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Calorimetric analysis of coarse-grained polycrystalline aluminum by IRT and DIC

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Abstract

This study aims at performing grain scaled energy balance in mechanically-loaded aluminum polycrystal specimen. Two complementary imaging techniques were used in order to investigate the so-called material thermomechanical behavior: Digital Image Correlation and InfraRed Thermography to investigate respectively the kinematic and the thermal response of the material and, combining these two techniques, its calorimetric response.

1. Introduction

Polycrystalline materials are solids that are composed of an aggregate of crystalline grain of varying size and orientation. Beyond some threshold [1], during a macroscopic monotonic tensile mechanical loading, the grain disorientation and the anisotropic nature of the crystal slips leads to a heterogeneous plastic deformation [2].

Heterogeneous phenomena on mechanical and thermal fields have been widely studied using imaging techniques such as InfraRed Thermography (IRT) since the end of the 1970s [3], and Digital Image Correlation (DIC) since the last two decades [4]. With the progress achieved in the fields of optical techniques associated with quantitative image processing, the quality and precision of displacement and temperature full-field measurements have tremendously increased in the last decade.

At the same time, the development of automated Electron BackScatter Diffraction (EBSD) imaging techniques has contributed to a better monitoring of the microstructure evolution during plastic strain. Therefore, samples containing only a small set of coarse grains have been recently investigated to evaluate the deformation-induced plastic heterogeneity of polycrystal [5-7].

This work intends to get coupled full-field kinematic and thermal measurements in order to investigate the relationship between thermomechanical heterogeneities and material microstructure during the mechanical loading.

2. Experimental preparation

2.1. Specimen elaboration

The raw material used in this study is 3 millimeters thick commercial-purity aluminum sheet denominated AA1050 following the Aluminum Association standards. By a classical thermo-mechanical processing (critical hardening, recrystallization), a quasi 2D layer of coarse grained aluminum sample with columnar morphology through its thickness was obtained [8].

Taking into account the dimension of the Scanning Electron Microscope (SEM) chamber, a sample size of 80 mm×20 mm×3 mm has been chosen. After a specimen surface preparation, with EBSD analysis, figure 1a shows the shape and crystallographic orientation of each grain of the sample before straining.

2.2. Experimental setup

In this study, mechanical tensile tests were performed at room temperature with a hydraulic machine (MTS-810) in a displacement-control mode. Starting with a known microstructure of the specimen (figure 1a) obtained by EBSD analysis, during the test, a simultaneous fully-coupled observation of both sides of the sample is performed by the visible radiation CCD (Phantom V12) and IR (Cedip Titanium) cameras.

3. Results experimental

In figure 1b the mechanical response of the aluminum sample for a load-unload tensile test is showed. In figure 1c and 1d, the equivalent strain field and the temperature field at the loading state specified by the A spot in figure 1b are respectively given with the material microstructure superimposed.

Furthermore, using those different maps, the average evolution of strain and temperature on different grains can be estimated and drawn as a function of time on figure 2.

The selected grain number is indicated in the figure 1. These two average quantities are the very first step allowing us to access the different thermomechanical variables in the microstructure scale.
4. Conclusion

With our experimental setup, the local distributions of strain and temperature have been estimated in aluminum polycrystal using classical DIC and IRT method. As expected those two classical techniques highlighted enough heterogeneity in both kinematic and thermal fields. Therefore, a specific data processing method which fits the polycrystalline problem is now being developed in order to obtain the different local thermomechanical variables and to build an energy balance at the scale of grain, so as to characterize the thermomechanical consistency of classical polycrystal plasticity modeling. The proposed communication aims at presenting (i) the developed data-processing allowing the determination of intragranular temperature and displacement fields and possible inter-granular discontinuities, and (ii) the first results obtained by this procedure on tensile tests performed on a coarse-grained aluminum alloy.

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