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Effect of residual stresses on individual phase mechanical properties of austeno-ferritic duplex stainless steel

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Abstract

The mechanical properties of both phases in duplex stainless steel have been studied in situ using neutron diffraction during mechanical loading. Important differences in the evolution of lattice strains are observed between tests carried out in tension and compression. An elastoplastic self-consistent model is used to predict the evolution of internal stresses during loading and to identify critical resolved shear stresses and strain hardening parameters of the material. The differences between tensile and compressive behaviours of the phases are explained when the initial stresses are taken into account in model calculations. The yield stresses in each phase of the studied steel have been experimentally determined and successfully compared with the results of the elastoplastic self-consistent model.

Keywords: Residual stresses; X-ray and neutron diffraction; Duplex stainless steel; Self-consistent model

1. Introduction

Diffraction-based techniques have frequently been used to study the stress states and the mechanical properties of two-phase polycrystalline solids [1–15]. The main advantage of diffraction methods is the possibility to obtain separate measurements for each phase of the material. The X-ray diffraction technique is widely used for the determination of surface stresses. The great advantage offered by the alternative use of neutron radiation is its large penetration depth, which is about 1000 times larger than for laboratory X-rays in most materials. Therefore, using neutron diffraction, information is obtained not only from near-surface regions, but also from the interior of the specimen. Recently, high-energy X-rays have become available at modern synchrotron sources, and have also been used for residual stress analysis. The main advantage of synchrotron sources is the fine collimation and great intensity, facilitating for example high-spatial-resolution measurements within single grains. These three techniques should in general be regarded as complementary techniques, each offering particular advantages.

The duplex stainless steels (DSSs) studied in this work have a two-phase microstructure of ferrite and austenite in approximately equal volume fractions. They combine many of the beneficial properties of austenitic and ferritic steels. To understand the mechanical properties of these duplex steels, it is necessary to understand the behaviour of crystallites at the scale of individual phases. Diffraction techniques provide a very useful tool to study the generation of internal stress in both phases. Recently, we used neutron diffraction to study the elastoplastic properties of DSS during an in situ tensile test [9]. To determine the effective properties of both phases, an original methodology based on comparison of experimental and theoretical data (self-consistent model

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[16–18]) was proposed. In the previous work [9] only one reflection for each phase was measured (1 1 0 for ferrite and 1 1 1 for austenite) and the comparison of the measured relative lattice strains with model results was performed assuming zero initial stress. However, the values of initial stresses can be significant [6–8] and they can influence the mechanical properties of the phases.

In the present study, the time-of-flight (TOF) neutron diffraction technique and self-consistent modelling were applied to investigate the in situ deformation of DSS during tensile and compressive loadings. The main advantage of TOF neutron diffraction over steady-state neutron diffraction is that it allows simultaneous measurement of interplanar spacings for many *hkl* reflections in each studied phase, using a single experimental setup. Thus the strains in a large number of crystallites are measured, providing a good estimation of macroscopic as well as intergranular stresses.

The aim of this work is to assess the ability of the elastoplastic self-consistent model to predict the distribution of strains, observed experimentally by neutron diffraction, between the phases and to identify critical resolved shear stresses and strain hardening parameters of the material. More attention is paid to the influence of initial residual stresses on the mechanical behaviour of both phases in the stainless steel during tension and compression. To this end, the levels of these residual stresses in the as-received non-loaded sample were measured by neutron and by X-ray diffraction methods. The experimental stresses were determined using the diffraction elastic constants calculated by the self-consistent model and taking into account the anisotropy of the studied material (crystallographic texture). The analysis of each phase's behaviour under tensile and compressive loads was taken into account of the presence of initial stresses within the model calculations.

2. Material and experimental methods

2.1. Studied material

The studied material is an austeno-ferritic stainless steel, containing approximately 50% austenite and 50% ferrite. It was obtained by continuous casting, and then hot rolling down to 15 mm sheet thickness. A solution annealing heat treatment at 1050 °C was given, followed by quenching in water in order to avoid the precipitation of secondary phases. The chemical composition and the mechanical characteristics of the alloy are presented, respectively, in Tables 1 and 2. The characteristic microstructure of the steel consists of austenitic islands elongated along the rolling direction (RD) and embedded in a ferritic matrix (Fig. 1). No precipitates were observed in neutron (see Fig. 5) TOF or in X-ray diffractograms.

2.2. Measurements

2.2.1. X-ray diffraction

The $\sin^2\psi$ X-ray diffraction method was used to determine the phase stresses in the initial sample [11–13]. This method is based on the measurement of peak positions for a given *hkl* reflection and for various directions of the scattering vector. Chromium Kα radiation was applied to measure the interplanar spacing for the 2 1 1 reflection in ferrite, while in the case of austenite the K_β wavelength and 3 1 1 reflection were used with the same radiation. Measurements were carried out in two perpendicular directions for three different surfaces of a cube ($10 \times 10 \times 10$ mm) taken from the centre of the sheet. The orientation of the sample with respect to the directions of rolling and the measured stress components are shown in Fig. 2. A layer of 200 μm was removed electrochemically from the three surfaces to avoid the plastically deformed zone during

Table 1
Chemical composition (wt.%) of DSS

Euronorm	C	Mn	Cr	Ni	Mo	Cu	S	N
X2 Cr Ni Mo 22.5.3 (UR45N)	0.015	1.6	22.4	5.4	2.9	0.12	0.001	0.17

Table 2
Tensile properties of DSS

DSS	Yield stress (0.2%) (MPa)	Ultimate tensile strength (MPa)	Elongation (%)
UR45N	480	680	25

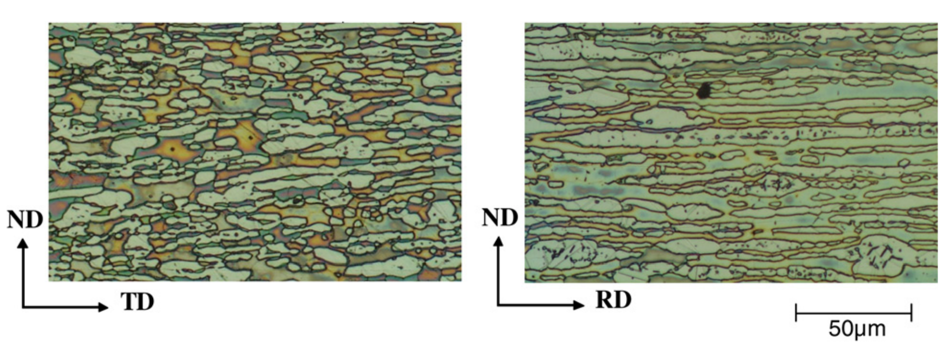

Fig. 1. Microstructure of the studied DSS for two different sections. The main directions of rolling are indicated: RD, rolling direction; TD, transverse direction; ND, normal direction.