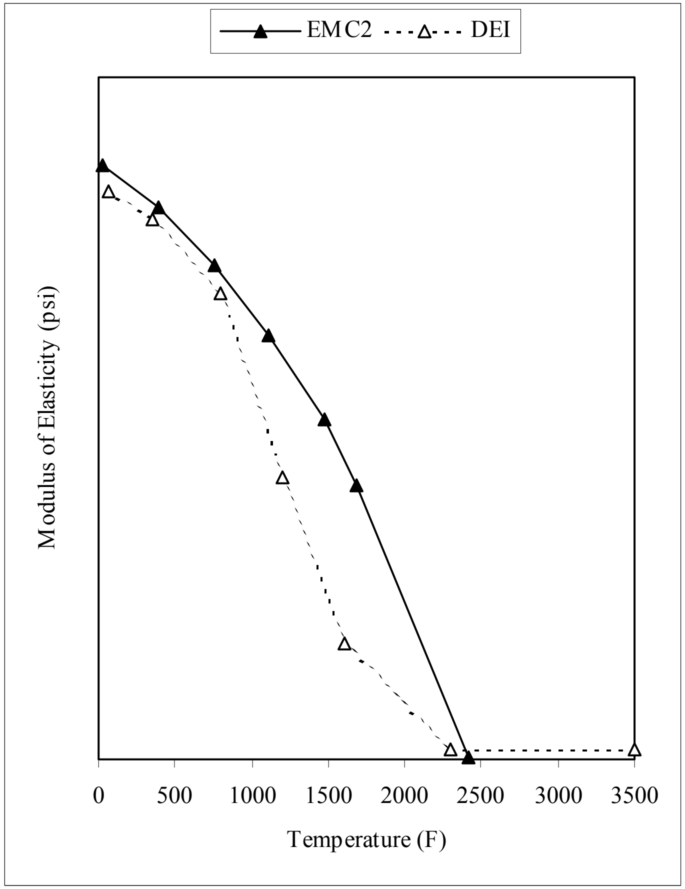


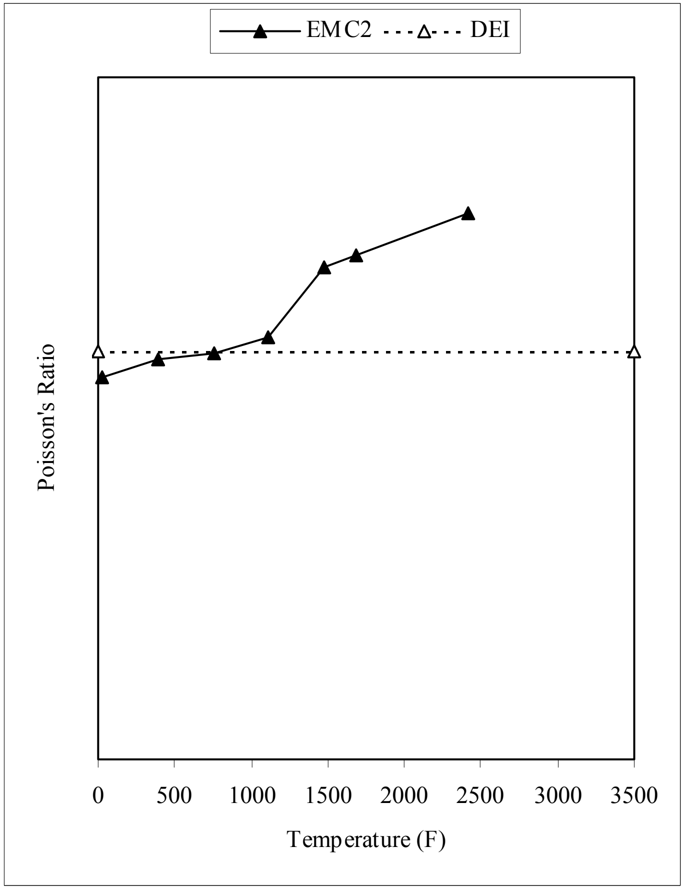
Comparison of DEI and EMC^2 Material Properties
Alloy 182 Weld

- EMC^2 has identical properties for Alloy 600 base metal and Alloy 182 welds
- DEI has two differences between the base metal and weld metal
  - Small difference in coefficient of thermal expansion
  - Significant difference in modeling stress-strain properties (See Slides 10-13 for discussion)

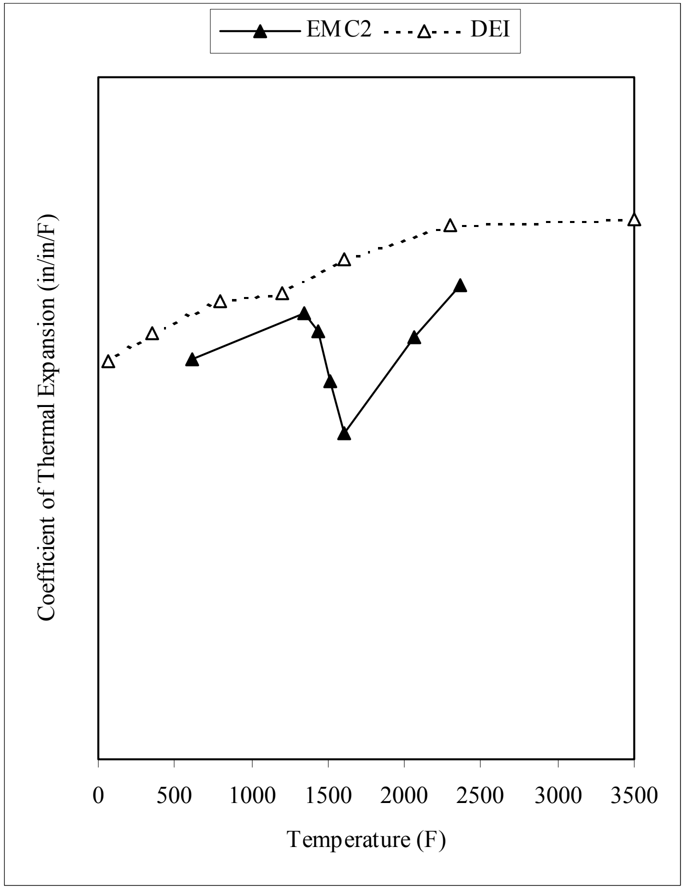


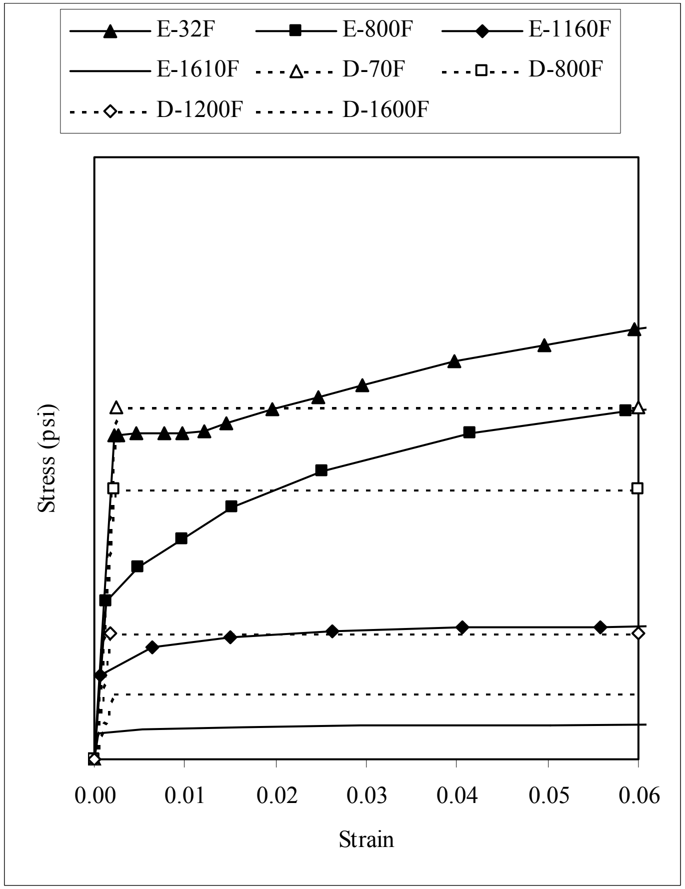
Comparison of DEI and EMC^2 Material Properties
Low Alloy Steel – Modulus and Poisson's Ratio



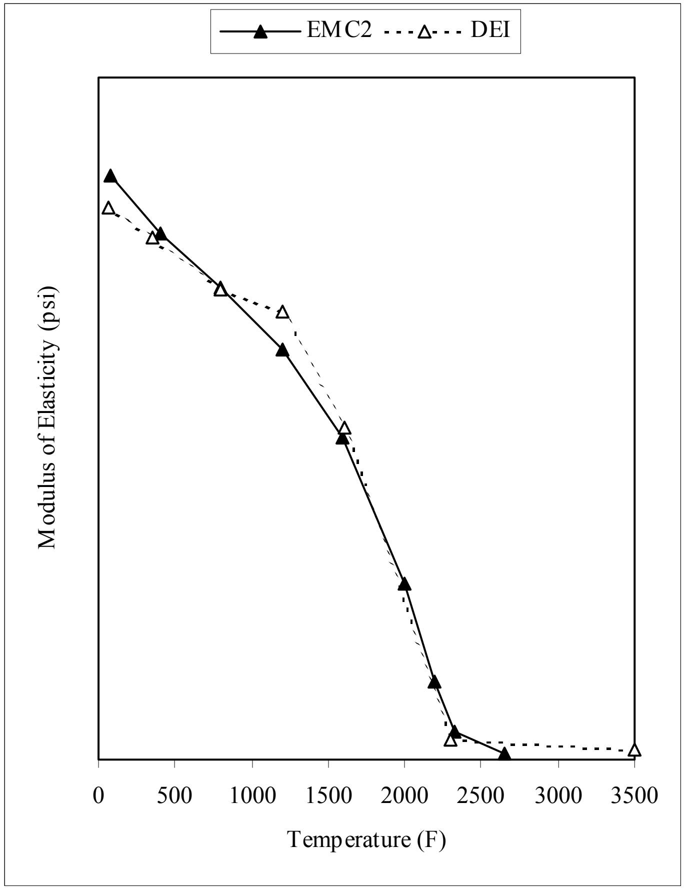


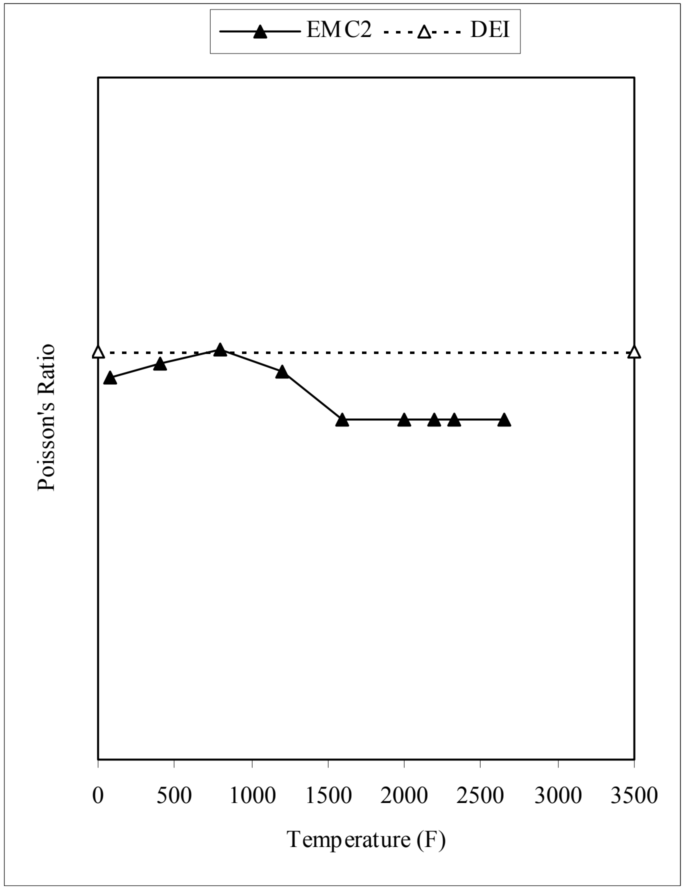
Comparison of DEI and EMC² Material Properties
Low Alloy Steel – Thermal Expansion and Stress-Strain



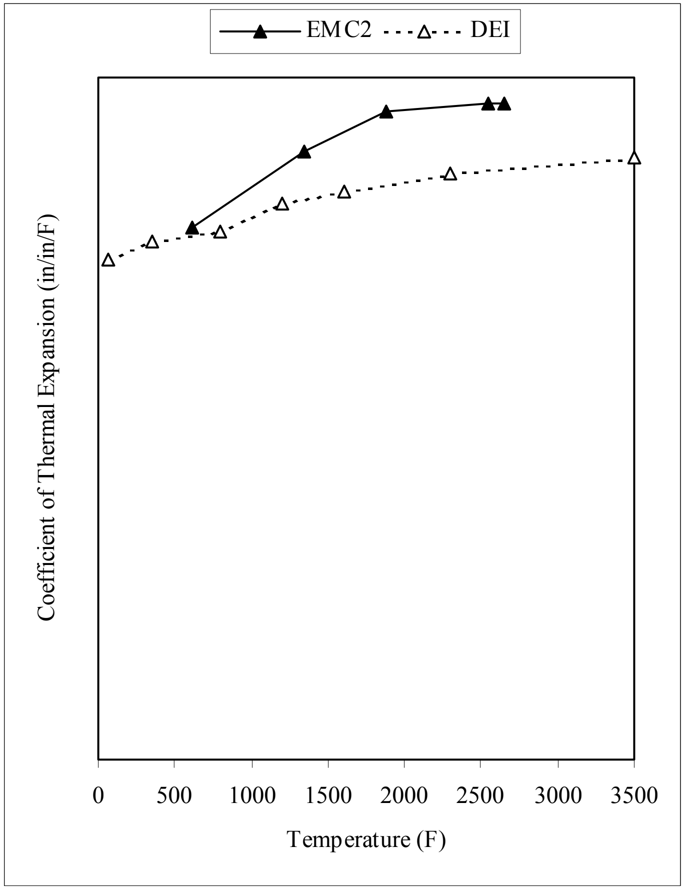


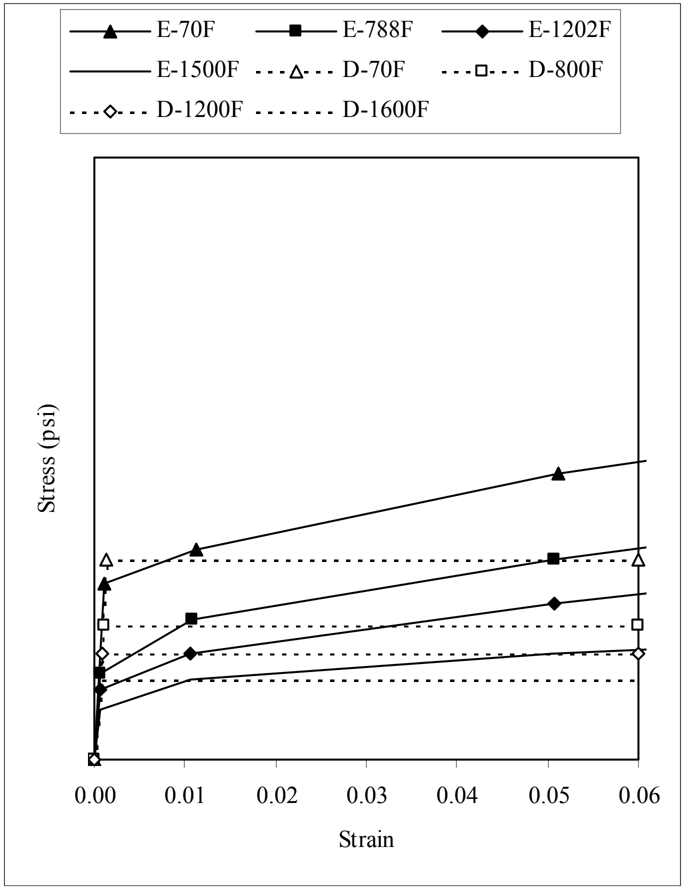
Comparison of DEI and EMC² Material Properties
SS Clad – Modulus and Poisson's Ratio





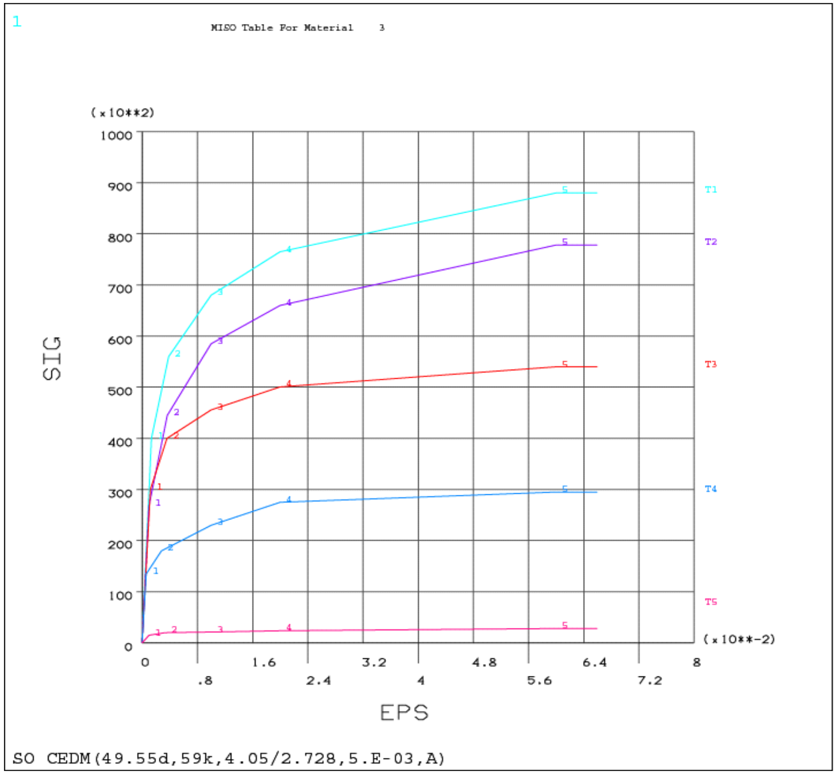
Comparison of DEI and EMC^2 Material Properties
SS Clad – Thermal Expansion and Stress-Strain





Weld Stress-Strain Curves
Early 1990's Model

- DEI's CRDM welding residual stress model was originally designed in the early 1990's for the purpose of simulating stresses on the nozzle ID surface
- Model made use of multilinear isotropic work hardening curves with similar shapes to those for Alloy 600 base material
- Yield strength as a function of temperature was derived from 0.2% offset yield data in ASME Code



Weld Stress-Strain Curves
Limitations of Original Model

- ANSYS predicted unrealistically high residual stresses in the weld metal (greater than 100 ksi)
  - The high weld stresses did not have a significant effect on nozzle ID stress levels, but were not representative of actual weld stresses
- High weld stresses were traced to work hardening behavior as the weld material solidifies from ≈3500 F to 1600 F
- ANSYS retains the plastic strain calculated at high temperatures, leading to high yield stress levels at lower temperatures
- This behavior is a limitation of the software, and does not represent a realistic model of the material behavior

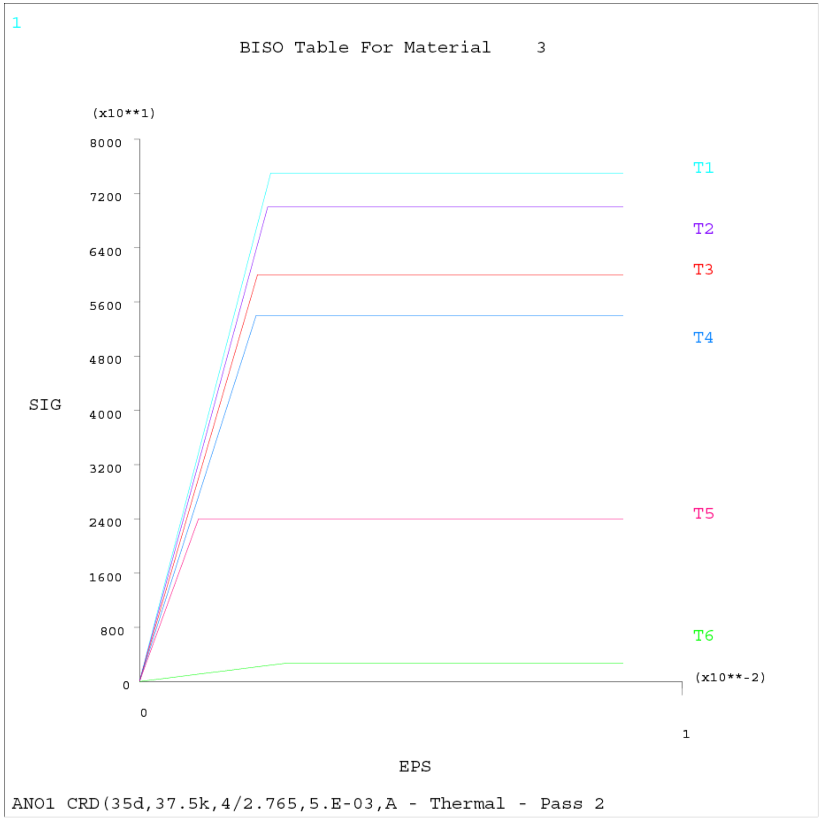
Weld Stress-Strain Curves
Revised Model (2001 and Later)

- Starting in early 2001, models were used to predict stresses in the weld and on the nozzle OD surface
- The issue of high-temperature work hardening was addressed by assuming elastic perfectly-plastic work hardening for the weld material
- Alloy 182 data published by Huntington Alloys supports the conclusion that the flow stress is a good approximation to the yield stress of the as-deposited weld material

Weld Stress-Strain Curves
Revised Model (2001 and Later)

- Current DEI models use elastic-perfectly plastic stress-strain curves for the Alloy 182 weld metal and buttering to avoid strain hardening issues

- Since stresses in the low-alloy steel vessel head are below yield this material is also modeled using elastic-perfectly plastic properties without compromising accuracy



Comparison of DEI and EMC^2 Properties
Conclusions

- Minor differences in modulus and coefficient of thermal expansion
  - DEI coefficient of thermal expansion for low-alloy steel was extrapolated for temperatures above ≈1200 F (actual steel temperatures <1000 F)
- Significant difference in modeling Poisson's ratio, but expected to have little effect on results
- Stress-strain curves for Alloy 600 base metal are very similar over range of strains encountered
  - DEI curve has more data points in area of greatest interest (near yield)
- Significant difference in modeling of Alloy 182 weld
  - EMC^2 models actual properties
  - DEI assumes elastic-perfectly plastic
  - DEI approach considered to represent actual residual stress levels in weld metal