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Research Article

A Comparative Study for Wear Resistant of Stellite 6 Coatings on Nickel Alloy Substrate Produced by Laser Cladding, HVOF and Plasma Spraying Techniques

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Abstract

Stellite 6 coatings were deposited using laser cladding, high velocity oxygen fuel (HVOF) thermal spraying and plasma spraying techniques on a nickel alloy substrate. The surface roughness, chemical composition and microstructure of these coatings were characterised by a surface profilometer, optical microscopy (OM) and scanning electron microscopy (SEM). The microhardness of the coatings was measured and the wear behaviour of the coatings was examined under controlled test conditions in a pin-on-plate (reciprocating) tribometer. The results showed that fully dense and crack-free laser clad Stellite 6 coatings can be formed on a high nickel steel substrate. Average microhardness values of the matrix for the coatings were in the range 350-520 HV and the pin-on-plate (reciprocating) wear tests showed the laser cladding coating performed the highest wear resistance compared to the other two coatings.

Keywords: *Laser Cladding, HVOF, Plasma Spraying, Stellite 6 Coating, friction and wear, nickel alloy.*

1. Introduction

Stellite 6 is a very versatile material that is used for hardfacing of various component parts for applications requiring wear resistance (Cobalt-Base Rods 1982). The microstructure of Stellite 6 contains hard M_7C_3 carbides in interdendritic regions in both as-cast and as welded conditions (Tribology Wear Resistance Intermettalic Materials 1980). Stellite alloys also contain a hard Laves phase in a softer matrix of eutectic or solid solution, which is useful for unlubricated wear conditions (Tribology T-900 Technical Data 2002). In high temperature corrosive environments, high nickel content superalloys such as Inconel 600 are used due to their good stress corrosion cracking (SCC) resistance. Despite good SCC resistance, industry has sought improved primary water SCC (PWSCC) resistance by using high chromium content nickel-based alloys (Ferguson, J.B *et al* 2006). An alternative is to use Co-based alloy coatings to provide both SCC resistance and improved resistance to sliding wear. Laser cladding is an advanced coating technology which is used to deposit a thin surface coating of controlled thickness on certain areas of a steel substrate (Tribology T-900 Technical Data 2002). (Steen, W.M 1986) and (Bruck, G.J 1987) have reviewed laser cladding processes. In the coaxial laser cladding process, metal powder is injected through a nozzle, which is coaxial with the laser beam. The powder absorbs laser energy and become partially melted before reaching the substrate. Part of the laser energy is also absorbed by the substrate to cause surface melting, forming a strong metallurgical bond between the substrate and the clad layer. Laser clad layers can be produced that are defect-free (Monson, P 1990). Thermal spraying techniques are coating processes in which melted (or heated) materials are sprayed onto a surface. The feedstock (coating precursor) is heated by electrical (plasma or arc) or chemical means (combustion flame). The flame spray process is basically the spraying of molten metal onto a surface to provide a coating. Material in wire form is melted in a flame (oxy-acetylene flame most common) and atomised using compressed air to form a fine spray. When the spray contacts the prepared surface of a substrate material, the fine molten droplets rapidly solidify forming a coating. This flame spray process carried out a cold process (relative to the substrate material being coated) as the substrate temperature can be kept low during processing avoiding damage, metallurgical changes and distortion to the substrate material. This flame spray process has been extensively used in the past and today for machine element work and anti-corrosion coatings (Gordon, E 2013). Plasma spray process is basically the spraying of molten or heat softened material onto a surface to provide a coating. Material in the form of powder is injected into a very high temperature plasma flame, where it is rapidly heated and accelerated to a high velocity. The hot material impacts on the substrate surface and rapidly cools forming a coating. The plasma spray gun comprises a copper anode and tungsten cathode, both of which are water cooled (Gordon, E 2013). The present work was designed to evaluate the microstructure and tribological properties of Stellite 6 coatings produced by laser cladding, HVOF thermal spraying and plasma spraying techniques. The sliding

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wear tests were carried out using a reciprocating wear testing configuration on a flat sample with a tool steel ball as a pin under dry condition.

2. Experimental

A typical high pressure steam valve spindle (42.5%Ni alloy similar to UNS N09901) was cut into discs (70 mm in diameter and 10 mm thick) and used as the substrate for coating tests. The nominal composition of the substrate material is 36.2% Fe, 42.5% Ni, 12.5% Cr, 6.0% Mo, 2.7% Ti and 0.1% C (wt%). The coating materials used in the experiments was a Stellite 6 (nominal composition 60% Co, 27% Cr, 2.5% Fe, 5% W, 2.5% Ni, 1% C, 1% Si and 1% Mn (wt%)) powder. All coating samples were produced by commercial coating manufacturing companies.

2.1 Sample Characterisation

The surface roughness of coatings was examined using a Taylor-Hobson profilometer. The microhardness of the coatings was measured using a Vickers microhardness tester at a load of 500 g. Wear testing was performed using a pin-on-plate (reciprocating) tribometer with a 6 mm diameter bearing ball. Tests were performed with normal loads (parallel to the axis of rotation of the disc) of 20 N. A rotating speed of 50 rpm was used and each test was performed for 1000, 2500, 5000 and 7500 revolutions under dry sliding conditions at room temperature and humidity. The samples were weighed before and after each test.

3. Results and Discussion

3.1 Surface Roughness

The surface appearance and roughness of the coatings produced by the laser cladding, HVOF and plasma sprayed have a different surface finish. In order to perform wear tests, the clad samples were ground to a flat surface and polished with a 3 µ diamond paste. The surface roughness of the polished samples is presented in Fig. 1. It is clear that the polished samples have a different roughness values. The values range from 40 to 82 nm. The highest roughness value is for the coating formed with plasma sprayed sample and the lowest with laser cladding. The reason for this variation is due to the difference of porosity formation on the coatings.

3.2 Microhardness

Fig. 2 displays the surface microhardness of all coatings and the substrate obtained by the Vicker'smicrohardness measurement at a load of 500 grams. The results show laser clad and HVOF Stellite 6 coatings have a higher surface hardness than the substrate and the plasma spray sample shows the lowest value (lower than the substrate) compared to the other coatings. Within the three Stellite 6 coatings, the laser cladding sample shows the highest surface hardness.

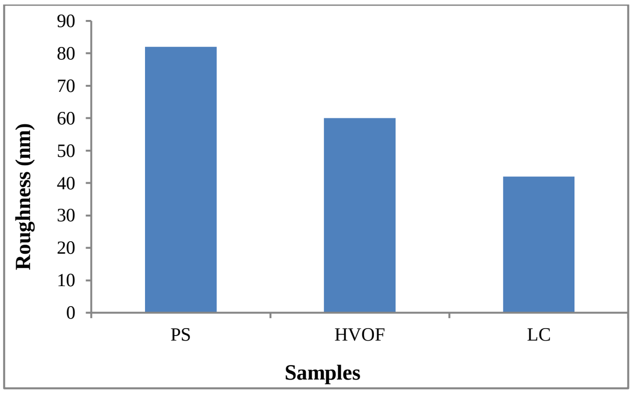

Fig. 1 Surface roughness of the coatings

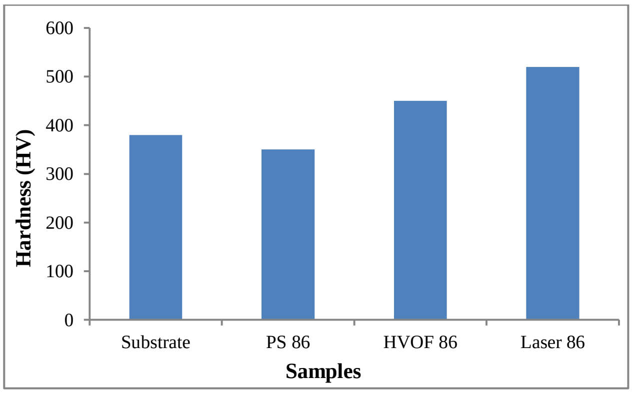

Fig. 2 Surface hardness of the coatings and substrate

3.3 Microstructure of the coatings

Cross-sectional SEM micrographs of the plasma spray, HVOF and laser cladding coatings are shown in Figs. 3, 4 and 5, respectively. The microstructure of Stellite 6 coatings produced with different deposition techniques displays a very similar microstructure which consisting of cobalt-rich dendrites surrounded by hard carbide particles.

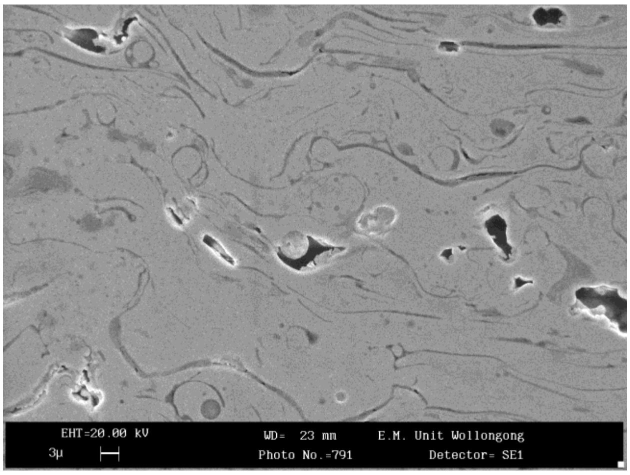

Fig. 3 SEM micrograph of Plasma Spray Stellite 6 coating

The coatings are similar on both PS and HVOF. The sections have a laminar appearance with some porosity and microcracks (refer to Figs. 3 and 4). The Laser cladding coating has a very fine dense dendritic structure typical of a fused metal, with no porosity and cracks (refer to Fig. 5).

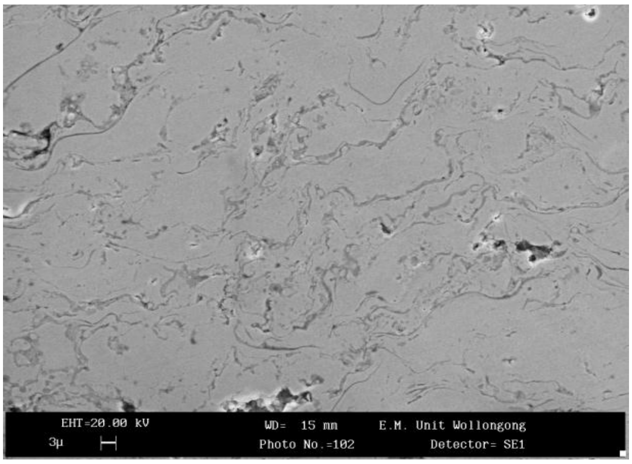

Fig. 4 SEM micrograph of HVOF Stellite 6 coating

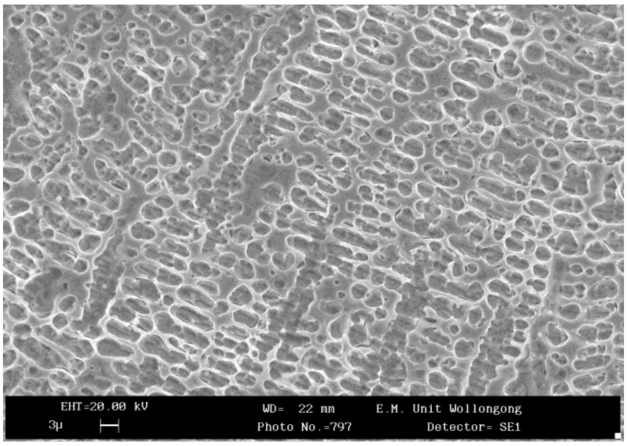

Fig. 5 SEM micrograph of laser cladding Stellite 6 coating

3.4 Wear Resistance

The variation of the weight loss with sliding revolutions for the coatings and steel balls are shown in Figs. 6 and 7,

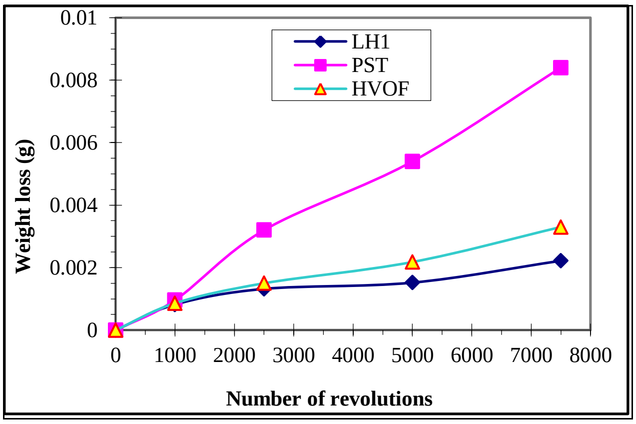

Fig. 6 Weight loss of the Stellite 6 coating samples for tests run for 0-7500 revolutions at speed of 50 rpm and load of 20 N.

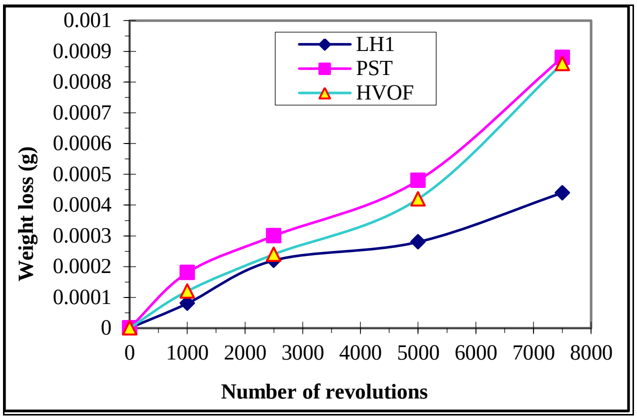

Fig. 7 Weight loss of the steel balls for tests run for 0-7500 revolutions at speed of 50 rpm and load of 20 N

respectively. The results from the comparative tests conducted with Plasma Spray (PS), Thermal Spray (HVOF) and Laser Clad (LC) coatings showed that the wear was less for the tests with the LC coated samples than for those with the HVOF and PS coated samples, while PS coated samples wore the greatest. The higher wear rate for the PS Stellite coated samples is consistent in view of their significantly lower average hardness of approximately 350 HV compared with 450 HV for the HVOF Stellite coated samples as well as compared with 520 HV for the LC Stellite coated samples (refer to Fig. 2). The difference in wear behaviour is more likely due to differences in the Stellite coated composition and microstructure. The PS, HVOF and LC Stellite coated all had a similar nominal composition of balance Co, 28% Cr, 4.5% W, 1% Mo, 1.2% C, 3% Fe, 3% Ni, 2% Si and 1% Mn. Moreover, the LC Stellite coated samples were laser cladded so that the wear surface would not have a formation of micro cracks and porosities (mostly dendritic) with no porosities or cracks (refer to Fig. 5), compared with to that of PS and HVOF Stellite coated samples (refer to Figs. 3 and 4). In addition, in HVOF and PS Stellite coated samples the wear surface would have some micro cracks and porosity. However the number of cracks and porosity present in HVOF Stellite samples considerably less than that present in PS Stellite coated samples (refer to Figs. 3 and 4). The lack of micro cracks and porosities in the LC coating are almost certainly responsible for the lower wear rate observed for the LC Stellite coated samples. The SEM micrographs of the wear tracks for the Stellite 6 coatings are shown in Figs. 8, 9 and 10. It can be clearly seen that PS coating is extensively damaged (refer to Fig. 8). In contrast, the LC coating is hardly changed except for wear traces (refer to Fig. 10). The dry sliding wear resistance is generally governed by surface hardness, although microstructure can play a major role (Karamis, M.B 1993). The wear particles generated during sliding are good indicators of the type of wear mechanism. Basically, the material removal in sliding wear occurs by asperity deformation and fracture, ploughing, adhesion, fatigue and abrasion (Nerz, T.C *et al* 1993). In this study, the wear mechanisms of the HVOF and laser clad coating identified include ploughing, adhesion and fatigue. No evidence of large wear sheets, characteristic of delamination wear was observed. However, average hardness values of the clad layers surfaces were lower than the pin (hardness of 800 HV). Hence, the wear could not occur by abrasion on the clad layer surface. Adhesive wear was found to be the rate controlling mechanism in these clad layers. However, the wear mechanism for PS coatings indicated a large damaged and peeled off surface is to be a combination of adhesive and abrasive wear (Lim, S *et al* 1987).

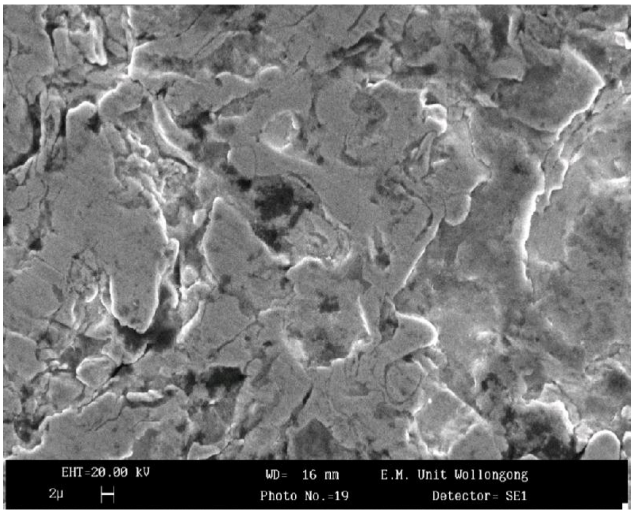

Fig. 8 SEM micrograph of worn surface of PS

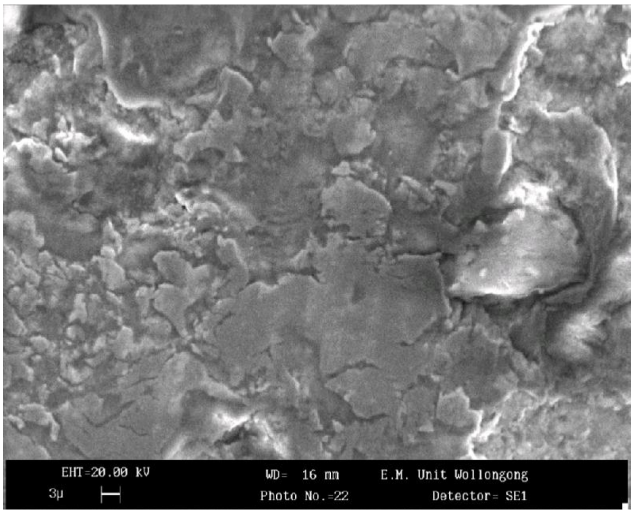

Fig. 9 SEM micrograph of worn surface of HVOF

For the tool steel balls the amount of wear was greatest for the tests conducted with the PS coated samples, followed by the tests conducted with the HVOF coated samples and the LC samples. Much of the difference is in the running in stage where the wear can be seen to be occurring much more rapidly in the tests conducted with the PS coated samples. The LC Stellite coated samples also produced less wear on the steel balls than did the HVOF and PS Stellite coated samples, while the HVOF Stellite coated samples also produced less wear on the steel balls than did the PS Stellite coated samples. In view of the relatively small differences in the chemical composition of the three Stellite coated materials, it is unlikely that the different wear rates produced on the steel balls are due to differences in the physical properties of the three Stellite coated steels and again the differences in composition and microstructure must be responsible for the different rates of steel ball wear produced by the different Stellite coated materials (Kusmoko, A *et al* 2014). The mechanism of wear appeared to prevent any porosity and cracks. Laser clad (LC) had smooth surfaces compared to that of HVOF had porosity then PS had more porosity as well as the surface roughness. It would seem that the higher quantity of dendritic structure in the LC samples may have limited the amount of micro cracking and porosity that occurred, resulting in reduced wear on the steel ball (Bowden, F. P *et al* 1964; Qiu, X *et al* 2012).

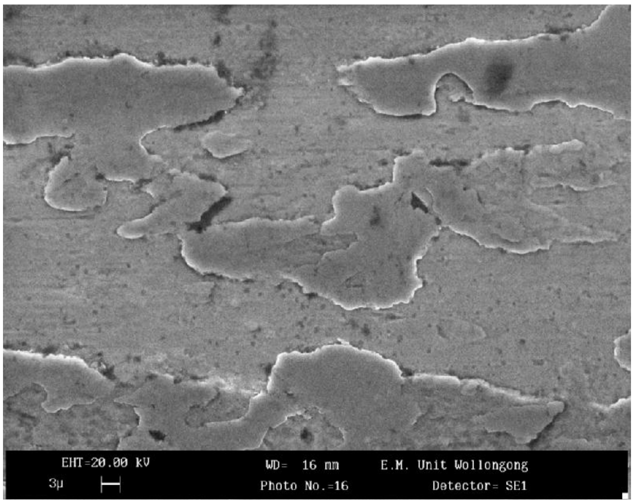

Fig. 10 SEM micrograph of worn surface of LC

Conclusions

The present study compared the wear behavior of Stellite coating samples (Plasma spray, Thermal spray and Laser clad) under reciprocating wear testing. The laser clad and thermal spray samples had a coating hardness of approximately 450-520 HV whereas plasma spray had a coating hardness of approximately 350 HV. Wear tests were carried out unlubricated using a load of 20 N and a sliding velocity 0.5 - 0.6 m/s. The results showed that the three Stellite coated samples and the steel balls wore more rapidly, in both the running in and the steady state, when the tests were carried out with plasma spray Stellite coated samples (PS). This is attributed to microstructural differences between the three materials. The laser clad Stellite coated samples (LC) had no micro cracks and porosities while the thermal spray Stellite coated (HVOF) and plasma spray Stellite coated (PS) samples had progressively greater levels of porosity, micro cracks and coating defects. This would result in a higher hardness which would reduce the wear rate of the laser clad Stellite coated samples. The results indicate that the wear rate of both the steel balls and the Stellite coated materials would be increased from laser clad (LC) materials to thermal spray (HVOF) materials and subsequently to plasma spray (PS) materials.

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