FATIGUE OF DUPLEX STEELS IN SYNTHETIC WHITE WATER ENVIRONMENT

M. Saarna

Abstract
Duplex stainless steels (DSS) are prime candidates for paper and pulp, off shore and mining industries due to their high corrosion fatigue resistance accompanied by good mechanical properties. The aim of the study is to obtain the fatigue data for two DSS steels in a modified TIP 0402-09 type II corrosive environment ("synthetic white water") resembling the "white water" found in the pulp and paper industry. The specimens were manufactured from two types of commercial DSS one hot rolled type and one PM hot isostatically pressed (HIP-ed) type. Axial fatigue testing method at 15 Hz and stress ratio (-1) on a servo-hydraulic testing machine was utilized for determining the fatigue limit and S/N curve.

Keywords: duplex steel, corrosion, fatigue, white water

INTRODUCTION
In the pulp and paper industry duplex stainless steels (DSS) are prime candidates for use in paper machine suction rolls [1]. Suction rolls are used in "white water" removal and to control the wet paper web during the paper making process [2]. "White water" is a corrosive agent containing Chloride (Cl\(^-\)), Thiosulphate (S\(_2\)O\(_3\)\(^2-\)) and Sulphate (SO\(_4\)\(^2-\)) ions [2]. DSS are manufactured as forged, cast, wrought and P/M products. They contain an approximately equal separate volume fraction of ferrite (\(\alpha\)) and austenite (\(\gamma\)), which grant them unique corrosion resistance along with good mechanical properties, which are not affected by the thickness of the specimen or the orientation of microstructure in fully dense PM HIP-ed DSS-s [3,5]. Low-nitrogen DSS good mechanical strength originates from the ferrite phase and high impact toughness from the austenite phase compared to conventional austenitic stainless steel [3]. DSS-s contain Ni to stabilize the austenite and to form a duplex structure, Cr to give them corrosion resistance and stabilise ferrite, Mo to enhance corrosion resistance and stabilise ferrite, N and Mn to stabilize austenite [4]. N is almost completely dissolved in the austenite [3]. DSS have excellent resistance to stress corrosion cracking compared to conventional austenitic stainless steels, fatigue cracks tend to grow in ferrite austenite phase and tend to retard the crack [3]. This can be explained by the alloying elements, especially Cr, Mo and N, and unique behaviour and portioning of the alloying elements of the two phases [3].

When testing DSS in a corrosive environment the fatigue crack could initiate at the pitting marks, which could act as a stress concentrators. Pitting marks occur when localized corrosion takes place. Resistance to pitting corrosion can be evaluated by the pitting corrosion resistance equivalent (PRE), which is calculated in literature [6] according to equation (1).

Mart Saarna, Tallinn University of Technology, Department of Materials Engineering, Ehitajate tee 5, 19086 Tallinn, Estonia
PRE = \text{wt.}\% \text{Cr} + 3.3 (\text{wt.}\% \text{Mo}) \quad (1)

DSS-s are divided into two groups according to PRE. Duplex PRE <35 and super duplex PRE >40. [6]

The aim of this paper is to obtain the S/N curve for two commercial DSS-s.

**EXPERIMENTAL**

To determine the fatigue limit of DSS-s, axial push-pull method with a constant stress ratio R=−1 was used. The testing was carried out under a load-controlled regime at 15 Hz on an Instron 8516 type 100 kN servo-hydraulic test machine. The test variable was the maximum stress level $S_{\text{max}}$, and corresponding output cycles count. The $S_{\text{max}}$ values were chosen to cover the S/N curve from $10^4$ to $10^7$ (run out) cycles. The specimens were prepared by cutting and turning. The specimens were round Ø 10 mm at the grips, Ø 6 mm at the 24 mm long parallel part and 150 mm in total length (Fig.1). Mechanical polishing on the parallel part to remove scratches using a polishing wheel and abrasive was used. After polishing the diameter and surface roughness $R_a$ of the parallel part was measured, the required $R_a$ was <0.6 $\mu$m.

A test chamber was made of stainless steel (Fig.1) and coated with Teflon. The test chamber window was made from acrylic plastic. A membrane pump was used to circulate the test solution about twice per hour (test chamber volume about 0.7 l).

The testing environment was a modified TIP 0402-09 type II test solution. The solution containing NaCl, Al$_2$(SO$_4$)$_3$·18H$_2$O and Na$_2$S$_2$O$_3$·5H$_2$O dissolved in distilled water.

The test solution pH was adjusted to 3.50 by adding 1 vol.% H$_2$SO$_4$ and the composition was the following (prior to pH adjustment):

- Cl$^-$ – (1000 ppm);
- SO$_4^{2-}$ – (800 ppm);
- S$_2$O$_3^{2-}$ – (200 ppm).

The expiration time for a solution was three days during which pH tended to increase about 0.1 pH units per 24 hours and then stabilise at about pH 3.70.

Specimens were submerged by the parallel part into the test solution. The test end criterion was failing of the specimen at any given stress level or reaching $10^7$ cycles.

![Fig.1. Test cell and specimen used for corrosion fatigue testing.](image-url)
TEST RESULTS AND DISCUSSION

Fine and homogeneous microstructure was preserved during the HIP-process in the case of Duplok 22™ (Fig.2a). The hot rolled 3RE60 SRG microstructure showed that the ferrite (etched black) and austenite distribution was not as fine as in Duplok22™ (Fig.2b).

![Fig.2. Microstructure of tested steels: a) Duplok22™; b) hot rolled 3RE60 SRG perpendicular to the fatigue specimen axis.](image)

Tested Duplok22™ and 3RE60 SRG are low alloy DSS-s and were supplied by Metso Powdermet. Duplok22™ has a higher alloying element concentration compared to 3RE60 SRG (Table 1).

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>C [%]</th>
<th>Mn [%]</th>
<th>Cr [%]</th>
<th>Ni [%]</th>
<th>Mo [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3RE60 SRG</td>
<td>0.02</td>
<td>1.48</td>
<td>18.29</td>
<td>5.14</td>
<td>2.46</td>
</tr>
<tr>
<td>Duplok22™</td>
<td>0.03</td>
<td>1.23</td>
<td>22.0</td>
<td>5.53</td>
<td>2.66</td>
</tr>
</tbody>
</table>

Both 3RE60 SRG and Duplok22™ belong to the first group with PRE number about 29 and about 34 respectively. The mechanical properties of the tested DSS-s are shown in Table 2.

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>Tensile strength Rm [MPa]</th>
<th>Yield strength R_{p0.2} [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3RE60 SRG</td>
<td>766</td>
<td>491</td>
</tr>
<tr>
<td>Duplok22™</td>
<td>832</td>
<td>529</td>
</tr>
</tbody>
</table>

The fatigue limit, as it follows from Fig.3 for the tested Duplok22™ was 350 MPa, which is higher then that of 3RE60 SRG, which as it follows from Fig.4 is 300 MPa.
CONCLUSIONS
The PM HIP process -ed Duplok22™ has superior fatigue resistance compared to hot-rolled 3RE60 SRG in the tested corrosion environment due to its fine microstructure, higher pitting resistance equivalent and higher tensile properties.

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REFERENCES