A STUDY ON THE EFFECT OF PROCESS PARAMETERS OF LASER HARDENING IN CARBON STEELS

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ABSTRACT

Surface hardening at functional areas of engineering components is an energy saving process. The components made of En8, En24, En36 and HCHCr steels are hardened in specific areas to meet the functional requirements at effective cost. The formation of martensite structure, leading to hardening, is decided by the composition of the material. Laser beams are used to perform hardening with almost zero deflection. The experimental study is to optimize the process parameters and selecting suitable material for manufacturing components working under critical loads. A 150 W, CO2 continuous wave laser source has been used in the experimental study. Power and scanning speed are the major influencing parameters in hardening process. The results showed that reducing the scanning speed increases hardness and depth due to increased interaction of beam with the work piece. Increasing the power starts melting the surface due to increase in energy. Improved hardness and wear resistance were observed in specimens with higher carbon content.

Keywords: Carbon steel, CO2 Laser, Surface hardening, Hardness and Wear resistance.


1. INTRODUCTION

Industrial steel components are serving for a longer run, effective functioning. Some component to do their function need to be harden to avoid wear and tear, withstand loads. In most applications wear, corrosion [1] and load concentration takes place only selected area of the components. Hence it is sufficient to harden these areas to enhance the performance of the components. So called surface hardening of the contact surface or hard outer and ductile core. Coming to the process for surface hardening the methods now adapted are namely flame hardening, case hardening, gas carburizing, Nitriding, Induction hardening, and laser transformation hardening. Various types of heat treatment processes are used to change the following properties or conditions of the steel: Improve the toughness, Increase the hardness, Increase the ductility, Improve the machinability, Refine the grain structure, Remove the
residual stresses, Improve the wear resistance. Laser beam hardening has some special features over the other processes. The advantages of laser hardening over the conventional technologies can be summarized as follows:

- Selective areas can be hardened without affecting the surrounding material and time saving by no heating-up or soaking time is required.
- Treatment depth is accurately controlled and highly reproducible.
- Superior hardness, strength, lubrication, wear and fatigue properties can be obtained compared to conventional processes without external quenching.
- Minimal heat input causes little macro distortion and reduces the need for additional machining and lesser-polluted operation.
- Very less air pollution process.

Except for single phase stainless steels and certain types of cast iron, most common steels, stainless steels and cast irons [2] can be surface heat treated by the laser process. Each kind of steel has special characteristics which need to be considered. Carbon Steels and Alloy Steel These materials are better choices than low carbon steel because the higher carbon content allows a longer period for quenching in order to reach high hardness. The maximum case depth without use of a water quench is around 2 mm. The alloy elements, specifically manganese, molybdenum, boron and chrome, aid in hardenability. The maximum hardness which can be achieved is dependent upon the carbon content.

**Problem Definition:**
The process of laser surface hardening performed on metal components reveals different types of responses like hardness, depth of hardness, grain structures. The material with few chemical compositions including Carbon, Chromium, Manganese, and Molybdenum in process shows different responses. The suitable parameter for required results and material is a task for the designers and manufacturers. The material selection and its function with respect to laser hardening only brings the successful components, at this juncture the materials EN8, EN24, EN36, HCHCr area selected for the experimental study.

**Objective:**
1. To identify the parameters which influence hardening characteristics on the contour surface of the bottom roller and investigate the effect of the laser power, and scanning speed, on the hardness, depth of hardness, wear resistance and microstructure.
2. In order to produce the required hardness and depth uniformity the complicated contour surfaces of the bottom roller are surface hardened by laser beam transport through flexible optic cables. Friedrich Bachmann hardened the torsion spring over 170° and depth 0.2-0.4 mm by two diode lasers, the rest of the component was not affected by the process. Because of the low distortion, localized hardening position, lower energy usage, oxidation free and other advantages in the laser hardening process compared with the conventional ways.
3. To fix, the better process variable combinations and find ways to improve service performance of laser hardened components.

**2. PROCESS VARIABLES**
The quality of hardening is highly influenced by the hardening conditions that are set by various process parameters which determine the HAZ size and shape. This, in turn affects the overall quality, microstructure and the resulting mechanical and metallurgical properties of
the surface. The identification of correct hardening conditions can be achieved by properly selecting the independently controllable process variables or factors which influence the heat treatment quality. The independently controllable process parameters [3] were identified as factors to carry out the experimental works for predicting hardness and hardness depth. The identified parameters are 1) Laser power, 2) Scanning speed, 3) Spot diameter, and 4) Focal length. The focal length is set as constant for defocusing beam to avoid melting of surface and it will produce lesser effect than the other parameters so it is omitted.

3. EXPERIMENTAL PROCEDURE

3.1. Laser hardening: The research work presented was undertaken to investigate the effect of hardening process parameters on micro hardness, hardness depth, and microstructure of En8, En24, En36 and HCHCr steel specimens, using CO₂ laser beam [4]. A CNC machine set up was used for this experiment which is an integrated unit of servo controlled 3 axes moving laser head, and organ gas shield attachment.

![Laser head and machine arrangements](image)

Figure 1 Laser head and machine arrangements

A 150W CO₂ continuous wave laser, transmitted from the source fitted on the moving head through optic lenses to the work center, the laser head and machine arrangement is shown in figure 1. The losses of energy considered at 5%. The focal length set for the beam with lense is 65mm as the wave length of the CO₂ laser beam is 10.64 μm.

3.2. Specimen preparation for hardening process:
The specimens prepared from HCHCr En36, En24, En8 and steels as 50 Ø x 40 thick cylinder, 38 Ø x 10 thick cylinder, 25 Wide x 60 long x 6 Thick flat and 40 Wide x 60 long x 10 Thick flat of sizes respectively and the shape of specimens are shown in figure 2. The chemical composition and pre hardness of specimens are tabulated in Table 1.

![Shape of specimens](image)

Figure 2 Shape of specimens
A Study on the Effect of Process Parameters of Laser Hardening in Carbon Steels

<table>
<thead>
<tr>
<th>% Composition</th>
<th>HCHCr</th>
<th>EN36</th>
<th>EN24</th>
<th>EN8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>2.0 - 2.35</td>
<td>0.15</td>
<td>0.36 - 0.44</td>
<td>0.15 - 0.20</td>
</tr>
<tr>
<td>Silicon</td>
<td>-</td>
<td>0.25</td>
<td>0.1 - 0.35</td>
<td>0.10 - 0.4</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.6</td>
<td>0.5</td>
<td>0.45 - 0.70</td>
<td>0.60 -1.0</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.04</td>
<td>0.005</td>
<td>0.04</td>
<td>0.005</td>
</tr>
<tr>
<td>Chromium</td>
<td>11.0 - 13.5</td>
<td>0.9</td>
<td>1.0 – 1.4</td>
<td>-</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>-</td>
<td>-</td>
<td>0.2 – 0.35</td>
<td>-</td>
</tr>
<tr>
<td>Nickel</td>
<td>-</td>
<td>3.5</td>
<td>1.3 – 1.7</td>
<td>-</td>
</tr>
<tr>
<td>Hardness Before hardening- HRC</td>
<td>37</td>
<td>23</td>
<td>26</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 1 Chemical composition and pre hardness of specimens

3.3. Fixing the Limits of the Process Variables:
The upper limit and lower limit of each process variable has to be first identified. This was done by conducting trial runs, for example to identify the lower and upper limit of laser power, the trial runs were conducted for varying values of power from 100 watts to 150 watts and scanning speed from 2 mm/s to 20 mm/s. The power at 150 W with scanning speed 2 mm/s produce melted surface due to more power and laser interaction time [5]. The range was so chosen to cover the appropriated processing window resulting in no-hardening effect to melting effect. When conducting these trials, the values of other variables were set at a particular value, i.e. scanning speed at 11mm/sec, Focal length 65mm, Beam diameter 0.2mm. Compressed air at 20 litres/min. Then the surface was inspected to identify any defects and for smooth appearance. From the trial runs 100 Watts to 150 Watts were fixed as lower and upper limits of laser power. The decided levels of the selected parameters of the experiments with their units and notations are given in Tables 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser power (w)</td>
<td>Watts</td>
<td>100 - 150</td>
</tr>
<tr>
<td>Scanning speed(v)</td>
<td>mm/s</td>
<td>2 – 20</td>
</tr>
<tr>
<td>Focal length(s)</td>
<td>ms</td>
<td>65 - 67</td>
</tr>
</tbody>
</table>

Table 2 Process variables and their levels in laser hardening

The moving laser head with 65 mm focal optic lens is mounted with varying beam spot size depending on defocus distance to obtain a wider scan area. The beam size is defocused from 0.1 mm to 0.2 mm diameter and the distance between the adjacent scan is 0.2 mm and the beam overlap [6] is set as 0.1 mm. Linear pattern laser heat treatment of specimen make it possible obtain uniform harden case of specified depth over their whole length. Figure 3 shows the laser hardened specimens after hardening with the selected parameters.

Figure 3 Laser hardened specimens

4. RESULTS AND DISCUSSIONS
The impurities and non-uniform energy distribution of the laser beam are the vital factors for surface homogeneties. The experiment was carried out with laser power 100 W with the scanning speed of 20 mm/s. It is known that as laser power increases, surface temperature [7]
increases owing to the direct impact of heat input. The surface temperature measured by non-contact infrared pyrometer shows $800^\circ C$ [8] indicating the occurrence of transformation hardening on the component. With further increase of laser power to 150 Watts surface temperature about $1100^\circ C$ indicating surface melting. In order to recover the surface from melting processed with reduced scanning speed 11 mm/s. Sequences of experiments were conducted on the 4 samples to study the power range on laser treated layer characteristics and optimize the process parameters. Trials were carried out on laser powers of 100, 110, 125, 140 and 150 watts.

![Figure 4 LHZ of HCHCr](image)

![Figure 5 LHZ of EN24](image)

Figure 4. Shows micro structures and longitudinal cross sectional case depth profiles [9] of the treated layers obtained with laser power 150W, scanning speed 11 mm/s. The case depth is up to 90 microns and hardness value 560HV for HCHCr specimens. The case depth 70 microns and hardness 420HV for EN24 specimen with the same parameters as above shown in figure 5.

![Figure 6 LHZ of EN36](image)

![Figure 7 LHZ of EN8](image)

Figure 5. Shows micro structures and longitudinal cross sectional case depth profiles of the treated layers obtained with laser power 150W, scanning speed 11 mm/s. The case depth is up to 90 microns and hardness value 560HV for HCHCr specimens. The case depth 70 microns and hardness 420HV for EN24 specimen with the same parameters as above shown in figure 5.

The micro structures and longitudinal cross sectional case depth profiles and region of overlap of EN36, treated layers obtained with laser power 150W, 11 mm/sec., and beam overlap 0.2mm is shown in figure 6. The case depth is 56microns and hardness value 300HV at overlapping region and 350 HV at remains. The case depth of the treated layer increased as a direct consequence of heat input. The process with 100 W and 125 W shows the hardness value decreases with decrease in depth from the surface as well as in LHZ i.e. 300HV to 350 HV to a depth ranging from 60 µm to 70 µm. The hardness value in the overlap region is 280HV and 300HV. Since hardening was done with overlapping, tempering occurs in the proceeding layer which causes reduction in hardness. The hardness value in the substrate zone is more or less constant. It is clear from the hardness profiles that the hardness in the hardness region increased from 530 HV to 560 HV with increased power. The formation of hardness in the hardened layer is governed by the thermal cycle and the cooling rates [10] experienced in the steel with depth resulting in the extent of martensite formation. The report studies involving laser hardening of different steel grades deals the theoretical assessment with experimental results as of hardened depth with variation in processing conditions. The layer processed with 140 W, 5.6 mm/s scanning speed shows hardness in HCHCr sample the range
of 490 to 560 HV to a depth of 70 microns and 500 to 530 HV to a depth of 65 microns in EN24 sample where as it is 350HV and 50 microns in EN36 and found no HAZ in EN8 sample. The reductions in hardness near the surface confirms the possible melting effect. From this analysis, it is suggested that improvement in hardness in the treated layers could be due to formation of fine martensite with dissolution of carbides. The untreated substrate comprising of pearlite and ferrite, the adjacent partially transformed zone and the highly hardened region are the major constitutes of the micro structure. The highly hardened region comprising of homogeneously distributed martensite plates with few pockets of un dissolved carbides and retained austenite. Hardness in the hardened regions indicates that the carbon concentration could be expected in the range of 0.6%. Although optimization of critical parameters like laser power and feed is achieved with the experimental result and analysis, it is not sufficient to adopt in actual practice.

As for industrial application like, issues connected with melting edges about to happen melting due to reduced heat sink and accumulation of heat at the edge. This problem can be solved by choosing appropriate process parameters within the permissible range. For any laser processing sequence the start and end points are critical. In the startup region no hardened depth could be observed as laser interacts with cold material. Before the substrate surface temperature reaches austenitization level [11]. And at end melting occurs when processed due to fraction of second delay in response to switching of the laser. These problems were resolved by appropriate defocusing of laser beam at faster acceleration and keeping start up end points of the laser treating cycle away from the work piece. The results of laser surface hardening by experiment shows improved hardness, micro structure and uniform case depth and very less warping. Wear test for the specimens conducted in Ducom TR20LE-PTM Machine has disc 100 mm diameter, weight 1000 grams, runs at 300 rpm, time 60 seconds. The wear with respect to time is plotted in the figure 8. The wear recorded for HCHCr is between 9 to 10 microns in 40 seconds, 7 to 9 microns for EN24 in 45 seconds, 4 to 12 microns for EN36 in 45 seconds and 1 to 12 microns for EN8 in 50 seconds. HCHCr, EN24 samples [12] starts wear after few seconds where as EN36 and EN8 samples starts wear from the beginning due to the lack of hardness in the surface. The HCHCr and EN24 specimens show very less wear in the time between 10 to 40 seconds. The formation martensite improves the wear resistance marginally in the LHZ with 80 microns.

![Figure 8 Wear with respect to time](image)

5. CONCLUSION
The work demonstrated on study of application of laser surface hardening of 4 grades of steels. Hardened layer and adaptation of suitable process parameters in the treated layer has hardness 500 to 560 HV and to a depth up to 90 microns, as compared to the substrate hardness 370 HV or less and higher carbon content samples. Further to this the depth of case
can be increased to about 200 microns by increasing laser power to 250 W. Various other critical issues concerned with melting of edges, beam overlap region on the samples has been appropriately addressed. From the analysis the case depth and hardness can be increased further by increase power and reduce scanning speed marginally. The final optimized processing condition shows validation of the process on HCHCr and EN24 materials are better to surface harden and produce components to withstand high stress loads and resistance to wear.

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REFERENCES