Local investigations of the thermomecanical behavior of a coarse-grained aluminium multicrystal using constrained DIC and IRT methods

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LOCAL INVESTIGATIONS OF THE THERMOMECHANICAL BEHAVIOR OF A COARSE-GRAINED ALUMINUM MULTICRYSTAL USING CONSTRAINED DIC AND IRT METHODS

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ABSTRACT: With the intention of achieving grain scale energy balances at finite strain, a mechanical test on a coarse-grained aluminium is presented in this paper using two complementary imaging techniques (visible and infrared). Specific image processing methods (Constrained DIC and Constrained IRT) are applied to investigate the thermomechanical behavior at the microstructural scale. In the long term, the ultimate goal is to provide energy balance during mechanically-loaded test at the granular scale in order to propose thermomechanically consistent constitutive modelling of crystalline plasticity.

1. INTRODUCTION

Polycrystalline materials are solids composed of an aggregate of crystalline grains of varying size and orientation. During a macroscopic tensile loading, the diversity of grain orientations and the intrinsic anisotropy of crystal plasticity leads to strong heterogeneities in the material plastic response, and consequently to an inhomogeneous thermal distribution due to thermomechanical effects.

Recently, heterogeneous phenomena on mechanical and thermal fields have been studied in metallic materials at the granular scale [1 - 6]. Our final goal here is to access to the evolution of the different energies (mechanical, calorimetric) involved in the transformation so as to contribute to a better knowledge of the local thermomechanical signature of the material deformation mechanisms.

In this paper the two data processing methods (Constrained DIC [7] and Constrained IRT [8]) are used to perform thermal and calorimetric measurements needed to conduct a local energy balance within each grain during a mechanically-loaded test.

2. EXPERIMENTAL PROCEDURES

2.1 Microstructure analysis

The as-received material used in this study consists in a 3 mm thick aluminium sheet, grade A1050. The chemical composition of this material and the sample preparation procedure is reported in [6].

The initial microstructure is analysed by EBSD before mechanical testing and represented in the following figure:

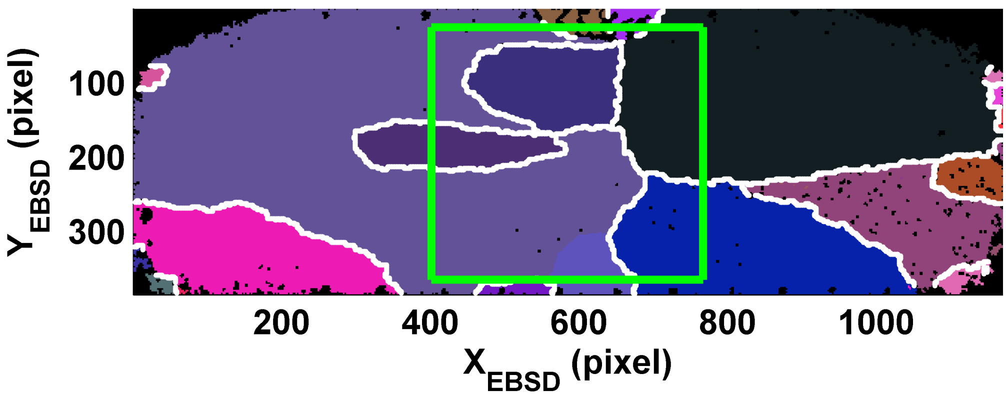

Figure 1- Initial microstructure analysis of specimen (60x20 mm²)

Each color in the **Figure 1** corresponds to a crystal orientation (interpreted here as a grain) and the white line materializes the high disorientation zone associated with grain boundaries. The green frame in this figure corresponds to the Zone Of Interest (ZOI) defined in the coordinate systems CCD and IR (see **Figure 2**) but transported in the EBSD coordinate system.

2.2 Experimental setup

In this study, mechanical (load-unload) tensile tests are performed at room temperature with a hydraulic testing machine (MTS-810) in a displacement-controlled mode. A simultaneous observation of both sides of the sample is performed by the CCD and IR cameras. The main characteristics of the cameras are reported in **Table 1**.

Thanks to a spatial matching procedure [6], the grain boundaries (white in **Figure 1**) are respectively transported in the CCD and IR coordinate systems (in **Figure 2a** and **2b**).

	Image size(pixels)	Scale factor (µm/pixel)	Frame rate(Hz)
IR: Cedip Titanium	512x640	97	40
CCD: Phantom V12	12080x800	45	80

Table 1 - Main camera characteristics

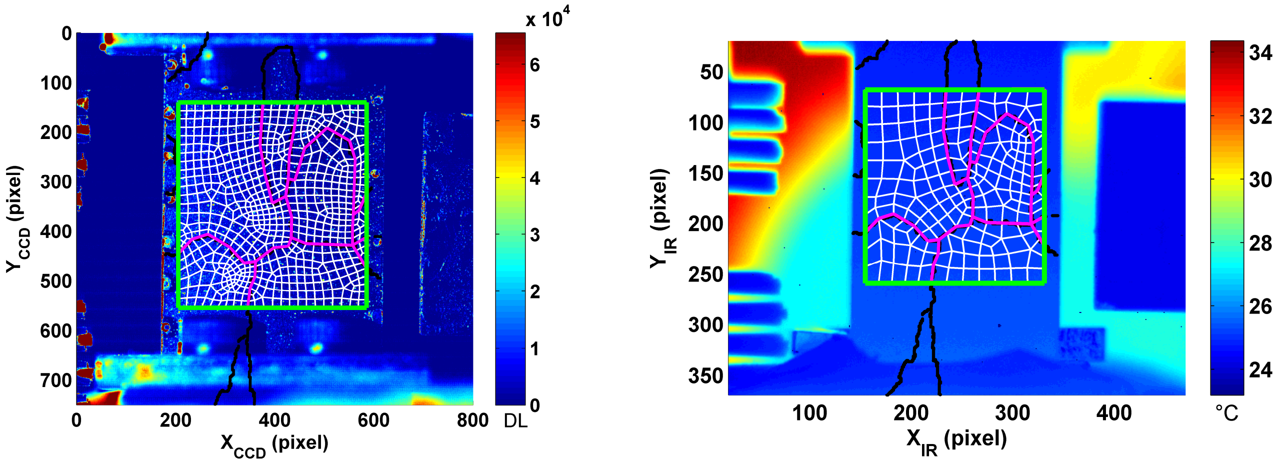

Figure 2a – Correlation analysis mesh

Figure 2b – Thermal analysis mesh

Figure 2 – Spatial description of the specimen in the coordinate systems CCD and IR

In **Figure 2**, the contour of the grain boundaries given by EBSD analysis are represented in black. In the ZOI (green frame), this microstructure is then "simplified" in order to obtain meshes with a "reasonable" size for the image correlation and the calorimetric analysis. The mesh sizes used here for the kinematic and the thermal analysis are respectively 18 and 40 pixels.

3. EXPERIMENTAL RESULTS

3.1 Macroscopic response

The macroscopic response of the aluminum sample for this load-unload tensile test (in Y direction) until failure is reported in **Figure 3**. The mechanical loading is represented in blue, the macroscopic kinematic and thermal responses (*i.e.* averaged over the ZOI) are respectively represented in green in the **Figure 3a** and **3b**.

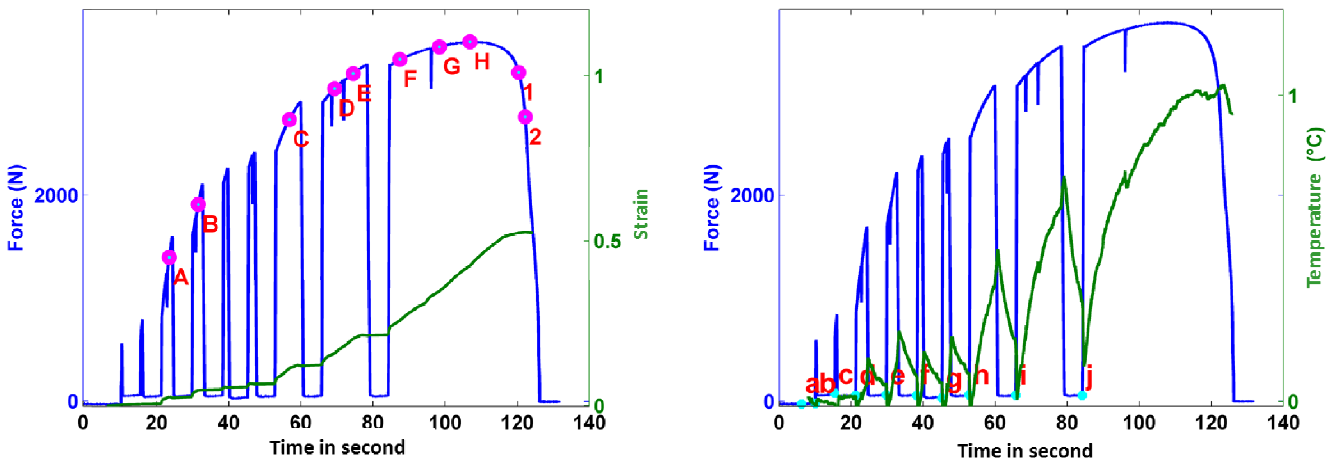

Figure 3a - Mechanical and kinematic response

Figure 3b - Mechanical and thermal response

Figure 3 - Macroscopic response of material

3.2 Full field analysis

The Constrained DIC and IRT methods are used in order to perform the full field analysis. In this abstract, only the results at the loading state specified by the D spot (in **Figure 3a**) are presented:

- Displacement fields:

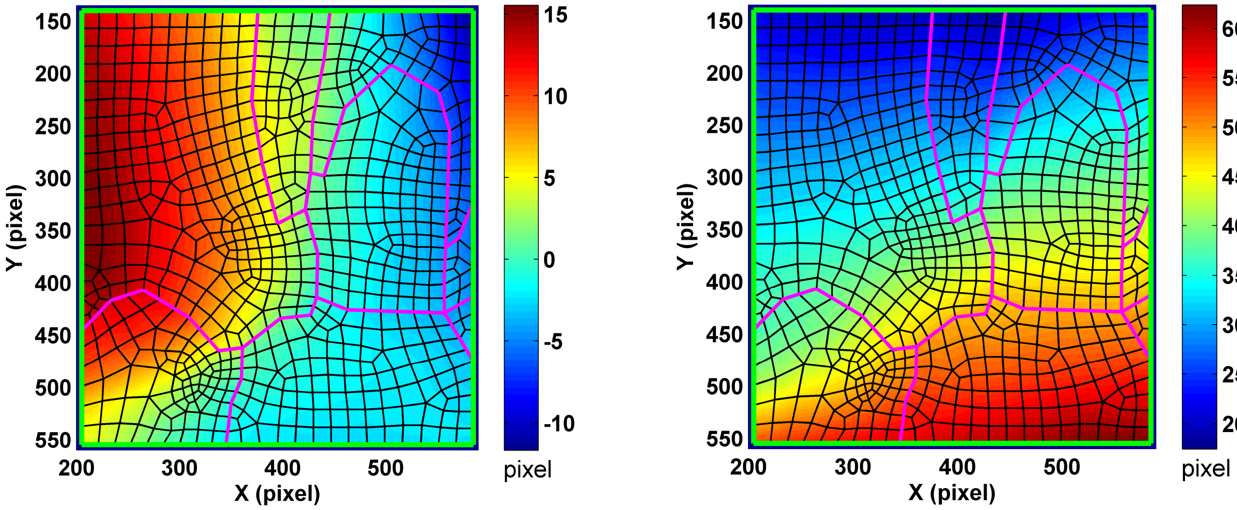

Figure 4 - Displacement fields obtained in X (left) and Y (right) direction at spot D in the Lagrangian configuration

- Initial and deformed measurement mesh:

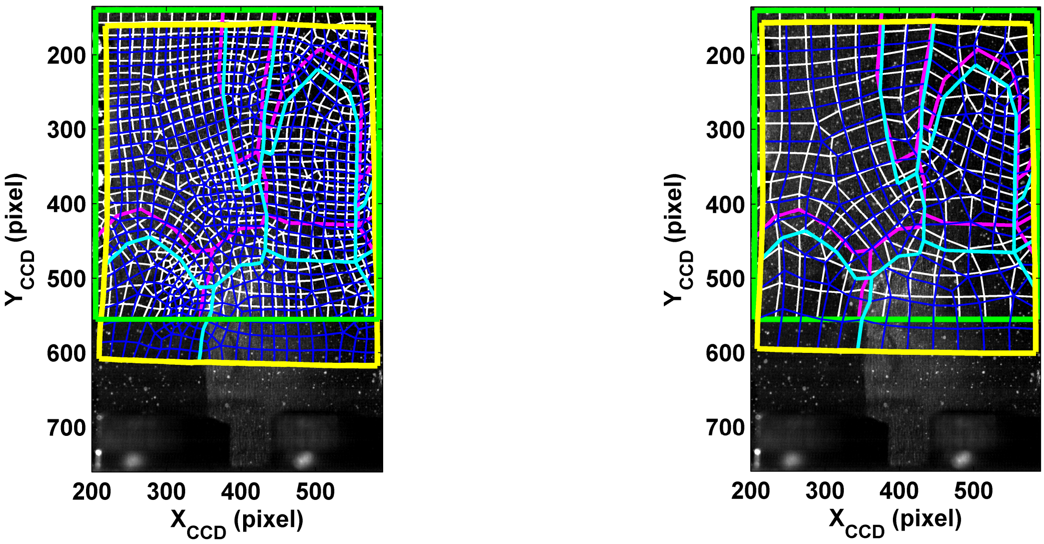

Figure 5 - Initial and deformed mesh (CCD and IRT) represented in the CCD coordinate system

Using the obtained displacement fields (**Figure 4**), the initial kinematic mesh (**Figure 2a**) can be deformed to obtain the deformed one in the CCD coordinate system (**Figure 5** in left). In the same manner, using the spatial matching procedure, the initial and deformed thermal mesh can be also represented in the CCD coordinate system (**Figure 5** in right) and then in the IRT coordinate system.

- Equivalent strain field and temperature field:

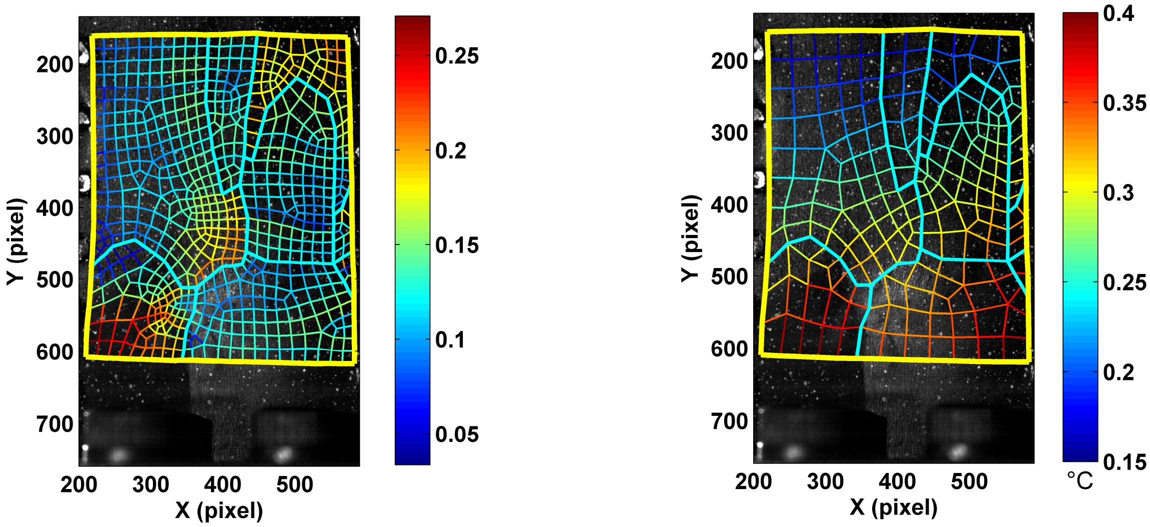

Figure 6 - Equivalent strain field (left) and temperature field (right)

The Figure 6 illustrates the heterogeneous development of plasticity within grains (strain and heat release localisation) in the current configuration at time D. These measurements will be confronted to EBSD analyses giving the grains initial orientation in order to estimate the local stress field within each grain which is necessary to determine the deformation energy locally developed.

4. CONCLUSION

Using this experimental procedure, the local distributions of strain and temperature fields have been measured in a coarse-grained aluminium polycrystal using Constrained DIC and IRT data processing method. A key feature of the methods, which fit the polycrystalline problem, is that material effects can be explicitly introduced in the data processing (intergranular cracking) while respecting the physical microstructure given by EBSD analysis. Therefore, the different local thermomechanical variables can be characterised specifically for each grain (without introducing correlations with the response of adjacent grains). The proposition of a complete energy balance at the scale of grain requires an additional estimate of the stress field using the EBSD information

5. REFERENCES

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