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Multiscale experimental investigation and numerical simulation of deformation and failure in polycrystalline alloys under shear loading

Ghahremaninezhad, Ali, a.ghahremani@miami.edu, University of Miami; Ravi-Chandar, Krishnaswamy, University of Texas at Austin, United States

ABSTRACT

Recently, there has been a revived interest in ductile fracture of metallic alloys, especially under dominant shear loading condition. Conventional ductile fracture models such as the Gurson–Tvergaard–Needleman model has been developed based on the mechanics of void growth due to volumetric strain and subsequent void coalescence leading to fracture. It has now become evident that these models are not capable of capturing fracture in dominant shear deformation scenarios, which arise commonly in the form of shear localizations in polycrystalline metallic materials. Ad-hoc phenomenological modifications by means of an artificial augmentation of void growth in shear have been introduced to extend the applicability of these models to low stress triaxiality regimes. However, the mechanics and physics of deformation and failure in dominant shear loading at the microstructure of polycrystalline alloys are not well understood. In this article, we report in-situ multiscale examination of deformation processes and failure mechanisms in Al 6061-T6 – a polycrystalline alloy with a dispersion of second phase particles in the microstructure – under low stress triaxiality levels using modified Arcan specimens. Strains at the grain and sub-grain levels are measured in a scanning electron microscope by in-situ tracking of the changes in grain size and morphology, and at the macroscale level using digital image correlation. Grain level strains in the range of 2–2.5 are sustained in the material without any indication of failure and shown to be significantly higher than estimates of strain measured using a specimen dimension as the gage length. A continuum material failure model based on grain level strain measurement was introduced and used in numerical simulations to assess the suitability of the proposed failure model. The results from the failure model were compared to those from commonly used Johnson–Cook model. It was noted that although the proposed failure model based on grain based deformation was able to reproduce the essential features observed in the experiments, the results from Johnson–Cook model predicted a premature failure in the material. It was concluded that calibration of failure models requires a suitable length scale and the grain size as an intrinsic property of the material can be used as an appropriate length scale to define strain in failure model calibrations.