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PRODUCTION OF HARD AND WEAR RESISTANT COATING THROUGH LASER SURFACE ENGINEERING

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ABSTRACT

Purpose-The objective of this paper is to fabricate a coating of Ni-WS_2-Al_2O_3 on SS304 substrate by fibre laser.

Design/Methodology/Approach- The SS304 samples were cladded at different laser cladding parameters. Effect of the coating parameters on the microstructure, surface morphology and chemical composition of the substrates were analysed by means of scanning electron microscope and electron dispersive x-ray spectroscopy. Variation in the friction and wear characteristics were studied by a pin-on- disc apparatus, in ambient air. Clad thickness was measured under optical microscope.

Findings-A good metallurgical bond existed between the substrate surface and the composite coating. Microhardness of the specimens metamorphosed to 380.6$HV_{0.5}$ from 131.5$HV_{0.5}$ which is approximately three times of the SS304 substrate due to the presence of hard Al_2O_3 particles. The wear and coefficient of friction values of the specimens reduced to almost 9 µm which is approximately 1/33 of the wear value of the parent material (306.7µm) for 180 seconds time duration which is attributed to variation in laser power and scan speed.

Originality/value-The paper is aimed at improving the hardness and tribological properties of SS304 by laser cladding techniques so as to reduce the wearing of gears and turbine blades made up of this material.

KEYWORDS: Surface Engineering, Laser Cladding, Friction, Wear, Microhardness

INTRODUCTION

The components of the machines have to withstand high temperature and extreme pressure which results in the wear of components. (Wang et al, 2008; Peng and Kang, 2014). As a result, the reliability and precision of machine systems is degraded due to the wear. Some components stop functioning due to the major surface damage (Peng et al, 2009; Peng et al, 2010; Peng, 2012). In the industrial applications special surface properties such as hardness, resistance to wear and corrosion etc are often required by machine parts to work smoothly and efficiently. But the cost of such metal alloys is generally very high and the best solution is the fabrication of hard and wear resistive coatings on these parts by certain surface engineering techniques (Santo, L. 2008). The surface modification technologies such as chemical vapour deposit (CVD), ion implantation and thermal oxidation, physical vapour deposition (PVD), thermal spray, plasma coating, and laser ablation or surface texturing can increase the wear resistance of industrial moving components (Wang et al, 2008; Peng and Kang, 2014; Peng, 2012; Bahrain et al, 2016). Laser cladding is beneficial in terms of smaller heat affected zone, localized heating and faster cooling rate, and thus produces much better coating with minimum dilution and distortion of work piece and weld bead. (Bhargava et al, 2014; Quintino, et al, 2007; Kinoshita et al, 2006; Salminen et al, 2010; Kawahito et al, 2007; Canning et al 2006; Khalid et al, 2009). It also provides a high degree of purity in treating implant surfaces(Sami et al, 2011). Also laser treatment lowers corrosion current and improves corrosion properties of treated specimens(Yilbas et al, 2015)

The maximum carbon content in grade 304 stainless steel is 0.03% which eliminates carbide precipitation which may occur due to welding. This characteristic enables this alloy to be used in the welded condition, even in severe corrosive conditions. Stainless steel also possesses excellent fatigue resistance. (Boudi et al, 2008) Chemical processing, oil & gas industries are the most demanding industries that use stainless steels. Stainless steel is also widely used for its heat resisting and corrosion resisting qualities in the steam and gas turbines. But its use is restricted in certain moving components due to poor hardness and low wear resistance (Lu et al, 2015). The gears and turbine blades made of stainless steel wear out faster hence to overcome these problems, self lubricating and anti wear coatings are deposited on the stainless steel through laser cladding. Such coatings tend to extend the life of critical components like turbine blades by improving its properties, reducing cost and ensuring better service conditions (Valsecchi et al, 2012).

A wide variety of coatings can improve hardness, strength and the wear resistance of a substrate thus making them suitable for use in the industrial applications. (Kang et al, 2009; Zhang et al, 2012) In this research, the coatings composed of $Ni\text{-}WS_2\text{-}Al_2O_3$ is obtained on SS304 substrate surface through laser surface technique and the different properties of the coated surface have been evaluated.

EXPERIMENTAL DETAILS

Sample Preparation

Cylindrical SS304 rods of diameter 6mm and length 30.5mm cut by wire electrode discharge machine were used as the substrate. The substrates were cleaned with acetone before carrying out the cladding process to remove contaminants (Lu et al 2015).The coating material $Ni\text{-}WS_2$ - Al_2O_3 is taken in powder form whose morphologies are shown in Figure 1, 2 and 3 respectively. The chemical composition of the $Ni\text{-}WS_2\text{-}Al_2O_3$ is shown in Table 1 and the particle size of the powder was in the range of 0.2~50µm. The powder was preplaced on the stainless steel substrates with the help of 4wt% of poly vinyl alcohol (PVA), which acts as an organic binder. The coating thickness was 0.8 mm and the specimens were baked for two hours at 40˚C.

Table 1: Chemical Composition of $Ni\text{-}WS_2$ - Al_2O_3 Powder

Elements	Weight %
Ni	60
WS_2	37
Al_2O_3	3

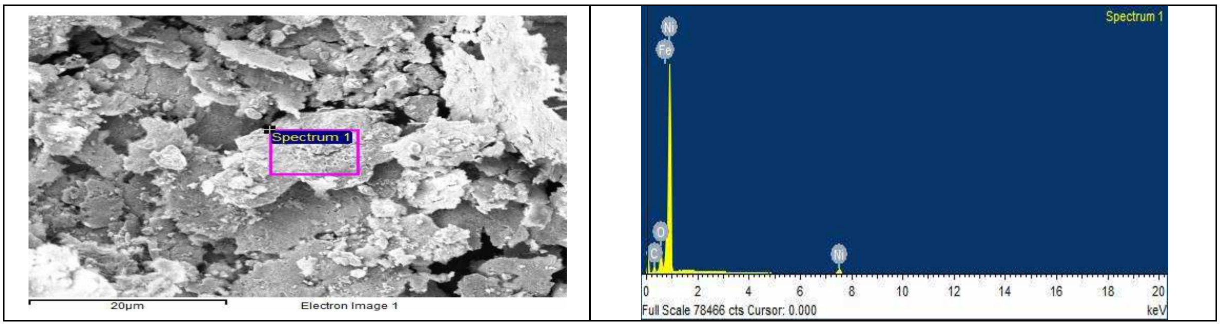

Figure 1: Morphology and Chemical Composition of Ni Powder

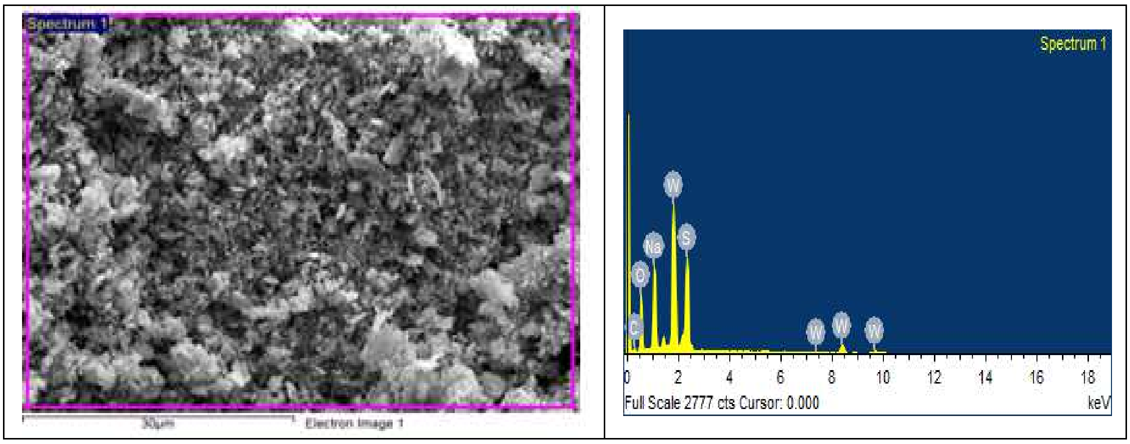

Figure 2: Morphology and Chemical Composition of WS_2 Powder

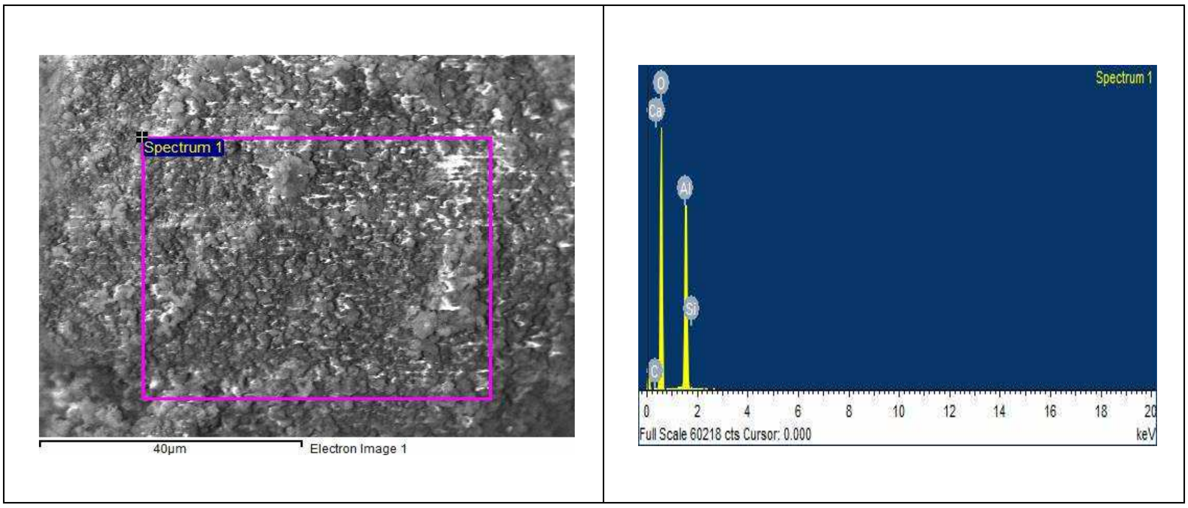

Figure 3: Morphology and Chemical Composition of Al_2O_3 Powder

Experimental Set Up

The experimental setup consists of following units:-

- Fibre Laser system(SPI make, 400W)
- Chiller unit
- Laser head(precitec, Germany)
- XYZ CNC Stage(Siemens)
- Argon gas cylinder

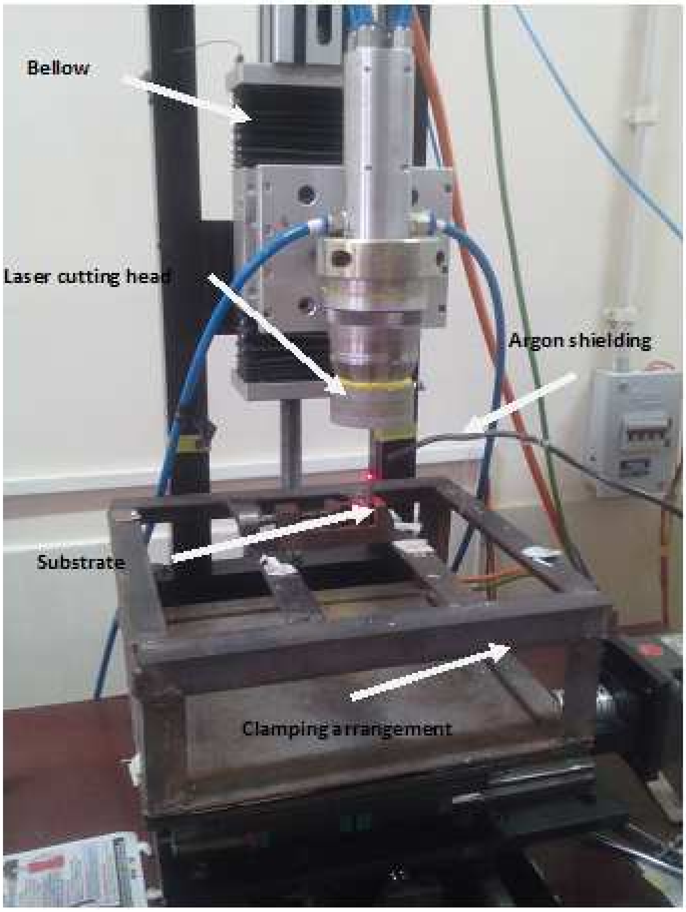

Figure 4: Experimental Setup for Laser Cladding

Experimentation

A 400W continuous wave fibre laser was used for carrying out the cladding and the parameters selected were; 100-180W laser power, 240-420 mm/min scanning speed and laser beam of spot diameter of 1 mm. Argon gas at 10 l/min was purged to provide the shielding of clad zone.

The morphology and microstructure of the laser cladding was evaluated through SEM. The friction and wear of the clad and unclad samples were tested on pin –on –disc apparatus which consisted a disc of EN31 of 100 mm diameter, 8 mm thickness and track diameter 75mm, at the load of 1kgf for 180 seconds. The coefficient of friction was calculated from friction torque and normal load applied (Zhang et al, 2008).Their microhardness was measured using a HVS-1000 Vicker microhardness tester at 0.5 kgf load and dwell time of 10 seconds. The process parameters and obtained results are listed in Table 2. Every experiment was repeated three times, and averaging of test results was applied. While experimenting it was seen that large globules were formed and powder was not completely melted at high speed and large thickness of powder mixture. Hence it can be seen that better coating can be obtained by providing high power and maintaining less scanning speed and thickness. The samples cladded at different laser powers are shown in Figure 5 below:

Table 2: Process Parameters and Obtained Results

Sample	Power (W)	Scanning Speed (mm/min)	Microhardness (HV)	Wear (µm)	Clad Thickness (mm)
1	100	240	281.3	25	0.70
2	100	360	228.5	63	0.67
3	100	420	205.7	44	0.62
4	140	240	310.4	79	0.72
5	140	360	344.5	36	0.68
6	140	420	252.8	56	0.63
7	180	240	380.6	9	0.74
8	180	360	354.1	45	0.71
9	180	420	372.2	89	0.65

Figure 5: Different Laser Cladded Samples

RESULTS AND DISCUSSIONS

Coating Thickness

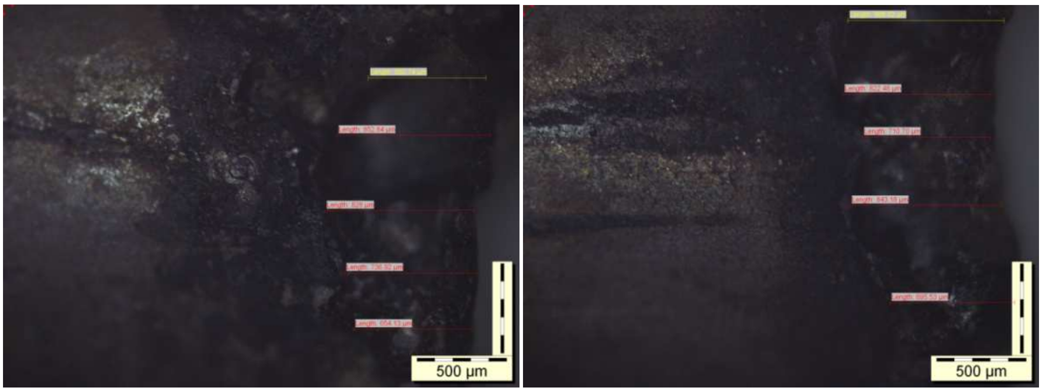

Figure 6: Optical Image of Clad Thickness

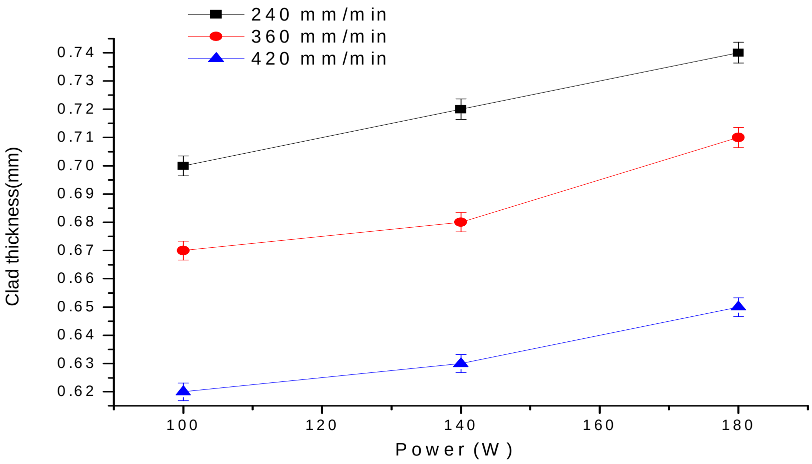

Figure 7: Variation of Clad Thickness with Power and Speed

The clad thickness was measured by optical microscope. An improper coating of the samples can be seen in the optical image depicted in the Figure 6 Gas evolution can be accounted as a reason for the non uniformity of the cladding thickness. A clear clad surface without pores can be observed from the image. Effect of laser process parameters i.e., power and scan speed on clad thickness can be observed in Figure 7. It can be seen that the clad thickness is directly proportional to power whereas it is vice versa for in case of scan speed. Higher laser power is responsible for more clad thickness as it causes maximum depth of the pool melting of the substrate.

Microstructure and Chemical Composition

a) FESEM Images

The FESEM images produced in experiment no. 7, 5 and 1 are indicated in Figure 8. No cracks and pores were observed in the images. Track diameter in pin-on-disc is taken as 75mm hence corresponding wear rate is also high as larger track diameter means more time substrate is in surface contact with wear disc and hence more chances of wear is possible. The SS304 substrates are coated with Ni (60 wt%), WS_2(37 wt%), Al_2O_3,(3 wt%). The thickness of the coating was 0.8 mm. The samples were cladded at different powers and scanning speeds and tested for friction and wear at 1kgf load and 200 rotational speed.

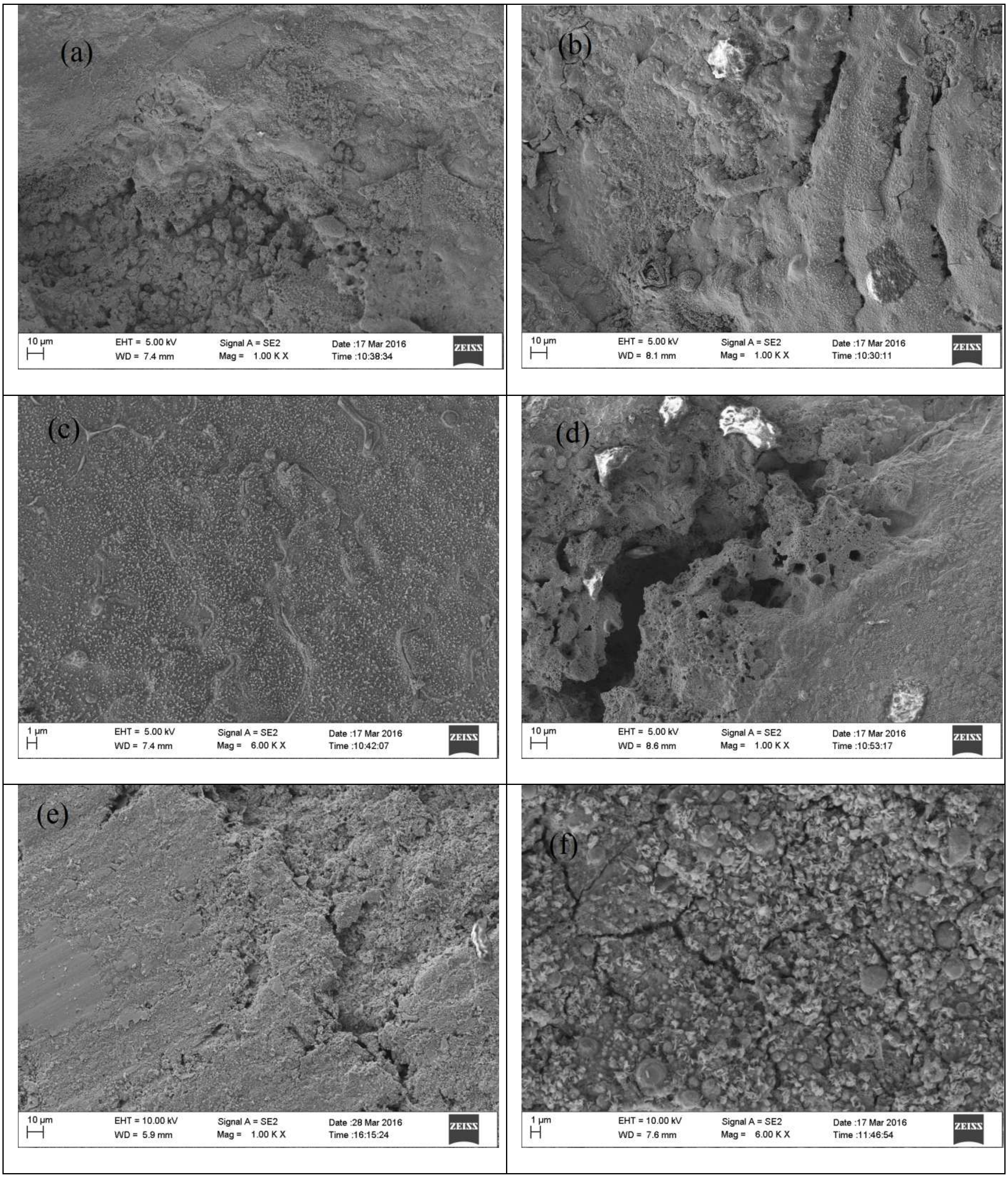

Figure 8: FESEM Micrographs of Untested and Tested Surfaces: (a) and (b) at 180W and 240 mm/min,(c) and (d) at 140W and 360mm/min,(e) and (f) at 100W and 240 mm/min

Figure (a and b), laser cladded at 180watt and 240mm/min, shows tested and untested FE-SEM images of SS304. Figure (a) shows uniform and mixed coating prepared by mixing Ni(60 wt%),WS_2(37 wt%), $Al_2O_{3,}$ (3 wt%) before testing .Figure (b) shows, that WS_2 being softer and having lamellar structure gets squeezed out from surface and got smeared on contact surfaces and deformed on application of load which can be seen in images. Figure (c and d) shows FE-SEM images of untested sample and tested substrate, cladded at 140 watt and 360mm/min, micro-ridges are seen in images due to improper coating. Cracked surface layer, due to heavy load application and high rotational speed (200 rpm) is seen.

Figure (e and f) shows untested and tested images, laser cladded at 100watt and 240mm/min. Figure (f) shows fracture lines present in images, patches of WS_2 and sliding wear at different places on images. Coating still remains intact in overall region however some part of coating applied on substrate has deformed due to applied load and sliding speed condition.

b) EDAX Analysis

The chemical composition of coatings was determined by the EDAX analysis. Figure 9 and 10 show the chemical characterization of worn and unworn sample cladded at 180W and 240 mm/min and 140W, 360mm/min respectively. In the worn sample cladded at 180W and 240mm/min the Ni content is 10.57%,W is 12.45%, S is 0.74,Al is 3.41% and oxygen is 31.19% whereas the weight% of Ni, W, S, Al and O, in the unworn sample cladded at 140W and 360mm/min is 4.87,6.45,0.25,5.21,34.65 respectively.

Vapourisation at high temperatures can be a reason of the low sulphur content in above samples.

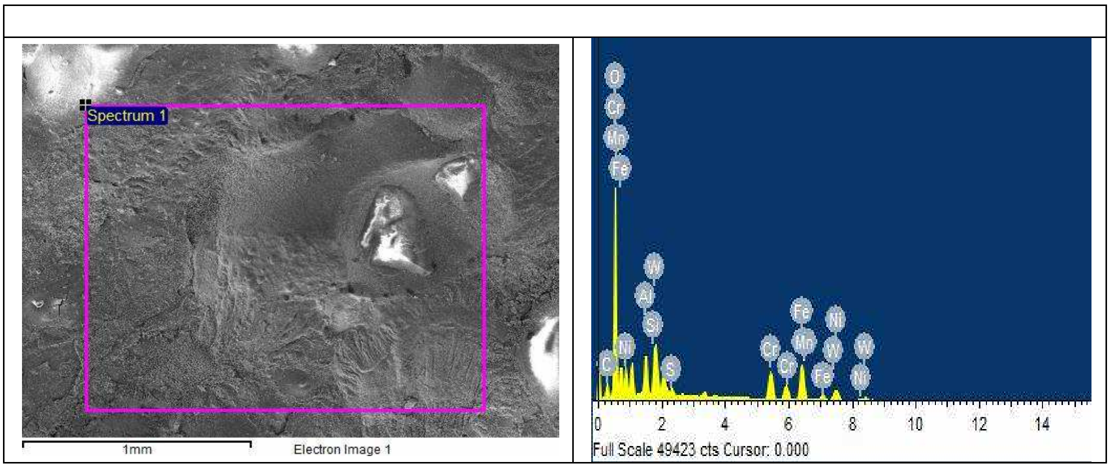

Figure 9: EDAX Image of Worn Surface Cladded at 180W and 240mm/min

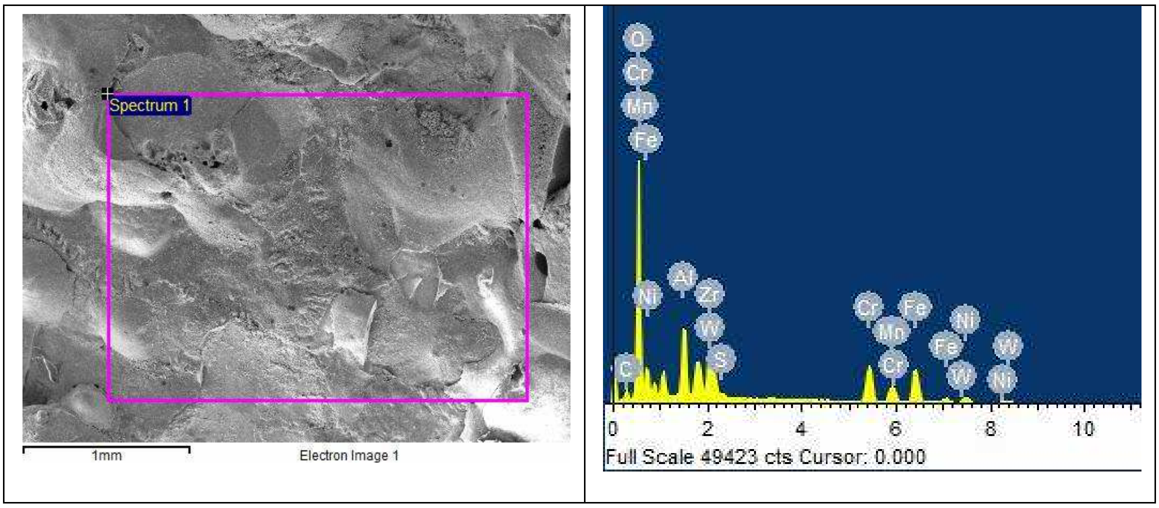

Figure 10: EDAX Image of Unworn Sample Cladded at 140W and 360 mm/min

Wear and Friction Measurement

Wear and friction test was performed on a pin-on-disk apparatus in ambient temperature. A EN31 disc of diameter 100 mm was used for conducting the test. A load of 1 kgf, a fixed rotation speed of 200 rpm, and 180 seconds as test time were set as the parameters of the apparatus.

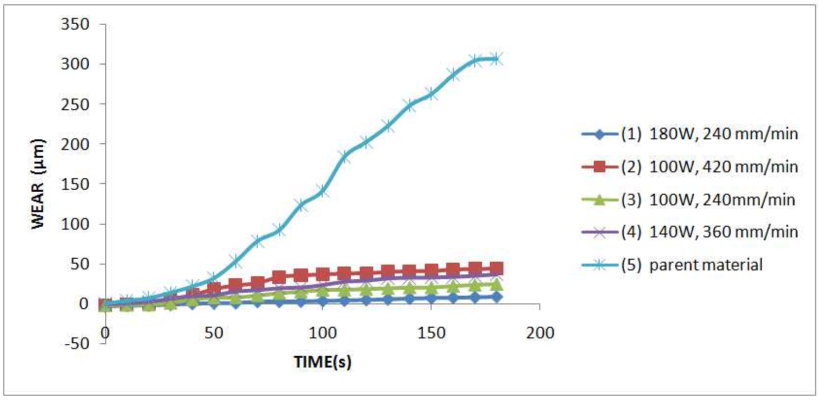

Figure 11: Variation in the Wear Rate of Laser Cladded Ni-$WS_2Al_2O_3$ Surface with Time

Wear resistance was performed on a pin-on-disk apparatus in ambient air. The wear test results are presented in the form of power versus wear rate at different speeds in Figure 11**.** Prior to the testing for wear and friction, the specimens were ground and polished with acetone. A EN31 disc with a diameter of 100 mm was used for testing. The parameters of the apparatus were set as an applied load of 1 kgf, a fixed rotation speed of 200 rpm of the workbench, and 180 seconds as test time. The wear graph increases initially because of greater asperity to asperity contact between the mating surfaces (Zhang et al, 2008). However it becomes constant after sometime**.**

The coatings have resulted in wear reduction of the substrate upto a great extent. The wear of sample no 7 reduced to 9µm which is approximately 33 times of the substrate whose wear is 306.7 µm at the same conditions of load and rotational speed, and is comparable with the wear generated by polymers.

Figure 12 shows variation in friction coefficient of samples cladded at different parameters after different time intervals. The coefficient of friction of the four coatings are lower than the coefficient of friction of the substrate (Zhang et al, 2008)

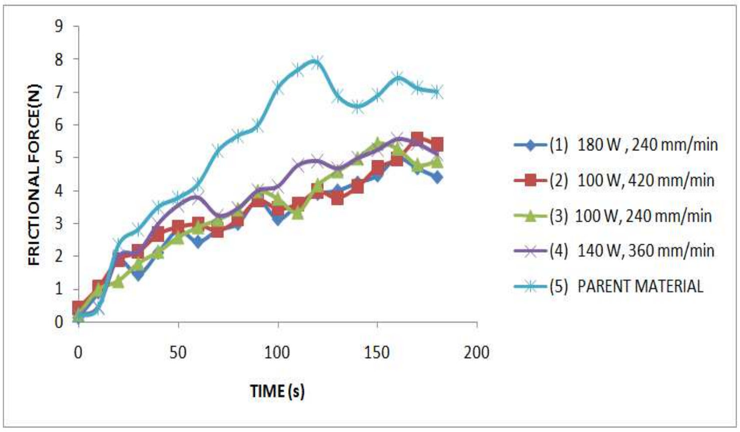

Figure 12: Variation in the Frictional Force of Laser Cladded Ni-WS_2 -Al_2O_3 Surface with Time

3.4 Microhardness

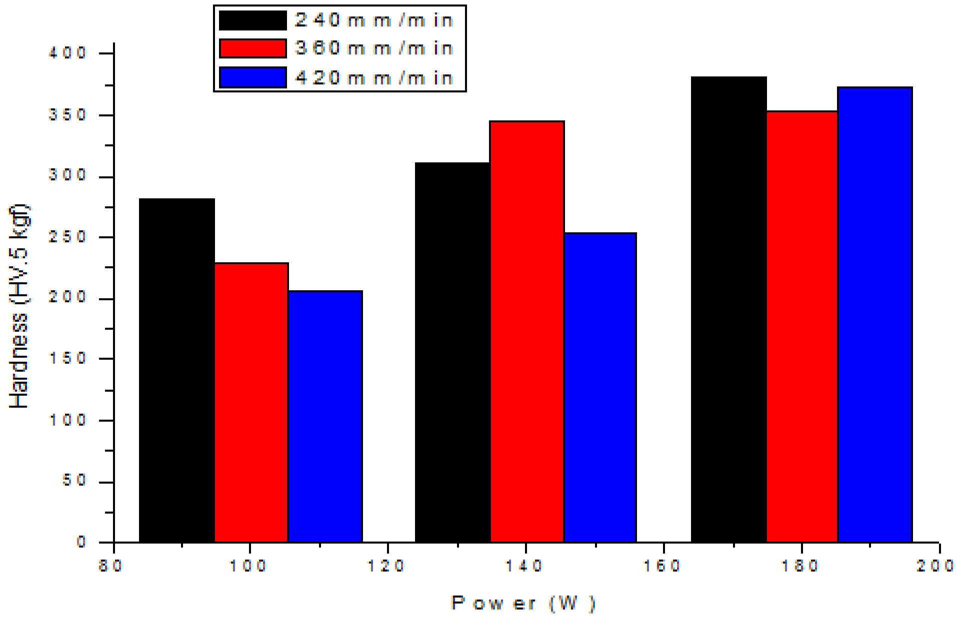

Figure 13: Microhardness Profile of Laser Clad Ni-WS_2-Al_2O_3 Coatings

Figure 13 shows microhardness profile of laser clad Ni-WS_2-Al_2O_3 coatings. It can be clearly seen that microhardness of the coating cladded at 180W laser power is highest which is 380HV and is approximately three times higher than that of base material. The addition of hard Al_2O_3 particles account for the increase in microhardness of the cladded samples although the Al_2O_3 was added in a very small amount.

CONCLUSIONS

The following conclusions can be drawn from above experiments:

Ni-WS_2-Al_2O_3 coatings were successfully fabricated on SS304 by fibre laser laser at various laser powers and scan speed. The solid lubricating performance of WS_2 is responsible for reducing the wear and coefficient of friction of the coatings upto a great extent. The highest clad thickness 0.74mm is obtained at power of 180W and 240 mm/min scan speed which may be attributed to greater melting of the parent material at higher power.

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