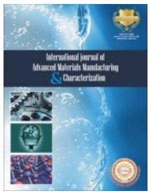

Advanced Materials
Manufacturing & Characterization

journal home page: www.ijammc-griet.com

Deposition of Stellite 6 on Nickel Superalloy and Mild Steel substrates with Laser Cladding

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ARTICLE INFO

Article history:
Received: 11-06-2013
Accepted: 29-07-2013

Keywords:
Laser cladding,
Stellite 6 coating,
friction and wear,
nickel superalloy and mild steel.

ABSTRACT

Stellite 6 was deposited by laser cladding of two different steel substrates (nickel superalloy and mild steel). 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 mild steel (MS) substrate. Further, the Stellite coating on mild steel was significantly harder than that deposited on the superalloy. The wear test results showed that the weight loss for the coating on mild steel was significantly lower than for the nickel superalloy substrate. It is concluded that the lower hardness of the coating on the nickel superalloy, together with the softer underlying substrate structure, markedly reduced the wear resistance of the Stellite 6 coating

Introduction

Stellite 6 is a very versatile material that is used for hardfacing of various component parts for applications requiring wear resistance [4,5]. The microstructure of Stellite 6 contains hard M_7C_3 carbides in interdendritic regions in both as-cast and as welded conditions [1]. Stellite alloys also contain a hard Laves phase in a softer matrix of eutectic or solid solution, which is useful for unlubricated wear conditions [7,8,9].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 [2]. An alternative is to use a Co-based alloy coatings to provide both SCC resistance and improved resistance to sliding wear.
Pre-placed laser cladding can be utilized to produce a cobalt rich Co–Ti alloy coating on a mild 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 [3,6].

Steen [10] and Bruck [11] 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 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 [12,13].The purpose of this study was to evaluate the sliding wear characteristics of Stellite 6 coating materials produced by laser cladding of mild steel and nickel superalloy steel substrates. 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.

Experimental Methods

Laser Cladding Deposition

The laser cladding process of mild steel and nickel superalloy substrates with Stellite 6 was carried out by a laser company in Sydney using 1 kW and 1.8 kW energy input. The initial coating thickness as received was about 0.35 mm for both steels and both energy inputs.

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- Doi: http://dx.doi.org/10.11127/ijammc.2013.07.01

Characterisation of Stellite Coated Samples

The Stellite 6 coatings were sectioned perpendicular to the coated surface using an automatic cutting machine with an alumina cut-off wheel operating at 3000 rpm and a cutting rate of 0.050 mm/s. The cut samples were then mounted in Poly Fast bakelite resin. 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.

Table 2 shows the nominal compositions of the mild steel, the nickel superalloy and the Stellite 6 alloy.

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. The specimens for wear testing were 5 mm thick, 37 mm long and 20 mm wide. The flat specimens were ground starting with 80 grit silicon carbide paper then progressing to 220 grit paper before diamond polishing on 9 μm and 3 μm diamond pads. The flat specimens were rinsed in water, then alcohol, before drying.

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 details of the various tests conducted are listed in the Table 1.

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 # 1-8 were examined after testing using a S440 scanning electron microscope (SEM) operating at 20 kV.

Results

Coating Compositions

The compositions of the Stellite 6 coatings were determined by AAS (Atomic Absorption Spectroscopy), see Table 3. Table 3 indicates that the two chemical analyses of the coatings obtained for the two energy inputs of 1 kW and 1.8 kW were similar for each substrate, but there was a significant difference in alloy content of the coating for the two different substrates. The coating on NIS was richer in Fe and Ni and lower in Co and Mn than that formed on MS substrate. The Cr level was also slightly lower and although not measured, the C content would be expected to be lower (see Table 2) because of dilution by the NIS substrate.

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

SEM micrographs showing the coating structures of the NIS 1, NIS 1.8, MS 1 and MS 1.8 samples are presented in Figs. 1(a-d), respectively. The coatings on nickel superalloy and mild steel substrates had a cellular-dendritic appearance. The higher heat input of 1.8 kW produced a coarser cellular-dendritic structure for both substrates. In general however, the cellular-dendritic structure was finer for the coating produced on the MS substrate.

Microhardness Testing of Coating Cross-Sections

Microhardness profiles for the two Stellite 6 weld samples are shown in Figs. 2 and 3. For the mild steel substrate, Fig. 2, the coating hardness was about 600 HV for 1 kW and about 500 HV for 1.8 kW heat input. However, the higher heat input resulted in a wider HAZ and a lower average heat affected zone (HAZ). A notable feature of the hardness profile in the HAZ region for the 1 kW deposit on the MS substrate was hardening up to about 900 HV. The inherently high hardenability of the substrate alloy and the rapid cooling after deposition has produced untempered martensite. A high HAZ hardness was also exhibited for the 1.8 kW deposit (up to 800 HV) despite the cooling rate being reduced by the higher heat input. In contrast, the coating on nickel superalloy substrate showed a lower coating hardness of about 450 HV for 1.0 kW and about 350 HV for 1.8 kW, Fig. 3. The HAZ hardness was generally lower than that of the coating and the substrate as well. The hardness of the unaffected substrate was about 350 HV, compared to 300 HV for the mild steel.

Wear Testing

Tests # 1-4 were conducted using an applied load of 2 kg. It was found that the deposit on MS wore substantially less, with only a shallow wear track, while the deposit on NIS showed significant wear with the deep grooves. Figs. 4(a-b) compare the typical wear tracks for a 2 kg load on deposits produced at 1 kW: NIS 1, Fig. 4 (a) and MS 1, Fig. 4 (b).

The effect of a higher load (5 kg), tests# 5-8, on deposits produced at 1 kW is shown in Fig. 5 (a) for NIS 1 and in Fig. 5 (b) for MS 1.

Mass Losses

Graphs showing the wear rate were prepared from the weight loss measurements for the Stellite coated samples. It can be seen in Figs. 6 (Tests # 1-4) and 7 (Tests # 5-8) that the wear rate increased with load and was higher for NIS samples.

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. SEM micrographs of worn surface on the NIS 1, NIS 1.8, MS 1 and MS 1.8 samples are shown in Figs. 8 and 9. The worn surface of MS 1, Fig. 8 (b) appears to be smooth compared to the NIS 1 surface which is more porous and shows greater surface roughness, Fig 8. (a). The worn surface of MS 1.8, Fig 8. (d), appears to be relatively rough but is still smoother compared to the surface of NIS 1.8 which is rougher and more porous, Fig 8. (c).

The effect of a higher load (5 kg) at 1 kW heat input is illustrated by Fig. 9 (a) (NIS 1) and Fig. 9 (b) (MS 1).

Table 1. Details of the various tests conducted

Test No	Flat samples	Applied load (kg)
#1	NIS 1	2
#2	MS 1	2
#3	NIS 1.8	2
#4	MS 1.8	2
#5	NIS1	5
#6	MS 1	5
#7	NIS 1.8	5
#8	MS 1.8	5

NIS: nickel superalloy substrate; MS: mild steel substrate; The number suffix indicates a laser energy of 1 kW or 1.8 kW.

Table 2. Nominal compositions (wt%) of the MS, NIS and Stellite 6 alloy

(%)	Stellite 6	MS	NIS
Co	60		
Cr	27	0.138	18
Fe	2.5	bal	18
W	5		
Ni	2.5	0.111	Bal
C	1	0.536	0.04
Si	1	0.214	
Mn	1	0.806	
P		0.020	
S		0.040	
Mo			3
B			0.004
Al			0.5
Ti			1
Nb			5

Discussion

The comparative tests conducted for laser clad mild steel (MS) and nickel superalloy (NIS) substrates showed that the wear rate was lower for MS coated samples for both heat inputs (1.0 kW and 1.8 kW).The amount of wear (mass loss) on the Stellite coated samples was greater for the tests conducted using NIS coated samples than for those using MS coated samples, as shown in Figs. 6-7. For deposits made at 1 kW, the weight loss increased in an approximately linear way with increasing test load up to 5 kg, but for the higher heat input the rate of weight loss strongly increased with increasing load. For both heat inputs, the weight loss was significantly lower for the MS substrate. It is likely that the greater incidence of microcracks and porosity observed after wear testing of NIS coated samples is due in part to the substrate, particularly in the HAZ, being softer and less rigid. The higher wear rate for the NIS Stellite coated samples is also consistent with their lower average surface hardness of approximately 400 HV compared with 600 HV for the MS Stellite coated samples, as shown in Figs 2 and 3. It is noted also that the hardness of the MS Stellite coated samples increased with distance beneath the surface, as shown in Fig. 2, while the hardness of the NIS Stellite coated samples decreased with depth. Acceleration of the wear rate is therefore likely for Stellite coated coatings NIS as the wear grooves penetrate the coating [14].

Table 3. Measured compositions (wt%) of the Stellite 6

(%)	NIS 1	NIS 1.8	MS 1	MS 1.8
P	0.22	0.23	0.23	0.24
Mn	0.28	0.34	0.35	0.39
Si	0.52	0.51	0.57	0.67
Ni	11.00	10.50	2.30	2.20
Cr	26.55	26.40	29.15	29.60
Mo	1.37	1.54	0.16	0.11
Cu	0.015	0.060	0.011	0.019
Nb	0.02	<0.01	0.02	<0.01
Ti	0.47	0.37	0.02	0.02
V	0.020	0.018	0.016	0.012
Fe	9.2	8.1	6.0	4.4
W	3.3	3.5	4.1	4.2
Co	45.0	45.7	54.5	55.2

The difference in wear behaviour for the two substrates is also likely to be due partly to differences in the Stellite coating compositions, microstructures and hardnesses. As Table 3 indicates, the Stellite composition was significantly modified by the substrate. This change occurred by melting of the substrate and mixing with the deposited alloy (dilution). The coating produced on the MS substrate showed markedly higher Cr and Fe contents than those of the nominal Stellite 6 composition given in Table 2, while the Co, Ni, Mn and W contents were reduced. The coating on NIS showed significant pick-up of Ni, Mo, Ti and Fe and the loss of Si, Cr, Mn and W relative to the nominal Stellite 6 composition. The higher Ni, Mo and Fe contents arise because the Ni-based superalloy substrate is rich in these elements. Because of the low C content of the NIS substrate (0.04%), C loss by dilution and diffusion out of the coating is expected to be significant. The coating composition was also depleted in Co, Si, Mn and Cr. Although not measured, the carbon content would also be expected to be reduced for the coating on MS, because of dilution by the substrate which contained 0.15% C. However, the coating C content would be expected to be high enough to promote the formation of Cr_7C_3 particles and to harden the deposit. The deposit on MS was about 200 HV points higher than for the coating on NIS (Figs. 2 and 3) and this difference would be expected to substantially increase wear resistance [15].

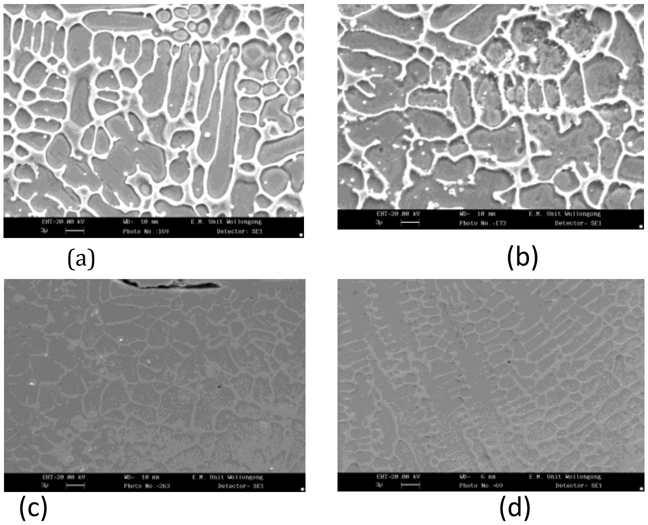

Figure 1. SEM micrographs of cross-sections of the Stellite 6 layers deposited on (a) NIS (1 kW), (b) NIS (1.8 kW), (c) MS (1 kW), (d) MS (1.8 kW).

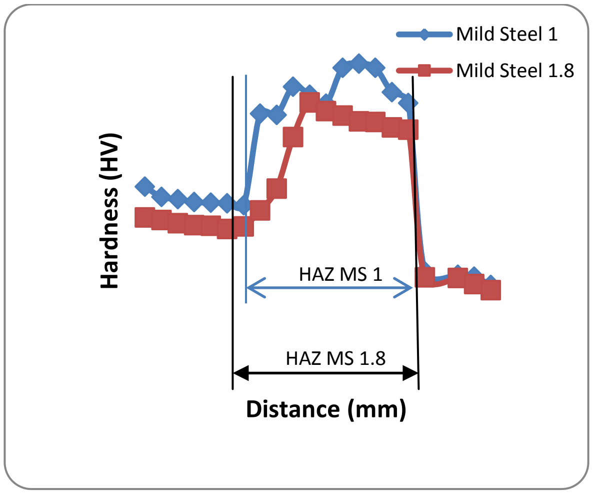

Figure 2. Graph of hardness profiles with distance from the coating surface for Stellite 6 deposited on mild steel.

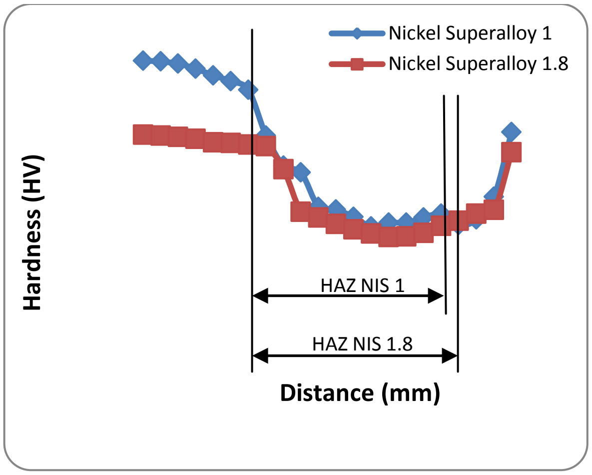

Figure 3. Graph of hardness profiles with distance from the coating surface for Stellite 6 deposited on nickel based superalloy.

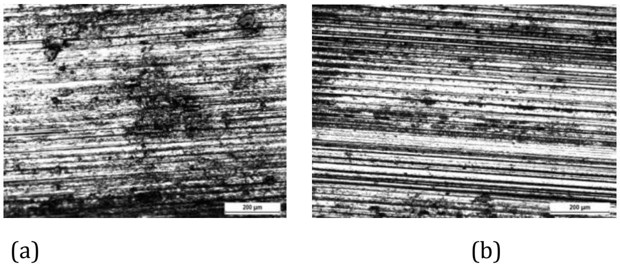

Figure 4. Wear tracks at a load of 2 kg, for (a) NIS 1, (b) MS 1.

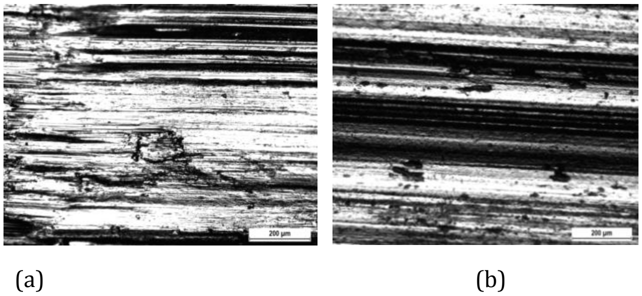

Figure 5. Wear tracks at a load of 5 kg, for (a) NIS 1, (b) MS 1.

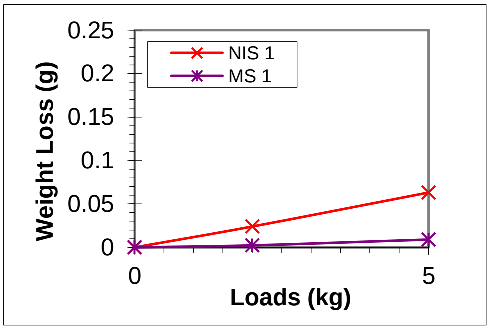

Figure 6. Graph of weight loss as a function of load for Stellite coatings deposited at a power input of 1 kW.

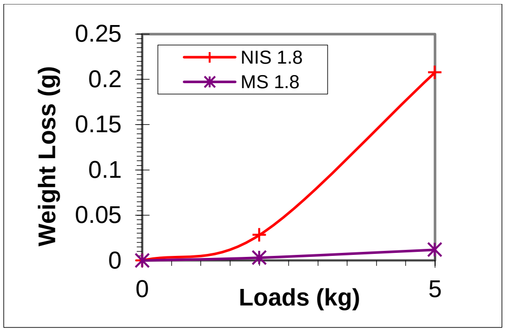

Figure 7. Graph of weight loss as a function of load for Stellite coatings deposited at a power input of 1.8 kW.

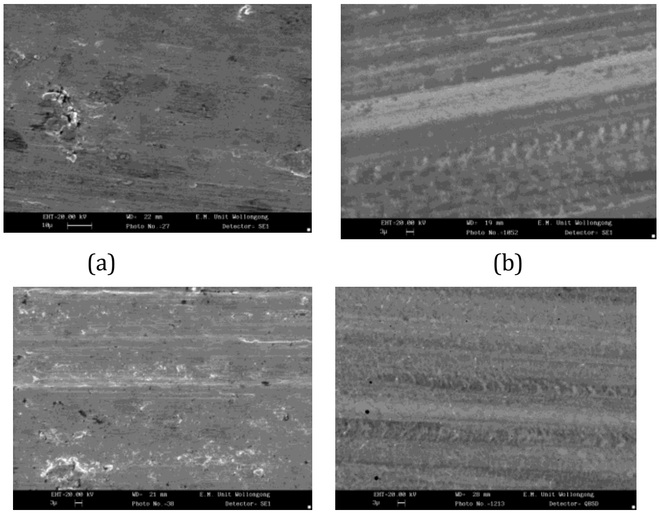
(a) (b)
(c) (d)

Figure 8. SEM micrographs of worn surfaces after testing at a load of 2 kg of (a) NIS 1, (b) MS 1, (c) NIS 1.8, (d) MS 1.8.

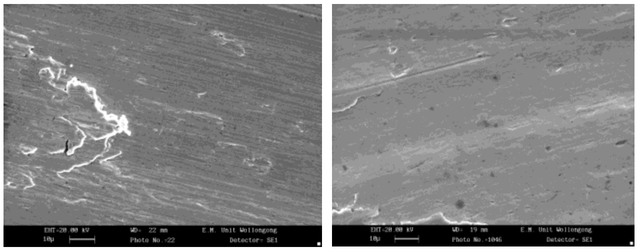
(a) (b)

Figure 9. SEM micrographs of worn surfaces after testing at a load of 5 kg of (a) NIS 1, (b) MS 1.

Conclusion

The present study compared the wear behaviour of Stellite 6 under reciprocating wear conditions as laser clad deposits on two different steel substrates: mild steel (MS) and nickel superalloy (NIS). The coating composition was markedly different in the two cases because of dilution by the substrate. As a result the coating hardnesses were substantially different. The coating on mild steel had a hardness of approximately 600 HV, while the coating on nickel superalloy had a hardness of approximately 400 HV. The tests were carried out unlubricated, using loads of 2 and 5 kg and a speed of 50 rpm for 10000 revolutions. The rate of weight loss and the total weight loss were higher for the higher load and also for the higher heat input.

The results showed that the wear rate was lower for MS coated samples at both heat inputs, with less cracking and pore development in the Stellite 6 coatings. It is suggested that these observations are due to two main factors. The deposit on MS was harder because of compositional and microstructural differences; and the harder and more rigid substrate provided by the mild steel, particularly in the underlying HAZ region, increased the wear resistance of the Stellite 6 coating.

Acknowledgement

The authors are grateful to Laser Company, Sydney, for providing materials for this research.

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