PLASTIC FLOW INSTABILITY IN AUSTENITIC STAINLESS STEELS AT A WIDE RANGE OF TEMPERATURES: FROM MACROSCOPIC TESTS TO MICROSTRUCTURAL ANALYSIS

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1. Introduction

Austenitic stainless steels (ASS) of AISI 304 (EN X5CrNi18-10), AISI 316L (EN X2CrNiMo17-12-2), AISI 316LN (EN X2CrNiMoN17-11-2) grades characterized by very good mechanical properties and corrosion resistance in a wide temperature range (4 K - 900 K). Thus, they find numerous applications in the automotive, aviation, nuclear and chemical industries as well as in space and superconducting technology where temperature changes from room temperature, even to absolute zero. The collars of dipole magnets in LHC, the steel expansion joints or the jacket of the Cable-In-Conduit Conductors (CICC) in ITER are good example of austenitic stainless-steel applications. The correct design of structural elements and instrumentation that operate without breakdown throughout the service time requires an understanding of the deformation and fracture mechanisms inherent in a wide range of temperatures, from near 0 K to room temperature. The lack of in-depth recognition of these processes has become a critical problem for large research infrastructures such as LHC or ITER. The plastic behaviour of metastable austenitic stainless steels is controlled by temperature. It is seen when comparing the stress-strain curves of ASS for a tensile test at 4 K, 77 K and at room temperatures. During tensile tests of austenitic stainless steels at cryogenic temperatures (4 K), unusual behaviour is observed – plastic flow instability. This effect also called a discontinuous plastic flow [1], is reflected by stress oscillations on the stress-strain curve. Moreover, the Lüders-type effect is observed (Fig. 1). At room temperature, in turn, for a 304 specimen with a long enough gauge length and below critical strain rate, the plastic front propagation occurs [2]. Therefore, the different modes of plastic flow instability in austenitic stainless steels are observed depending on the temperature. When temperature approaches absolute zero the tendency of metastable ASS to diffusion-free phase transformation during plastic deformation increases. It is experimentally proven that in ASS at cryogenic temperatures, the deformation-induced phase transformation is coupled with discontinuous plastic flow [3]. It appears that the plastic deformation of austenitic stainless steels at a wide range of temperatures is determined by two key phenomena: diffusion-free transition of initial austenite with a face-centred cubic (FCC, γ) structure into martensite α’ with a body-centred cubic (BCC) arrangement and plastic flow instability.

The aim of the work is to investigate the plastic flow and hardening processes of metastable 304 and 316L steels in the context of 316LN stable due to diffusion-free martensitic transformation. The basis is in-situ tensile tests at room temperature, registered using the DIC and EBSD methods. In this way, the development of deformation fields and the accompanying evolution of the microstructure are identified. The coupling of the observations carried out on two levels allows us to explain the differences in the mechanical and microstructural response of the considered steel grades.

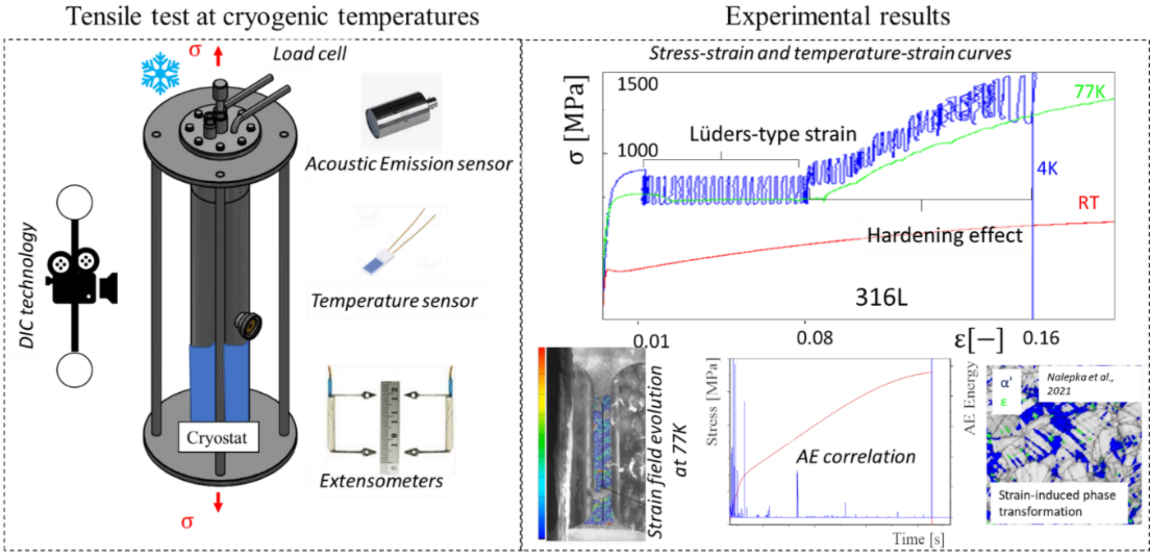

Fig. 1. DIC-enhanced experimental platform with a multi-detector array. Results of preliminary research: strain field evolution, acoustic emission spectrum and temperature distribution during tension at 77K; after test the microstructural analysis was carried out.

2. Conclusion

A plastic flow instability occurs when a commercial 304 stainless steel sheet undergoes tensile deformation at room temperature as well as at 4K. Using the backscattered electron diffraction (EBSD), it was found that the reason is not only a difference in the content of the secondary phase – martensite α' across the front face but also the change in the volume fraction of austenite grains with Copper (Cu) and Goss-Brass (GB) orientation. The in-situ EBSD tension studies for the 304, 316L and 316LN reveal three developing textures, the comparison of which shows a gradual decrease in the preferences of the Cu and GB components. Thus, in 316L, appearing bands of accumulated deformations are limited by Cu and GB areas, while in 316LN such blockage does not occur. The presented strengthening mechanism is confirmed by the measurement on a DIC-enhanced experimental platform with a multi-detector array for materials testing at cryogenic temperatures. First time, the root mean square function (RMS) of strain amplitude along the line, is introduced as a tool for linking the micro and macro scales.

In general, it can be concluded that the intense deformation-induced phase transformation in metastable austenitic stainless steels results in the delocalization of plastic deformation. This phenomenon impacts the mechanical properties and plastic deformation behaviour of metastable stainless steels, both at cryogenic and room temperatures.

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