
Investigating strain heterogeneity leading to fracture in an aluminium alloy under plane strain tension using 3D (nano)tomography and crystal plasticity simulations

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Abstract

Aluminium alloys are increasingly utilized in the automotive industry as substitutes for steel to address the demand for lightweight materials and contribute to reducing CO emissions. New challenges thus arise to optimize their formability to obtain the complex geometries required for automotive body panels. Given that most stamping defects occur under conditions close to plane strain tension, this study focuses on analyzing the strain heterogeneity that leads to ultimate fracture in plane strain tension specimens made of 6016 T4 aluminium alloy. The polycrystalline effects on the internal strain heterogeneity are investigated using correlative 3D tomography techniques within the material bulk, and finite element simulations based on the real grain structure of the tested specimen, including grain shape and orientation.

A miniaturized plane strain tensile specimen, based on the design proposed by Park et al. (1), validated via surface DIC to confirm the plane strain state, is used. The specimen is tested *in situ* testing within a laboratory tomograph. Initially, a non-destructive 3D grain map of the central region is obtained using lab-based Diffraction Contrast Tomography (DCT) (2). This is followed by an *in situ* tensile test performed in 12 loading steps until fracture, imaged by Absorption Contrast Tomography (ACT). Taking advantage of the plane strain condition, the evolution of the internal strain field is measured by projection-DIC (P-DIC) within the material bulk, using the natural speckle pattern provided by intermetallic particles. The strain measurements reveal a heterogeneous field with early, spatially stable slanted bands that coincide with the fracture location.

In parallel, 3D crystal plasticity finite element simulations (CP-FE) are performed using the meshed DCT-measured microstructure as input. The predicted strain fields from these simulations describe well the experimental measurements. Conversely, simulations using macroscopic anisotropic plasticity models or CP-FE with random grain orientations fail to

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reproduce the observed results. Besides, a strong statistical correlation is found between the experimentally measured and CP-FE-predicted average strain per grain along the loading direction. This finding supports the hypothesis that crystallographic effects are responsible for the initiation of early strain heterogeneities, which subsequently lead to localization and ultimately dictate the fracture path.

To characterize the strain heterogeneity bands with more precision, an *in situ* nanotomography experiment was performed on a dedicated plane strain tension specimen. P-DIC applied to the collected data at 100 nm resolution provided a far better spatial resolution that could be achieved thanks to the capture of a second population of smaller intermetallic particles. It was thus possible to measure the width of the deformation bands, which is of the order of the grain size of the material, confirming the role of the polycrystalline structure in the strain heterogeneity.

- (1) N. Park, H. Huh, S. J. Lim, Y. Lou, Y. S. Kang, and M. H. Seo, "Fracture-based forming limit criteria for anisotropic materials in sheet metal forming," *Int. J. Plast.*, vol. 96, pp. 1–35, Sep. 2017, doi: 10.1016/j.ijplas.2016.04.014.
- (2) F. Bachmann, H. Bale, N. Gueninchault, C. Holzner, and E. Lauridsen, "3D grain reconstruction from laboratory diffraction contrast tomography," *J. Appl. Crystallogr.*, vol. 52, Jun. 2019, doi: 10.1107/S1600576719005442.