International Journal of Innovative Research in Technology, Science & Engineering (IJIRTSE)
www.ioirp.com
ISSN: 2395-5619, Volume – 2, Issue – 5. May 2016

STUDIES ON CUTTING PERFORMANCE OF PLASMA SPRAY COATED SWING HAMMER

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Abstract

Stellite 12 coatings were deposited using laser cladding, high velocity oxygen fuel (HVOF) thermal spraying and plasma spraying techniques on a GI250 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-disk tribometer. The results showed that fully dense and crack-free laser clad Stellite12 coatings can be formed on a high GI250 steel substrate. Average microhardness values of the matrix for the coatings were in the range 300-640 HV and the pin-on-disk wear tests showed the plasma spray coating performed the highest wear resistance compared to the other two coatings.

Keywords: Laser Cladding, HVOF, Plasma Spraying, Stellite12 Coating, friction and wear, GI250 alloy.

1. INTRODUCTION

The optimization of sugarcanes cutting swing hammers, subjected to mechanical stresses, depends on combinations of properties. Surface modification is a generic term, now applied to a large field of diverse technologies that can be harnessed to achieve increased reliability and enhanced performance of industrial components. The development of a suitable high performance coating on a component fabricated using an appropriate high strength metal/alloy offers a promising method of meeting both the bulk [1] and surface property requirements of virtually all sugarcane applications. The newer surfacing techniques, along with the traditional ones, are eminently suited to modify a wide range of engineering properties. The properties that can be modified by adopting the surface engineering approach include tribological, mechanical, thermo-mechanical, electrochemical, optical, electrical, electronic, magnetic, acoustic and biocompatible properties. Driven by technological need and fuelled by exciting possibilities, novel and spray methods for applying coatings, improvements in existing methods and new applications have proliferated in recent years [2]. The wear encountered in here in found to be complex, which makes the selection of an optimal material and the design of the required component practically hard, if only one of these properties is relied upon. It is desirable, for the chosen material, to withstand the forces during cutting [3]. Also, it should be resourceful to absorb and dissipate the heat in a little while. [4] Stellite 12 is a very versatile material that is used for hardfacing of various component parts for applications requiring wear resistance [5].

2. Experimental

A total of 9 specimens of the base material were prepared [6]. The samples have circular cross section of diameter 10mm and of length 100mm each. The pin samples were numbered from 1 to 9 for identification. Emery papers of five different grades viz. 220, 400, 600, 800, and 1000 were employed to grind the end faces of the samples. Polishing was done, post grinding, using polishing papers of various grades such as 1/0, 2/0, 3/0, and 4/0. All coating samples were produced by commercial coating manufacturing companies.

Table 2.1 Chemical composition (Wt %) of the GI250 grey iron

	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
GI250	3.35	2.16	0.53	0.118	0.127	0.658	0.025	0.293	0.250

Table 2.2 Hardness values of GI250 grey iron

Material	GI250
Hardness(HB)	285

2.3. DEPOSITION OF COATINGS

2.3.1 Plasma Spray Coating Powders

Plasma spray coating process was suggested with two coat materials [7] .Stellite-12 after a detailed study. Both the preferred materials are said to posses' better wear resistance.

2.3.1.1 Stellite-12

The coating of stellite-12 using plasma spray coating process facilitates the formation of a highly impenetrable (dense) and harmonized (homogeneous) coat on the base material. The constituent elements of the powder are Carbon (1.8%), Fe (5%), Tungsten (9%), Chromium (29%), and Cobalt (remaining) .The powder particle size is found to be in the range 10-45 microns. [8]

2.4 Experimental Set Up

Dry sliding wear tests for the uncoated and detonation spray coated cylindrical specimens were conducted using a pin- on –disc machine (Wear and Friction Monitor Tester TR-201made by M/S DUCOM, Bangalore, INDIA) conforming to ASTM G 99 standard . The tests were conducted in air with a room temperature of 30-32°C. Wear tests were performed on the pin specimens that had flat surfaces in the contact regions and the rounded corner. The pin was held stationery against the counter face of a rotating disc made of carbon steel (EN-31) at 40 mm track diameter. EN-31 steel is a plain carbon steel; case hardened 62 to 65 HRC as provided with the pin-on-disc machine. The composition of the material of the steel disc is given in Table 2.3.

Table 2.3 Chemical composition (wt %) of the En-31 carbon steel disc

C	Si	Mn	S	P
0.42 (max)	0.05-0.35	0.40-0.70	0.05(max)	0.05(max)

2.5 Sample Characterisation

The surface Ducom wear tester. 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 [7].. 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.

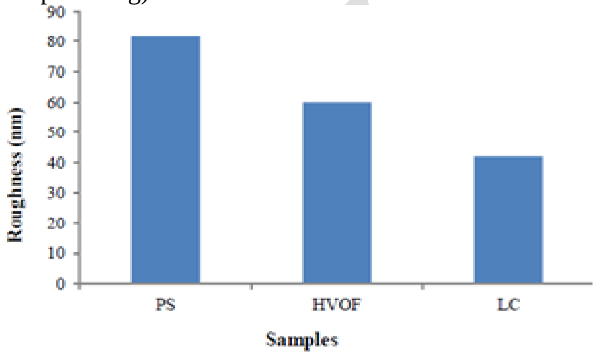

Fig. 1 Surface roughness of the coatings

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 [8].. 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's microhardness measurement at a load of 500 grams. The results show laser clad and HVOF Stellite12 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 stellite12 coatings, the laser cladding sample shows the highest surface hardness [9]..

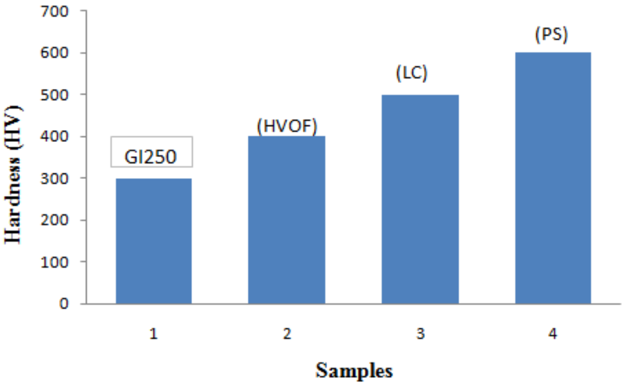

Fig. 2 Surface hardness of the coatings and substrate

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 [10]. The microstructure of Stellite 12coatings produced with different deposition techniques displays a very similar microstructure which consisting of cobalt-rich dendrites surrounded by hard carbide particles

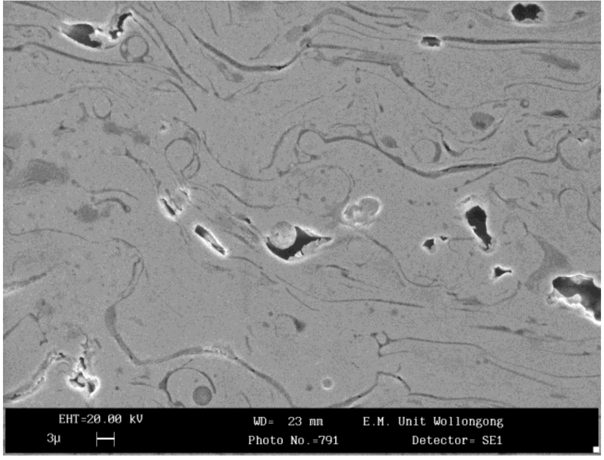

Fig. 3 SEM micrograph of Plasma Spray Stellite 12 coating

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).

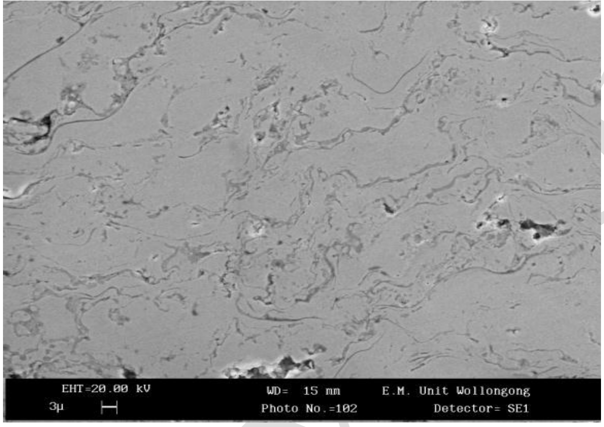

Fig. 4 SEM micrograph of HVOF Stellite 12 coating

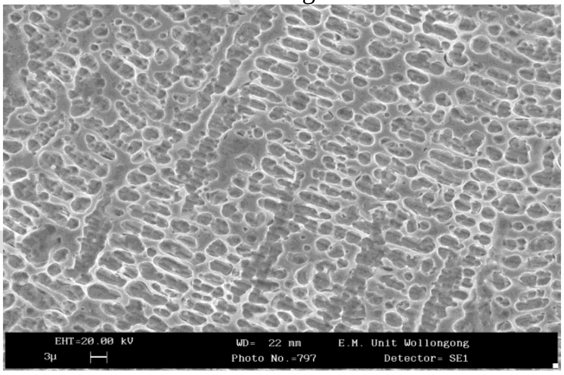

Fig. 5 SEM micrograph of laser cladding Stellite 12 coating.

3.4 Wear Resistance

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

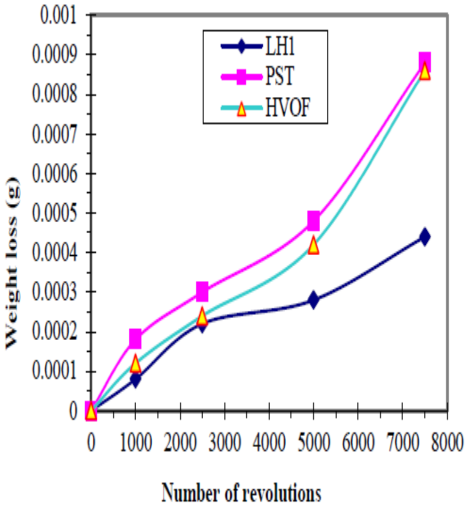

Fig. 6 Weight loss of the Stellite 12coating samples for tests run for 0-7500 revolutions at speed of 50 rpm and load of 20 N.

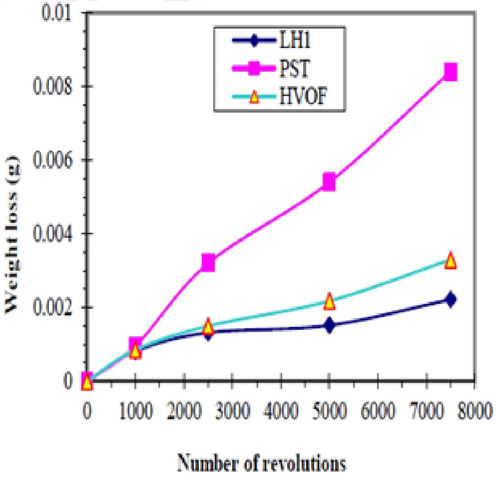

Fig. 7 Weight loss of the steel balls for tests run for 0-7500 revolutions at speed of 50 rpm and load of 20 N respectively.

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 12coated samples is consistent in view of their significantly lower average hardness of approximately 350 HV compared with 450 HV for the HVOF Stellite 12coated samples as well as compared with 520 HV for the LC Stellite 12coated samples (refer to Fig. 2). The difference in wear behaviour is more likely due to differences in the Stellite 12coated composition and microstructure. The PS, HVOF and LC Stellite12coated 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 12coated 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 12coated samples (refer to Figs. 3 and 4). In addition, in HVOF and PS Stellite 12coated samples the wear surface would have some micro cracks and porosity. However the number of cracks and porosity present in HVOF Stellite 12samples considerably less than that present in PS Stellite 12coated 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 12coated samples. The SEM micrographs of the wear tracks for the Stellite 12coatings 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).

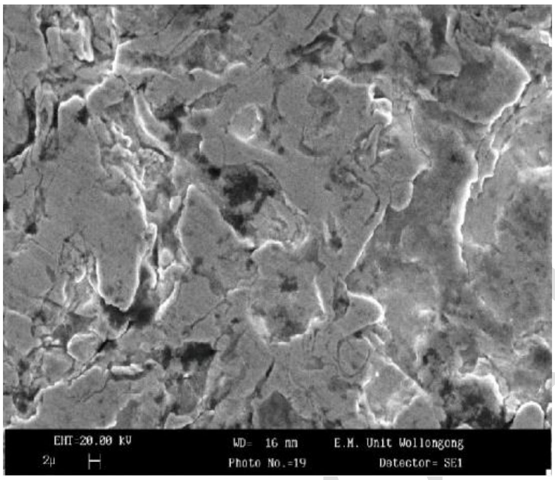

Fig. 8 SEM micrograph of worn surface of PS

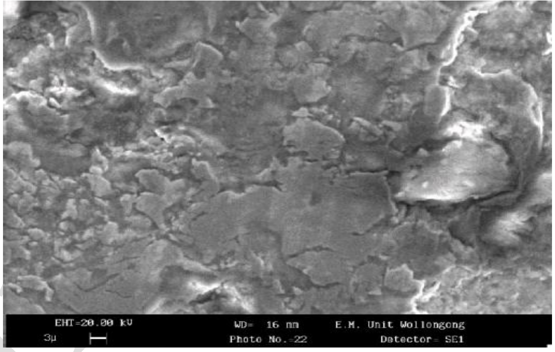

Fig. 9 SEM micrograph of worn surface of HVOF

For the tool steel pin 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 12coated samples also produced less wear on the steel balls than did the HVOF and PS Stellite 12coated samples, while the HVOF Stellite 12coated samples also produced less wear on the steel balls than did the PS Stellite 12coated samples. In view of the relatively small differences in the chemical composition of the three Stellite 12coated 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 12coated 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 12coated 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).

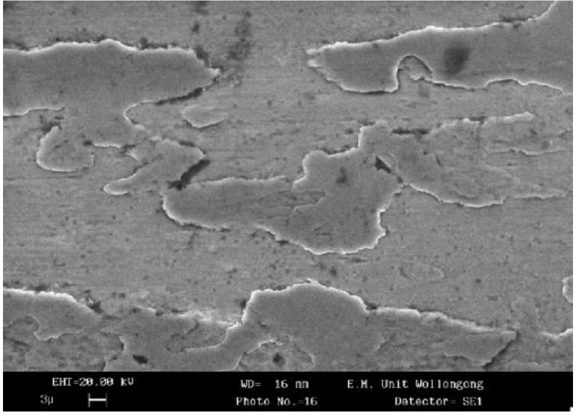

Fig. 10 SEM micrograph of worn surface of LC

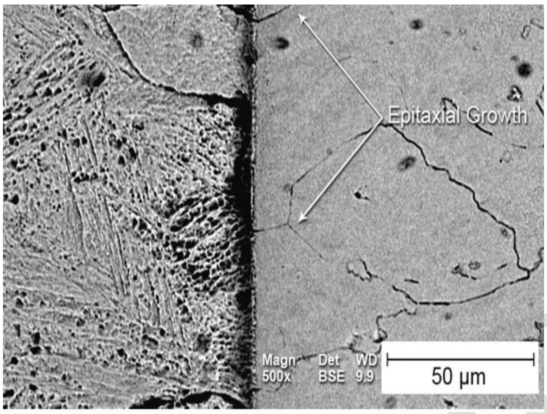

Fig. 11 The interface between stellite12 coated and GI250 substrate

Interface between stellite12 coating and GI250 substrate. As can be seen, the first type of boundary is formed. This type of boundary is likely to have formed in similar PS and is different from the second type which generally forms in coating of dissimilar metals. In the second type boundaries, grains grow parallel to the interface of the cladding. Grain growth in the first type of boundaries is different. In this condition, grain boundaries form from the boundaries within the base metal and then grow in a direction perpendicular to the weld interface into the weld pool shown in Figure 4.13. This kind of growth is called epitaxial growth. Similarities in crystal structure and chemical composition result in the evolution of such growth.

4.4 X-ray Diffraction (XRD) analysis

The X-ray diffraction patterns for plasma sprayed stellite 12 shown in Figure 12. Graph shows the X-ray diffraction patterns for as coated samples of Stellite 12 coating on GI250 from Figure 3.2 it is identified that coating stellite12 shows the excess of desired coating elements such as C, Cr, O, Co and small amount of Fe and Si. The no. of peaks corresponding to elements of coatings can be seen from diffraction patterns of different coatings for GI250

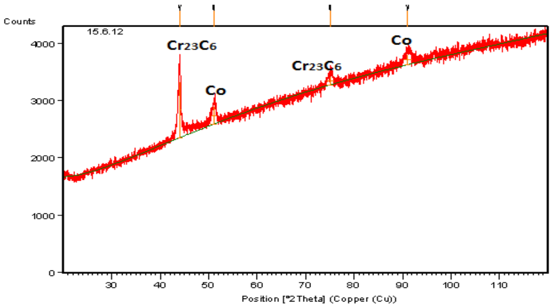

Figure 12 X-ray Diffraction patterns of as coated GI250 material Stellite12

Conclusions

The present study compared the wear behavior of Stellite12 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 Stellite12coated samples and the GI250 wore more rapidly, in both the running in and the steady state, when the tests were carried out with plasma spray Stellite 12coated samples (PS).

This is attributed to microstructural differences between the three materials. The laser clad Stellite 12coated samples (LC) had no micro cracks and porosities while the thermal spray Stellite 12coated (HVOF) and plasma spray Stellite 12coated (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 12coated samples. The results indicate that the wear rate of both the steel balls and the Stellite 12coated materials would be increased from plasma spray (PS) materials to thermal spray (HVOF) materials and subsequently to laser clad (LC) materials.

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