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Effect of Heat Input on Stellite 6 Coatings on a Medium Carbon Steel Substrate by Laser Cladding

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Abstract

Stellite 6 was deposited by laser cladding on a medium carbon steel substrate (MS) with energy inputs of 1 kW (MS 1) and 1.8 kW (MS 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 assessed using a pin-on-plate (reciprocating) wear testing machine. The results indicated less cracking and pore development for Stellite 6 coatings applied to the medium carbon steel substrate with the lower heat input (MS 1). Moreover, the Stellite coating for MS 1 was significantly harder than that obtained for MS 1.8. The wear test results indicated that the weight loss for MS 1 was much lower than for MS 1.8. It is concluded that the lower hardness of the coating for MS 1.8, markedly reduced the wear resistance of the Stellite 6 coating.

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Keywords: Laser cladding, Stellite 6 coating, heat input, wear, medium carbon steel.

1. 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

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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].

Pre-placed laser cladding can be utilized to produce a cobalt rich Co–Ti alloy coating on a medium steel substrate. Coating of steel substrates with a layer of hard and high temperature resistant alloy, which also possesses good magnetic properties and the potential for glass formation, can be of commercial interest for various engineering applications [4,5]. A medium carbon steel substrate, however, has not been extensively studied for the development of wear resistance by laser cladding.

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 becomes 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 bonding between the substrate and the clad layer. Laser clad layers can be produced that are defect-free and result in low dilution and a small heat affected zone in the substrate [8,9].

The purpose of this study was to evaluate the sliding wear characteristics of Stellite 6 coating materials produced by laser cladding of a medium carbon steel substrate with low (1 kW) and high (1.8 kW) heat inputs. The sliding wear tests were carried out on a flat sample in an unlubricated (dry) condition using a reciprocating wear tester with a tool steel ball.

2. Experimental Method

2.1. Materials

A steel plate was cut into 70 mm x 70 mm x 10 mm thick pieces and used as the substrate for coating. The nominal composition of the substrate material was 0.138% Cr, bal% Fe, 0.111% Ni, 0.536% C, 0.214% Si, 0.806% Mn, 0.020% P, 0.040% S and 0.147% Mo (wt%). The coating material used in the experiments was a Stellite 6 powder (nominal composition 60% Co, 27% Cr, 2.5% Fe, 5% W, 2.5% Ni, 1% C, 1% Si and 1% Mn (wt%)).

The laser cladding of flat steel substrate with Stellite 6 was completed by a commercial coating company using 1 kW and 1.8 kW heat inputs. The initial coating thickness was about 0.35 mm for both heat inputs.

2.2. Sample characterization

Samples were sectioned and 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.

2.3. 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 to produce flat coated samples with the required surface finish for wear testing. 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, MS 1 with applied load of 2 kg; Test# 2, MS 1.8 with applied load of 2 kg; Test# 3, MS 1 with applied load of 5 kg; Test# 4, MS 1.8 with applied load of 5 kg.

2.4. Examination of wear damage

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.

3. Results

3.1. Coating compositions

The compositions of the Stellite 6 coatings were determined by AAS (Atomic Absorption Spectroscopy), see Table 1. Table 1 shows that the chemical analyses of the two coatings were similar, but there were some differences in alloy content. The coating for MS 1 was richer in Mo, Ni and Fe and lower in Co and Mn than that for MS 1.8. The coating compositions are compared to the nominal composition of the Stellite 6 powder in Table 1. The lower Co content and the higher Fe content of the coatings are indicative of dilution by the substrate.

Table 1. Measured compositions (wt%) of the Stellite 6 coatings.

(%)	Stellite 6 (undiluted)	MS 1	MS 1.8
C	1.00	*	*
P		0.23	0.24
Mn	1.00	0.35	0.39
Si	1.00	0.57	0.67
Ni	2.50	2.30	2.20
Cr	27.00	29.15	29.60
Mo		0.16	0.11
Cu		0.011	0.019
Nb		0.02	<0.01
Ti		0.02	0.02
V		0.016	0.012
Fe	2.50	6.0	4.4
W	5.00	4.1	4.2
Co	60.00	54.5	55.2

*Not determined

3.2. Scanning electron microscopy

SEM micrographs showing the coating structures of the MS 1 and MS 1.8 samples are presented in Figs. 1(a-b). The coatings on the medium carbon steel substrate had a cellular-dendritic appearance. The higher heat input of 1.8 kW produced a coarser cellular-dendritic structure.

3.3. Microhardness testing of coating cross section

Microhardness profiles for the Stellite 6 weld samples are shown in Fig. 2. For the coating deposited at 1 kW, the coating hardness was about 600 HV compared with 500 HV for 1.8 kW. The higher heat input resulted in a wider HAZ and a lower average hardness. A notable feature of the hardness profile in the HAZ region for the 1 kW deposit was hardening up to about 1000 HV with an average of about 900 HV. The inherently high hardenability of the substrate alloy and the rapid cooling after deposition has produced untempered martensite. A lower but relatively high HAZ hardness was also exhibited for the 1.8 kW deposit (800 HV). The cooling rate was reduced by the higher heat input, which also resulted in a coarser coating microstructure, Fig. 1. The hardness of the unaffected substrate was about 300 HV.

3.4. Wear testing

Tests # 1-2 were conducted using an applied load of 2 kg. It was found that the deposit on MS 1 wore substantially less, with only a shallow wear track, while the deposit on MS 1.8 showed significant wear with the deep grooves. Figs. 3(a-b) compare the typical wear tracks for a 2 kg load.

The effects of a higher load (5 kg), tests# 3-4, on deposits produced at 1 kW are shown in Fig. 4 (a) for MS 1 and in Fig. 4 (b) for MS 1.8.

3.5. Mass loss

Table 2 shows the weight loss measurements for the Stellite coated samples. It can be concluded from Table. 2 (Tests # 1-4) that the weight loss increased with load and was higher for MS 1.8.

3.6. Characterisation of wear

In order to study the effect of load on the wear track, Stellite coated samples were evaluated at the completion of the wear test by scanning electron microscopy to establish the nature of wear. SEM micrographs of worn surface on the MS 1 and MS 1.8 samples are shown in Figs. 5 and 6. The worn surface of MS 1 using an applied load of 2 kg, Fig. 5 (a) appears to be smooth compared to the MS 1.8 surface which is more porous and shows greater surface roughness, Fig 5. (b).

The effects of a higher load (5 kg) at 1 kW and 1.8 kW heat inputs are illustrated by Fig. 6 (a) (MS 1) and Fig. 6 (b) (MS 1.8).

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

Fig.2. Graph of hardness profiles with distance from the coating surface for Stellite 6 deposited on the steel substrate.

Fig 3. Wear tracks at a load of 2 kg for (a) MS 1, (b) MS 1.8.

Fig.4. Wear tracks at a load of 5 kg for (a) MS 1, (b) MS 1.8.

Table 2. Weight loss for Stellite coatings deposited at a power input of 1 kW and 1.8 kW.

Load (kg)	MS 1 (g)	MS 1.8 (g)
2	0.0023	0.00302
5	0.009	0.01177

Fig.5. SEM micrographs of worn surfaces after testing at a load of 2 kg for (a) MS 1, (b) MS 1.8.

Fig.6. SEM micrographs of worn surfaces after testing at a load of 5 kg for (a) MS 1, (b) MS 1.8.

4. Discussion

The comparative tests conducted for laser clad medium carbon steel showed that the weight loss was lower for coated samples deposited at a heat input of 1 kW (MS 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 2.

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 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 MS 1.8 samples is due to the significantly lower coating hardness (approximately 500 HV compared with 600 HV), Fig. 2 [10,11].

The difference in wear behaviour for the two heat inputs arises primarily from differences in the Stellite coating microstructures and hardnesses [12].

As Table 1 shows, 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 composition, 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. In general, there was little difference in the compositions of the two coatings, but the lower heat input would be expected to produce less dilution. For this reason, the carbon content for the coating MS 1 would be expected to be higher than that for MS 1.8, therefore allowing more copious precipitation of Cr_7C_3 particles that harden the deposit. Moreover, 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 MS 1 was about 100 HV points higher than for the coating on MS 1.8 (Fig. 2) and this difference is the primary reason for the substantial increase in wear resistance [13,14,15].

5. Conclusion

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) on medium carbon steel. Differential dilution by the substrate, combined with different cooling rates after deposition resulted in substantially different coating hardnesses. The coating on MS 1 had a hardness of approximately 600 HV, while the coating on MS 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 showed 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 MS 1 coated samples, with less cracking and pore development in the Stellite 6 coatings. It is concluded that the deposit obtained at 1 kW was harder because of compositional and microstructural factors; and the harder coating resulted in the higher wear resistance than the Stellite 6 coating deposited at the higher heat input of 1.8 kW.

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