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Ductile Failure Under Combined Tension and Shear

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Abstract. Recent tension-torsion experiments on Al-6061-T6 tubes have shown that strains inside localization zones that precede failure are much higher than previously reported. Furthermore, contrary to some other results, the measured strain at failure monotonically decreases as the triaxiality increases. This paper will review these results and subsequently present numerical simulations that demonstrate that suitably calibrated plasticity models can reproduce the measured deformations. The strains in the simulations approach the values measured at failure without the introduction of damage.

1. Extended Summary

Scales et al. [1] reported experimental results from experiments in which custom Al-6061-T6 tubular specimens are loaded to failure under radial paths of shear and tension, spanning a range of triaxiality from 0.07 to 0.58. For all cases the nominal stress developed maxima followed by localized deformation into a circumferential band with width the order of the wall thickness. Stereo digital image correlation (DIC) was used to monitor the deformation inside these localization zones up to failure. The measured strains at failure are plotted against triaxiality in figure 1. Clearly they monotonically decrease as the triaxiality increases, a trend that is in concert with long accepted theory but contrary to more recent results [2]. Furthermore, the failure strains are significantly larger than previously reported values approaching measurements based on statistical grain-level measurements [3]. In addition, scanning electron microscopic evaluation of the failure zones showed that void formation and coalescence is delayed until very close to the onset of failure.

This paper will first review the tension-torsion experiments and will subsequently present numerical simulations that reproduce the measured responses and localized deformations. The 18-parameter, non-quadratic, anisotropic yield function of Barlat et al. [4] is adopted for this effort. The model is calibrated using data from the tension-torsion experiments and a set of internal pressure-axial tension experiments conducted on the same stock tubing. A material hardening response to large strains is extracted from a pure shear test and the constitutive model is implemented in a finite element model.

The numerical results show that the measured responses and localization to strains that approach the values measured at failure can be reproduced without the introduction of damage if the following requirements are met: (a) a properly calibrated anisotropic plasticity model; (b) a stress-strain response that correctly represents the material behavior to large strains; and (c) a refined solid element mesh that can capture the high deformation gradients that develop.

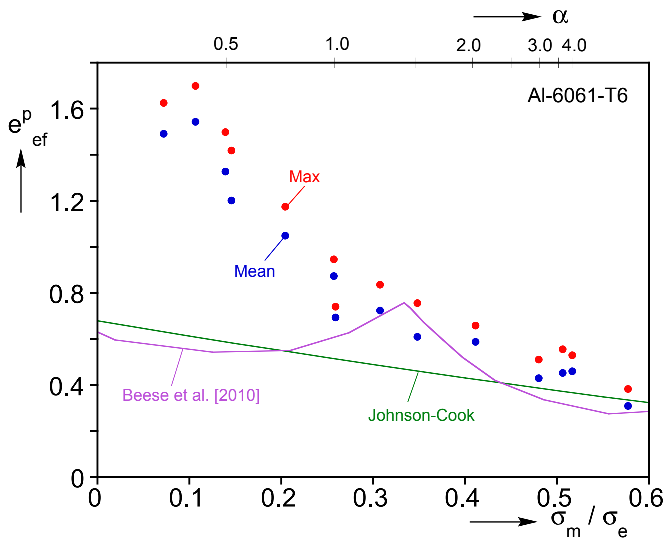

Figure 1. Measured failure strains plotted against triaxiality. Included are maximum and mean values from inside the localization zones. Drawn with solid lines are failure strains reported in Beese et al. [2], and values based on the Johnson-Cook failure criterion.

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