SAND2022-2779C

Validation Experiments for Extensive Mechanical Deformation of a 304L Stainless Steel Geometry

Bonnie R. Antoun[1], Kimberley Mac Donald[1], Brandon Talamini[3], Andrew Stershic[1], Xai Lao[1], Amanda Jones[2], Sharlotte Kramer[2]

[1]Sandia National Laboratories, Livermore, CA 94551
[2]Sandia National Laboratories, Albuquerque, NM 87185
[3]Lawrence Livermore National Laboratory, Livermore, CA 94551

ABSTRACT
A complex can geometry was designed and built from 304L stainless steel to conduct model validation experiments for extensive mechanical deformation under complex loading conditions. Experiments were conducted in compression at a complex loading angle on a corner of the specimen at several loading rates, from 0.25 mm/s to 125 mm/s to study rate effects, including adiabatic heating. Experimental data collected included global three-axis load response, 3D DIC on two specimen sides and IR imaging of one specimen side. Additionally, a precise replica of each validation specimen was developed of each specimen post-test using a high-resolution optical 3D scanner.

Keywords: Validation, Deformation, 304L stainless steel, buckling

INTRODUCTION

To verify and validate computational modeling of ductile materials subjected to large deformation levels, significant experimental data and detailed, quantified observations are needed. The ductile material needs to be characterized under relevant loading states, loading rates and environments of interest to populate a relevant constitutive model, in this case an elastic-plastic constitutive model that includes failure. The model needs to include sufficient physics-based complexity to adequately represent the material response once the model has been implemented into a mechanics-based finite element program. The ability of the developed computational model and associated tools to predict deformation and failure must then be assessed with well-designed validation experiments.

The ductile material used in the study was in the form of a 190 mm (7.5 inch) diameter bar of 304L-VAR stainless steel. The material was previously characterized in tension, torsion and shear with additional notched tensile testing [1, 2]. A validation experiment was conceptualized and developed, with a geometry constraint of fitting within the bar stock. After a preliminary design of general shape and size was completed, several finite element simulations were completed to assess possible experimental boundary conditions, loading angles, loading rates and geometric features such as wall thickness and various radii. The validation specimen geometry was ultimately defined as a can-like structure with one open end, machined from the bar stock to eliminate the need for welds so that the material deformation, buckling, and possible tearing was prominent and uninfluenced by weldments. A schematic and photograph of the extraction locations of the six validation specimens from the bar stock are shown in Figure 1. Nominally, the specimens were 70 mm tall, 130 mm long and 70 mm wide with a wall thickness of 1.5 mm. The corner to which the load is applied in the experiments was located to coincide spatially with mechanical characterization data.

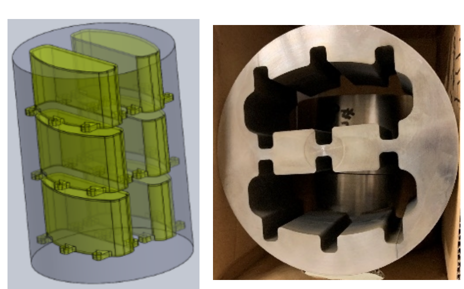

Fig. 1 Validation specimen extraction mapping and post-machined 304L-VAR stainless steel bar.

EXPERIMENTS AND RESULTS

Experiments were designed and conducted to produce a set of combined global and local response data towards validation of plasticity and damage models and methods for a ductile material. Experiments were conducted in compression at a complex loading angle on a corner of the specimen attached with six ¼-28 bolts to a custom steel attachment fixtures that rigidly held the specimen at 45 degrees to vertical and 30 degree tilt, see Figure 2. Experiments were conducted on a 220 Kip MTS test frame (see Figure 3) at four loading rates of 0.25, 2.5, 25 and 125 mm/s.

Experimental data collected included global three-axis load response, 3D DIC on two specimen sides and IR imaging of one specimen side. The load response is shown in Figure 4; the axial load increased with loading rate, as anticipated. The features of the load response were repeatable and correspond to various deformation and buckling stages that are captured well by the modeling efforts underway.

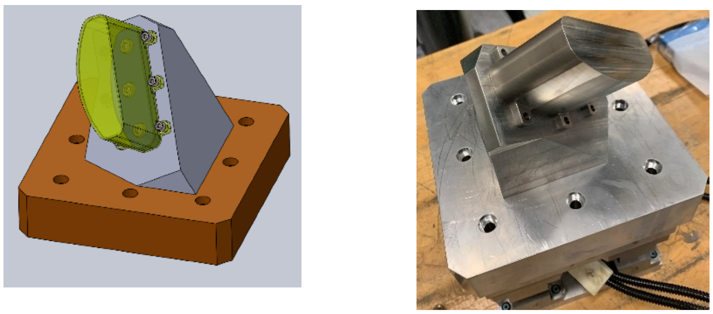

Fig. 2 Rendering and photograph of validation specimen attached to fixture.

Fig. 3 MTS test frame and close-up of a specimen set up and ready for testing.

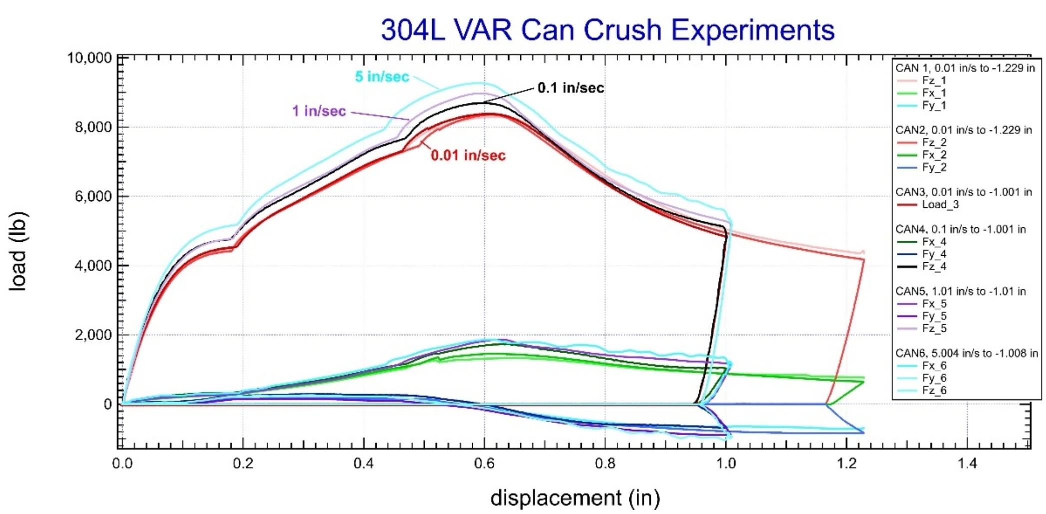

Fig. 4 Load response in x, y, z directions during loading at four rates.

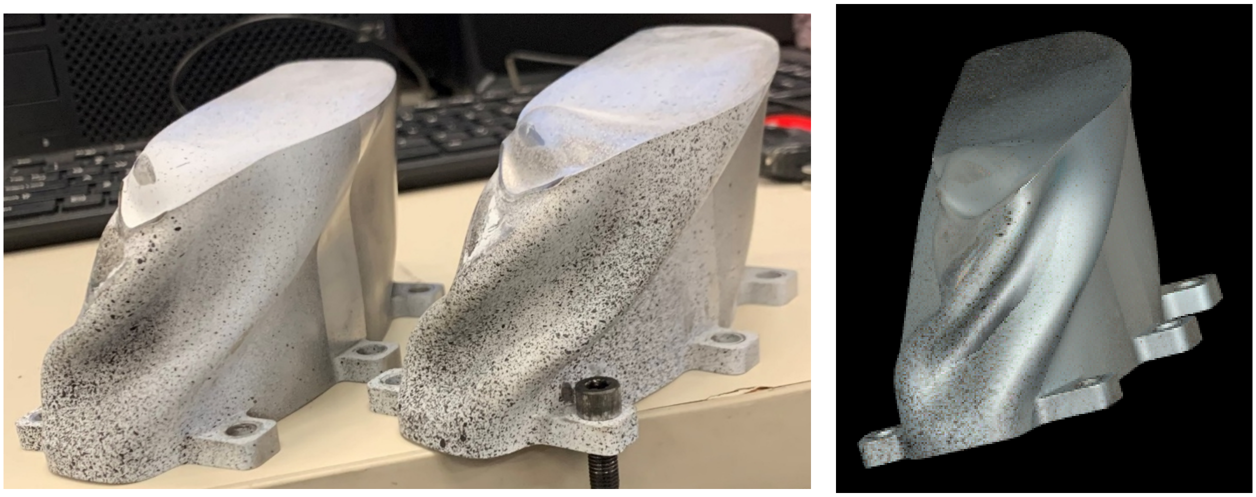

Fig. 5 Post-test photographs showing deformation and buckling, 3D replica using optical scanner.

CONCLUSION

Large deformation experiments were successfully designed and executed towards validating modeling efforts of ductile deformation and failure. The load response was rate dependent and the final deformed shape changed slightly with rate. DIC and IR imaging results are currently being used as additional metrics to assess model accuracy in more detail but the global load and deformation and buckling response is captured well. Direct comparisons of the model predictions are being made with the digital replicas of the final deformed geometries.

ACKNOWLEDGEMENTS

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

REFERENCES

[1] Kramer, S.L., Jones, A., Jin, H., and Lu, W-Y., DE Ductile Failure Data, Sandia National Laboratories (unpublished), 2018.

[2] Lu, WY., Jin, H., Foulk, J., Ostien, J., Kramer, S.L., and Jones, A., Solid Cylinder Torsion for Large Shear Deformation and Failure of Engineering Materials. *Exp Mech* **61,** 307–320 (2021). https://doi.org/10.1007/s11340-020-00620-6