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Abstract

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Keywords

different, two, cladding, laser, substrate, steel, stainless, austenitic, produced, coatings, 6, stellite, behaviour, wear, inputs, heat

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Wear Behaviour of Stellite 6 Coatings Produced on an Austenitic Stainless Steel Substrate by Laser Cladding using Two Different Heat Inputs

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Keywords: Laser Cladding; Stellite 6 Coating; HAZ; Friction and Wear; Austenitic SS.

Abstract. Stellite 6 was deposited by laser cladding on an austenitic 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 assessed 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 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. 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.

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 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 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 austenitic stainless 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.

Experimental Methods

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. Table 1 shows the nominal compositions of the austenitic stainless steel and the Stellite 6 alloy.

Table 1 Nominal compositions (wt%) of the austenitic stainless steel and Stellite 6 alloy.

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

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.

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.

Results

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

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.

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.

Microhardness Testing of Coating Cross-Sections. Microhardness profiles for the Stellite 6 weld samples is shown in Fig. 1. 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.

Figure 1 Graph of hardness profiles with distance from the coating surface for Stellite 6 deposited on austenitic stainless steel.

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. 2. 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. 3.

Figure 2 Optical micrograph showing wear track at a load of 2 kg for ASS 1.

Figure 3 Optical micrograph showing wear track at a load of 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

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.

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 ASS 1, Fig. 4, 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.

Figure 4 SEM micrograph of worn surface tested at load of 2 kg for ASS 1.

Figure 5 SEM micrograph of worn surface tested at a load of 5 kg for ASS 1.8.

Discussion

The comparative tests conducted for laser clad austenitic 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.

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. 1. Acceleration of the wear rate is therefore likely for the Stellite coating ASS 1.8 as the wear grooves penetrate the coating [8,9].

The difference in wear behaviour for the two heat inputs is a result of differences in the Stellite coating compositions, microstructures and hardnesses.

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 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.

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 14% dilution of the coating for the higher heat input of 1.8 kW and 12.5% for the lower heat input. 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. 1); this difference would be expected to substantially increase wear resistance [10,11]. The underlying HAZ was also marginally harder for the lower heat input (Fig. 1), providing a more rigid layer beneath the coating.

Summary and Conclusions

The present study compared the wear behaviour of Stellite 6 under reciprocating wear conditions as laser clad deposits on an austenitic steel substrate using two different heat inputs (1.0 kW and 1.8 kW) of austenitic stainless steel. 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 carried out 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. It is concluded that these characteristics and the higher wear rate are due to two main factors. The higher wear resistance of the Stellite 6 coating, ASS 1, is a result of compositional and microstructural differences arising from the lower heat input and the faster cooling rate. These factors increased the coating hardness, as well as providing a harder and more rigid HAZ in the underlying substrate.

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