Heterogeneities in the mechanical accommodation of α-γ transformation in iron

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Abstract. The goal of this work is to perform *in situ* observation of ferrite-austenite allotropic transformation in iron. An in-house experimental device is developed to capture images of pure iron samples at high temperatures without degradation. Kinematic fields on the surface of the samples are then computed thanks to Digital Image Correlation technique with a subgrain resolution. Electron Backscattered Diffraction analyses are conducted to relate the influence of microstructure on transformational behaviour.

Introduction

Automotive parts, often made of iron-based alloys, undergo both strong loads and extreme temperature variations. Therefore, a coupled investigation of thermal and mechanical behaviours is required. A zone of particular interest lies around the temperature at which the crystal structure of iron changes from Body-Centred Cubic to Face-Centred Cubic. Indeed, stored elasto plastic energy acts as an additional driving force for transformation. Besides, α-γ transformation involves a change in volume of approximately 1.2% that has to be accommodated mechanically [1]. To observe the intricacy between these phenomena, an experimental device with subgrain resolution is required. Scanning Electron Microscope, combined with Digital Image Correlation (DIC) technique has been proven reliable to compute kinematic fields at these scales [2,3]. However, studying α-γ transformation involves working at temperatures and rates that are not currently accessible to SEM. The objective of this work is to come up with a new experimental testing method that would permit to both monitor microstructural changes during the allotropic transformation and measure their effects on mechanical fields thanks to DIC.

Design of the experimental set-up

Experimental device is shown in Figure 1. The optical system is made of a 29 MPx camera running at about 4 fps. A telecentric lens magnifies the view so that the zone of study has a size of 7mm*5mm. A 5kW power supply with 500A maximum current provides the electrical current. This current passes through the sample, causing a Joule heating effect. The main advantages of this kind of heating are its volumetric character and the high heating rates that can be achieved. At full speed, the sample can be heated at 500°C/s. An operative clearance is preserved in the copper clamps to prevent buckling during heating. Temperature of the sample is measured by means of a 2-color pyrometer. Observation windows are made of sapphire glass not to deteriorate temperature measurements. A PID regulation is implemented for the temperature to follow controlled profiles. In the frame of this work, heating and cooling ramps are imposed at a rate of about 300°C/min. Finally, a vacuum pump is used to clean the testing atmosphere previous to experiments.

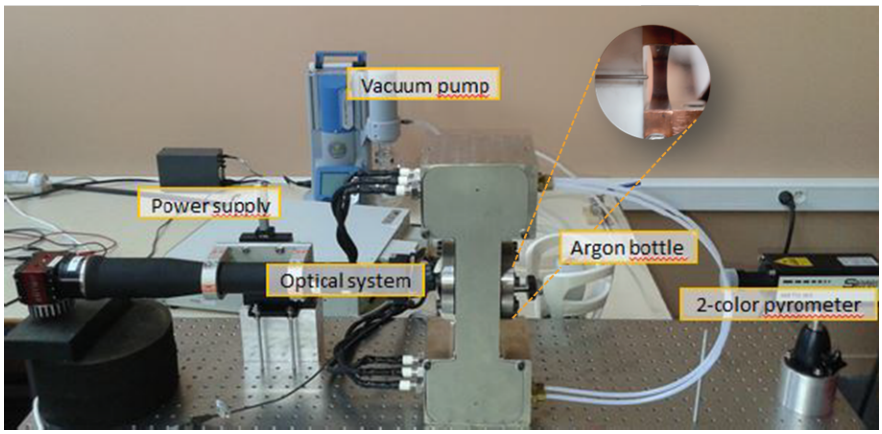

Figure 1: Photo of the experimental set-up

Sample protection

Following previous works on DIC at high temperatures [4,5], some elements of the experimental equipment are specifically designed so as to avoid modifications in the image properties that would be unrelated to the sample behaviour and could hinder image correlation computations.

For instance, degradation of sample surface may occur through oxidation. Samples are thus put under an argon atmosphere. A detrimental effect of this is that local modifications of the refraction index of the gas induced by temperature could bring up small offsets that distort the images. To limit the influence of this so-called heat haze effect, a constant controlled flow of gas is maintained during the experimental tests. However no image distortion has been noticed so far.

Finally, the surface of the sample radiates a light whose energy evolves with temperature following Planck's law. When thermal radiation gets brighter than the source of light used in the experiments, images luminosity exhibit strong variations that interfere with correlation results. To tackle this problem, sample is lit by a blue LEDs illumination system that maintains lighting in the low wavelengths range and a blue passband filter is put in front of the camera.

Testing procedure

Samples are obtained by cold crucible melting. They are tested according to the following procedure:

- An Electron Backscattered Diffraction (EBSD) analysis is performed before thermal solicitation in order to extract initial grain morphologies and orientations;
- A speckle pattern made of alumina-based paint is deposited on the surface of the samples which are then submitted to a heating and cooling cycle;
- Another EBSD analysis is made at the end of the test in an attempt to relate final microstructure to the thermo mechanical history of the samples.

Displacement fields are computed thanks to UFreckles software [6]. Strain fields are then obtained through a finite difference scheme. As a way to put to fore transformation occurrence, max shear strain is computed (where E_{ij} are the in-plane components of the strain tensor):

$$s_{max} = \sqrt{\left(\frac{E_{yy}-E_{xx}}{2}\right)^2 + E_{xy}^2} \quad (1)$$

This quantity equals zero when there is only isotropic dilatation and starts to evolve when transformation appears.

Experimental trends

Three main phases can be identified as the experiment progresses:

- Temperature is homogeneous and maximum in the central part of the sample. Consequently, transformation first initiates in this zone. Its occurrence is betrayed by max shear strain localizations;
- The rest of the sample exhibits a strong temperature gradient. In this zone, a rectilinear transformation front develops and progresses in the direction opposite to the temperature gradient;
- Once heating is finished, the front stabilizes. During cooling, it advances backwards and most of shearing history is erased. Fronts coming from the two extremities of the sample finally join in the central part of the sample and strong elasto plastic strains arise to accommodate orientation incompatibilities.

During the first two phases, strain localizations are shown to be in accordance with the underlying microstructure, extracted from the EBSD data. Besides, nucleation events are associated with strong localizations of the strain field whereas they are more diffuse in the case of growth.

Conclusion

An experimental equipment suitable for high-temperature solicitations is designed. It allows the observation of iron samples during ferrite-austenite phase change without loss in image quality. DIC computations can be performed in order to obtain strain fields. The onset of transformation and its subsequent progress can both be characterized.

References

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