CHAPTER 4

EXPERIMENTATION

4.1 Introduction

One of the Pune based leading diesel engine manufacturers consulted for hardening diesel engine liners by using laser. At present their liners are getting treated with the conventional methods. Especially, they are found to be interested in reducing the time required for treating liners and obtaining the maximum case depth (in required region) to increase the service life of the liners. Considering this industrial problem, the experimentations are planned and carried out.

The problem identifies the need of conducting series of experiments for

1. evaluating the feasibility of hardening the liners by Nd: YAG laser
2. examining the shape and size of the heat affected zone
3. finding out the most pertinent process parameters and optimizing the process
4. determining increase/variation in the microhardness of the treated surface
5. finding out the effect of overlapping on the microhardness of the treated surface and
6. identifying the improvement in wear resistance of the treated surface.

In tune with these objectives, this chapter goes on describing the details of the experimental set-up, procedures, observations and results of the pilot experiments.

It is further intended to optimize the process parameters so as to obtain the maximum case depth by using Taguchi technique. The microhardness variation due to back tempering in laser transformation hardening is studied by using optimum process parameters through further experimentation.
4.2 Steps in experimentation

The experiments are planned in three stages for Pearlitic Grey Cast Iron liner material of diesel engine manufactured by the diesel engine manufacturer as below:

i) Pilot experimentation to identify the process parameter range and finalize the plan of experiments.

ii) Experimentation for optimization of process parameters by using Design of experiments.

iii) Experimentation for finding percentage overlap to obtain the uniform transformation hardness over the surface and

iv) To study the improvement in wear characteristics.

The pilot experiments are discussed in this chapter and remaining three stages in the next chapter.

4.3 Material for experimentation

The material (diesel engine liner) is supplied by the diesel engine manufacturer in untreated condition. The chemical analysis was carried out and it reveals that, the material is grey cast iron and its composition is as given in the Table 4.1. The microstructure of the material is as shown in Fig. 4.1.

<table>
<thead>
<tr>
<th>% C</th>
<th>% Si</th>
<th>% Mn</th>
<th>% S</th>
<th>% P</th>
<th>With graphite Flakes in a pearlitic matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.35</td>
<td>2.48</td>
<td>0.84</td>
<td>0.068</td>
<td>0.068</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1 Composition of material used in experiments

4.4 Experimental set-up-Nd: YAG Laser System

The schematic diagram of laser system along with 3-axis gantry used during experimentation is as shown in the Fig. 4.2. Fig 4.3 is the actual photograph of the system. The specifications of the laser head and 3-axis gantry attached with the system are as below.
Chapter 4  Experimentation

Fig. 4.1 Microstructure of parent material

Fig. 4.2 The schematic set-up showing Nd: YAG laser system with 3-axis gantry
**Laser head specifications**

Laser type- Pulsed Nd: YAG

Wavelength- 1.06μm

Maximum average output power-200 watts

Pulse repetition rate- 1~200Hz

Maximum power per pulse @20msec pulse width- 80Joules

Pulse width- 100μsec to 20msec

Beam divergence – 20mrad

Maximum Beam diameter-8mm

Beam expander- 2X to 8X with input aperture of maximum 20mm

Power supply- 3 phase 440 V AC mains input power supply with 32 Amp of current

Pulse shaping- increasing and decreasing steps for welding

**3-axis gantry specifications**

Multi- Axis CNC motion systems

Model: SLP- CNC1824SS

Table Area: - X = 200, Y = 200, Z = 50 & with θ (Rotary axis)

All axes precision pre loaded ball screws.

Resolution: - 2 microns

Motors: Micro stepping motors 2 phase.

Micro stepping motor with gearbox, on all axes
4.5 Preparation of test specimens

The liner supplied has inner bore and outer diameter as 100 and 114 mm respectively. The liner is divided in 30 parts. Each part is magnitude of $12^\circ$ perpendicular to the linear axis as shown in Fig 4.4. The test specimens prepared are of 30X10 mm size. Specimens are cut out of cylinder liner by using Wire EDM and then prepared. The specimens are used in as-received condition.

4.6 Post-experimental specimen preparation

After the laser treatment, the surface is grounded by using different grades of emery papers (200, 400, 600 and 800). Then specimens are polished by using different grades of polishing papers (1/0, 2/0, 3/0, 4/0 and 5/0) followed by lapping on polishing machine. After polishing, the surface is thoroughly washed with soap solution and dried with a hot drier. The hardness variation along the surface is computed.
Fig. 4.4 Scheme of specimen preparation

For the purpose of metallographic analysis, the treated specimens are transversely cut on Wire EDM as shown in Fig. 4.5, after grounding the surface. Subsequently the surface is etched. To observe the martensitic structure, the recommended enchant 5% Nital (5cc HCl + 95cc alcohol) solution is used. This made the specimens ready for the study of microstructure. The above procedure is followed for each specimen. The specimens are carefully stored in different airtight desiccators.

4.7 Metallographic analysis

The microstructure of the laser treated specimen is as shown in Fig. 4.6. It reveals that the austenite to martensite transformation is complete. The finer microstructure is of untempered martensite formed during the cooling part of thermal cycle. This can result in increased hardness of the surface.
Fig. 4.5 Scheme of specimen cutting on Wire EDM

Fig. 4.6 Sample microstructure of laser treated specimen
On cooling, the microstructure comprises coarse martensite, retained austenite and undissolved graphite. The amount of retained austenite decreases at greater depths, while the amount of incompletely transformed pearlite increases.

The case depth and width of the spot is measured by using image analyzer (Leica DM1000). It is assumed that the maximum depth and width of the spot are available at the centre of the spot. Therefore, to ensure the same successive polishing of the specimen is carried out to remove the minimum possible material. The new case depth and width of the spot after every successive polishing is recorded through image analyzer. The procedure is repeated for the required number of times till the case depth and width of the successive spot is found to be less than the previous image. Ensuring the same, the case depth and width of the previous image is considered as the maximum.

4.8 Measurement of micro hardness

A microhardness testing machine (Future Tech. Corporation, Japan FM-700) is used to measure hardness at different points across the laser treated surface. The basic principle used is the indentation by a sharp diamond indenter. The load range selected for hardness measurement is 500 gm with dwell time of 15 sec. The hardness at a particular point is directly obtained in Vickers scale (Hv) by measuring the diagonal distances of the indentation. The procedure is followed as per the sequence mentioned in the instruction manual of the equipment.

4.9 Pilot experimentation

Number of spots are considered with different power (interaction time) and beam spot size to identify the appropriate range. The schematic arrangement of laser hardened spot is as shown in Fig. 4.7. The pilot experiments are divided into two groups.

1. Spots of different beam power at constant beam spot size and
2. Spots of different beam spot size at constant beam power.
4.9.1 Spots of different beam power at constant beam spot size

The various spots are taken for constant beam spot size 1.166 mm within the power range of 795 to 1000 Watts. The obtained case depths and widths of the spots are summarized in Table 4.2. Fig 4.8 and 4.9 shows the variation of case depth and hardened spot width of the spots at constant spot size respectively.

It is found that, the case depth and width of the hardened spots increase till 928 Watts. Through successive image analysis it is observed that, for higher power, though the obtained case depth is considerable but the spot surfaces are subjected to irregularities in terms of crests and troughs (grooves) at the circumference. Trough is the result of molten metal splashing out. It is found that the spot at 877 and 905 Watts has good surface profile as shown in Fig. 4.10. A few irregularities are observed for the spots with 928 Watts. This effect is found to be increasing with further increase in power as shown in Fig. 4.11.

Further, spots are taken to find the most appropriate beam power range which can produce the spots with minimum surface irregularities and maximum case depth in the power range of 877 to 928 Watts. It is found that, the spot obtained in the range
of 890 to 918 Watts has the desired characteristics. Therefore beam power range is finalized as 890 to 918 Watts.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Spot No.</th>
<th>Image No.</th>
<th>Pulse duration (msec)</th>
<th>Beam power (Watts)</th>
<th>Max. Case Depth (μm)</th>
<th>Hardened spot width (μm)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ASD11</td>
<td>ASD11</td>
<td>9.0</td>
<td>795</td>
<td><strong>115.66</strong></td>
<td>701.59</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ASD12</td>
<td>ASD12-1</td>
<td>10.0</td>
<td>816</td>
<td><strong>94.92</strong></td>
<td>447.78</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ASD14</td>
<td>ASD14</td>
<td>12.0</td>
<td>858</td>
<td><strong>169.21</strong></td>
<td>827.46</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>ASD15</td>
<td>ASD15-1</td>
<td>13.0</td>
<td>877</td>
<td>156.83</td>
<td>755.24</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>ASD41</td>
<td>ASD41-1</td>
<td>13.0</td>
<td>877</td>
<td><strong>274.44</strong></td>
<td>1025.55</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>ASD42</td>
<td>ASD42-1</td>
<td>13.5</td>
<td>890</td>
<td><strong>255.87</strong></td>
<td>1009.05</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>ASD43</td>
<td>ASD43-1</td>
<td>13.5</td>
<td>890</td>
<td>218.73</td>
<td>740.79</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>ASD45</td>
<td>ASD45</td>
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<td>905</td>
<td><strong>268.25</strong></td>
<td>1009.25</td>
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</tr>
<tr>
<td>9</td>
<td>ASD46</td>
<td>ASD46</td>
<td>14.5</td>
<td>918</td>
<td><strong>272.38</strong></td>
<td>1013.17</td>
<td></td>
</tr>
<tr>
<td>10</td>
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<td>ASD51-1</td>
<td>15.0</td>
<td>928</td>
<td><strong>303.97</strong></td>
<td>905.87</td>
<td>Crest up to 85.24 μm &amp; grooving on both edges up to 101.11 μm</td>
</tr>
<tr>
<td>11</td>
<td>ASD52</td>
<td>ASD52-1</td>
<td>15.0</td>
<td>928</td>
<td>293.02</td>
<td>980.16</td>
<td>Crest up to 86.67 μm &amp; grooving up to 84.6 μm</td>
</tr>
<tr>
<td>12</td>
<td>ASD53</td>
<td>ASD53-1</td>
<td>15.0</td>
<td>928</td>
<td>218.73</td>
<td>885.24</td>
<td>Grooving at edge up to 165.08 μm</td>
</tr>
<tr>
<td>13</td>
<td>ASD54</td>
<td>ASD54</td>
<td>16.0</td>
<td>950</td>
<td><strong>239.36</strong></td>
<td>874.92</td>
<td>Grooving at edge up to 103.17 μm</td>
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<tr>
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<td>ASD56</td>
<td>ASD56</td>
<td>16.0</td>
<td>950</td>
<td>226.98</td>
<td>963.65</td>
<td>Grooving at edge up to 198.1 μm</td>
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<td>ASD62</td>
<td>ASD62</td>
<td>17.0</td>
<td>973</td>
<td><strong>272.38</strong></td>
<td>965.71</td>
<td>Grooving at both edges up to 154.76 μm</td>
</tr>
<tr>
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<td>ASD63</td>
<td>ASD63</td>
<td>17.0</td>
<td>973</td>
<td>174.55</td>
<td>908.25</td>
<td>Grooving at edge up to 106.57 μm</td>
</tr>
<tr>
<td>17</td>
<td>ASD65</td>
<td>ASD65</td>
<td>18.0</td>
<td>1000</td>
<td><strong>282.7</strong></td>
<td>938.89</td>
<td>Grooving at edge 109.37 μm</td>
</tr>
</tbody>
</table>

Table 4.2: Case depths and hardened spot widths at constant beam spot size 1.166 mm
Chapter 4 Experimentation

Variation of case depth at constant beam spot size

Fig. 4.8 Variation of case depth at constant beam spot size 1.166 mm

Variation of hardened spot width at constant beam spot size

Fig. 4.9 Variation of hardened spot width at constant beam spot size 1.166 mm
Fig. 4.10 Spot at beam spot size 1.166 mm and beam power 905 Watts
Fig. 4.11 Surface irregularities at beam spot size 1.166 mm beam power 928 Watts
4.9.2 Spots of different beam spot size at constant beam power

The various spots are taken for constant beam power 918 Watts for beam spot size ranging from 1.032 to 1.520 mm. The obtained case depths and widths of the hardened spots are summarized in Table 4.3. Fig 4.12 and Fig. 4.13 shows the variation of case depth and hardened spot width at constant power 918 watts. It should be noted that, case depths and hardened spot widths are not affected with increase in beam spot size.

Through the successive image analysis, it is found that surface irregularities in terms of troughs and crests are dominant at the higher and lower spot size values. The surface profiles at these spot sizes are as shown in Fig. 4.14 and 4.15 respectively.

The spots obtained with beam spot size ranging from 1.166 to 1.456 mm are found to be ideal as shown in Fig. 4.16. Therefore, the appropriate range for the beam spot size is finalized as 1.166 to 1.456 mm.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Spot No.</th>
<th>Image</th>
<th>Beam spot size (mm)</th>
<th>Max. Case Depth (μm)</th>
<th>Hardened spot width (μm)</th>
<th>Trough depth (μm)</th>
<th>Crest height (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ASP1</td>
<td>111-1,2&amp;3</td>
<td>1.032</td>
<td>369.3</td>
<td>1328.73</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ASP2</td>
<td>ASP2-1</td>
<td>1.032</td>
<td>375.56</td>
<td>1147.3</td>
<td>---</td>
<td>63.97</td>
</tr>
<tr>
<td>3</td>
<td>ASP3</td>
<td>333-1&amp;2</td>
<td>1.082</td>
<td>335.54</td>
<td>1137.3</td>
<td>99.62</td>
<td>121.47</td>
</tr>
<tr>
<td>4</td>
<td>ASP4</td>
<td>444-1&amp;2</td>
<td>1.082</td>
<td>349.69</td>
<td>987.55</td>
<td>84.69</td>
<td>132.67</td>
</tr>
<tr>
<td>5</td>
<td>ASP5</td>
<td>555-1,2&amp;3</td>
<td>1.166</td>
<td>360.39</td>
<td>1283.33</td>
<td>Less</td>
<td>Less</td>
</tr>
<tr>
<td>6</td>
<td>ASP6</td>
<td>ASP6-2</td>
<td>1.166</td>
<td>377.62</td>
<td>1258.73</td>
<td>Less</td>
<td>Less</td>
</tr>
<tr>
<td>7</td>
<td>ASP11</td>
<td>ASP11</td>
<td>1.456</td>
<td>321.9</td>
<td>1194.76</td>
<td>Less</td>
<td>Less</td>
</tr>
<tr>
<td>8</td>
<td>ASP13</td>
<td>ASP13</td>
<td>1.456</td>
<td>305.4</td>
<td>1089.52</td>
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<td>Less</td>
</tr>
<tr>
<td>9</td>
<td>ASP14</td>
<td>ASP14</td>
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<td>342.54</td>
<td>1211.87</td>
<td>Very high on one side</td>
<td></td>
</tr>
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<td>ASP15</td>
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<td>---</td>
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<td>ASP1</td>
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<td>344.61</td>
<td>1221.59</td>
<td>---</td>
<td>163.02</td>
</tr>
</tbody>
</table>

Table 4.3 Case depths and hardened spot widths of spot at constant beam power 918 Watts
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Spot width variation at 918 Watts
Case depth variation at 918 Watts

Fig. 4.12 Variation of case depth at constant beam power 918 Watts

Fig. 4.13 Variation of hardened spot width at constant beam power 918 Watts
Fig 4.14 Surface irregularities of spot at beam spot size 1.520 mm & beam power 918 Watts
Fig 4.15 Surface irregularities of spot at beam spot size 1.082 mm & beam power 918 Watts
Fig. 4.16 Spot at beam spot size 1.166 mm & beam power 918 Watts
4.10 Surface hardness variation

The hardness of the parent material is reported as 240-250 Hv. The hardness values along the surface of different spots at various powers and beam spot size 1.166 mm are as shown in Table 4.4 and Fig.4.17.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Pulse duration (t) (msec)</th>
<th>Power (P) (Watt)</th>
<th>Micro-hardness (Hv) along the surface, at different distances (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>795</td>
<td>652.5</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>816</td>
<td>580.9</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
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<td>570.5</td>
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<td>12</td>
<td>858</td>
<td>660.2</td>
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<td>13</td>
<td>877</td>
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<td>6</td>
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<td>603.7</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>928</td>
<td>597.5</td>
</tr>
</tbody>
</table>

Table 4.4 Variation of surface hardness at different beam powers

(a) Surface hardness variation at beam power 816 Watts
Fig. 4.17 Surface hardness variation at constant beam size 1.166 and different beam powers

(b) Surface hardness variation at beam power 833 Watts

(c) Surface hardness variation at beam power 858 Watts

(d) Surface hardness variation at beam power 877 Watts
(e) Surface hardness variation at beam power 905 Watts

(f) Surface hardness variation at beam power 928 Watts

Fig. 4.17 Surface hardness variation at different beam powers

It is found that, an increase in surface hardness from 600 Hv to 700 Hv is common for the recast layer. The increase in hardness more than 700 Hv and above is also observed in some cases.

It is observed that, the increase in surface hardness is neither affected by beam power or spot size. Moreover the hardness values along the surface observe the same pattern. The surface hardness depends on the formation of martensite. The martensite formation starts to take place when austenite is retained below critical temperature. Therefore, rapid heating and quenching ensures greater values of hardness. As a result of it, the hardness values are found to be increasing from the edge to the centre of the spot and again declines towards the edge of the spot.
As discussed earlier in 4.2, the optimization of process parameters and other experimentation details about percentage overlap and wear test are explained in Chapter 5.