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Measuring Dilution and Wear for Stellite 6 Deposited on P22 Steel Substrate by Laser Cladding

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***Abstract* – Stellite 6 was deposited by laser cladding on a P22 steel substrate with energy inputs of 1 kW (P22-1) and 1.8 kW (P22-1.8). The chemical compositions and microstructures of these coatings were characterized by atomic absorption spectroscopy, optical microscopy and scanning electron microscopy. The microhardness of the coatings was measured and the wear mechanism of the coatings was examined using a pin-on-plate (reciprocating) wear testing machine. The results showed less cracking and pore development for Stellite 6 coatings applied to the P22 steel substrate with the lower heat input (P22-1). Further, the Stellite coating for P22-1 was significantly harder than that obtained for P22-1.8. The wear test results showed that the weight loss for P22-1 was much lower than for P22-1.8. The measurements of dilution and C content showed that P22-1 possess lower dilution and higher concentration of C than P22-1.8 It is concluded that the lower hardness of the coating for P22-1.8, together with the softer underlying substrate structure, markedly reduced the wear resistance of the Stellite 6 coating and the lower hardness of the coating for P22-1.8 was due to higher level of dilution and lower concentration of C.**

***Keywords* – Dilution, P22 Steel, Stellite 6 Coating, Wear.**

I. Introduction

Stellite 6 is a very versatile material that is used for hardfacing of various component parts for applications requiring wear resistance [1]. The microstructure of Stellite 6 contains hard M_7C_3 carbides in interdendritic regions in both as-cast and as welded conditions [2]. Stellite alloys also contain a hard Laves phase in a softer matrix of eutectic or solid solution, which is useful for unlubricated wear conditions [3].

High temperature strength and high temperature corrosion resistance are the conditions to consider a material for the power plant industry. Heat resistant steels, such as P22 (2.25Cr – 1Mo), are extensively used for high temperature applications, and are generally classified into ferritic steels. The research on the development of high-strength ferritic steels has produced new alloys able to operate in the supercritical range. These steels show good weldability and improved resistance to sliding wear [4]. However, the P22 steel has not been extensively studied for the development on wear resistance of laser cladding using Stellite 6 especially with different heat input.

Surface alloying is usually done by advanced techniques such as laser cladding due to significant advantages like fast processing speed, relative cleanliness, a very high heating/cooling rate (105 K/s) and high solidification velocity (up to a maximum of 30 m/s) [5]. As a result, the process has a low energy input and causes less distortion of the component than hand or arc welding. Steen and Bruck [6] 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 [7].

The purpose of this study was to evaluate the sliding wear characteristics of Stellite 6 coating materials produced by laser cladding of a P22 steel substrate with low (1 kW) and high (1.8 kW) energy inputs. The sliding wear tests were carried out on flat samples in an unlubricated (dry) condition using a reciprocating wear tester with a tool steel ball. This paper discussed further on dilution measurements and estimation of C content of Stellite 6 coatings and the role of C content in forming Cr_7C_3 particles to harden the deposit and contribute the increase wear resistance.

II. Experimental Methods

A. Laser Cladding Deposition

The laser cladding process of P22 steel substrates with Stellite 6 was carried out by commercial coating manufacturing companies using 1 kW and 1.8 kW energy input. The initial coating thickness as received was about 0.35 mm for both energy inputs. Table 1 shows the nominal compositions of the P22 steel and the Stellite 6 alloy.

Table 1. Nominal compositions (wt%) of the P22 steel and Stellite 6 alloy [3].

(%)	**Co**	**Cr**	**Fe**	**W**	**Ni**	**C**	**Si**	**Mn**
S 6	60	27	2.5	5	2.5	1	1	1
P22		2.25	Bal			0.11	0.34	0.58
(%)	**P**	**S**	**Mo**	**V**	**Al**	**Ti**	**Nb**	**B**
S 6								
P22	0.01	0.01	0.93					

B. Characterisation of Stellite Coated Samples

The microhardness measurements were made at intervals of 0.05 mm through the coating thickness using a Leco M-400-H1 hardness testing machine with a load of 300 g. The samples were then etched in a mixed acid solution to reveal the microstructure of the Stellite 6 coating. Subsequently, coatings were studied using a Leica DMRM optical microscope.

C. Wear Testing

Wear testing was carried out using a pin-on-plate (reciprocating) mode with a 6 mm tool steel ball as the pin. A ball was fixed in a collet and during operation, the ball remained stationary while the flat specimen moved in a linear, back and forth sliding motion, under a prescribed set of conditions.

Since the aim of the work was to examine the wear of Stellite 6 coating materials, it was necessary to grind and polish the flat specimens (coatings) to the required surface finish for the wear test. The coatings were about 0.3 – 0.4 mm thick and approximately 0.05 mm of the coating was removed.

Prior to carrying out the wear tests, the test specimens were weighed to an accuracy of 0.0001 g. The flat specimen was then screwed firmly in place on the base of the wear tester. After the test was complete, wear debris was removed from the sample, which was then washed in alcohol, dried, and reweighed.

The tool steel ball was also washed in alcohol, dried and weighed to an accuracy of 0.0001 g at the start of each test and at the same time as the flat specimen. The ball was re-weighed after testing but, as the weight of the steel ball did not change significantly, it was not considered in assessing the wear damage.

The test speed, number of cycles and test duration were held constant: 50 rpm, 10,000 cycles and 200 minutes. The various tests conducted are: Test# 1, P22-1 with applied load of 2 kg; Test# 2, P22-1.8 with applied load of 2 kg; Test# 3, P22-1 with applied load of 5 kg; Test# 4, P22-1.8 with applied load of 5 kg.

D. Examination of Wear Surface

In order to study the effect of laser heat input and the applied load during wear testing on the wear track, the surfaces of the samples from Tests# 1-4 were examined after testing using a S440 scanning electron microscope (SEM) operating at 20 kV.

E. Measurements of Dilution and Estimation of C Content

A measured compositions of Stellite 6 coatings has been conducted using AAS (Atomic Absorption Spectroscopy) to determine the chemical analyses present using two different laser power (1 kW and 1.8 kW). However, the C content was not detected. Therefore it was necessary to estimate the C content by calculating dilution. The method of calculation is shown in Fig. 1.

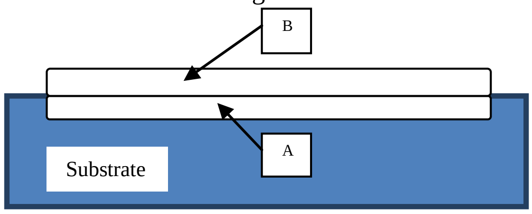

Fig. 1. Schematic diagram showing the clad layer, which consist of two parts: added Stellite 6 alloy (region B) and melted base plate (region A). The dilution D of the Stellite alloy is given by A/(A+B) [8].

If the C content (wt%) of the base metal or substrate is given by $[C]_{BM}$ and the C content (wt%) of the Stellite is $[C]_s$, then the estimated C content of the weld deposit $[C]_{WD}$ is given as follows:

$$[C]_{WD} = D \times [C]_{BM} + (1-D) \times [C]_s. \quad (1)$$

III. Results

A, Coating Compositions

The compositions of the Stellite 6 coatings were determined by AAS (Atomic Absorption Spectroscopy), see Table 2. Table 2 shows that the two chemical analyses (P22-1 and P22-1.8) of the coatings were similar, but there were some differences in alloy content of the coatings. In particular, the coating for P22-1 was significantly lower in Fe than for P22-1.8.

B.Scanning Electron Microscopy (SEM) of Deposit Coating Cross-Sections

The coatings on the P22 steel substrate had a cellular-dendritic appearance. The higher heat input of 1.8 kW produced a coarser cellular-dendritic structure, see Fig. 2 (a-b).

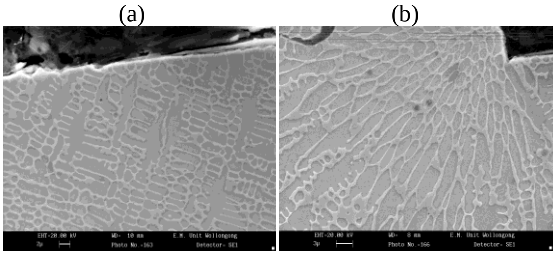

Fig. 2. SEM micrographs of cross sections of the Stellite 6 layers deposited on (a) P22-1, (b) P22-1.8.

C. Microhardness Testing of Coating Cross-Sections

Microhardness profiles for the Stellite 6 weld samples is shown in Fig. 3. For the coating deposited at 1 kW, the coating hardness was about 600 HV compared with 500 HV for 1.8 kW. The HAZ hardness was generally lower than that of the coating. The hardness of the unaffected substrate was about 250 HV.

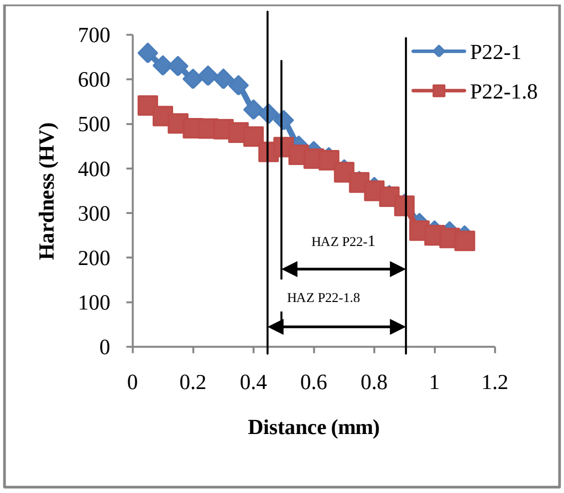

Fig. 3. Graph of hardness profiles with distance from the coating surface for Stellite 6 deposited on P22 steel.

D. Wear Testing

Tests # 1-2 were conducted using an applied load of 2 kg. It was found that the deposit for P22-1 wore substantially less, whereas the deposit for P22-1.8 showed significant wear with deep grooves. The effect of a higher load (5 kg),Test# 3-4, was generally similar to that for Tests# 1-2, see Fig. 4 (a-b).

E. Mass Loss

Table3 shows the weight loss measurements for the Stellite coated samples. It can be seen in Table 3 (Tests# 1-4) that the weight loss increased with load and was higher for P22-1.8.

Table 2. Measured compositions (wt%) of the Stellite 6 coatings

(%)	P22-1	P22-1.8
P	0.23	0.25
Mn	0.34	0.39
Si	0.66	0.53
Ni	2.45	2.05
Cr	29.75	28.75
Mo	0.26	0.092
Cu	0.013	0.028
Nb	0.01	<0.01
Ti	0.03	0.02
V	0.019	0.008
Fe	4.3	6.3
W	4.0	4.2
Co	55.1	54.8

F. Characterisation of Wear

In order to study the effect of load on the wear track, Stellite coated samples were examined at the completion of the wear test by scanning electron microscopy to establish the nature of wear.

The worn surface of P22-1, Fig. 5 (a) is smooth compared to the P22-1.8 surface which was more porous and showed greater surface roughness.The effect of a higher load (5 kg) at 1.8 kW heat input is illustrated by Fig. 5 (b)

G. Dilution Measurements and Estimation of C Content

In order to estimate the C content of the Stellite 6 coatings as the C was not determined in Table 2, it was necessary to measure the dilution shown in Fig. 1, subsequently the C content was estimated. Tables 4 and 5 show the estimation of dilution and C content of Stellite 6 coatings.

Table 3. Weight loss for Stellite coatings deposited at a power input of 1 kW and 1.8 kW

Loads (kg)	P22-1 (g)	P22-1.8 (g)
2	0.0027	0.00312
5	0.0091	0.01558

(a) (b)

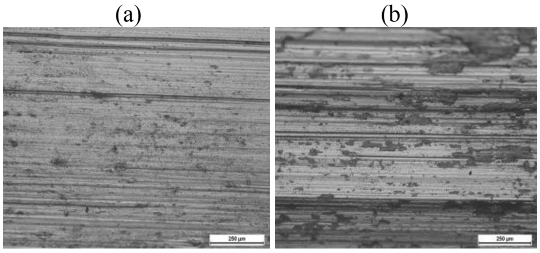

Fig. 4. Optical micrographs showing wear tracks at a load of (a) 2 kg for P22-1, (b) 5 kg for P22-1.8.

(a) (b)

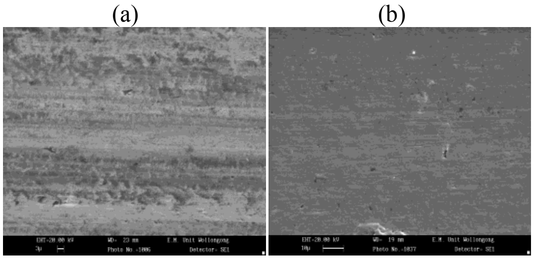

Fig. 5. SEM micrograph of worn surface tested at a load of (a) 2 kg for P22-1, (b) 5 kg for P22-1.8.

IV. Discussion

The comparative tests conducted for laser clad P22 steel substrate showed that the weight loss was lower for coated samples deposited at a heat input of 1 kW (P22-1). The amount of wear (mass loss) of the Stellite coated samples was greater for the tests conducted on coatings deposited with 1.8 kW than for those deposited at 1 kW, as shown in Table 3.

For deposits produced at 1 kW, the weight loss increased by a factor of about 3 with increasing test load up to 5 kg, but for the higher heat input the rate of weight loss strongly increased by a factor of about 5 with increasing load. It is likely that the greater incidence of microcracks and porosity detected after wear testing of P22-1.8 samples is due in part to the substrate, particularly to the HAZ, being softer and less rigid [9].

Table 4. Measurements of dilution of the Stellite 6 coatings

	Area A (μm^2)	Area B (μm^2)	Dilution, D (wt%)
P22-1	33504.401	725704.533	0.0441
P22-1.8	177074.912	904045.255	0.1638

Table 5. Estimation of C content of the Stellite 6 coatings

	$[C]_{BM}$ (wt%)	$[C]_S$ (wt%)	Dilution, D (wt%)	$[C]_{WD}$ (wt%)
P22-1	0.11	1.00	0.0441	0.961
P22-1.8	0.11	1.00	0.1638	0.855

The higher wear rate for the P22-1.8 Stellite coated samples is also consistent with the lower surface hardness of approximately 500 HV compared with 600 HV for the P22-1 Stellite coated samples, as shown in Fig.3. Acceleration of the wear rate is therefore likely for the Stellite coating P22-1.8 as the wear grooves penetrate the coating [10,11].

As Table 2 indicates, the Stellite composition was modified by the substrate. This change occurred by melting of the substrate and mixing with the deposited alloy (dilution). Compared to the Stellite 6 nominal composition (Table 1), the coatings were significantly lower in Co, Mn, Si and W due to dilution by the substrate. However, the Ni and Cr contents remained similar to those of Stellite 6, while the Mo and Fe contents were increased due to pick-up from the substrate. The coating produced for P22-1 showed slightly higher Cr, Mo and Co contents than those for P22-1.8, while the Fe, Mn and W contents were lower. In general, these differences are consistent with less dilution of the coating produced at the lower heat input. For this reason, the carbon content for the coating P22-1 would be expected to be higher than that for P22-1.8, therefore allowing more copious precipitation of Cr_7C_3 particles that harden the deposit [10]. Further, the faster cooling rate associated with the lower heat input is expected to result in structural refinement that contributed to the hardness of the coating. The deposit on P22-1was about 100 HV points higher than for the coating on P22-1.8 (Fig.3) and this difference accounts for the substantial increase in wear resistance [12].

As discussed previously, the higher level of dilution for P22-1.8 Stellite coated samples, Table 4 are consistent with higher wear rate, Table 3 and lower surface hardness, Fig. 3 of approximately 500 HV compared with 600 HV for the P22-1 Stellite coated samples suggesting that the higher heat input produced higher dilution [13].

As table 5 indicates, the C content of weld deposit for the P22-1 Stellite coated samples was higher by a factor of about 1.124 than P22-1.8 Stellite coated samples, indicating that the higher of C content of weld deposit consistent with a lower level of dilution, Table 4, hence promoting the carbide morphology of Cr_7C_3 particles and to harden the deposit, Fig. 3 thus producing higher wear resistance [14,15].

V. Summary and Conclusions

The present study compared the wear behaviour of Stellite 6 under reciprocating wear conditions as laser clad deposits on two different heat inputs (1.0 kW and 1.8 kW) of P22 steel. The coating composition was slightly different in the two cases because of differential dilution by the substrate. The compositional differences combined with different cooling rates after deposition resulted in substantially different coating hardnesses. The coating on P22-1 had a hardness of approximately 600 HV, while the coating on P22-1.8 had a hardness of approximately 500 HV. The tests were carried out unlubricated, using loads of 2 and 5 kg and a speed of 50 rpm for 10000 revolutions.

The results indicated that the rate of weight loss and the total weight loss were higher for the higher load and also for the higher heat input. The wear rate was lower for P22-1 coated samples, with less cracking and pore development in the Stellite 6 coatings. The calculation of dilution showed that the level of dilution was higher for the higher heat input and the C content estimation also indicated that C content was lower for the higher heat input.

It is concluded that the deposit obtained at 1 kW was harder because of compositional, microstructural and level of dilution differences; and also the harder coating in weld deposit of P22-1 resulted in the higher wear resistance due to higher C content to form carbide (Cr_7C_3 particles) to harden the deposit than the Stellite 6 coating deposited at the higher heat input of 1.8 kW.

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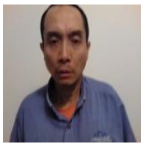
Author's Profile



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