Wrinkling and Creasing in Crystalline Metals under Bending

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Abstract

Creasing first reported by Gent (1999) in elastomers under bending has been extensively studied and widely predicted numerically for elastomeric materials. This presentation uses experiments and numerical simulations to show that creasing is a mode of failure for metal alloys as well. The creasing was observed in the concertina folds of axially crushed aluminum 6061-T6 tubes. As is well known, the folding can lead to tensile fracture and tearing. However, it has been observed that concurrently the compressed sides of the folds tend to develop wrinkles that lead to cleft-like features. Careful microscopic examination showed that, as the bending in the folds increases, the amplitude of the wrinkles increases and they evolve into folds, creases, and dangerous sharp discontinuities. Metallographic examination of axial sections of axisymmetric concertina folds of several tubes revealed that the surface wrinkles encompass several grains, which deform and conform to the imposed local geometric changes. This implies that this surface instability is mainly governed by continuum level kinematics. The grain deformation conforms to the growth of the wrinkles, to the subsequent folds, and to the early stages of creasing that follows. As the creases deepen and develop into clefts, the highly deformed microstructure appears to interact more strongly with these surface features.

The events observed in the experiments were simulated using an axisymmetric finite element analysis of the concertina folding in a tube under axial compression. An independently calibrated non-quadratic anisotropic constitutive model is used to model the elastic-plastic behavior of the material. The analysis simulates successfully the development of several concertina folds in the model tube. Special attention is paid to the evolution of surface instabilities on the intrados of one of the folds, which was discretized with a sufficiently fine mesh. Instability was primed by the introduction of measured surface roughness to the inner surface of this fold. As the local compressive strain reaches a level of about 50%, surface wrinkles develop, and as the local bending increases, their amplitude grows. With additional bending, the wrinkles evolve into local folds and creases that resemble surface features observed in the experiments. The presentation will use details of the experiments and the microscopic evaluation of the surface wrinkles, clefts, and creases to motivate the numerical modeling performed, and will discuss the sensitivity of the surface instabilities on model parameters.

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