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Research Article

Dilution and Wear Properties of Laser Cladding Stellite 6 on an Inconel 718 Substrate

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Abstract

Stellite 6 was welded by laser cladding on an Inconel 718 (NIS) substrate with laser powers of 1 kW (NIS 1) and 1.8 kW (NIS 1.8). The chemical compositions and microstructures of these coatings were analysed by X-Ray Florescense spectroscopy, optical microscopy, and scanning electron microscopy. The microhardness of the coatings was characterised and the wear mechanism of the coatings was assessed using a ball-on-plate (reciprocating) wear testing machine. The results indicated less cracking and pore development with Stellite 6 coatings applied to the Inconel 718 (NIS) substrate at a lower laser power (NIS 1), while NIS 1 was much harder than that obtained for NIS 1.8. The results of the wear test indicated that the weight loss for NIS 1 was much lower than NIS 1.8. The evaluations of dilution and calculation of the C content showed that dilution for NIS 1 was less than for NIS 1.8 while the C content for NIS 1.8 was less than NIS 1. It was concluded that the lower hardness of the coating for NIS 1.8 was due to a higher level of dilution and lower concentration of C, which markedly reduced the wear resistance of the Stellite 6 coating.

Keywords: *Dilution, Laser Cladding, Inconel 718, Stellite 6 coating.*

1. Introduction

Stellite 6 is a very versatile material that is used for hardfacing various component parts for applications requiring wear resistance. The microstructure of Stellite 6 contains hard M_7C_3 carbides in interdendritic regions in both as-cast and as welded conditions. Stellite alloys also contain a hard Laves phase in a softer matrix of eutectic or solid solution, which is useful for unlubricated wear conditions (Tribology T-900 Technical Data, 2002).

In high temperature corrosive environments, nickel superalloys such as Inconel 600 and Inconel 718 have consistent chemical composition with high nickel content are used because their resistance to stress corrosion cracking (SCC) is very good, but despite this good SCC resistance, industry has sought for improved primary water SCC (PWSCC) resistance by using Ni based alloys with a high chromium content (Fergusson, *et al*, 2006). An alternative is to use Co-based alloy coatings to provide SCC resistance and improved resistance to sliding wear.

(Steen and Bruck, 1987) have reviewed laser cladding processes. In the coaxial laser cladding process, metal powder is injected through a nozzle that 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, causing surface melting while forming a strong metallurgical bond between the substrate and the clad layer. Laser clad layers that are free of defects can be produced, and they result in low dilution and a small heat affected zone in the substrate (Monson and Steen, 1990).

The purpose of this research was to examine the sliding wear characteristics of Stellite 6 coating materials produced by laser cladding on an Inconel 718 (NIS) substrate with low (1 kW) and high (1.8 kW) laser powers. This paper also discusses the dilution evaluations and calculation of C content of Stellite 6 coatings and how the C content helps to form Cr_7C_3 particles to harden the deposit and increase wear resistance.

2. Experimental Methods

2.1 Laser Cladding Deposition

The laser cladding process of Inconel 718 substrates with Stellite 6 was carried out by laser companies in Sydney and Melbourne using 1 kW and 1.8 kW laser power. The thickness of the initial coating, as received, was about 0.35 mm for both laser powers. Table 1 shows the nominal compositions of the Inconel 718 (NIS) and Stellite 6 alloy.

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Table 1 Nominal compositions (wt%) of the Inconel 718 (NIS) and Stellite 6 alloy (Tribology T-900, 2002)

(%)	Co	Cr	Fe	W	Ni	C	Si	Mn
S 6	60	27	2.5	5	2.5	1	1	1
NIS		18	18		54.5	0.04		
(%)	P	S	Mo	B	Al	Ti	Nb	
S 6								
NIS			3	0.0004	0.5	1	5	

2.2 Characterisation of Stellite Coated Samples

The microhardness was examined at 0.05 mm intervals through the thickness of the coating 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 undertaken using a ball-on-plate (reciprocating) mode with a 6 mm tool steel ball as the pin. A ball was fixed in a collet and while in operation the ball remained stationary while the flat specimen moved in a linear, back and forth sliding motion, under a prescribed set of conditions. Prior to undertaking the wear tests, the test specimens were weighed to an accuracy of 0.0001 g.

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

2.4 Examination of Wear Damage

To evaluate the effect of laser power and 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.

2.5 Examinations of Dilution and Calculation C Content

Compositions of Stellite 6 coatings were measured with XRFS (X-Ray Florescence Spectroscopy) to assess the chemical analysis present using two different laser powers (1 kW and 1.8 kW). However, the C content was not detected, so the C content was measured by calculating dilution using the method shown in Figure 1:

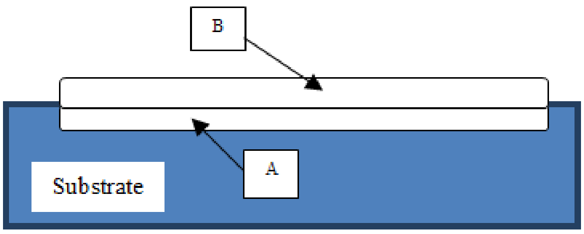

Fig. 1 Schematic diagram showing the clad layer, which consists of two parts: added Stellite 6 alloy (region B) and melted base plate (region A). Dilution D of the Stellite alloy is given by A/(A+B) (Meriaudeau, *et al*, 1997)

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,

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

3. Results

3.1 Coating Compositions

The compositions of the Stellite 6 coatings were examined by XRFS (X-Ray Florescense Spectroscopy), as shown in Table 2 where the two chemical analyses (NIS 1 and NIS 1.8) of the coatings were similar, but there were some differences in their alloy content. The coating for NIS 1 was richer in Fe and Ni and lower in Co and Mn than for NIS 1.8.

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

The coatings on the nickel superalloy 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-Sections

Microhardness profiles across the coating are shown in Figure 2. For the coating deposited at 1 kW, the coating hardness was about 450 HV compared with 350 HV for 1.8 kW. The HAZ hardness was 200 HV which is lower than that of the hardness of the coating and the unaffected substrate.

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

(%)	P	Mn	Si	Ni	Cr	Mo	Cu
NIS 1	0.22	0.28	0.52	11	26.55	1.37	0.015
NIS 1.8	0.23	0.34	0.51	10.5	26.40	1.54	0.060
(%)	Nb	Ti	V	Fe	W	Co	
NIS 1	0.02	0.47	0.02	9.2	3.3	45.0	
NIS 1.8	<0.01	0.37	0.018	8.1	3.5	45.7	

3.4 Wear Testing

Tests# 1-2 were conducted using an applied load of 2 kg, from which it was found that wear on the NIS 1 deposit was much less, while the deposit for NIS 1.8 showed a lot of wear with deep grooves. A higher load (5 kg) in Tests# 3-4 had a similar effect to the load in Tests # 1-2.

3.5 Mass Loss

Table 3 shows the weight loss measurements for the Stellite coated samples, with Table 3 (Tests# 1-4), showing that the weight loss increased with load and was higher for NIS 1.8.

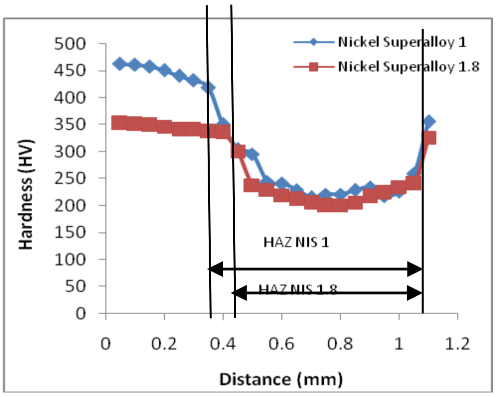

Fig. 2 Graph of hardness profiles with distance from the coating surface for Stellite 6 welded on Inconel 718 (NIS)

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

Loads (kg)	NIS 1 (g)	NIS 1.8 (g)
2	0.024	0.02808
5	0.06312	0.2076

3.6 Characterisation of Wear

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

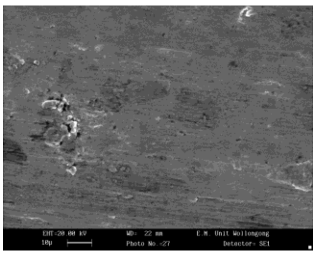

Fig. 3 SEM micrograph of worn surface tested at a load of 2 kg for NIS 1

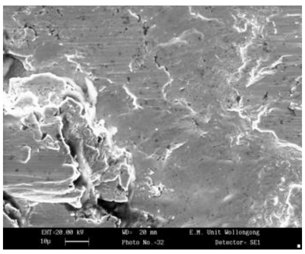

Fig. 4 SEM micrograph of worn surface tested at a load of 5 kg for NIS 1.8

The worn surface of NIS 1, Figure. 3, was smooth compared to the NIS 1.8 surface, which was more porous and showed greater surface roughness. The effect of a higher load (5 kg) at 1.8 kW laser power is illustrated by Figure. 4.

3.7 Dilution Measurements and Estimation of C Content

In order to estimate the C content of the Stellite 6 coatings because the C was not determined in Table 2, the dilution shown in Figure 1 was measured and then the C content was estimated. Tables 4 and 5 show the results of estimating the dilution and C content of Stellite 6 coatings.

Table 4 Measurements of dilution of the Stellite 6 coatings

	Area A (μm^2)	Area B (μm^2)	Dilution D(wt%)
NIS 1	586267.681	1095884.651	0.3485
NIS 1.8	999890.784	1450746.493	0.4080

Table 5 Estimation of C content of the Stellite 6 coatings

	$[C]_{BM}$ (wt%)	$[C]_{S}$ (wt%)	Dilution D (wt%)	$[C]_{WD}$ (wt%)
NIS 1	0.04	1.00	0.3485	0.665
NIS 1.8	0.04	1.00	0.4080	0.608

4. Discussion

The comparative tests conducted for laser clad Inconel 718 (NIS) substrate showed that the weight loss for coated samples deposited at a laser power of 1 kW (NIS 1) was lower, whereas the amount of wear (mass loss) on the Stellite coated samples was greater for tests carried out on coatings deposited with 1.8 kW than for those deposited at 1 kW, as shown in Table 3 (Kusmoko, *et al*, 2014).

For deposits produced at 1 kW, the weight loss increased by a factor of about 3, with an increasing test load up to 5 kg, but for a higher laser power the rate of weight loss increased by a factor of about 7 as the load increased. It is likely that the greater incidence of microcracks and porosity observed after wear testing the NIS 1.8 samples were partly due the substrate, particularly the HAZ because it was softer and not as rigid (Kusmoko, *et al*, 2014).

The higher wear rate on the NIS 1.8 Stellite coated samples was also consistent with the lower surface hardness of approximately 350 HV compared with 450 HV for the NIS 1 Stellite coated samples, as shown in Figure 2. This behaviour of the wear rate was more likely to occur on the Stellite coating NIS 1.8 because the wear grooves penetrated the coating (Kusmoko, *et al*, 2014).

As Table 2 shows, the Stellite composition was modified by the substrate because it melted and mixed with the deposited alloy (dilution). The coating produced for NIS 1 had higher amounts of Cr, Ni, and Fe than for NIS 1.8, while the amounts of Co, Mn, and W were lower. The higher amounts of Ni and Fe in both deposits occurred because the Inconel 718 substrate is richer in these elements. Although not measured, the carbon content for NIS 1 was expected to be high enough to promote the formation of Cr_7C_3 particles and to harden the deposit. The deposit on NIS 1 was about 100 HV points higher than the coating on NIS 1.8 (Figure 2), the difference that would be expected to significantly increase wear resistance (Kusmoko, *et al*, 2013 and Vilar, 1999).

As discussed earlier, the higher level of dilution for NIS 1.8 Stellite coated samples, Table 4 is consistent with higher wear rate, Table 3 and lower surface hardness, Figure 2 of approximately 350 HV compared with 450 HV for the NIS 1 Stellite coated samples (Kusmoko, 2016).

Table 5 shows that the C content of weld deposit for the NIS 1 Stellite coated samples was higher by a factor of about 1.09%, indicating that a higher amount of C concentration is consistent with a lower level of dilution, as shown in Table 4; this promotes the carbide morphology of Cr_7C_3 particles and hardens the deposit, as shown in Figure 2, thus producing higher wear resistance (Kusmoko, 2016).

Summary and conclusions

The present study compared the wear characteristic of Stellite 6 under reciprocating wear conditions as laser clad deposits on two different laser powers (1.0 kW and 1.8 kW) of Inconel 718 (NIS). The composition of this coating was slightly different in the two cases due to differential dilution by the substrate. These compositional differences combined with different cooling rates after deposition resulted in coatings with significantly different hardnesses. The coating on NIS 1 had a hardness of approximately 450 HV, while the coating on NIS 1.8 had a hardness of approximately 350 HV. The tests were conducted under unlubricated conditions, under 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 laser power. The wear rate for NIS 1 coated sample was lower, and there was less cracking and pore development in the Stellite 6 coatings. The examinations of dilution indicated that the level of dilution was higher for the higher laser power, whereas estimated amount of C indicated that the C content was higher for the lower laser power.

It was concluded that the deposit obtained at 1 kW was harder due to differences in composition, microstructure, level of dilution, whereas the harder coating resulted in the higher wear resistance due to higher C content of weld deposit to form carbide (Cr_7C_3 particles) and harden the deposit, than the Stellite 6 coating deposited at a higher laser power of 1.8 kW.

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