Projection-DIC analysis of projected 3D data for a 6xxx aluminium alloy under plane strain tension imaged by *in situ* absorption contrast tomography

M. Gille[1a], H. Proudhon[1], J. Oddershede[2] and T.F. Morgeneyer[1]

[1]MINES Paris, PSL University, Centre des Matériaux, CNRS UMR 7633, BP 87, 91003 Evry, France,

[2] Xnovo Technology ApS, Galoche Alle 15, 1st floor, 4600 Køge, Denmark

[a] maryse.gille@minesparis.psl.eu

Abstract. This work focuses on experiments developed to better understand the deformation and damage mechanisms leading to failure when stamping 6xxx aluminium alloy sheets. A miniaturized plane strain tensile specimen was developed and validated using Digital Image Correlation (DIC) on the specimen surface to verify the plane strain condition. An *in situ* tensile test imaged with absorption contrast lab-tomography was then performed on the miniaturized specimen up to failure. Finally, advantage was taken of the plane strain condition to perform two-dimensional image correlation in the material bulk, so called projection-DIC (p-DIC). Intermetallic particles provided image contrast that was registered during the correlation analyses. The p-DIC method was used to compute internal strain fields that were consistent with fracture location observed on the post-mortem scan.

Introduction

Aluminium alloys are widely considered by car manufacturers to replace steel and meet the light weighting demand to reduce CO_2 emissions. For automotive body panels, formability is crucial to obtain complex geometries while guaranteeing a good surface aspect and a sufficient ductility in service. Most of the stamping failures are found to occur in a state close to plane strain tension [1]. This strain state, critical for formability, is thus investigated in this work aiming at assessing internal strain heterogeneity up to fracture in an aluminium alloy sheet. The experimental technique of 4D imaging enables the *in situ* investigation of the deformation and damage mechanisms by acquiring 3D scans at several time steps of a mechanical test with non-destructive imaging techniques like absorption contrast tomography [2]. The natural grey level contrast of scans coming from differently absorbing elements in the material (particles, voids, …) is used by image correlation techniques such as Digital Volume Correlation (DVC) or the more robust p-DIC to compute the displacement field between a reference image and a deformed image and deduce the internal strain field [3,4].

Material and specimen geometry

The material is a 6016 aluminium alloy in T4 temper typically used for automotive body panels and provided as a metal sheet with nominal thickness of 1.15mm.
To create the plane strain condition, the specimen design was inspired by flat grooved specimens presented by Bai et al. [5] and Park et al. [6]. The geometry was then optimized by Finite Element method to have miniaturized specimens suitable for tomography with a wide enough central region of interest satisfying the plane strain condition defined in Eq. 1.

$$|\varepsilon_{yy}/\ \varepsilon_{xx}| > 10 \qquad (1)$$

ε_{yy} corresponds to the strain in the loading direction Y and ε_{xx} is the strain in the horizontal direction X. Axes are defined on Fig. 1 presenting the specimen geometry.

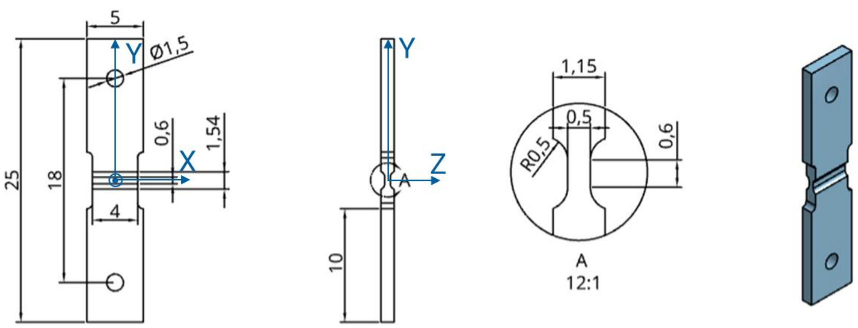

Fig. 1 – Miniaturized plane strain tensile specimen geometry

To validate the geometry, a tensile test was performed with camera instrumentation to perform DIC on the surface of the specimen where a paint speckle was applied. It was thus verified that the plane strain condition was satisfied on a 2 mm-wide region of interest and that the fracture initiated in this plane strain region. Loading curve as well as $|\varepsilon_{yy}/\ \varepsilon_{xx}|$ field at maximal load are displayed on Fig. 2 to illustrate this.

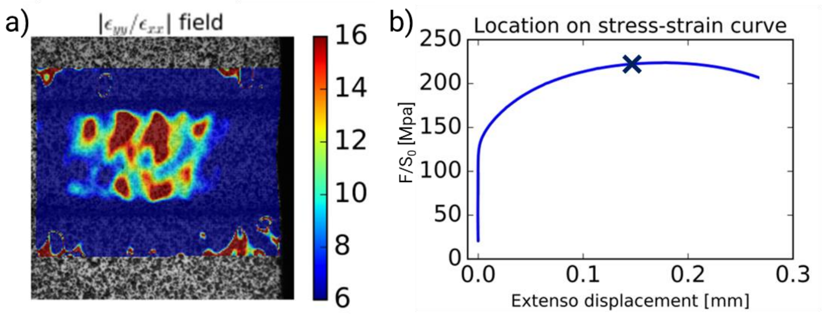

Fig. 2 – a) $|\varepsilon_{yy}/\ \varepsilon_{xx}|$ field obtained with DIC on miniaturized specimen at maximal load and b) loading curve of plane strain tensile test

Projection-DIC to assess internal strain field evolution during in-situ plane strain tensile test

An *in situ* tensile test was performed on the validated plane strain specimen and 12 loading steps as well as the post-mortem one were imaged with the lab tomograph ZEISS Xradia 520 Versa with a resolution of 0.8 µm. For the selected 6016 alloy, image contrast in the reconstructed 3D images (mainly provided by intermetallic particles) was low, and it would be difficult to reliably perform DVC measurements. For this reason, contrast was increased by projecting the maximum grey levels (white) found in a stack of 40 slices along the X direction (i.e. the direction without strain) onto a single 2D section. In other words, contrast provided by intermetallic (white) particles and aluminium matrix (grey) in a 32 µm thick slice was projected onto a 2D image and subsequently used for the 2D registrations. This approach was deemed valid since plane strain conditions prevailed. From the natural speckle provided by the projected intermetallic particles, it was possible to compute the internal strain field using the previously introduced p-DIC technique. As shown on Fig. 3, an heterogeneous ε_{yy} field was revealed with the localization of strain corresponding to the location of the final fracture.

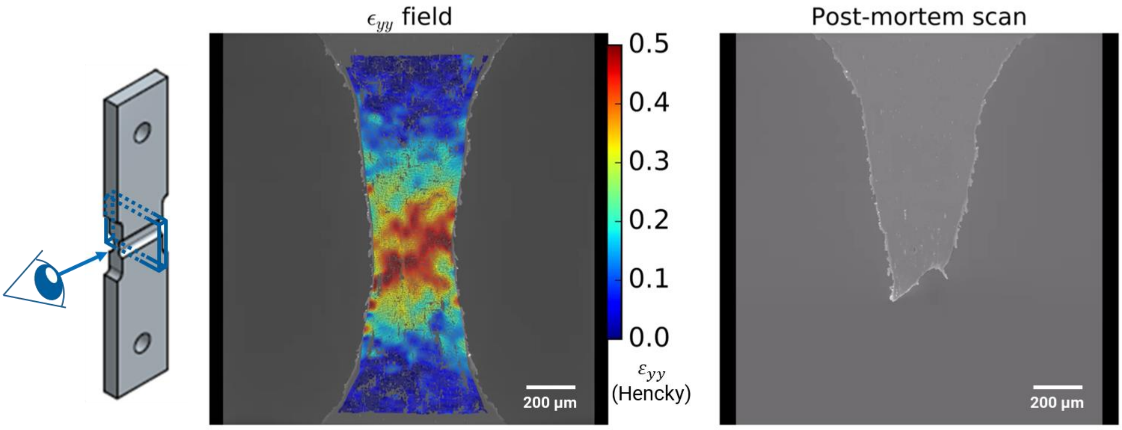

Fig. 3 – Comparison of the strain field in tension direction at last step before fracture with the location of final fracture

Conclusions

A miniaturized plane strain tensile specimen was designed and validated to be in plane strain condition thanks to DIC performed on the surface. An *in situ* tensile test later performed on this specimen provided 4D data from which an analysis by the p-DIC method revealed an internal heterogeneous strain field with localization bands corresponding to the fracture location.

References

[1] J. Bottema, C. Lahaye, R. Baartman, L. Zhuang, P. De Smet and F. Schoepen: *Recent Developments in AA6016 Aluminium Type Body Sheet,* SAE Transactions, Vol. 107 (1998) p. 900-907

[2] H. Proudhon, M. Pelerin, A. King and W. Ludwig: *In situ 4D mechanical testing of structural materials: The data challenge,* Current Opinion in Solid State and Materials Science, Elsevier (2020), p. 100834

[3] A. Buljac, F. Hild, L. Helfen, and T. F. Morgeneyer: *On deformation and damage micromechanisms in strong work hardening 2198 T3 aluminium alloy,* Acta Materialia, Vol. 149 (2018) p 29-45

[4] T. F. Morgeneyer, M. Khadyko, A. Buljac, L. Helfen, F. Hild, A. Benallal, T. Børvik and O. S. Hopperstad: *On crystallographic aspects of heterogeneous plastic flow during ductile tearing: 3D measurements and crystal plasticity simulations for AA7075-T651,* International Journal of Plasticity, Vol. 144 (2021) p 103028

[5] Y. Bai, X. Teng and T. Wierzbicki: *On the Application of Stress Triaxiality Formula for Plane Strain Fracture Testing,* Journal of Engineering Materials and Technology, Vol. 131 n2 (2009)

[6] N. Park, T. B. Stoughton, and J. W. Yoon: *A new approach for fracture prediction considering general anisotropy of metal sheets,* International Journal of Plasticity, Vol. 124 (2020) p 199-225