Laser Surface Hardening of Groove Edges

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Abstract
Surface hardening of groove-edges made of 3Cr13 Stainless Steel has been carried out using 500 W CO$_2$ laser with a rectangular beam of 2.5x3 mm$^2$. The processing speed was varied from 150-500 mm/min. It was seen that the hardened depth increases with increase in laser interaction time. A maximum hardened depth of around 1mm was achieved. The microhardness of the transformed zone was 2.5 times the hardness of base metal. The XRD’s and microstructural analysis were also reported.

Keywords: Surface hardening, CO$_2$ laser, Microhardness, Microstructure

1. Introduction
Laser surface hardening (LSH) is well known process in automotive industries. The various components require high hardness, low wear resistance, high elasticity and toughness [1, 2], since they are normally used in poor working environment. The high abrasion and wear enhance the friction which leads to premature failure. Thus it is important to improve the surface properties of the component. Extensive studies of LSH have been carried out for various components like the piston head in diesel engines [3], automotive shaft [2], bearing rings [4], different hollow parts [5], valves and valve seats of internal combustion engine [6] etc.
LSH process is applicable where conventional hardening process does not give the localized heating and low distortion associated with laser. A hardened layer of 0.5 to 1mm is sufficient to ensure the improvement in wear and fatigue resistance. Laser beam heats the surface to austenite temperature followed by self-quenching of the layer by the substrate. This allows the transformation of austenite to martensite. In practice, it is advisable to avoid surface melting which result in coarse structure and lower value of hardness on the surface. LSH process improves the fatigue life because cracks are usually initiated at the surface and propagated under continuous stresses. The developed compressive stresses in laser treated area must be over come before the crack can propagate in to the material.
The laser hardened layer contains high strength structure and residual compressive stresses which would slow down crack growth rate near early stage of fatigue crack propagation. This slowing down (retarding) effect is increased when hardened depth is increased [7].
A threefold increase in the surface hardness under optimum conditions has been reported [8]. Such a large increase is important for increasing the residual stresses, wear properties, corrosion resistance and fatigue life of the steel [9, 10].
In this work, LSH of groove-edges for V-type railing system of 3Cr13 SS has been carried out using 500 W CO$_2$ laser with a rectangular beam shape. The variation of case depth with speed, XRD’s analysis and their microstructure were studied.

2. Material
The material was received in the form of component as shown in the Fig. 1. The microhardness hardness of the as received sample was 180-200Hv.
The composition of the base metal is given in the table 1.
Table-1. Composition of the material

| Elements | C   | S    | Cr   | Mn  | Si   | Fe   |
|----------|-----|------|------|-----|------|------|
| Composition (Wt.%) | 0.308 | 0.0164 | 12.86 | 0.6 | 0.49 | Balance |

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Fig. 1 shows (a) slide rail having V-shaped groove and (b) the surface area “A” to be hardened. The main objective was to harden the surface “A” as shown in the Fig. 1 up to a required hardness of 450-550 Hv.

3. Experimental setup

The experimental set up for CO₂ laser hardening process is shown in Fig. 2. A rectangular laser beam of size 3 x 2.5 mm² was adjusted on the work piece with a focusing mirror of 280 mm focal length, which was used to harden the required surface. The beam size was selected to cover the full width of the surface to be hardened, so that the required results were obtained in a single pass. The surface of the sample was black coated to increase the absorption of the laser beam. For laser treatment, the samples were fixed on a CNC table which moves under the laser beam along x-axis. The sample was positioned at an angle of 45° with the horizontal surface to access the area to be hardened. Shielding gas (nitrogen) was used to prevent the formation of oxide on the sample surface. The laser treated samples were cut and mounted along the cross-section. For metallography, the samples were ground and polished, and then etched in 2% Nital. The microstructure of the laser treated zone was examined under optical microscope and Vickers hardness was measured as a function of case depth. XRD’s analysis was also carried out to compare the base metal and top surface of the laser treated specimens.
4. Results and Discussions

4.1 Effect of Laser Power and Traverse Speed on the Depth of Hardness: The important parameters in laser processing are laser power, working speed and spot size which determine the input power/energy to treat the materials. Fig. 3 shows a graph between the depth and width of the laser hardened zone versus the working speed. It depicts that the depth and width of the hardened zone decreases with increase of speed for fixed laser power because shorter laser interaction times lower the thermal input to the material. Fig. 4 shows that the depth and width of the hardened zone increases as the laser power is increased at constant speed due to higher heat input.

Fig. 3. Depth and width of hardened zone versus speed at laser power of 450W. Fig. 4. Depth and width of hardened zone against laser power at constant working speed of 150mm/min

4.2 Microhardness and XRD’s analysis: The microhardness as a function of case depth for various speeds at constant power level is presented in the Fig. 5. It shows that the case depth decreases with increasing the speed. When speeds are 150mm/min and 200mm/min, the surface melting occur which lowers the microhardness at the top surface of specimen. In order to attain such a large transformed depth i.e., about 1mm, the top surface melting of the order 0.1-0.2mm in depth could not be avoided. However, the surface grinding up to depth of 0.2mm can be used to completely remove the melted layer before final assembly.

Fig. 5. Variation of microhardness with speed at constant laser power 450 W

Fig. 6(a & b) show the XRD’s analysis of the base metal and laser treated samples, respectively. The samples were scanned with X-ray (CuKα) radiation source at the rate of 3°/min from 0 to 100°. In Fig. 6-a, the peaks of XRD’s analysis correspond to the planes (110), (200) & (211) showing the BCC structure and represent the base metal is martensitic stainless steel. On the other hand the laser treated
sample without any polishing/grinding was scanned. The XRD’s analysis in Fig. 6-b shows that the iron carbides (Fe₃C) is the major phase present on the surface along with minor intensity peaks remained unidentified.

4.3 Microstructure: Fig. 7(a-d) shows the microstructure of the laser hardened samples. In order to achieve hardened depth of 0.7mm to 1mm, the specimen was treated at low speed of 150mm/min and 450W laser power. The microstructure of the laser treated region is divided into four zones. The regions consist of a) melted zone, b) hardened zone, c) partially transformed zone, and d) unaffected zone or base metal. In Figure 7-a, the top surface of the sample consists of a small melted layer/portion. This layer mostly consists of different types of carbides and retained austenite as confirmed by XRD’s analysis. During melting, the material approaches to boiling point and carbon comes from lower to upper melted part and reacts with iron and makes iron carbides on the surface. The value of microhardness is lower in this zone due to coarse structure. In Fig. 7-b, the microstructure is not resolved properly due to martensite formation and has the microhardness about 450 to 550HV. In this case the different phases dissolved uniformly and formed fine structure due to self quenching process. This hardened layer is responsible for enhancing the wear resistance and lowers the crack propagation to the base metal and also increase the fatigue life of component. Fig. 7-c shows the partially transformed zone which consists of martensite and base metal. Here the temperature was insufficient to dissolve all types of phases into austenite due to high cooling rate. Most of the heat is rapidly conducted to the adjacent bulk material. In this region the microhardness rapidly decreases as shown in the Fig. 5. Fig. 7-d shows the microstructure of the base metal having hardness of about 200HV.

The top surface melted layer has softening effect, since it contains different types of carbides and retained austenite which reduces the hardness, in addition, due to temperature distribution generated by laser beam, the grains gradually transform to fine from top surface to bottom. As subsurface has relatively lesser amount of retained austenite due to high cooling rate resulting in fine grain structure which gives high value of hardness. The top surface melted layer can be avoided, if the increased working speed is used at constant input laser power but at the cost of hardening depth. This melted layer provides an additional benefit by providing machining allowance for the final product.
5. Conclusions

- For a fixed laser power, the depth and width of the laser treated zone decreases as the working speed is increased. This is due to lower interaction time at higher working speed.
- For a fixed working speed, the depth and width of the laser treated zone increases with the increase of laser power. This is due to more heat input.
- 2.5 fold increase in the hardness was achieved by this process.
- The top surface melted layer can be avoided, if the working speed is increased for constant input laser power. However this melted layer provides an additional benefit by giving machining allowance for the final product.

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