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Estimation of Dilution and Carbon Content of Laser Cladding on Stellite 6 Coatings Deposited on an AISI 316L Stainless Steel Substrate

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Abstract : *Stellite 6 was deposited by laser cladding on an AISI 316L stainless steel substrate (ASS) with energy inputs of 1 kW (ASS 1) and 1.8 kW (ASS 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 conducted using a pin-on-plate (reciprocating) wear testing machine. The results showed less cracking and pore development for Stellite 6 coatings applied to the austenitic stainless steel (AISI 316L stainless steel) substrate with the lower heat input (ASS 1). Further, the Stellite coating for ASS 1 was significantly harder than that obtained for ASS 1.8. The wear test results showed that the weight loss for ASS 1 was much lower than for ASS 1.8. The measurements of dilution and estimation of carbon content also showed that ASS 1 has lower dilution and higher concentration of carbon than that of ASS 1.8. It is concluded that the lower hardness of the coating for ASS 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 ASS 1.8 was due to higher level of dilution and lower of carbon content.*

Keywords – *Dilution, Laser Cladding, Stellite 6 Coating, Wear, AISI 316 L stainless steel*

I. INTRODUCTION

AISI 316L stainless steel is widely used as structural materials in oil and gas industry, refineries, chemical, petrochemical and nuclear power plants due to its good corrosion resistance. However, a relative poor wear resistance of AISI 316L stainless steel possesses problem for its prolonged applications [1]. Therefore, it is very important to improve this property by surface treatment.

Stellite 6 is a very versatile material that is used for hardfacing of various component parts for applications requiring wear resistance [2]. Stellite alloys have been considered as candidate materials for surface hardening of AISI 316L stainless steel (austenitic stainless steel). The microstructure of Stellite 6 contains hard M_7C_3 carbides in interdendritic regions in both as-cast and as welded conditions [3]. Stellite alloys also contain a hard Laves phase in a softer matrix of eutectic or solid solution, which is useful for unlubricated wear conditions [4].

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 [6] and Bruck [7] 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. However, the technique has not been extensively studied for the development of austenitic stainless steel (AISI 316L stainless steel) with different energy input.

The purpose of this study was to evaluate the sliding wear characteristics of Stellite 6 coating materials produced by laser cladding of an AISI 316L stainless steel substrate with low (1 kW) and high (1.8 kW) energy inputs. The sliding wear tests were conducted on flat samples in an unlubricated (dry) condition using a reciprocating wear tester with a tool steel ball. This paper also discussed about dilution measurements and estimation of carbon content of Stellite 6 coatings and its importance in forming Cr_7C_3 particles to harden the deposit and contribute the increase wear resistance.

II. EXPERIMENTAL METHODS

1. Laser Cladding Deposition

The laser cladding process of austenitic stainless steel substrates with Stellite 6 was carried out by a laser company in Sydney, Australia using 1 kW and 1.8 kW energy input. The initial coating thickness as received was about 0.35 mm for both energy inputs. The heat input was changed by adjusting the speed of laser scanning. A lower speed was used for the higher heat input with the Stellite powder distribution rate being reduced to produce a similar coating thickness to that for the lower heat input. Table 1 shows the nominal compositions of the AISI 316L stainless steel (austenitic stainless steel) and the Stellite 6 alloy.

Table 1. Nominal compositions (wt%) of the AISI 316L SS and Stellite 6 alloy [3]

(%)	**Co**	**Cr**	**Fe**	**W**	**Ni**	**C**	**Si**	**Mn**
Stellite 6	60	27	2.5	5	2.5	1	1	1
316L SS		17	Bal		11	0.08	1	2
(%)	**P**	**S**	**Mo**	**B**	**Al**	**Ti**	**Nb**	**V**
Stellite 6								
316L SS	0.045	0.030	2					

2. 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.

3. 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, ASS 1 with applied load of 2 kg; Test# 2, ASS 1.8 with applied load of 2 kg; Test# 3, ASS 1 with applied load of 5 kg; Test# 4, ASS 1.8 with applied load of 5 kg.

4. Examination of Surface Worn

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.

5. Measurement of Dilution and Estimation of Carbon 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 carbon 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:

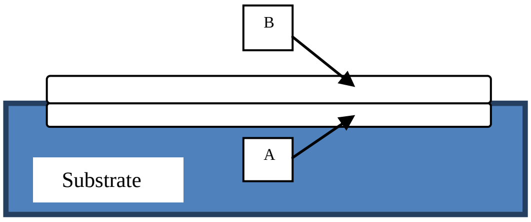

Figure 1. Schematic diagram showing the clad layer, which consists of two parts: added Stellite 6 alloy (region B) and melted base plate (region A). The dilution D of the Stellite alloy is given by A/(A+B) [8].

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.

$$[C]_{WD} = D \times [C]_{BM} + (1-D) \times [C]_S \qquad (1)$$

The nominal carbon content $[C]_S$ of the Stellite 6 alloy is 1.0 wt% C. Therefore,

$$[C]_{WD} = D \times [C]_{BM} + (1-D) \qquad \{2\}$$

III. RESULTS

1. Coating Compositions

The compositions of the Stellite 6 coatings were determined by AAS (Atomic Absorption Spectroscopy), see Table 2. The carbon content was not determined. Table 2 shows that the two chemical analyses (ASS 1 and ASS 1.8) of the coatings were similar, but there were some differences in alloy content of the coatings. The most significant differences were the lower Fe and Mn contents of the coating for ASS 1, consistent with a lower level of dilution of the Stellite coating by the substrate.

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

The coatings on the austenitic stainless 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).

3. 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 500 HV compared with 450 HV for 1.8 kW. The HAZ hardness was generally lower than that of the coating. The hardness of the unaffected substrate was about 200 HV.

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

(%)	**P**	**Mn**	**Si**	**Ni**	**Cr**	**Mo**
ASS 1	0.024	0.54	0.59	3.35	28.50	0.39
ASS 1.8	0.024	0.63	0.55	3.30	27.95	0.36
(%)	**Nb**	**Ti**	**V**	**Fe**	**W**	**Co**
ASS 1	0.02	0.03	0.030	10.9	3.5	48.3
ASS 1.8	<0.01	0.02	0.026	11.9	3.6	48.6

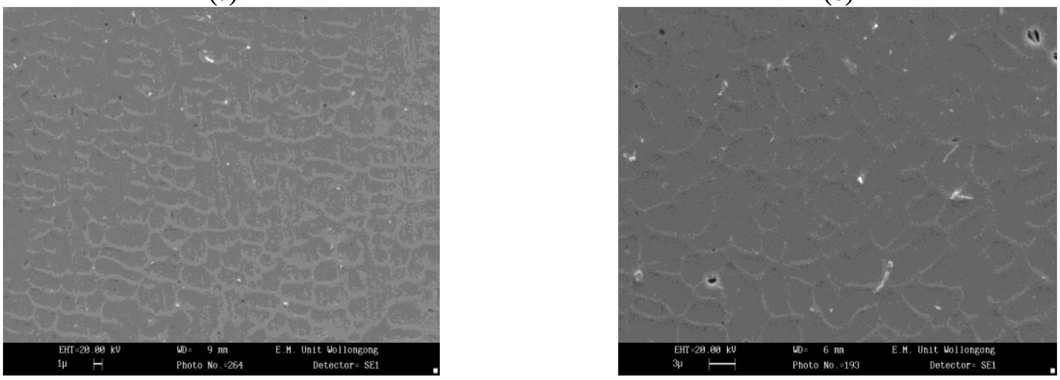
(a)
(b)

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

4. Wear Testing

Tests# 1-2 were conducted using an applied load of 2 kg. It was found that the deposit for ASS 1 wore substantially less, Fig. 4 (a). The deposit for ASS 1.8 showed significant wear with deep grooves. The effect of a higher load (5 kg) at 1.8 kW heat input is shown in Fig. 4 (b).

5. Mass Loss

Table 3 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 ASS 1.8.

6. Characterisation of Surface Worn

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 ASS 1, Fig. 5 (a), is smooth compared to the ASS 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).

7. Dilution Measurements and Estimation of Carbon Content

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

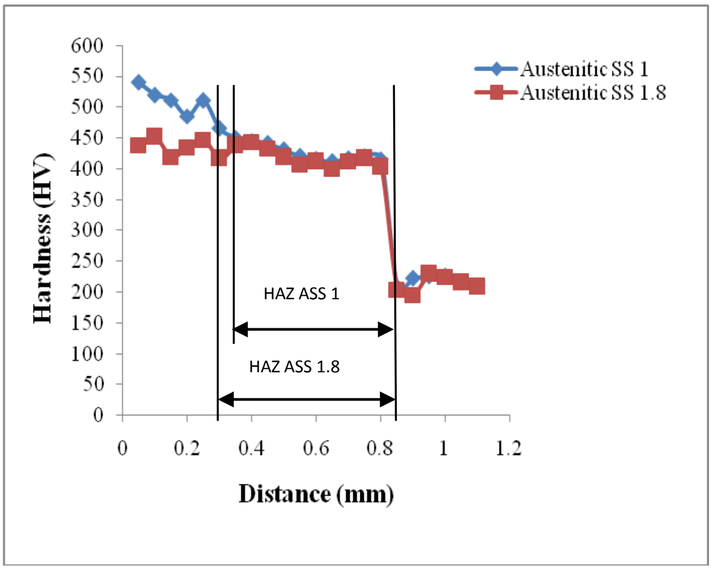

Figure 3. Graph of hardness profiles with distance from the coating surface for Stellite 6 deposited on AISI 316L stainless steel (austenitic stainless steel).

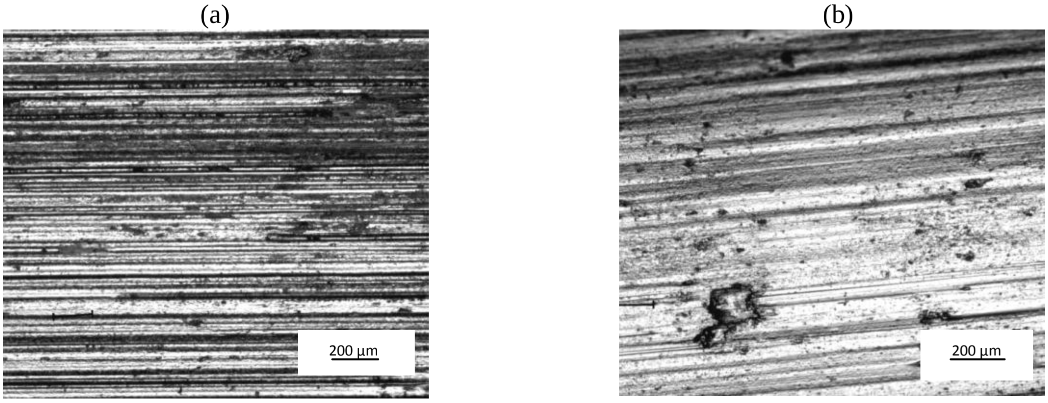

Figure 4. Optical micrograph showing wear track at a load of (a) 2 kg for ASS 1 and (b) 5 kg for ASS 1.8

IV. DISCUSSION

The comparative tests conducted for laser clad AISI 316L stainless steel (ASS) substrate showed that the weight loss, as expected, was lower for coated samples deposited at a heat input of 1 kW (ASS 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 2 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 4 with increasing load. It is likely that the greater incidence of microcracks and porosity observed after wear testing of ASS 1.8 samples is due in part to the substrate, particularly to the HAZ, being softer and less rigid [9].

The higher wear rate for the ASS 1.8 Stellite coated samples is also consistent with the lower surface hardness of approximately 450 HV compared with 500 HV for the ASS 1 Stellite coated samples, as shown in Fig. 3. Acceleration of the wear rate is therefore likely for the Stellite coating ASS 1.8 as the wear grooves penetrate the coating [9].

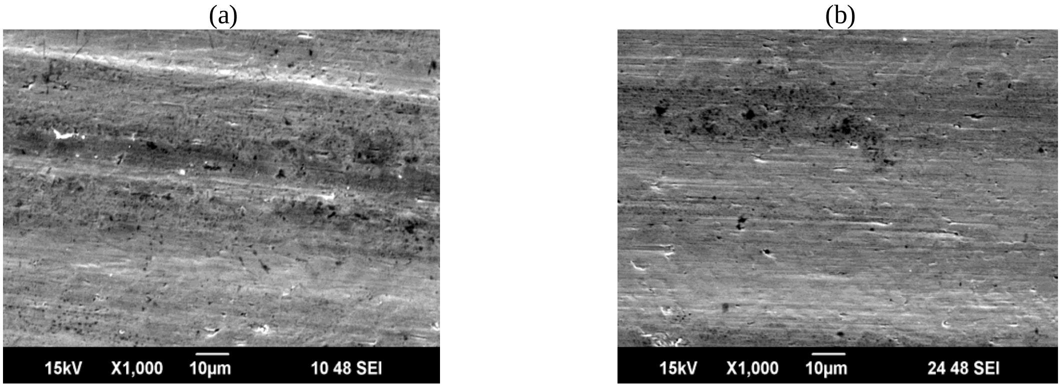

Figure 5. SEM micrograph of worn surface tested at load of (a) 2 kg for ASS 1 and (b) 5 kg for ASS 1.8.

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

Loads (kg)	ASS 1 (g)	ASS 1.8 (g)
2	0.00868	0.00996
5	0.01984	0.0358

Table 4. Measurements of dilution of the Stellite 6 coatings

	Area of A (μm^2)	Area of B (μm^2)	Dilution D (%)
ASS 1	105754.446	561466.0335	0.1585
ASS 1.8	441629.143	1475301.224	0.2304

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

	Carbon content substrate $[C]_{BM}$ (wt%)	Carbon content Stellite $[C]_S$ (wt%)	Dilution D (wt%)	Carbon content weld deposit $[C]_{WD}$ (wt%)
ASS 1	0.08	1	0.1585	0.854
ASS 1.8	0.08	1	0.2304	0.795

As Table 2 shows, the Stellite composition was modified by the substrate. This change occurred by melting of the substrate and mixing with the deposited alloy (dilution). Because of substrate dilution, the coatings produced on the AISI 316L stainless steel (austenitic stainless steel) substrate showed higher Fe, Mo and Ni contents than those of Stellite 6 (Table 1) and reduced W and Co contents (Table 2). However, the Cr levels in the coatings were not changed significantly, probably because it is a major component of both the Stellite and the substrate [10].

Although the compositions of the two coatings are similar, there are significantly lower Fe and Mn contents for the coating deposited at 1 kW, consistent with a lower level of dilution of the Stellite coating by the substrate. Using the rule of mixtures for the coating Fe contents, the data indicate approximately 23% dilution of the coating for the higher heat input of 1.8 kW and 15% for the lower heat input, Table 4. Although not measured, the carbon content for ASS 1 would be expected to be higher, because of a lower extent of dilution, thereby promoting the formation of Cr_7C_3 particles and hardening of the deposit. The deposit on ASS 1 was about 50 HV points higher than for the coating on ASS 1.8 (Fig. 3); this difference would be expected to substantially increase wear resistance [11]. The underlying HAZ was also marginally harder for the lower heat input (Fig. 3), providing a more rigid layer beneath the coating.

As explained earlier, the higher level of dilution for ASS 1.8 Stellite coated samples, Table 4 are consistent with higher wear rate, Table 3 and lower surface hardness, Fig. 3 of approximately 450 HV compared with 500 HV for the ASS 1 Stellite coated samples, it is likely higher level of dilution as reduced the wear resistance of the Stellite 6 coating [12].

As table 5 indicates, the carbon content for the ASS 1 Stellite 6 coated samples was higher by a factor of about 1.07%, indicating that the higher of carbon concentration 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 [12].

V. CONCLUSIONS

The present study compared the wear behaviour of Stellite 6 under reciprocating wear conditions as laser clad deposits on an AISI 316L stainless steel (austenitic stainless steel) substrate using two different heat inputs (1.0 kW and 1.8 kW). The coating compositions were 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 ASS 1 had a hardness of approximately 500 HV, while the coating on ASS 1.8 had a hardness of approximately 450 HV. The tests were conducted on unlubricated, using loads of 2 and 5 kg and a speed of 50 rpm for 10000 revolutions.

The wear test results showed that the rate of weight loss and the total weight loss were higher for the higher load and also for the coating produced at the higher heat input. The lower wear rate for ASS 1 coated samples was associated with less cracking and pore development in the Stellite 6 coatings. The measurements of dilution described that the level of dilution was higher for the higher heat input and the carbon content estimation also indicated that it was higher for the lower heat input.

It is concluded that the deposit obtained at 1 kW was harder because of compositional, microstructural and level of dilution differences arising from the lower heat input and faster cooling rate; and also the harder coating resulted in the higher wear resistance of Stellite 6 coating ASS 1. These factors increased the coating hardness due to higher carbon 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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