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Sandia National Laboratories
Albuquerque, New Mexico 87185

date: September 16, 2021

to: Distribution

from: E. Corona

subject: Rate and temperature independent model calibrations for J2 plasticity and Wilkins failure models for 17-4PH H1150 stainless steel

1 Introduction

This memo's objective is to report a calibration of the J2 plasticity model with the Wilkins ductile failure criterion for 17-4 PH H1150 stainless steel under slow loading at room temperature. The calibration of the hardening function was based on uniaxial tension tests, while that of the failure model included data from tension tests on notched specimens, a butterfly specimen shear test, and a set of interrupted compression tests on shear hat specimens. The procedure was that described in [1], minus the rate and temperature dependence.

2 Calibration of the Hardening Function

Figure 1 shows the results of two uniaxial tension tests conducted at strain rates of 1.6×10^{-4} and 0.1 1/s, but the target of the calibration was the slower experiment. The curve for the faster one is only provided to indicate the differences between the two strain rates. A power-law-hardening form given by

$$\bar{\sigma} = \sigma_y + A\left(\bar{\varepsilon}^p\right)^n$$

was used to represent the hardening function. Here $\bar{\sigma}$ and $\bar{\varepsilon}^p$ are the equivalent stress and plastic strain, while σ_y, A and n are the yield stress, hardening constant and hardening exponent whose values are found by a trial-and-error calibration procedure. The calibrated values are $\sigma_y = 80$ ksi, $A = 112$ ksi and $n = 0.14$, respectively. From [2], the Young's modulus and Poisson's ratio are $E = 28.5\times10^3$ ksi, and $\nu = 0.27$. Reasonable agreement between test and experiment exists over most of the strain range, indicating that the power-law expression is appropriate for this material.

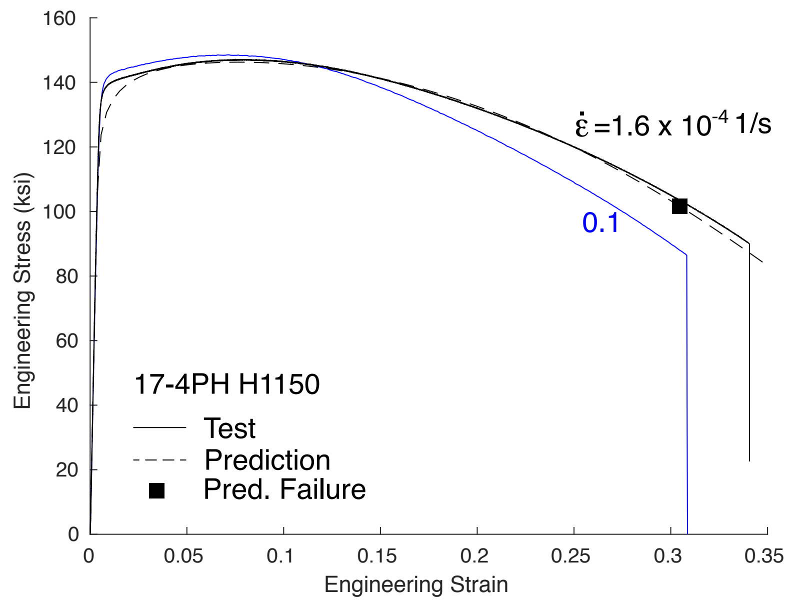

Figure 1. Uniaxial tension engineering stress-strain curves. Test and prediction from calibration.

3 Calibration of the Wilkins Failure Criterion

Load-deflection curves from the notch tension tests, both from tests and predictions, are shown in Fig. 2. Here the radius of the notch is r and the radius of the narrowest section is R. The agreement between the experiment and the simulations is good overall, the most noticeable differences being observed for the sharpest notch (lowest r/R). Load-deflection curves for the butterfly test are shown in Fig. 3. As mentioned in [1], the main difficulty with the butterfly test is to prescribe the appropriate boundary conditions to track the complex deformation of the specimen. As a result, the agreement between test and predictions does not look as close as for the other tests, mostly because the boundary conditions in the analysis were prescribed using simple two-segment piecewise linear functions. The approximation in the vicinity of the failure in the test is reasonably good, but the history is somewhat imperfect. Finally, Fig. 4 shows a similar comparison for the hat specimen. The prediction is reasonable through the yield knee of the curve, but then deviates spomewhat as the curve from the predictions is a little steeper than measured.

The displacements at failure were taken as shown in Table 1 for each of the five tests. All but the one for the hat specimen correspond to the displacements at which the specimens failed catastrophically. The value for the hat specimen was determined from examination of the photographs of the sectioned specimens for each of the interrupted tests, as shown in Fig. 4 as a likely displacement for the initiation of fracture. Following the procedure described in [1] to determine the parameters of the Wilkins model gave the model parameters shown in Table 2.

Table 1. Target displacements at failure.

Test	Notch 1.6	Notch 0.96	Notch 0.32	Butterfly	Hat
Displ. (in)	0.0424	0.0276	0.0145	0.019	0.045

Table 2. Values of Wilkin's model parameters.

Parameter	a (ksi)	α	β	D_{cr}
Value	300	1.6	1.7	2.0

Predicted displacements for the initiation of failure obtained from the failure criterion are shown as solid squares in Figs. 1 to 4.

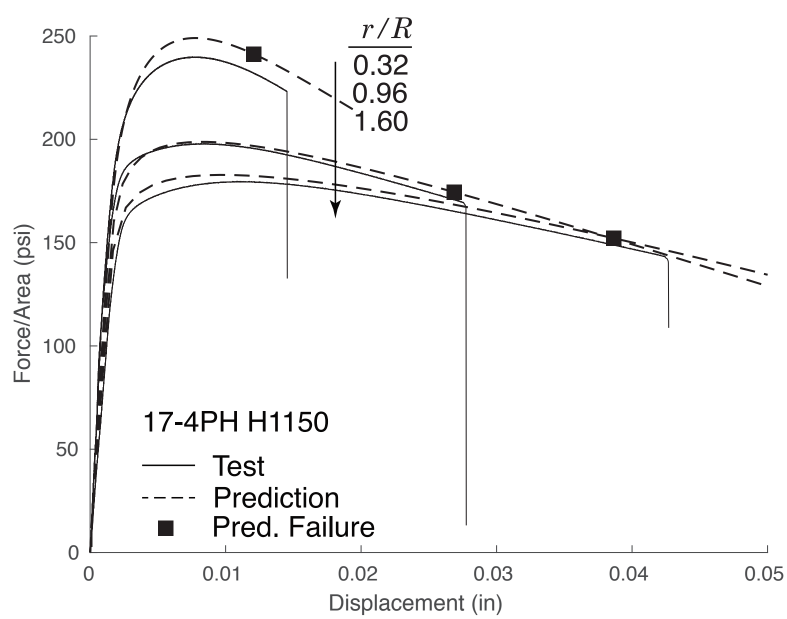

Figure 2. Load-deflection curves from the butterfly specimen.

4 Conclusions

Material model parameter fits have been presented for 17-4PH H1150 stainless steel. Appendix A contains the calibrated model input for the J2 plasticity model. The system of units is US-customary with force in pounds, distance in inches and time in seconds.

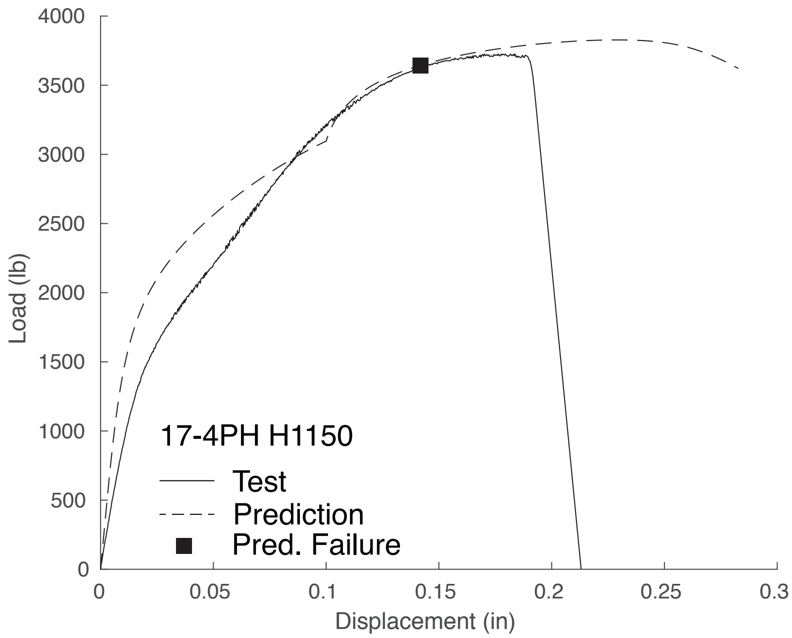

Figure 3. Load-deflection curves from the butterfly specimen.

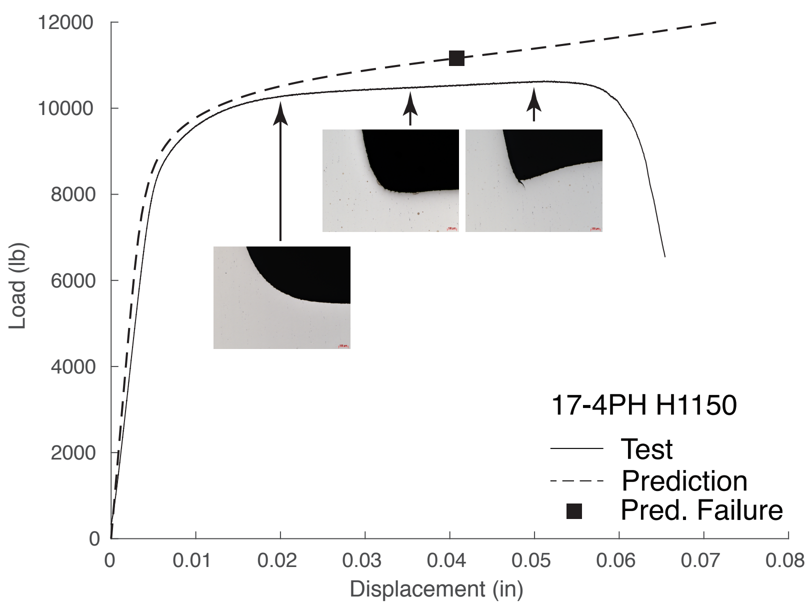

Figure 4. Load-deflection curves from the tests on a hat specimen.

Acknowledgments

Many thanks go to Amanda Jones and Sharlotte Kramer for coordinating the testing of the material. Brian Lester's review and suggestions for improvement of this memo are also acknowledged.

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References

[1] Corona, E., Kramer, S.L.B., Lester, B.T., Jones, A.R., Sanborn, B., Shand, L. and Fietek, C.J. (2021). Thermal-mechanical elastic-plastic and ductile failure model calibrations for 6061-T651 aluminum alloy. Sandia Technical Report SAND2021-2983.

[2] Batelle Memorial Institute (2013). Metallic material properties development and standardization (MMPDS-08).

Appendix A

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# 17-4 PH H1150
# Units: US-customary:  lb-in-s
#{matl = '174_SS'}
#{modl = 'j2_plasticity'}
begin property specification for material 174_SS
density = 7.25e-4
begin parameters for model j2_plasticity
youngs modulus = 28.5e6
poissons ratio = 0.27
yield stress = 80.e3
                        hardening model = power_law
                        hardening constant = 112.e3
                        hardening exponent = 0.14
               failure model = modular_failure
                   critical failure parameter = 2.0
                 pressure multiplier = wilkins
                   wilkins pressure = 300.e3
                   wilkins alpha = 1.6
                 lode angle multiplier = wilkins
                   wilkins beta = 1.7
end parameters for model j2_plasticity
end property specification for material 174_SS
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