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Technical Note

Influence of artificial seawater on the cyclic response of superduplex stainless steels

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Abstract

Superduplex stainless steels (SDSSs) are a family of alloys originally designed to resist corrosion in seawater. The aim of this work has been to study the low cycle fatigue behaviour of a SDSS in air and in artificial seawater. Three different plastic strain amplitudes corresponding to distinct positions on the cyclic stress–strain curve were selected in order to compare the number of cycles to failure in both environments. The results showed a remarkable reduction in fatigue life in the presence of the aqueous solution, especially for high strain amplitudes. These experimental findings are rationalised considering the different mechanisms governing the corrosion fatigue process as a function of the plastic activity developed by the ferritic phase.

Keywords: Superduplex stainless steels; Low cycle fatigue; Cyclic stress–strain curve; Corrosion fatigue; Artificial seawater

1. Introduction

Duplex stainless steels (DSSs) are two-phase materials, whose microstructure consists of austenite and ferrite in equivalent amounts. DSSs are reported to have very good corrosion resistance in a wide number of environments and they are proposed to replace standard austenitic stainless steels in some industrial applications because of their cost efficiency, high mechanical properties and good stress corrosion cracking resistance [1]. This is particularly true for the new generation of DSSs with a higher content on alloying elements, called superduplex stainless steels (SDSSs), which have proved to offer a high performance in chloride containing environments, e.g. seawater in offshore oil rigs [2,3].

Many of the applications in which DSSs are used involve cyclic loading under normal operating conditions [4]. As a consequence, in recent years there has been sustained activity towards understanding the cyclic deformation behaviour of these two-phase alloys [5–17]. From these studies, it was established that the cyclic stress–strain curves (CSSCs) of DSSs can be described in terms of three stages as a function of the plastic strain amplitude ($\Delta\varepsilon_{pl}/2$). For low values of $\Delta\varepsilon_{pl}/2$, i.e. $\leq 10^{-4}$, the behaviour could be qualified as austenitic because this phase mainly accommodates the plastic deformation; whereas for medium $\Delta\varepsilon_{pl}/2$ values plastic deformation is shared by both phases; and for $\Delta\varepsilon_{pl}/2 \geq 10^{-3}$ DSSs exhibit a ferritic-like character.

In contrast, if corrosion fatigue is considered, the number of works dealing with this subject is scarce, and most of them are devoted to fatigue crack propagation [18,19]. Perdriset et al. [10] studied the cyclic response of the standard duplex type 2205, while Magnin and Lardon [20] investigated a low-nitrogen DSS, both in artificial seawater. In the latter case, fatigue life reduction at $\Delta\varepsilon_{pl}/2 = 4 \times 10^{-3}$ was pointed out, but environmental effects were not discerned at $\Delta\varepsilon_{pl}/2 = 10^{-3}$.

SDSSs are characterised for a nitrogen content higher than 0.2%. Since nitrogen alloying exerts a beneficial effect in terms of improved corrosion resistance [21], the corrosion fatigue strength of this new generation of DSSs may be superior of that of low- and medium-nitrogen DSSs. To the authors' best knowl-

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edge, only two works concerning the influence of artificial seawater on the cyclic deformation of SDSSs have been published. Coudreuse and Charles [22] and Massol et al. [23] have reported the detrimental effect of a 3% NaCl solution on the low cycle fatigue (LCF) properties of different SDSSs, finding a progressive reduction in fatigue life with increasing strain. However, in these works the $\Delta\varepsilon_{pl}/2$ considered are always higher than 10^{-3}. Referring to lower strain amplitudes, no published results have been found for any SDSS.

From the above brief review, it is clear that a more complete description of the SDSS performance in artificial seawater and within a wider range of strain amplitudes is still required in order to increase reliability in the design of components and structures, taking the maximum benefit of the properties of SDSSs. Therefore, this research has been mainly focused on the cyclic deformation of SDSS in artificial seawater. Special attention has been paid to fatigue crack initiation, i.e. crack nucleation sites and role of microstructural barriers to small crack propagation, since this stage typically dominates life within the LCF regime.

2. Material and experimental procedure

The SDSS studied is the most industrially used, i.e. type EN 1.4410 (commercial designation by Sandvik, SAF 2507). Its microstructure consisted of 54% austenitic grains on a ferritic matrix and the grain shape is highly elongated in the rolling direction. This direction corresponded with the loading axis in all tested specimens. Table 1 gives the chemical composition and the main microstructural parameters of the material studied.

Cylindrical specimens with a gauge length of 10 and 8 mm in diameter were machined from the original bars of 20 mm in diameter. Cyclic deformation testing was carried out in a servohydraulic machine using a clip-on axial extensometer (protected within a polymethyl methacrylate box and sealed with silicone rubber) to measure and control strain. All tests were conducted under fully reversed total strain control, at a constant total strain rate of 10^{-2} s^{-1} and at room temperature. Three different total strain amplitudes ($\Delta\varepsilon_t/2$): 9.5×10^{-3}, 5×10^{-3} and 3.3×10^{-3}, were imposed in order to obtain three different plastic strain amplitudes at saturation ($\Delta\varepsilon_{pl}/2$): 6×10^{-3}, 2×10^{-3} and 6×10^{-4}, each corresponding to markedly different positions within the CSSC previously obtained for this steel [15]. Tests in aerated artificial seawater (30 g/l NaCl) were conducted at free potential. A time of 90 min was left in order to attain potential stabilisation before beginning cyclic loading. A corrosion cell of 1 dm^3 in volume was used and, to ensure the homogeneity of the electrolytic solution within the cell, a constant-through flow was produced by using a peristaltic pump. Also, LCF tests were performed in air under the same mechanical conditions. At least two tests were carried out for each experimental condition.

Table 1
Chemical composition in weight percent, equivalent grain diameters and volume fractions of the constitutive phases of the EN 1.4410 steel studied

C	N	Cr	Ni	Mo	d_α (μm)	d_γ (μm)	% α/γ
0.011	0.24	25.0	7.0	3.8	7	10	46/54

Surface damage features developed within each constitutive phase of the SDSS were investigated through scanning electron microscopy (SEM). Particular attention was paid to the observation of lateral surfaces of the tested specimens in order to discern fatigue damage mechanisms leading to small crack nucleation and subcritical growth.

3. Results and discussion

The cyclic hardening–softening curves corresponding to tests performed in air and in artificial seawater for the three different total strain amplitudes were practically identical in both environments (Fig. 1), except for the different values of fatigue life attained for each experimental condition (Table 2). A very short period of initial hardening, followed by a softening stage and then a saturation state until rupture are the three stages of the curves discerned for all tests. An exception to such behaviour was found at the highest $\Delta\varepsilon_{pl}/2$ where saturation was not reached before failure. This response is typical of DSSs in the as-received or annealed condition [12,15].

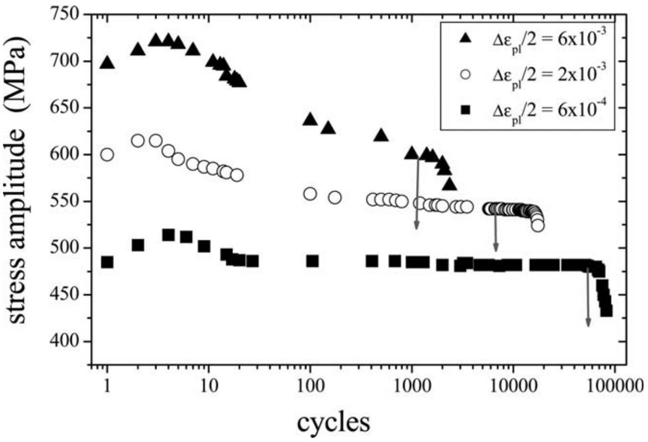

Fig. 1. Cyclic hardening–softening responses of the EN 1.4410 DSS tested in air and in seawater. Arrows indicate failure for seawater tests.