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subject: ***Experimentally Determined Anisotropic Yield Surfaces for Al 7079***

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Abstract:

Isotropic von Mises and anisotropic Hill yield surfaces for Al 7079 were fit using experimental data gathered from 12 dog-bone specimens that captured the highly variable microstructural texture of the aluminum alloy. Strain gauges or the digital image correlation technique were utilized to determine the strain histories in the specimen as they were subjected to uniaxial tension. The final yield surface fits displayed a high degree of variability that was dependent upon how the yield functions were calculated, i.e. which size and shape information was used. The findings display that a model with a higher number of anisotropic parameters is needed to better and more consistently capture the anisotropic properties of Al 7079, such as the Barlat, Yld2004-18, model that has 20 parameters.

Introduction:

The manufacturing techniques and methods used in the processing of metal alloys can dramatically change the microstructural texture of a material and significantly influence its continuum level performance. Al 7079 cylindrical extrusions exhibit a highly textured microstructure and can be expected to exhibit anisotropic yield characteristics at the continuum level. Figure 1 displays a sketch of a cylindrical extrusion for Al 7079 and Figure 2 shows two electron backscatter diffraction images that highlight the highly textured grain orientations for the two section cuts denoted in Fig. 1.

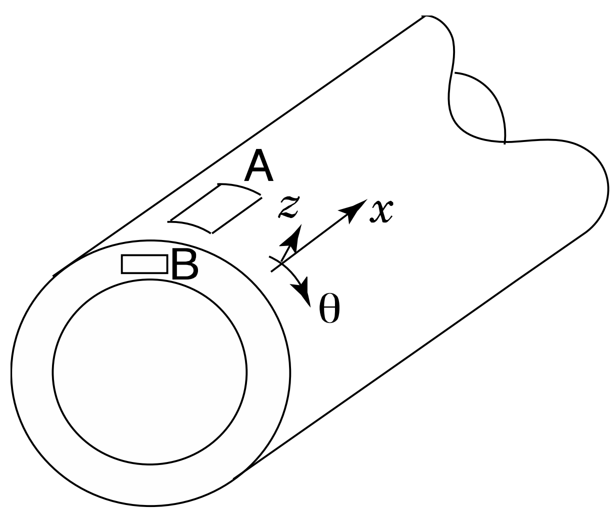

Fig. 1. Cylindrical Extrusion

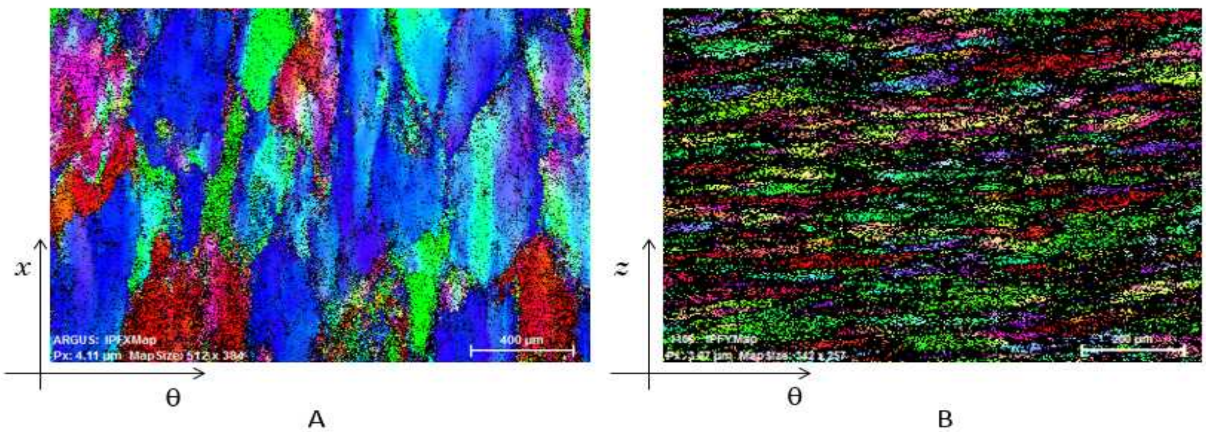

Fig. 2. Electron Backscatter Diffraction images of Al 7079.

The texture variability of extruded Al 7079 along its cylindrical coordinates warrants a need to quantify its anisotropic response to load. Developing an anisotropic material model, specifically a yield surface for Al 7079 that captures the elastic-plastic regime of the material, will allow for solid mechanics simulations to provide more accurate results and effectively lead to a higher level of surety in design and service for projects of interest to Sandia National Laboratories.

Specimen Design and Experimental Methods:

Two different sizes of dog bone specimens were gathered from the extruded cylinder of Al 7079. Differing from traditional dog bone specimens, the cross section of the gauge length of the specimen was square – this geometry was essential as it allowed for the determination of the lateral strains on the orthogonal faces of the specimen under uniaxial load. The orientations of the small specimens (A, B, C) can be seen in Figure 3. Three specimen orientations at 45^o, 60^o and 90^o with respect to the extrusion direction were obtained from slab A. The overall sizes of the A, B, and C orientation specimens was limited due to the fact that the section cuts are placed through the thickness of the cylinder, which had an original thickness of (9/10)”. The cross sections of these specimens measured approximately (1/16)” on the side. The P orientation specimens were so that they laid in the x-θ plane - see Figure 4. Ultimately, there were 12 different specimens developed out of the four orientation cuts (three from A, one each from B, C, and seven from P) and three of each specimen type have or will be tested for matters of repeatability.

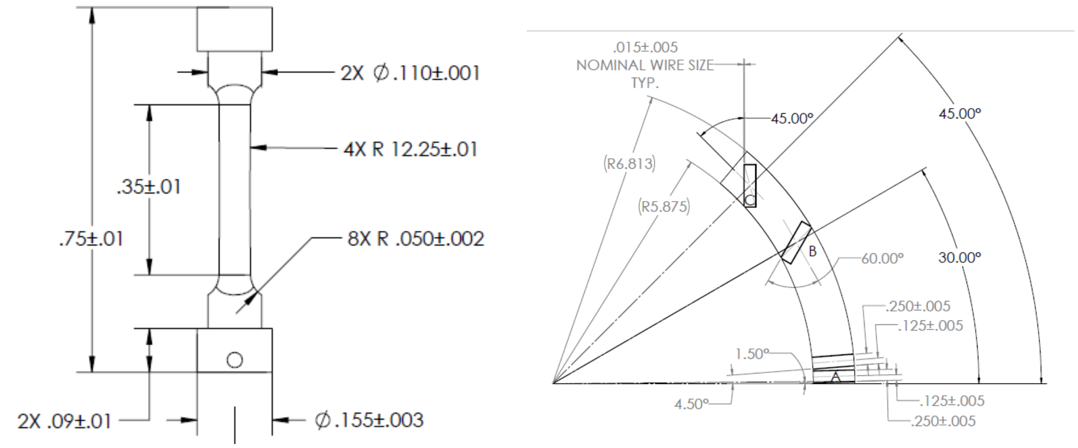

Fig. 3. A, B, and C Specimen Design and Orientation – all measurements in inches.

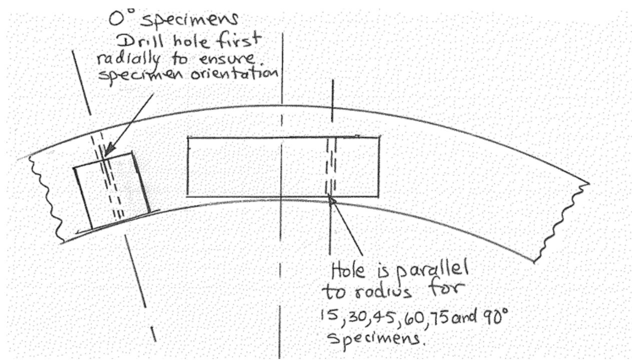

Fig. 4. P Specimen Orientation.

Each of the 12 specimens was tested under uniaxial tension using a standard load frame. The P orientation, due to its larger cross-sectional area, employed rosette strain gauges on all faces of the specimen's gauge length to gather the longitudinal and lateral strains. The A, B, and C specimens employed orthogonally placed DIC stereo rigs to capture the strain fields on either side of the tested specimens – all of the DIC data were post-processed in VIC3D and yielded regional strain and deformation data. Figure 5 displays the DIC set-up that captured the strain history on the orthogonal faces of the A, B, and C specimen orientations.

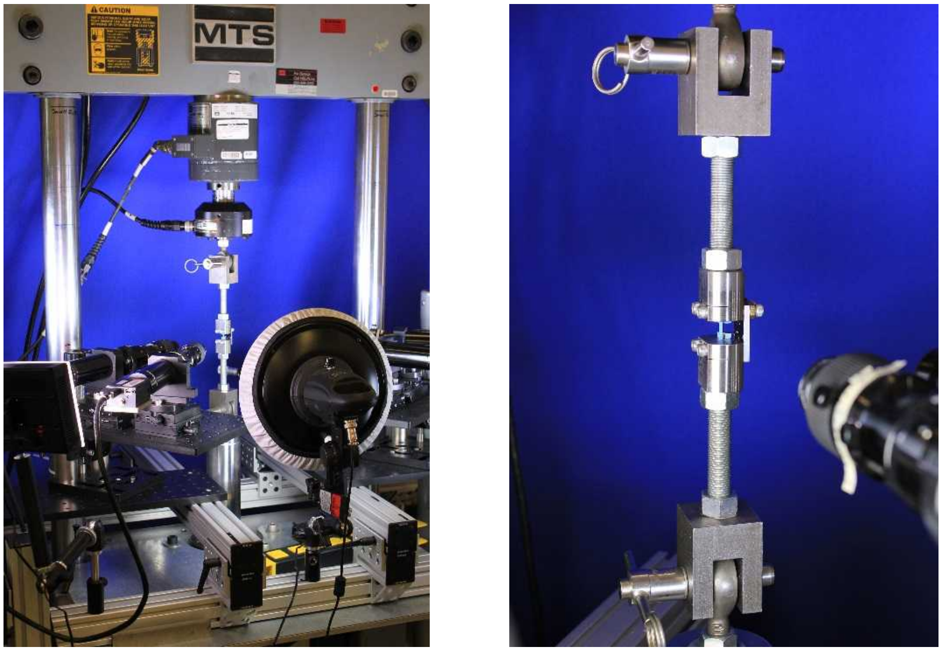

Fig. 5. Experimental DIC Setup.

In order to select a reliable analysis method to determine each specimen's associated stress-strain curve and plastic strain response, two different approaches were taken to investigating the collected strain and deformation data. The first method, which was significantly less intensive, placed one 4.2mm by 1.2mm rectangle and a 1.2mm by 1.2mm square along the critical section of specimen – the areas were defined as R_0 and R_1. The second method implemented two sets of parallel lines populated with 25 individual points that also encapsulated the critical section of the specimen. Figure 6 displays each of these analysis methods. Using both of these methods, the longitudinal and lateral strains were compared for matters of precision – it was found that they were nearly replicates of one another. Figure 7 and Figure 8 display the longitudinal and lateral strain histories of specimen A-45-15 using both the area and extensometer/line method. Ultimately, the rectangular method was used due to the fact it was less intensive and saved significant amounts of calculation time.

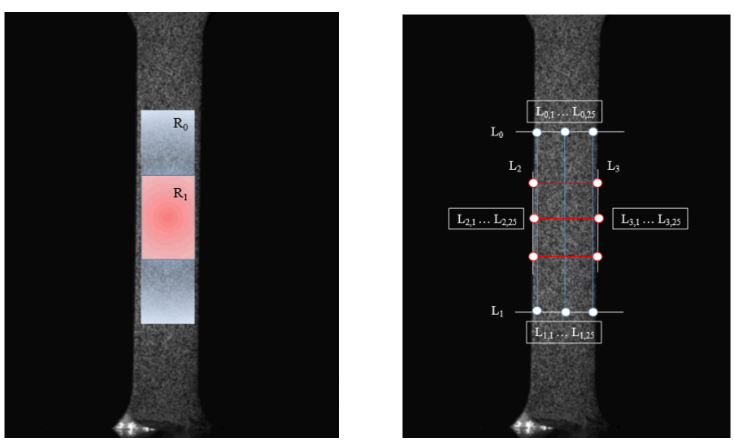

Fig. 6. Area and Line/Extensometers Analysis Methods.

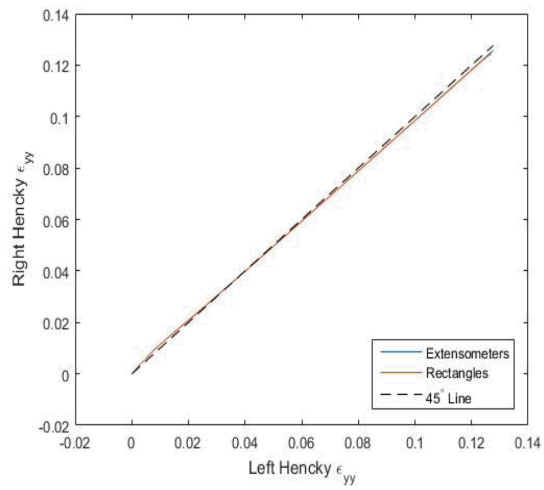

Fig. 7. A-45-15 Longitudinal Strain history for both analysis methods.

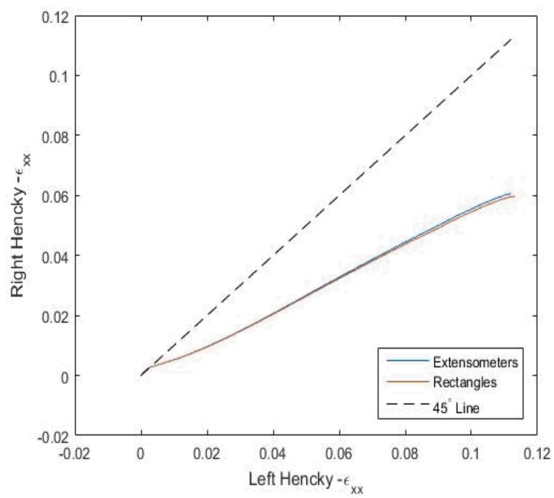

Fig. 8. A-45-15 Lateral Strain history for both analysis methods.

Findings:

Following the analysis of the data for the 5 different A, B, and C specimen orientation cuts, the different stress-strain curves were plotted together to gather an understanding of how the specimen orientation influenced its response. Figure 9 displays stress-strain response curves for one each of the A, B, and C dog bone specimen orientations. Figure 10 displays the plastic lateral strains of all of the test A, B, and C specimen orientations where each of the repeated tests were included.

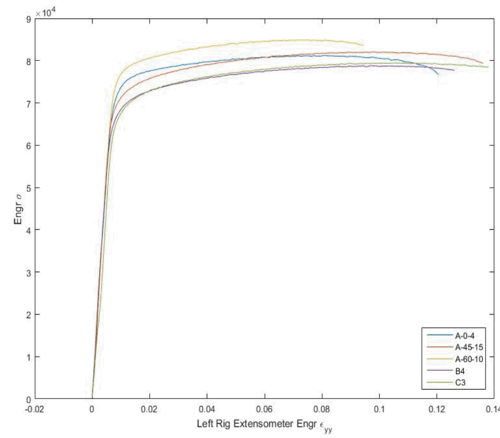

Fig. 9. Stress-Strain Response Curves for Specimen Cuts A, B, and C.

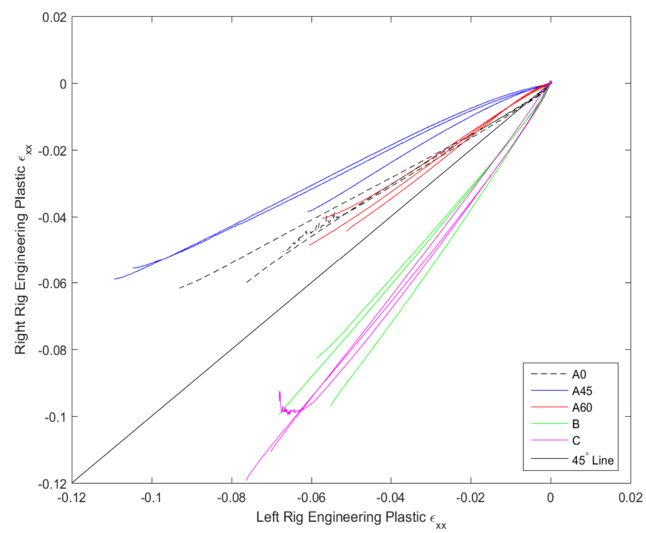

Fig. 10. Plastic Lateral Strain Response for Specimen Cuts A, B, and C.

Once the stress-strain and the lateral plastic strain response curves were plotted, a value of plastic work was selected that correlated a longitudinal strain of 1.5 in the P specimen aligned with the extrusion axis (532 psi). The associated value of plastic work was used to determine the point at which the yield stress and Lankford ratio would be measured for each specimen. These two values effectively allowed for the von Mises and Hill yield functions to be fit. The von Mises yield criterion assumes the material to be perfectly isotropic, while Hill adapts the yield function to include anisotropic weights (F, G, H, L, M, N) that can be solved for using size (yield stress) or shape (Lankford ratio) data. Equations 1 and 2 below display the von Mises and Hill yield functions. The yield surfaces for associate values of plastic work equivalent to 532 psi can be found in Figure 11.

$$\sigma_0^2 = \frac{1}{2}[(\sigma_{11}-\sigma_{22})^2+(\sigma_{22}-\sigma_{33})^2+(\sigma_{33}-\sigma_{11})^2+6(\sigma_{12}^2+\sigma_{23}^2+\sigma_{31}^2)] = 3J_2 \quad \textbf{Eq. 1}$$

$$\varphi(\boldsymbol{\sigma})^2 = F(\hat{\sigma}_{22}-\hat{\sigma}_{33})^2+G(\hat{\sigma}_{33}-\hat{\sigma}_{11})^2+H(\hat{\sigma}_{11}-\hat{\sigma}_{22})^2+2L\hat{\sigma}_{23}^2+2M\hat{\sigma}_{31}^2+2N\hat{\sigma}_{12}^2 \quad \textbf{Eq. 2}$$

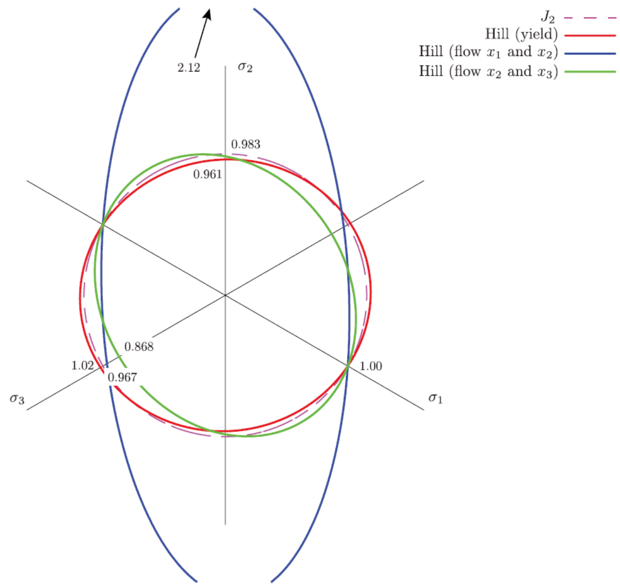

Fig. 11. von Mises and Hill Yield Surface Fits.

Conclusions:

The yield surfaces shown in Figure 11 detail how the method in which the Hill yield surface is solved, i.e. which size and shape information is implemented to solve for the Hill parameters, can drastically alter the realization of the surface. The final results display that neither the von Mises nor Hill yield surfaces repeatedly represent how the Al 7079 is influenced under loading. The lack of repeatability of the yield surface is largely dependent upon the mathematical formulation of the yield function and the associated number of parameters, weights, and error reduction techniques that can be implemented. The Yld2004-18p is a 20 parameter anisotropic yield function that should be able to better characterize Al 7079.

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