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Effect of impact angle on the slurry erosion-corrosion of Stellite 6 and SS316

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ABSTRACT

This study is an investigation of the effect of impingement angle on slurry erosion-corrosion of Stellite 6 manufactured by sand casting, lost wax casting and SS316. The tests were performed using an impingement rig in which a slurry with 3.5% NaCl and 1.177 g/l suspended angular sand particles at 19 m/s were recirculated for 1 h. The results were obtained for angles of 20°, 45°, 60° and 90° to the exposed surface. Post-experimental analysis using light microscopy, surface profiling and SEM assisted with clarification of the wear mechanisms and assessment of the severity of surface damage. Stellite 6 consistently exhibited superior wear resistance compared with SS316. The most severe regime for SS316 was experienced at low angle of impingement, 45°, due to its ductility. Alternatively, the brittle network of chromium carbides showed significant impact on the behavior of cast Stellite 6 under solid-liquid impingement with the most critical erosion-corrosion damage occurring at 60°.

1. Introduction

Erosion-corrosion is a form of material degradation involving mechanical wear coupled with electrochemical corrosion processes. This phenomenon generally occurs in components that transport corrosive slurries, such as pipe work, pump casings, impellers, valves. The erosion-corrosion occurrence can be very destructive on equipment and components that come into contact with corrosive slurries and may contribute significantly to problems such as loss of efficiency, increased maintenance costs and possible catastrophic failure leading to total breakdown.

Stellite 6, a cobalt-based Corrosion Resistant Alloy (CRA) alloy with a hard chromium carbide phase, is used extensively for industrial applications where the components are exposed to highly erosive and corrosive conditions. CRA's are a group of materials that form a passive oxide film providing protection to the metals against corrosion and include other commonly used materials such as SS316.

The interaction of erosion and corrosion has been studied as the combined mass loss of pure erosion (E) and pure corrosion (C) which does not equate the total mass loss (T) when a material is exposed to both simultaneously [1]. The mass loss attributed to the interaction of the electrochemical and mechanical processes is named the “synergistic” effect (S). The equation for this erosion-corrosion phenomenon is deduced in Eq. 1.

$$T = E + C + S \quad (1)$$

The total mass loss was recorded in this study but the effect of corrosion and synergy were not individually investigated.

Neville and Hodgkiess [2] have studied the performance of Stellite 6 in perpendicular angle of attack under solid-liquid impingement compared with Superduplex and Inconel 625. In their work, Stellite 6 showed similar erosion-corrosion resistance in solid-liquid impingement with Inconel 625 and slightly better than Superduplex. Neville et al. [3] also reported good erosion-corrosion behavior of Stellite X40 in saline solutions when the solid loading of the liquid impingement jet is low or negligible. Stellite X40, as a part of the Stellite family, gives an indication of the erosion-corrosion performance of Stellite 6 under solid-liquid impingement and renders this significant for the present study.

Yu et al. [4] have evaluated the abrasive wear resistance of sand cast and hot isostatically pressed (HIPed) Stellite 6 in a dry sand rubber wheel abrasion test rig. The results showed that both cast and HIPed Stellite 6 had no significant difference in their wear resistance. Malayogu and Neville [5] reported on similar work on sand cast and HIPed Stellite 6 by comparing their erosion-corrosion performance with two stainless steels in perpendicular angle of impingement. The results proved that Stellite 6 generally possesses better erosion-corrosion performance, especially HIPed

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Stellite 6, which showed superior erosion-corrosion performance compared to all comparative materials.

The angle of impingement aspect of this current work refers to the angle between the eroded surface and the particles impacting on that surface which has previously been reported by Stachowiak et al. [6]. Angle of impingement is an important industrial consideration as slurry erosion handling components such as piping systems, valves and impellers experience impacting erosive particles in a full spectrum of angles. The severity of the erosion performance of the material is highly dependent on its ductility. Stellite 6 is a predominantly ductile material but the cast structure is composed of a network of brittle chromium carbides, thus the wear mechanism at varying angles of impingement is unknown. Ninham [7] investigated the response of numerous metals including Stellite 6 using silicon carbide particles as the erodent in dry erosion at 30°, 60° and 90°. This research [7] resulted in the maximum erosion rate occurring at 60° impingement but the material was not exposed to a saline solution therefore not considering the effect of erosion-corrosion.

Burstein and Sasaki investigated the erosion-corrosion mechanism at oblique angles between 10° and 90° of 304 L Stainless Steel [8] under 0.8 wt% slurry and 0.6 M NaCl aqueous solution. SS304L is a ductile material and it demonstrated [8] a peak mass loss between 40° and 50°. As SS304L and SS316 are both austenitic stainless steels, the results can possibly be used as an indicator to the response of SS316 in the current study. The effect of particle velocity and impact angle on SS304 and the martensitic SS420 has also been documented at 30° and 90° in a slurry composed of 0.5 M H_2SO_4+3.5% NaCl and 30 wt% quartz particles at fluid velocity of 4.5 m/s and 8.5 m/s [9]. Interestingly, harder martensitic stainless steel, SS420, presented a significant corrosion influence giving a lower overall erosion-corrosion resistance than SS304. In this testing regime corrosion was a more relevant factor than hardness. This research [9] verifies that the most severe regime for stainless steels, both martensitic and austenitic, is at an acute angle of 30° and high velocity of 8.5 m/s.

The present study is highly novel in that the effects of impact angle on two manufacturing routes of Stellite 6 (sand cast and lost wax) and SS316 have not been investigated in erosion-corrosion conditions. Measured against the reference material, SS316, the key objective of this study was to compare the erosion performance of the two Stellite 6 manufacturing/casting routes under various angles of impingement. Hence, this comparator study reports on the corrosive wear mechanisms of Stellite 6 manufactured by two different casting techniques. The high NaCl content slurry was used to develop the electrochemical processes and the mechanical damage processes were generated by the inclusion of angular sand particles within the slurry. The angles of impingement were 20°, 45°, 60° and 90°.

2. Experimental

The main experimental phase of this study concentrated on the erosion-corrosion phenomena and the materials studied (sand cast Stellite 6, lost wax cast Stellite 6 and SS316) were initially characterized using light microscopy and Scanning Electron Microscopy (SEM) with a 20 kV accelerating voltage and secondary electron detector. Hardness testing was conducted on each specimen using a standard Vickers Hardness Testing machine with a 20 kg load.

This comparator study focused on two different methods of casting Stellite 6: lost wax casting and sand casting. In both cases, the cast alloy forms a classic dendritic type structure as a result of the typically sluggish solidification process in which the cast alloy exhibits a hypoeutectic microstructure in which the primary Co-rich dendrites are surrounded by Cr-rich M_7C_3 (M=Metal) eutectic carbides in a solid solution cobalt matrix [10]. Evidence of these carbides is clearly shown in Fig. 1 from an energy dispersive x-ray analysis in a region of lost wax cast Stellite 6. In terms of bulk chemical analysis, an SEM average analysis over a cross-sectional area encompassing both Cr-rich carbides and the Co matrix provided the chemical composition of both lost wax cast and sand cast Stellite 6 and compared well with the proprietary chemical analysis available in the literature [4,10]. Lost Wax Cast Stellite 6 is 38%Cr, 54%Co, 6%W, 2%Fe and Sand Cast Stellite 6 is 30% Cr, 61%Co, 6%W, 1.26%Fe, 0.8%Mn, 0.9%Si. The hardness values of Lost Wax Cast and Sand Cast Stellite 6 are 394HV(20) and 386HV (20), respectively. SS316 had a recorded hardness of 186HV(20).

The two Stellite 6 casting methods presented similar microstructures; Fig. 1 displays the 2-phase microstructure of lost wax cast Stellite 6. The dark gray areas are Cr-rich carbides and the light gray areas represent the cobalt-rich matrix. A small percentage of carbon is combined with tungsten and it results in tungsten carbides which were confirmed by the SEM spot inspection of the white areas in Fig. 1. A spot analysis was also used to determine the composition of the chromium carbide areas and cobalt matrix for each casting technique which is presented in Table 1.

The erosion-corrosion performance of the comparator materials was assessed using a recirculating impinging jet apparatus which is shown in Fig. 2. The nozzle delivered solid-liquid slurry to the specimen surface at velocity of 19 m/s. The nozzle diameter was 3.8 mm and offset from the specimen by 5 mm. The exposed surface of each test specimen to impingement was 25 mm^2 and grinded using an incrementally finer grade of silicon carbide paper through 120, 220, 500 and 800 grit. Each specimen was weighed before and after the experiment using a mass balance of accuracy 0.1 mg. The experiments involved a 1 h exposure in which the temperature rose from 10° to 20 °C.

The specimen holder was altered to attain solid-liquid impingement angles of 20, 45, 60 or 90°. At each angle, the specimens

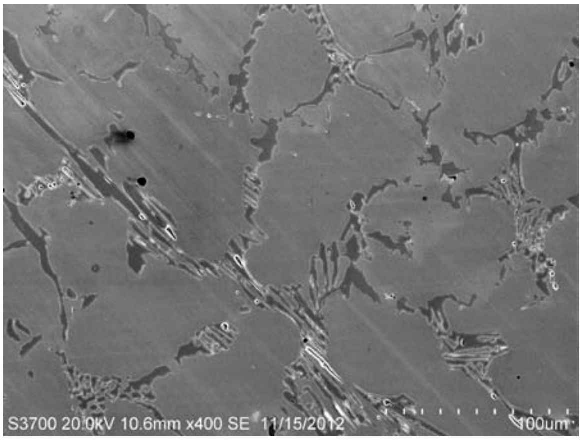

Fig. 1. Typical Lost Wax Cast Stellite 6 microstructure (SEM photo).

Table 1
Compositional analysis of Stellite 6.

Material	Cr-rich carbide /wt %			Co-rich Matrix /wt%		
	Cr	Co	W	Cr	Co	W
Lost wax cast stellite 6	73.8	20.7	4.5	27.3	64.8	5.2
Sand cast stellite 6	77.3	17.1	5.2	24.8	67.7	4.5