Effect of laser power on microhardness of NiCrBSi laser clads deposited on AISI410 stainless steel

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Abstract: In the present experimental study, NiCrBSi alloy was deposited on martensitic stainless steel (AISI 410 grade) using laser cladding technique. High power diode laser (HPDL) was used to obtain good fusion, optimum dilution & crack free single track laser clad by varying laser input power (3200 W, 3600 W & 4000 W) while keeping other processing parameters constant. Powders of NiCrBSi alloy with different wt. % of Ni, Cr, B and Si (50HRC & 60HRC) were used in the current study for the deposition. Pre-heating of the substrate was carried out at around 300°C using oxyacetylene flame before deposition in order to reduce the cracks and porosity. Effect of power on microhardness of laser clad was not prominent in the range of power 3200 to 4000 W. In the case of alloy 1 maximum microhardness 692.2 HV0.3 was observed for power 3600 W, while for alloy 2 with power 3600 W maximum microhardness of as-deposited was 755.1 HV0.3.

1. Introduction

With the rapid development taking across all over the world, a vast development in laser technology has taken place and laser cladding is a widely used technique for repairing and remanufacturing work in industries such as aerospace, automotive etc. Laser cladding technologies have led to a significant increase in reliability of the product developed by it. Laser cladding is a process in which a high power laser beam is directed to melt the cladding material and lead to the fabrication of very thin layer on the substrate. The coatings produced by laser cladding have many advantages over other process such as low dilution, metallurgical bonding with the substrate, minimum thermal distortion etc [1].

The AISI 410 grade martensitic stainless steel is used as a substrate. The AISI 410 stainless steel have many applications in manufacturing of bolts, bushings, gas turbine parts, mine equipment, steam turbine parts, valve parts etc. Material is magnetic in all conditions. NiCrBSi is one of the most frequently used material for laser cladding, as it has many advantages such as low price, high hardness and more corrosion resistance in comparison with other similar alloys [2, 3].The corrosion and wear-resistant NiCrBSi coating is found to be the most reliable solution to protect the low-alloyed steel substrate having a significantly lower melting temperature than the deposited alloy [4].

The laser powers used for analysis were 1500, 2000, 2500, 3000, 3500 W and with the increase of the laser power, the average microhardness of the cladding layer was found to be reduced. This was because the increase of laser power led to entrance of more Fe element into the cladding layer, which enhanced the dilution effect of the cladding layer. Therefore, the average hardness of cladding layers decreased with the increase of laser power [5].

Preheating of the substrate material was done at 450 °C to avoid cracking. The laser power was varied from 1100 to 1900 W in two equal steps of 400 W and keeping other parameters constant. Slower cooling rate and high dilution at higher laser powers was supposed as the reason for the decrease in microhardness. Also, the dilution rate was found minimum at the laser power 1100 W and 1500 W and it also showed higher hardness [6].
As we know, the melted volume of the substrate is an important parameter which measures the quality of the laser cladding process. This is due to the fact that the melted volume of the substrate material together with the deposited material volume determines the dilution (%). The best cladding quality is achieved when the base material surface just melts enough to obtain a good metallurgical bonding between the clad layer and the substrate material. Among the various varying parameters used for laser cladding such as laser power, cladding speed, and powder feed, the most significant factors for the substrate melted volume are the laser power [7].

The aim of the present work is to study the effect of laser power on the microhardness of cladded layer of NiCrBSi alloy of 50HRC & 60HRC on AISI 410 Stainless steel plate. Laser cladding is done using high power diode laser by varying the power by 3200W, 3600W & 4000W. High power diode laser is used for cladding process because the high power direct diode laser is an excellent heat source for many cladding applications. A combination of the large beam profile and the short wavelength make it ideal for the rapid deposition of relatively large areas of clad material. The simplicity, ease of use, high efficiency, and compact nature of the direct diode laser make it appropriate for many industrial applications [8]. The substrate material is preheated at temperature 300°C before performing laser cladding operation as maximum microhardness is achieved by preheating for nickel alloy [9].

2. Experimental Details
Laser cladding is performed on AISI 410 Stainless steel plate, for fabricating NiCrBSi alloy onto it and argon gas is used as the carrier and shielding gas. During the process, a shielding gas is always used to protect the molten material from the atmosphere [10]. Two different alloys of NiCrBSi powder having microhardness 50 HRC and 60 HRC are being used. Laser cladding is performed for 3 powers i.e 3200W, 3600W and 4000W using high power diode laser. Pre-heat treatment of the substrate material is carried out at 300°C using oxyacetylene flame before deposition in order to reduce the cracks and porosity. Chemical composition (Wt. %) of stainless steel 410 is given in Table 1:

| Material     | C   | Cr  | Si  | Ni  | Mn  | Fe   |
|--------------|-----|-----|-----|-----|-----|------|
| Stainless Steel 410 | 2.86 | 18.52 | 0.6 | 6.88 | 1.90 | Bal  |

NiCrBSi powder is fed using co-axially powder feeder in a controlled rate. NiCrBSi powder of 50HRC and 60HRC is used having the chemical composition as mentioned in Table 2:

| Hardness | Ni   | Cr  | B   | Si  | C  | Fe  |
|----------|------|-----|-----|-----|----|-----|
| 50 HRC   | Balance | 12.5 | 2.3 | 3.3 | 0.5 | 3.9 |
| 60 HRC   | Balance | 15   | 3.1 | 4.3 | 0.7 | 4.2 |

To deposit laser clad, Laserline LDF 4000-100 Fibre coupled diode laser integrated with CNC is used. The powder is delivered by a Sulzer Metco Twin-10 C powder feeder and injected into the processing area through a co-axial nozzle. All the optics and nozzles are integrated with a Kuka KR16 robot arm having 6 DOF.

The processing parameter used during laser cladding operation are given in Table 3.
Table 3: Processing parameter used during laser cladding operation:

| Sample No. | Power (W) | Parameters values                                      |
|------------|-----------|--------------------------------------------------------|
| S 1        | 3200 W    | Scanning speed - 20mm/s                                |
|            |           | Powder feed rate - 60g/min                             |
| S 2        | 3600 W    | Spot size - 5mm                                        |
|            |           | Stand-off distance - 20mm                              |
| S 3        | 4000 W    |                                                        |

Figure 1- Laser cladded sample (50HRC & 60HRC) at powers 3200W, 3600W & 4000W

Figure 1 shows the laser cladded samples of 50HRC and 60HRC alloys by varying laser power as 3200W, 3600W and 4000W.

2.1 Microhardness Testing

Microhardness of the transversely sectioned surface of the sample is measured using Vickers hardness tester [Mitutoyo (Model- HM 112)] at a load of 300g with the loading time of 15sec. A minimum of 8 indentations has been executed for each sample.

3. Results & Discussions

Microhardness of the as-deposited NiCrBSi alloy of 50HRC and 60HRC deposited using the laser at different powers are measured using Vicker hardness tester and the graph is plotted for showing the variation in microhardness for both the alloys.

Microhardness is measured on the tranverse section at eight different points. Results shows that the microhardness of the clad layer is fairly uniform except near the top surface. The hardness value decreased in the dilution zone till reaching the base metal. Figure 2 and Figure 3 represents the comparison of microhardness of three samples 50HRC NiCrBSi alloy. Effect of laser power on microhardness of the cladding layer is studied which shows that as the laser power is increased from 3200W to 3600W, the microhardness of as-deposited coating is found to be increased from 752.7HV to
755.1 HV for 60HRC alloy and 691.9HV to 692.2HV for 50HRC alloy, which doesn’t show much significant change in microhardness on raising power. When the laser power is further increased to 4000W the microhardness decreased to a value of 724.6HV for 60HRC alloy and 688.8HV for 50HRC alloy. This is because more Fe element enters into the cladding layer, with the increase of laser power, which enhances the dilution effect of the cladding layer [7]. Therefore, the average hardness of cladding layers decreases with the further increase of laser power above 3600W.

Figure 2- Micro-hardness plot of 50HRC as-deposited NiCrBSi alloy for different power

Figure 3- Micro-hardness plot of 60HRC as-deposited NiCrBSi alloy for different power

Figure 4- Microhardness plot of single track clad of 50HRC & 60HRC NiCrBSi alloy on

a) S1-3200W  b) S2-3600W  c) S3-4000W
For laser power of 3200W (S1), the maximum microhardness of 60HRC alloy is about 752.7 HV in the top part of cladding layer for as-deposited coating, and the microhardness of clad layer ranges from 710.5 to 752.7 HV and that for 50HRC alloy the microhardness value ranges from 641.3 to 691.1 HV. Similarly, for laser power of 3600W (S2), the maximum value of microhardness of 60HRC alloy is about 755.1 HV in the top part of cladding layer for as-deposited coating and the microhardness of clad layer ranges from 723.1 to 755.1 HV and that for 50HRC alloy the value ranges from 643.9 to 692.2 HV. For laser power of 4000W (S3), the maximum microhardness value of 60HRC is about 724.6 HV in the top part of cladding layer for as-deposited coating, and the microhardness of clad layer ranges from 709.9 to 724.6 HV and for 50HRC alloy the microhardness ranges from 622.6 to 688.8 HV.

Effect of power on microhardness of laser clad was not prominent in the range of power 3200 W to 4000 W and for all laser powers, the microhardness of 60HRC alloys are higher than the 50 HRC alloys.

4. Conclusions
NiCrBSi alloys of 50HRC and 60HRC is fabricated on AISI410 stainless steel using high power diode laser by varying the laser power as 3200W, 3600W and 4000W by the laser cladding process. From this research work we came to conclusions as mentioned below:

4.1 Effect of power on microhardness of laser clad is not prominent in the range of power (3200 to 4000 W).

4.2 Microhardness is measured on the transverse section of cladded specimen by making 8 indentation at different points including the top portion as well as the dilution zone of cladded layer. Maximum hardness is obtained at top most point, which continuously decreased with increasing depth and dilution zone is having the least microhardness.

4.3 For all three samples cladded at powers (3200W, 3600W & 4000W), microhardness of 60 HRC alloy clad is higher than that of 50HRC alloy clad.

5. References
[1] P. Monson, W. Steen, Comparison of laser hardfacing with conventional processes, Surface Engineering, 6 (1990) 185-193.
[2] I. Hemmati, V. Ocelik, J.T.M. De Hosson, Effects of the alloy composition on phase constitution and properties of laser deposited Ni-Cr-B-Si coatings, Physics Procedia, 41 (2013) 302-311.
[3] F. Weng, H. Yu, C. Chen, K. Wan, Influence of Nb and Y on hot corrosion behavior of Ni–Cr-based superalloys, Materials and Manufacturing Processes, 30 (2015) 677-684.
[4] Z. Bergant, U. Trdan, J. Grum, Effect of high-temperature furnace treatment on the microstructure and corrosion behavior of NiCrBSi flame-sprayed coatings, Corrosion Science, 88 (2014) 372-386.
[5] W. Kai-ming, F. Han-guang, L. Yu-long, L. Yong-ping, W. Shi-zhong, S. Zhen-qing, Effect of power on microstructure and properties of laser cladding NiCrBSi composite coating, Transactions of the IMF, 95 (2017) 328-336.
[6] S. Gnanasekaran, G. Padmanaban, V. Balasubramanian, Effect of Laser Power on Metallurgical, Mechanical and Tribological Characteristics of Hardfaced Surfaces of Nickel-Based Alloy, Lasers in Manufacturing and Materials Processing, 4 (2017) 178-192.
[7] D.M. Goodarzi, J. Pekkarinen, A. Salminen, Effect of process parameters in laser cladding on substrate melted areas and the substrate melted shape, Journal of Laser Applications, 27 (2015) S29201.
[8] S. Barnes, N. Timms, B. Bryden, I. Pashby, High power diode laser cladding, Journal of Materials Processing Technology, 138 (2003) 411-416.
[9] J. Jiang, G. Lian, M. Xu, C. Li, B. Chen, B. Li, Influence of Preheating Temperature on Mechanical Properties of Laser Cladding Layer, in: ASME 2016 11th International Manufacturing Science and Engineering Conference, American Society of Mechanical Engineers, 2016, pp. V001T002A031-V001T002A031.
[10] S. Zanzarin, S. Bengtsson, A. Molinari, Study of carbide dissolution into the matrix during laser cladding of carbon steel plate with tungsten carbides-stellite powders, *Journal of Laser Applications*, 27 (2015) S29209.