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# Coupled Thermal-Mechanical Experiments for Validation of Pressurized, High Temperature Systems

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High fidelity finite element modeling of coupled thermal-mechanical failure processes in complex systems requires, as a precursor, high quality experimentation on several levels. The materials must be characterized such that the entire range of loading parameters is encompassed. Meaningful validation experiments must be developed that allow for the steady, incremental ascension of validation towards system level complexity and, eventually, predictability. This paper describes a combined experimental/modeling effort towards validating failure in pressurized, high temperature systems.

Instrumented, fully coupled thermal-mechanical experiments were conducted to provide validation data for finite element simulations of failure in pressurized, high temperature systems. The design and implementation of the experimental methodology is described in another paper of this conference [1]. Experimental coupling was accomplished on tubular 304L stainless steel specimens by imparting mechanical loading by internal pressurization and thermal loading by side radiant heating. Additionally, mechanical characterization experiments of the 304L stainless steel tube material was completed for development of a thermal elastic-plastic material constitutive model used in the finite element simulations of the validation experiments.

The tubular 304L stainless steel material was characterized in tension at a strain rate of 0.001/s from room temperature to 800°C. The tensile behavior was found to differ substantially from 304L bar stock material characterized in a prior study, with the plasticity characteristics and strain to failure differing at every test temperature. This data, shown in Figure 1, emphasizes the importance of characterizing material of the exact form that will be used in the validation experiment.

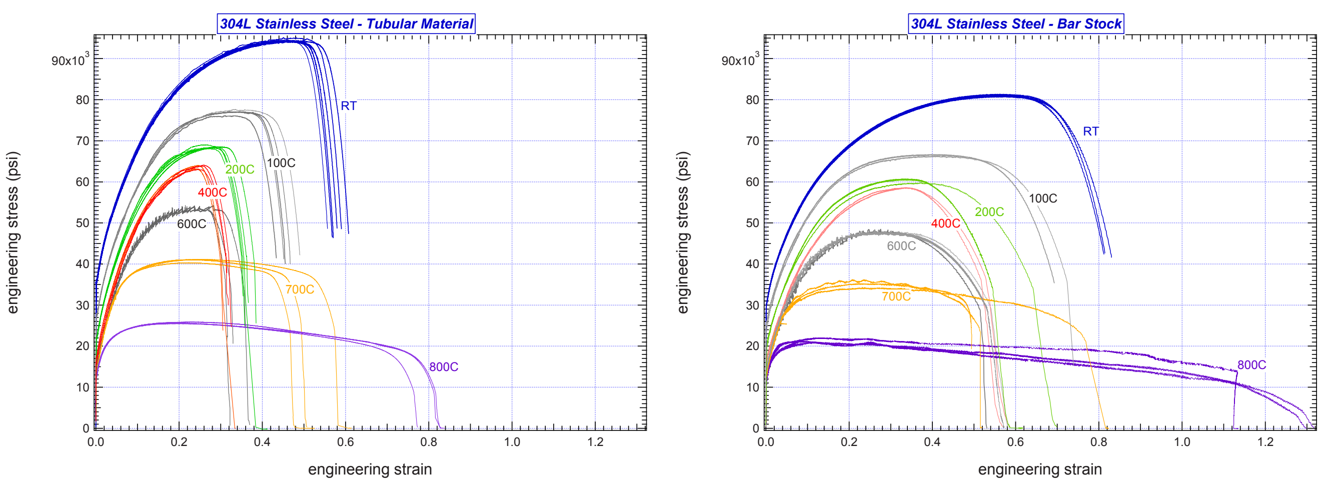


Fig. 1. Comparison of 304L stainless steel tensile behavior with material form

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The first generation validation specimen, shown in Figure 2, was machined from the 89 mm (3.5 in.) diameter tube with a wall thickness of 6.35 mm (0.25 in.). Specimens had an overall length of 355 mm (14 in.) and a reduced gage section with a wall thickness of 1.27 mm (0.05 in.). Specimens were instrumented with an array of thermocouples and validation experiments were conducted with various ramp rates of the thermal and mechanical (pressurization and axial load) loads. Figure 3 shows the thermal response of a specimen during the experiment. Pressure was ramped at a rate of 72 psi/min. from 40psi, and temperature at 32 degrees/minute from room temperature. A compressive axial load was ramped to compensate for the pressurization loading the fixtures. Specimen failure occurred after 1188 seconds, at a pressure of 1498 psi. A photograph of the failed specimen is shown in Figure 4. The loading inputs and measured thermal response were used in coupled finite element analyses to predict failure; the predictions were extremely close at 1213 seconds and 1533 psi. The next generation of validation experiments uses a similar geometry with additional complexity of a secondary reduced section.


Fig. 2. Validation specimen in fixtures

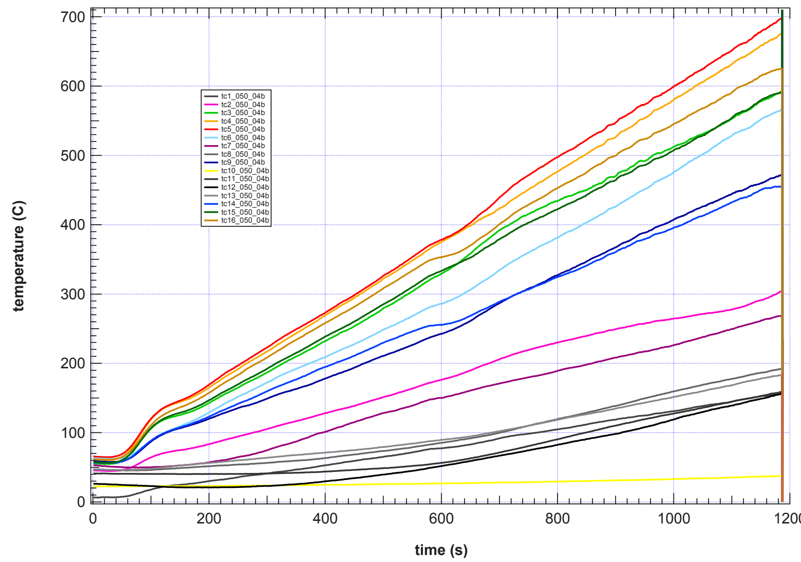


Fig. 3. Measured thermal response of specimen

Fig. 4. Failed validation specimen

## ACKNOWLEDGEMENTS

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## REFERENCES

1. Antoun, B. R., Dempsey, J. F., Wellman, G. W., Scherzinger, W. M., and Connelly, K., "Design and Implementation of Coupled Thermomechanical Failure Experiments," *Proceedings of the 2010 SEM Annual Conference and Exposition on Experimental and Applied Mechanics*, Indianapolis, Indiana, June 7-10, 2010.