WEAR ASSESSMENT OF STELLITE COATING IN SEVERAL CORROSIVE SOLUTIONS

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Abstract: Stellite™ 6 coatings deposited by HVOF on a Super Duplex Stainless-Steel substrate and wear performance was subsequently assessed. Thus, reciprocating ball-on-plate wear tests were performed in several conditions, for both coating and substrate. Results showed better wear resistance for the coating in all test conditions.

Keywords: duplex, stainless steel, stellite, HVOF, sliding wear.

1. INTRODUCTION

Some engineering applications require the use of materials that combine high mechanical strength with good corrosion and wear resistance. Such is the case for marine environments [1] or during the transport of liquid-particle suspensions in pipes [2, 3].

Stainless steels (SS) form a characteristic surface oxide film, rich in chromium, that generates a passivating effect over the bulk alloy. In stainless steel pipes, this coherent film resists breakdown even during high liquid flow rates and temperatures up to 60 °C, providing good corrosion resistance in these conditions [4]. Some of this durability is lost during erosion-corrosion, such as when solid particles are suspended in the flowing liquid and mechanical damage to the passivating film occurs [4] [5, 6]. Localised wear damage to the passive layer leads to the corrosion of the exposed metal, accelerated by the micro-galvanic coupling between the bare metal (anode) and the remaining passivated metal (cathode) [6, 7].

Stainless steels are classified into grades based on the predominant microstructure. Austenitic grades are commonly used and offer relatively high corrosion resistance, ductility, toughness and weldability [5].

Duplex stainless steels have a microstructure composed of both stainless ferrite and austenite, each present in approximately equal volume fractions [8, 9]. Relative to standard austenitic stainless steels, this fine grained ferritic-austenitic microstructure improves corrosion resistance and doubles the yield strength, without any substantial loss in toughness [8].

Super duplex stainless steels have a pitting resistance equivalent (PRE) number greater than 40. This number provides an estimate for the pitting corrosion resistance of a duplex stainless steel and is proportional to Cr, Mo and N content [8, 10].

Relative to conventional and austenitic stainless steels, the good erosion-corrosion or tribocorrosion resistance of duplex and super duplex steels has been mainly attributed to their high hardness and work hardening capabilities of the austenite phase. This suggests the predominance of mechanical wear in those conditions [1, 5]. Bello et al. [6] have, however, found that for sufficiently low abrasion rates, the S32760 super duplex stainless steel did not suffer depassivation, in contrast to other austenitic stainless steels.
Cobalt-based alloys are also frequently selected for wear applications. The Stellite™ hard cobalt alloys are highly resistant to corrosion and wear, preserving high hardness values at high temperatures [11]. These alloys are used in dental and surgical implants, valves, turbine blades, exhaust pipes, pressurised water reactors, among others [12, 13].

The commonly used Stellite 6™ alloy is composed of approximately Co–28Cr–4.5–1.1C (wt. %) [13]. Alloyed Cr provides mechanical strengthening as well as oxidation and corrosion resistance. The strengthening effect originates from M7C₃ and M23C₆ carbide formation while corrosion resistance is provided by a Cr–rich passivating surface oxide film, similar to the one formed on 304L stainless steel [12].

2. EXPERIMENTAL

The objective of the present study is to evaluate the wear resistance of a Stellite 6™ type alloy deposited on WRn. 1.4501 super duplex stainless (SS) by High velocity Oxy–Fuel deposition (HVOF) in several conditions. The hardfacing alloy used was the Diamalloy™ 4060NS (S6) of composition Co 28Cr 4W 3Ni 3Fe 1.5Si 1Mo (wt. %).

Prior to testing, all samples were polished up to 1 µm diamond paste. The microhardness tests were carried out with a Vickers indenter under 1 Kg applied load.

Sliding wear tests on coated and uncoated SS were performed using a reciprocating tribometer using a ball-on-flat contact geometry. Samples underwent wear testing under both dry conditions and while submerged in corrosive media. The following aqueous corrosives were used: 3.5 wt. % NaCl, 0.2 M NaOH and 0.2 M H₂SO₄. A 6 mm diameter alumina ball was used as counter body. The coefficient of friction (COF) was assessed during each test. The operational tests conditions are given in Table 1. Three wear tests were performed for each condition.

<table>
<thead>
<tr>
<th>Normal load</th>
<th>Frequency</th>
<th>Sliding distance/cycle</th>
<th>Total number of cycles</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 N</td>
<td>1 Hz</td>
<td>6 mm</td>
<td>7200</td>
<td>Room temperature</td>
</tr>
</tbody>
</table>

The wear volume was quantified using surface wear track section profiles assessed using a Mitutoyo SJ–201P profiler with along with the Surftest SJ201 acquisition software. After testing, the surfaces were observed by SEM (FEG–SEM Jeol JSM–7001F).

Corrosion tests were carried out in a three-electrode electrochemical flat cell connected to a computer driven potentiostat (Gamry Reference 600). A platinum counter-electrode was used along with a saturated calomel reference electrode (SCE). The test samples (working electrodes) were exposed to the solution and the open circuit potential (OCP) was read until its stabilization was ensured. The samples were then positively polarized to a scan rate of 1 mV, starting at –0.5 V below OCP vs SCE up until 1 V over OCP vs SCE.

3. RESULTS AND DISCUSSION

The S6 coating was measured to have a hardness of 600 HV while the softer super duplex SS measured 309 HV.

Figure 1 summarises the average sliding wear volume loss for all testing conditions.

The improved wear resistance of S6 under dry conditions is clearly shown in Figure 1. Worn volume was decreased by about 20 times compared to the SS substrate.
Dry SS substrate wear volume was at least 13 times greater than that of all SS testing under corrosive aqueous solution. Therefore, for SS wear tests, the aqueous media is thought to have acted mainly as a lubricant, while also dissipating heat and removing wear particles from the wear track.

The above aqueous media effect is also thought to occur, to a lesser extent, for S6 wear tests, since S6 wear volume loss in acid media is approximately the same as the one obtained upon dry testing.

When comparing both tested materials, S6 tests yielded the lowest wear losses across all testing conditions. In fact, S6 is about 2 times harder than the substrate, which results in lower counter-body asperity penetration and better mechanical support of the passive film.

Figure 2 illustrates the COF taken during wear testing. The lowest values were observed during sliding in H₂SO₄ solution and, on average, S6 generated a lower COF for all conditions except in NaOH media.

**Figure 1.** Sliding wear volumes for all wear tests.

**Figure 2.** COF obtained for different test conditions.
Figure 3 shows the polarisation curves attained for all tested materials when exposed to each corrosive media. SS exhibited superior steady-state corrosion resistance, as indicated by a significantly lower corrosion current density \( I_{\text{corr}} \). These results show that even though S6 showed worse corrosion resistance in all test media, its tribocorrosive wear resistance was higher than SS.

**Figure 3.** Anodic polarization curves for all materials and corrosive media.

Figure 4 pictures SEM analysis results for the wear tracks of each sample. The wear tracks obtained for SS, under dry conditions, exhibited ploughing and/or cutting and severe plastic deformation of the surface, along with some oxides and delamination (Figure 4 a). In contrast, dry tested S6 tracks exhibited a smother surface along with some oxidation (Figure 4 b).

Observation of NaCl solution test results revealed corrosion deposits along the edges of the SS wear track as well as light ploughing and/or cutting and few pits (Figure 4 c). For this same corrosion medium, S6 wear tracks exhibited a comparatively more prominent ploughing and/or cutting (Figure 4 d).

SS wear tracks obtained within a NaOH solution showed significant surface ploughing and/or cutting and deposit formation (Figure 4 e). For S6 under NaOH, the polished pristine surface showed signs of corrosion by NaOH and few pits. The same sample contained pits within the wear track, along with some very light ploughing or cutting (Figure 4 f).

The H\(_2\)SO\(_4\) solution etched the entirety of the SS sample surface along. This surface also exhibited pits, that became more numerous on the track surface. The track surface showed deep ploughing and/or cutting (Figure 4 g). For S6 in acid H\(_2\)SO\(_4\), pits were present evenly throughout the pristine and worn surfaces of the sample. The worn surface also suffered deep ploughing or cutting (Figure 4 h).

These results suggest that the aqueous media mitigated adhesive wear processes in stainless steel samples.

For S6 samples, wear occurs mainly through ploughing and/or cutting due to the abrasive action of the hard alumina ball asperities and hard carbide three body particles. This result is in good agreement with several other studies [14–16]. The pits observed within the wear tracks for S6 samples may be the result of carbide pull-out according to some sources [14, 16]. The extensive pitting found on S6 samples exposed to the H\(_2\)SO\(_4\) may be the result of the dissolution of a dispersed phase, most likely carbide.
Figure 4. SEM analysis of wear tracks.

4. CONCLUSIONS

Wear tests were conducted in a Stellite™ 6 type coating and Duplex Stainless Steel under several conditions (dry, and aqueous solutions of NaCl NaOH and H$_2$SO$_4$) and the conclusions are:
• The coating showed the highest wear resistance for all test conditions.
• The lowest wear resistance for the coating was obtained for dry and 0.2M H₂SO₄ solution.

Overall the results point out that coating duplex stainless steel with Stellite6 leads to an increase of the wear resistance.

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