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Surface modification of low alloy steel by laser melting

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Abstract

Surface modification of low alloy steel (LAS) has been achieved by laser melting and Ni alloying. Specimens of LAS were coated with Ni by PVD and electro-deposition techniques followed by laser beam melting. The Ni coating produced by PVD technique could not produce the requisite alloying during the laser melting. In case of LAS specimens coated electrochemically, the iron–nickel binary alloys of different compositions were formed with varying laser beam traverse speed. The surface alloys produced ranged in composition from 20.8 to 33.6 wt.% Ni, where laser beam speed was varied from 10 to 100 mm/min. The binary alloy containing 20.8 wt.% Ni was produced, at 10 mm/min laser beam speed, with martensite as major harder phase, whereas alloys with higher Ni content, produced at higher laser beam speed, retained soft γ-phase.

Keywords: Surface modification; Laser processing; Microstructure; Martensitic transformation; Hardness

Surface modifications or treatments of metals by laser beam application are gaining importance in addition to their industrial applications like welding, drilling micromachining, etc. Surface hardening of low alloy steel (LAS) by laser have already been reported [1], where maximum hardness was achieved by martensitic transformation. Alloys of different compositions using laser can successfully be produced on the surface of any low alloy materials by supplying alloying elements during laser treatment. The surface alloying is usually achieved by spraying alloy powder while the laser beam is being traversed [2]. This process involves rapid melting, intermixing and solidification of pre- or co-deposited alloying elements with part of the underlying substrate to form an alloyed zone, which is confined only to the near-surface region [3–5]. The alloys so produced can also be hard-faced with overlaying of alloy powder layers, which can be melted and bonded by laser as thin cladding layer on the surface of LAS [6,7]. The present study describes surface modification of LAS by supplying the alloying element Ni in two different manners by PVD and electrochemically and then surface melting by laser beam. Optical and Scanning Electron Microscopes (SEM) having attachment of Energy Dispersive System (EDS) were employed to study the microstructure and concentration variations. Microhardness measurements of the modified areas were performed and correlated with the microstructure and phases.

Low alloy steel ASTM A516; G-70 was selected as base metal to modify its surface by laser melting and Ni addition. Rectangular specimens of size $25\times12\times8$ mm^3 were prepared with surface finish of 600 grit for better adhesive properties of Ni coatings. Prior to coating polished specimens were cleaned using trichloroethylene and heated to 200 °C for 20 min in vacuum of 5×10^{-5} Torr. These specimens were coated with 2 to 5 μm thickness of Ni using PVD technique. These specimens were subjected to a CO_2 laser with beam diameter 0.6 mm for surface melting. Laser tracks were made using laser power of 40, 47, 50, 60, 70 and 300 W. Tracks were made at different speeds of 10, 20,

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40 and 100 mm/min to observe the effect of speed at each power level. Another set of LAS specimens of the same dimensions $25\times12\times8$ mm^3 was prepared and Ni plating was done by electrochemical method. A bath containing Ni-sulfate, Ni-chloride and Boric acid, with concentrations of 240, 60 and 40 g/l, respectively, was used for this purpose. Plating was done at room temperature for 5 min at a current density of 5 A dm^{-2}, which resulted in a 20-μm thick Ni-coatings on the specimens. The Ni-electroplated specimens were subjected to 300 W laser treatment at beam speed of 10, 20, 40 and 100 mm/min for the individual tracks. All the laser treated areas on specimens were studied at their cross-sections using optical and scanning electron microscopes after etching in 2% Nital by swabbing at room temperature. The etchant did not reveal modified area, but revealed areas adjacent to it. The microhardness was measured on Vicker's scale at the cross-sections of modified regions.

Microstructural examination and analyses showed that specimens coated by PVD technique could not produce Ni alloying on the specimens surface at any laser traverse parameter studied. It could be due to the fact that Ni coating produced by PVD technique was very thin and was not strong enough to withstand the laser thrust or its alloying may be below the detection limit of EDS. However, the micrographs of the entire laser treated areas showed complete transformation into martensitic structures. Microhardness values of these areas on Vickers's scale did confirm the martensitic transformation, as already explained by Nisar et al. [1]. A typical cross-section of the laser track made with 300 W laser at a speed of 20 mm/min along with EDS spectra of point analyses performed at two spots are shown in Fig. 1(a–c). The analysis shown at spot "A" belongs to the area melted under the laser track but it does not show presence of any Ni traces. However the analysis at spot "B", the adjacent area of the laser-track, did confirm the presence of Ni coating. Complete martensitic transformation of localized area under the laser track was obtained and it was without any traces of Ni element. So, EDS analysis confirmed that Ni was not alloyed at laser treated area even though its presence is confirmed in the form of coating at adjacent area of the laser track.

The electrochemically Ni-plated specimens produced the desired results when melting and mixing were achieved by laser beam at the LAS surface. Laser tracks on Ni-plated specimens produced with different speeds resulted in Fe–Ni binary alloys of different compositions. Surface modified zones under these laser tracks appeared with different case depth and width as shown in Fig. 2(a–d) at the cross-sections of the specimens. The line profile shown in Fig. 2(e) gives variation of Ni and Fe in the alloyed and adjacent areas along the line in Fig. 2(a). The quantitative analyses of these modified regions were performed by EDS and it was found that melting at laser beam speeds 10, 20, 40, and 100 mm/min produced iron–nickel alloys with 20.8, 25.3, 33.6 and 31.9 wt.% Ni, respectively. The composition was determined by taking average of analyses at six points in each region. The results indicate that the Ni content increases with the beam

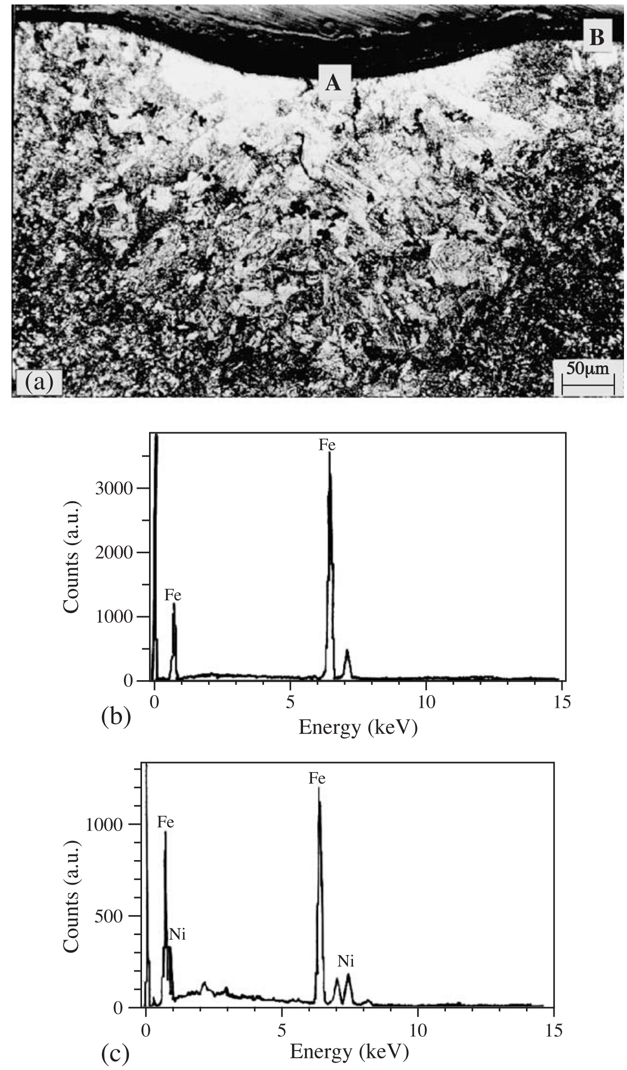

Fig. 1. (a) Cross-sectional view of PVD Ni coated and laser treated surface showing the complete martensitic transformation. (b) EDS analysis spectrum in the laser treated area at spot A in (a). (c) EDS analysis spectrum at spot B in (a), the area without laser treatment confirming the presence of Ni as coating.

travel speed up to 40 mm/min and then remain almost constant. Manganese content (0.9 wt.%) in the alloy remained almost constant for all the SEM/EDX analyses performed and it is assumed that it did not play any role in the present studies. Therefore, for highlighting other factors affecting the surface alloying of LAS, the role of Mn is ignored. The case depth and case width of tracks as well as microhardness measured at various cross-sections are plotted in Fig. 3 as a function of laser beam travel speed. All the three quantities decrease with increase in beam travel speed up to 40 mm/min and then become almost constant. The change in microhardness is associated with wt.% of Ni in the alloys produced at the surface. The resulting binary alloys could be placed in the Fe–Ni phase diagram [8] within the region marked by dotted lines shown in Fig. 4. It is evident that when laser beam traversed at slow speed (10 mm/min), it resulted in low content of Ni and faster speeds produced alloys rich in Ni. It is due to the fact