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Laser Surface Alloying of AISI 304 Stainless Steel with WC+Co+NiCr for Improving Wear Resistance

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Abstract

The present investigation aims at improving the wear resistance of AISI 304 stainless steel by laser surface alloying of AISI 304 stainless steel with WC+Co+NiCr (in the weight ratio of 20:40:40). Laser surface alloying was carried out by melting the surface using a 5 kW continuous wave (CW) Nd:YAG laser at a beam diameter of 4 mm, with the output power ranging from 1-3 kW and scan speed from 0.005 m/s to 0.1 m/s by simultaneous feeding of precursor powder at a flow rate of 20 mg/s using Ar shroud at a gas flow rate of 5 l/min. The effect of laser parameters on the microstructure, composition and phases was studied in detail. Finally, the wear and corrosion behavior of the laser surface alloyed stainless steel was evaluated and compared to that of as-received AISI 304 stainless steel. It was discovered that laser surface alloying leads to formation of a defect free and continuous alloyed zone. The microhardness of the alloyed zone was improved to 250-320 VHN as compared to 232 VHN of as-received substrate. The wear resistance property was improved significantly due to grain refinement and presence of WC,W_2C, CoC as precipitates and Cr, Ni in solution. The optimum parameters for laser processing were derived.

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Keywords: AISI304 stainless steel; wear; corrosion; laser surface engineering

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1. Introduction

AISI 304 stainless steel is widely used steel for structural applications in mild to very severe oxidizing environments due to its excellent corrosion resistance [1]. Such austenitic steel exhibits relatively low hardness and poor tribological properties in aggressive environment like gaseous and liquid environment. Pitting and crevice

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corrosion are common features in environments containing chlorides [2]. Several attempts have been made in the past to improve wear resistance of AISI 304 stainless steel by physical vapor deposition, sol-gel coating, weld overlaying and thermal spray deposition techniques [3-6]. Laser surface alloying involves melting of the surface of substrate along with coating, intermixing and rapid solidification to form the alloyed zone on the surface of the substrate [7]. Faster processing kinetics, precision, narrow heat affected zone and formation of refined microstructures are the notable advantages associated with laser surface alloying [7]. Laser surface alloying can successfully be applied to improve the wear resistance of any substrate by dispersion of ceramic particles in the metal matrix by addition of ceramics particles externally during laser surface melting of the substrate or by the in-situ reaction by addition of reactant powders [8]. The addition of WC, which is a hard material, in metallic matrix improves the strength and wear resistance of the same significantly [9]. However, the quantity of WC to be dispersed needs to be optimized to have an improved property of the coating. Furthermore, the volume and quantity of the binders added with WC particles determines the overall properties of the alloyed surface [10].

The present investigation aims at improving the wear and corrosion resistance of AISI 304 Stainless Steel by laser surface alloying of AISI 304 stainless steel with WC+Co+NiCr. Laser surface alloying was carried out by melting the surface using a 2 kW Nd:YAG laser and simultaneous feeding of a powder mixture of WC, Co and NiCr at a ratio of 2:4:4. The effect of laser parameters on the microstructure, composition and phases would be studied in detail. The wear and corrosion behavior of the laser surface alloyed stainless steel would also be evaluated.

2. Experimental

In the present study, stainless steel samples of dimension: 20 mm x 20 mm x 5 mm were sand blasted using Al_2O_3 particles of 10-25 μm particle size. It was later subjected to laser surface alloying using a 5 kW fiber optics delivery continuous wave (CW) Nd:YAG laser with a beam diameter of 3 mm by simultaneous feeding of WC-Co-NiCr (weight ratio of 20:40:40) in the molten pool at a powder feed rate of 10 g/s using Ar as shrouding environment (flow rate of 5 l/min). Laser surface alloying has been carried out using a 5 kW continuous wave (CW) Nd:YAG laser (beam diameter of 4 mm), with the output power ranging from 1-3 kW and scan speed from 0.005 m/s to 0.1 m/s by simultaneous feeding of precursor powder (flow rate of 20 mg/s) and using Ar shroud at a gas flow rate of 5 liters/min. Followed by laser surface alloying, the microstructures of the coating (both the top surface and the cross section) were characterized by field emission scanning electron microscopy (SUPRA 40, Zeiss SMT AG, Germany). A detailed analysis of the phase was carried out by X-ray diffraction technique (D8 Advances, Bruker AXS, Germany) technique. The microhardness of the coated surface, both on the top surface and along the cross-sectional plane, was measured by a Vickers microhardness tester (UHL-VMHT, Leica) using a 100 gm applied load. The kinetics of wear of the treated surface was compared to that of the as-received one by a Fretting wear testing unit (DUCOM, TR-283M-M4) against WC ball of 5.2 mm diameter as the counter body. Prior to conducting the test, all samples were diamond polished with a particle size of 6 μm and cleaned properly. The wear test was conducted at an applied load of 10 N for a constant test duration of 30 min, constant frequency of 10 Hz and constant stroke length 1 mm. The cumulating loss of depth with time was calculated using the Winducom 2006 software while the microstructure of the worn out debris was analyzed using a scanning electron microscopy to understand the mechanism of wear. The wear depth was also measured by a surface profilometer. .

3. Results and Discussions

Fig. 1 shows the influence of laser parameter on the surface roughness of the alloyed zone. It may be noted that average surface roughness of the alloyed zone varies from 5-14 μm for different conditions. It may further be noted that increase in applied power decreases the surface roughness of the alloyed zone. This could be attributed to adequate power supply available for complete melting and homogenization of the surface. However, application of excessive power causes evaporation of the materials from the surface leading to crater formation. On the other hand increase in scan speed reduces the surface roughness significantly, due to a reduced surface ripple formation resulting from the small surface tension gradient related to low thermal gradient with depth associated with laser processing. However, too high a scan speed causes inadequate melting and intermixing leading to inhomogeneous alloyed zone formation. Hence, it may be concluded that by proper choice of laser parameters surface roughness of the alloyed zone may be minimized.

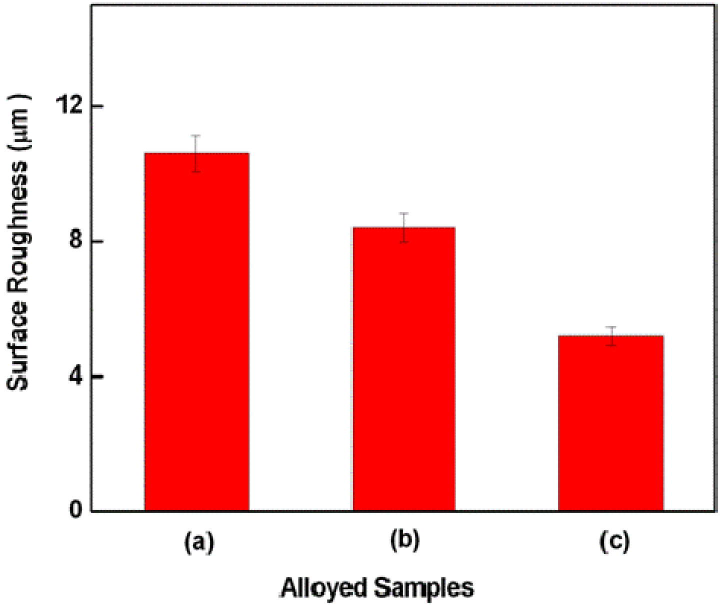

Fig. 1 Average surface roughness (R_a) of the laser treated samples as a function of laser power and scan speed on the top surface of laser surface alloyed AISI 304 stainless steel with WC+Co+NiCr lased with (a) a power of 2.0 kW, scan speed of 12 mm/sec; (b) 2.5 kW, 12 mm/sec; c) 2.5 kW, 16 mm / sec.

Fig. 2 (a-c) shows the microstructure of the cross section alloyed zone from AISI 304 WC+Co+ NiCr lased with a) laser power of 2.00 kW, scan speed of 12 mm/s; b) laser power of 2.5 kW, scan speed of 16 mm/s; c) laser power of 2.5 kW, scan speed of 12 mm/s. A close comparison between Figs. 2a and 2b show that increase in scan speed reduces the depth of the alloyed zone. On the other hand, comparison between Fig. 2a and 2c shows that decrease in applied power reduces the depth of alloying. The variation of alloyed zone width with laser parameters is summarized in Fig. 3 which shows the value of melt depth with power at a scan speed of 12 mm/s in plot-a and scan speed at power of 2.5 kW in plot b for laser surface alloying on AISI 304 stainless steel. From Fig. 3 it may be noted that increase in laser power increases the depth of melting which is attributed to an increased energy density absorbed on the surface. On the other hand, an increase in scan speed decreases the melt depth due to decrease in interaction time during laser surface alloying. Depth of alloyed zone is an important parameter which determines the life time of component subjected to wear and erosion, hence laser parameter should be carefully chosen to achieve the desired alloyed zone depth. Fig. 4 (a-b) shows the scanning electron micrograph of the top surface of laser surface alloyed AISI 304 stainless steel with WC-Co-NiCr lased with; (a) power of 0 .75 kW, scan speed of 0.012 m/s, and (b) power of 1.5 kW, scan speed of 0.012 m/s. From Fig. 4 it may be noted that the microstructure of alloyed zone consists of presence of large grains (size ranging from 5-7.5 μm) with very fine sub grains with average grain size (0.25 – 0.5) μm, inside the big grains. Furthermore, there is presence of very fine precipitates of carbides dispersed randomly within the grains. A detailed X-ray diffraction analysis of the alloyed zone show the presence of WC, W_2C, $M_{23}C_6$ phases in austenite matrix. The mass fractions of individual phases were found to vary with laser parameter. Detailed studies of the variation of mass fraction of phases with laser parameter are reported elsewhere.

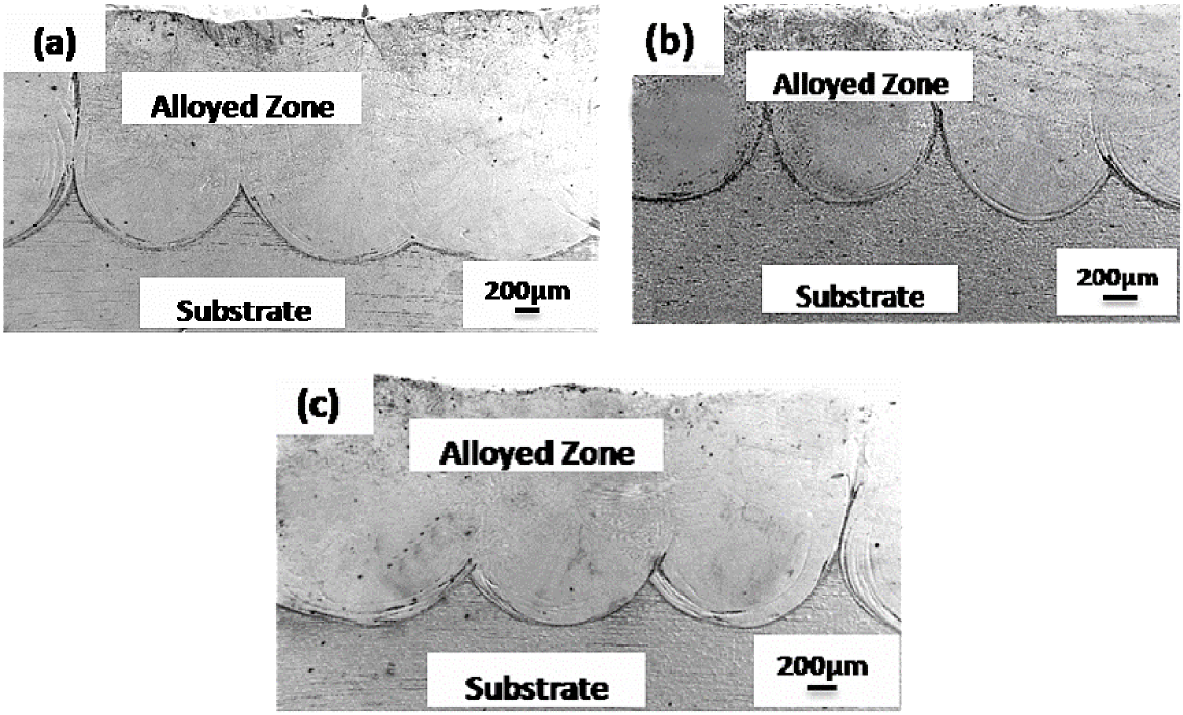

Figure 2 Scanning electron micrographs of the cross-section of the alloyed zone formed in laser surface alloyed AISI 304 stainless steel with WC+Co+NiCr lased with (a) power of 2.5 kW, scan speed of 12 mm/sec; (b) 2.5 kW, 16 mm/sec; (c) 2.0 kW, 12 mm/sec.

Few carbide precipitates are also observed along the grain boundary region. A comparison of Figs. 4(a) and 4(b) shows the significant conversion of grain size and sub grain size due to the application of high power. The area fraction of carbide precipitated inside the grains were also reduced by application of higher power. The grain morphology was also changed from equiaxed to cellular, when applied power is higher. The morphology and size of the grains vary with the depth while the microstructure of top and interface are courser in nature. However, in the intermediate region, there is a substantial refinement of the microstructure. The microstructure shows presence of fine carbides precipitate along the grain boundary region and inside the grain. Detailed investigation of the nature and distribution of the precipitates has been done in the study. The X-ray diffraction profiles of the alloyed zone shows that there are WC, W_2C, $M_{23}C_6$ phases in austenite matrix. The mass fractions of individual phases were found to vary with laser parameter.

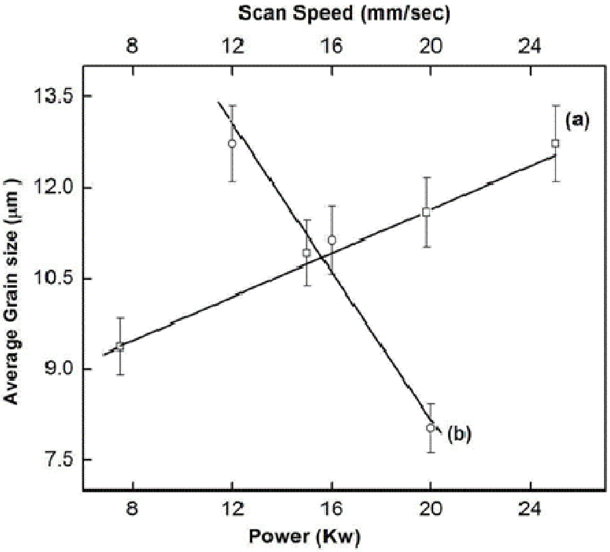

Figure 3 Variation of the depth of alloyed zone with (a) applied laser power (at a scan speed of 12 mm/s) and (b) scan speed (at an applied power of 2.5 kW)

A detailed measurement of the microhardness of the alloyed zone showed that there is an improvement of hardness from 250 VHN to 320 VHN due to laser surface alloying .Furthermore, a maximum hardness is achieved on the surface which decreases gradually with depth from the surface. Decrease in micro hardness is attributed to coarsening of the microstructure with increase in depth and to decrease in the mass fraction of precipitated with depth. A comparison of micro hardness value with process parameter shows that laser parameter does have marginal influence on the hardness and its distribution. However, with an increase in scan speed there is an increase in micro hardness value while a decrease in applied power leads to an improvement in hardness.

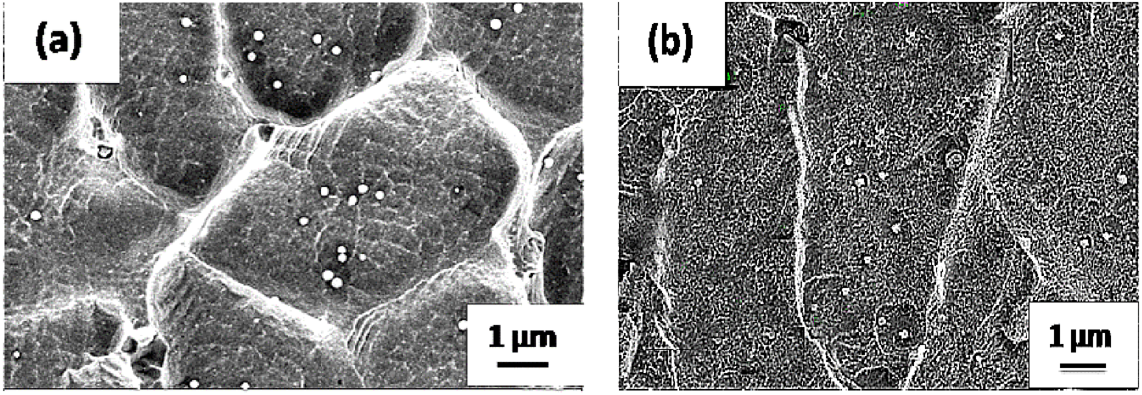

Figure 4 Scanning electron micrographs of the top surface of laser surface alloyed AISI 304 stainless steel with WC+Co+NiCr lased with a) a power of 0.75 kW, scan speed of 0.012 m/s and b) 1.50 kW, 0.012 m/s.

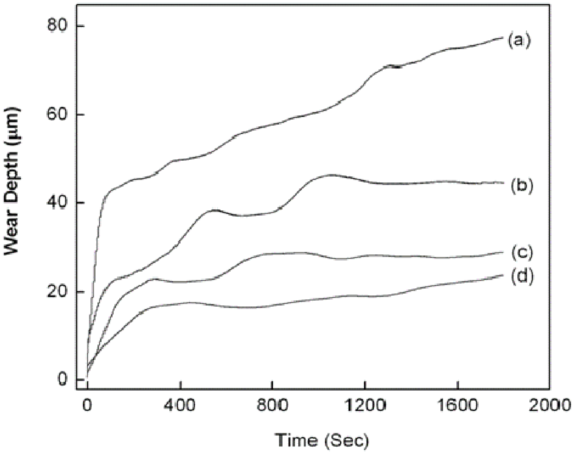

Figure 5 Wear Depth as a function of time from the top surface on the of Laser Alloyed 304 Stainless Steel , a) 304 Stainless Steel Base metal,; b) with laser power = 2.5 kw , Scan speed = 12 mm / sec ; c) with laser power = 2.5 kw , Scan speed = 16 mm / sec ; d) with laser power = 2.0 kW , Scan speed = 12 mm / sec

Fig. 5 shows the kinetics of fretting wear regarding the depth of wear with time. It may be noted that the kinetics of wear is higher at the initial stage following which it decreases. This could be attributed to the increased pressure in the contact areas of asperities. Once the wear starts, due to wearing of the surface, there is smoothening of surface asperities leading to a gradual decrease in pressure, which causes a decreased rate of wear at a later stage. However, the kinetics of wear varies with process parameters to a large extent. The increased wear resistance due to laser surface alloying is attributed to an increased hardness of the alloyed zone. A maximum improvement in wear resistance is observed for the samples lased with an applied laser power of 2.0 kW and scan speed of 12 mm/sec. Detailed study of the mechanism of wear is under investigation.

Conclusions

In the present study, laser composite surfacing of AISI 304 stainless steel has been conducted by Laser Surface Alloying of AISI 304 stainless steel with WC+Co+NiCr at weight ratio of 20:40:40. The following conclusions may be drawn from the work;

1. there is formation of a defect free alloyed zone consisting of presence of WC, W_2C, $M_{23}C_6$ phases in austenite matrix. The depth of melting increases with increase in applied power and decrease in scan speed;
2. there is improvement of hardness from 250 VHN to 320 VHN due to laser surface alloying as compared to 0 VHN of as-received substrate; and
3. the Laser surface alloying helps in increasing the fretting wear resistance significantly with a maximum improvement in wear resistance achieved in laser surface alloyed AISI 304 stainless steel at a power of 2.0 kW, scan speed of .012 m/s.

Acknowledgements

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