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Effect of nitriding on the corrosive wear performance of a single and double layer Stellite 6 weld cladding

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ABSTRACT

This study investigates the corrosive wear behaviour of single and double layer Stellite 6 (UNS R30006) weld claddings and the effectiveness of nitriding on their erosion-corrosion resistance. Tests were conducted by utilising an impinging slurry jet. The slurry consisted of 3.5% NaCl aqueous solution which contained 500 μm spherical silica sand with a concentration of 2.4 g/l. The velocity of the jet was 18 m/s and the testing temperature ranged from 16–27°C. The erosion-corrosion tests were conducted at low angle (20°) and at normal incidence (90°). Mass losses, wear scar depths and a volumetric analysis technique were used to assess the damage in the Direct Impinged Zone (DIZ) and the Outer Area (OA) of the specimens. Electrochemical monitoring was also utilised to assess the inherent corrosion resistance of the materials. Although nitriding was found to reduce the pure corrosion resistance of the Stellite 6 weld claddings and did not appear to affect the 90° direct impingement damage, nitriding did yield benefits in terms of low angle sliding abrasion resistance.

1. Introduction

Engineering component surfaces which are in contact with impinging or flowing fluids are subject to corrosive wear. The component will suffer from electrochemical attack by the corrosive nature of the fluid and especially if solid particles are entrapped in the fluid, mechanical degradation processes will also occur. Typical engineering components which experience these deterioration mechanisms are pump impellers, casings, side-liners and piping components [1–3]. There is a significant demand to identify alternative material candidates which will increase the service life of such components.

Stellite 6 is a cobalt based alloy which contains hard chromium carbides and is widely used in industrial applications for components that experience extremely erosive and corrosive environments. This is attributed to the good corrosive wear resistance of cobalt based alloys, which has been demonstrated in previous studies [4–7]. The chemical composition of Stellite alloys has also been found to play an important role in their corrosive wear performance. Modification of Stellite alloys with additional molybdenum and tungsten has been discovered to improve both corrosion and wear resistance [8,9]. Another influencing factor which has been found to affect the wear resistance of Stellite 6 is the manufacturing process. Hot Isostatic Pressed (HIPed) Stellite 6 has been found to have significantly better impact toughness, contact fatigue and erosion-corrosion resistance than a cast Stellite 6 [10,11].

Surface engineering treatments such as diffusion processes, electroplating, induction hardening etc. represent other ways of improving the resistance of a material to corrosion and wear. Nitriding is a heat treating process which involves diffusing nitrogen into the surface of a metal to create a case hardened surface layer [12]. This process is commonly used on low alloy and carbon steels as well as titanium and aluminium alloys. The benefits of nitriding steels have been found to include improvement of dry sliding wear [13–15] as well as improved erosion-corrosion resistance of steels in both liquid and solid/liquid impingement conditions [16–18].

There have been no studies assessing the corrosive wear behaviour of nitrided Stellite 6. However, there have been a small number of studies which have assessed the corrosion and abrasion resistance of nitrided CoCr alloys (UNS R30605 and UNS R30075). It was found that the nitriding process improved the abrasive wear resistance of UNS R30075 in dry conditions [19]. However, when the nitrided CoCr alloy was tested in a simulated body fluid, specimens nitrided above 450 °C were found to suffer extensively from corrosion. A similar trend was found for the nitrided UNS R30605 CoCr alloy when it was corrosion tested in a static Ringer's solution (saline solution). The nitrided CoCr alloy demonstrated

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poorer corrosion resistance than the untreated CoCr alloy [20]. It was postulated that the surface of the nitrided alloy did not passivate, as chromium has a high affinity with nitrogen. This immobilised the chromium and hence prohibited the surface from passivating.

The effect of impingement angle is a vital feature which should be assessed when evaluating the corrosive wear behaviour of materials, as slurry handling components will experience impacting particles in a wide variety of angles. Burstein et al. found that the corrosion rate of UNS S30400 increased with decreasing angle and that the maximum slurry erosion wear rate was found between 40° and 50° angle of impingement [21]. A similar trend was found by Lopez et al. where an impinging angle of 30° yielded greater mass loss for UNS S30400 and UNS S42000 than at normal incidence [22]. Andrews et al. tested UNS S31600 and cast Stellite 6 in erosion-corrosion conditions at a range of angles between 20° and 90° [23]. UNS S31600 was found to have greatest mass loss at 45°, while the cast Stellite 6 had greatest mass loss at 60°.

This study assesses the effect which nitriding has on the corrosive wear behaviour of a Stellite 6 weld cladding as well as evaluating the difference in performance, if any, between a single and double layer weld cladding. Erosion-corrosion tests were conducted in an impinging aqueous saline solution at 20° and 90° impingement angles. Mass loss measurements, potentiodynamic measurements, wear scar depths and an in-house volumetric analysis technique [24] were used to assess the corrosive wear behaviour of the tested materials.

2. Methodology and materials

2.1. Methods

A light microscope (Olympus GX51) was used to evaluate the microstructure of the tested materials. Image J software was used to measure the case depth of the compound nitride layer. The materials were polished to 3 μm diamond and etched with Murakami's reagent. A Scanning Electron Microscope (SEM - Hitachi SU-6600) with a 20 kV accelerating voltage and secondary electron detector was used to conduct energy dispersive x-ray spectroscopy (EDS) analysis was to provide a semi-quantitative indication of the chemical composition of the test materials.

The erosion-corrosion testing utilised a recirculating slurry impingement test rig (Fig. 1) of similar design as discussed previously [25]. The solid-liquid impingement testing was conducted with a 3.5%NaCl aqueous solution with 500 μm spherical silica sand (1160Hv) and a sand concentration of 2.4 g/l. The submerged jet had a velocity of 18 m/s and the nozzle diameter was 3.8 mm. The nozzle was consistently offset from the specimen surface by 5 mm. The diameter of the test samples was 38 mm. The testing temperature began at 16 °C and rose to 27 °C during the 1 h test due to heat input from the pump. The sand size distribution was measured by sieving the sand incrementally by way of fine sieves; the sand size distribution is given in Table 1. Prior to testing, the non-nitrided specimens were ground on 220–1200 SiC grit papers. Mass loss measurements of the specimens were conducted with a mass balance with accuracy ±0.1 mg. Surface topography was performed by using a non-contacting optical 3-D imaging system (Alicona Infinite Focus) with a wear scar depth accuracy of ±1 μm and a wear scar volume accuracy of ±0.02 mm^3. The scatter bands (shown in Figs. 5, 11 and 14) represent the maximum and minimum values found on a minimum of four test replicates. Macrohardness measurements were conducted with a Vickers hardness testing apparatus with a 5 kgf load.

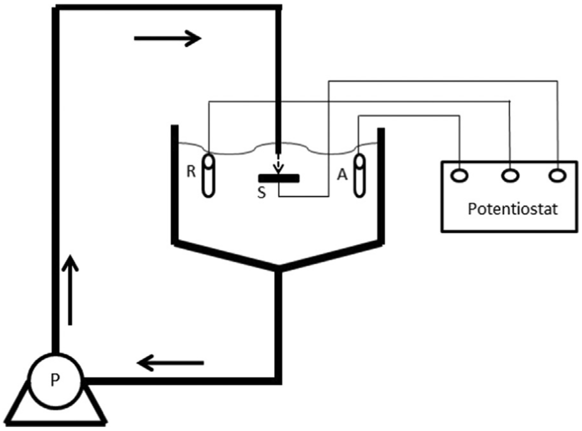

Fig. 1. Schematic of erosion-corrosion test rig.

Table 1
Sand size distribution.

Particle Size (μm)	Percentage (%)
≤ 250	2.5
250–420	18.4
421–500	50.7
501–600	23.3
≥ 601	5.1

Potentiodynamic scans were conducted to assess the electrochemical corrosion rates in static and in-situ solid-liquid impingement conditions. The potentiodynamic scans were conducted 15 min after the sample was submerged to allow for the free electrode potential, E_{corr}, to stabilise. A Gill AC potentiostat was utilised for the potentiodynamic polarisation and cathodic protection tests. Platinum was used for the auxiliary electrode and Ag/AgCl was used as the reference electrode. The tests were conducted by shifting the initial potential either 20 mV more positive (cathodic) or 20 mV more negative (anodic) than the free electrode potential, hence ensuring that transition point would occur. Scans were then made 300 mV more negative (cathodic) or 300 mV more positive (anodic) at a sweep rate of 15 mV/min. The chosen ranges were sufficient to evaluate corrosion current measurements by way of Tafel extrapolation. The measured current densities were then used to evaluate the associated mass losses due to corrosion via calculation by Faraday's Law. To conduct the polarisation tests, an electrically conductive wire was connected to the rear of the specimens, which were then cold mounted in epoxy resin. This ensured that only the tested surface was corroding. The cathodic protection (CP) experiments were focused at impingement angles at 90° impingement angle only. For these the electrode potential was maintained at −800 mV using an Ag/AgCl reference electrode at which potential back extrapolation of the anodic polarisation curves demonstrated that residual anodic reaction rates were negligible.

2.2. Materials

The materials studied were a Hot Wire Tungsten Inert Gas (HWTIG) Stellite 6 weld cladding – single and double layers. The substrate used for the weld cladding was a low alloy steel (UNS G43400). Samples of both single and double weld cladding layers were also ammonia gas nitrided (hereafter referred to as Nit.) at 520 °C for 72 h. The chemical compositions (Table 2), determined by EDS, of the untreated and nitrided Stellite 6 weld deposits were found to be similar to a nominal composition of Stellite 6.

Cross sections of the single and double layer Stellite 6 and nitrided single Stellite 6 were polished and etched in Murakami's reagent, shown in Figs. 2 and 3. Stellite 6 has a typical dendritic