EFFECT OF DIFFERENT SURFACE COATINGS ON LASER FORMING OF MILD STEEL SHEETS

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Abstract

In the present work, the effect of different surface coatings, namely lime and cement, on laser forming of mild steel sheets is studied. The performance of the coatings is evaluated at different values of laser power and scan speed. It is found that the cement coating leads to higher deformation. This means that in case of line heating of sheets cement coating leads to higher bend angles. For other complex shapes for e.g. bowl or dome it leads to higher heights.

Keywords: Sheet Metal, Laser Forming, Bending, Coating

1. Introduction

Laser forming is an unconventional form of shaping a metallic or non-metallic material, usually work piece in the form of sheets, into a desired shape. In laser forming process, the work piece is irradiated with a high power laser beam. This leads to development of thermal stresses, especially near the heated area, in the work piece. The heated area of the work piece expands and when it is restrained by the surrounding material localized plastic deformation takes place. The surrounding material of the work piece is in the state of elastic deformation. On cooling this zone is under tension from the surrounding material. This tension causes the material to bend. Thus, the desired shape of the work piece is achieved by controlled plastic and elastic deformation. Laser forming is different when compared to the traditional forming techniques like drawing, stamping, pressing, etc. in the sense that it is a noncontact technique.

2. Literature Review

Application of laser forming in the field of manufacturing specially forming is relatively new. One of the first references to the use of laser as the heat source for bending was in the work of Scully (1987). Further details and references on the laser forming process and process mechanisms can be found in Steen and Mazumder (2010) and references cited therein. A recent review on modelling of laser forming has been presented by Shen and Vollersten (2009) and some recent developments applicable to macro and micro laser forming has been discussed by Dearden and Edwardson (2003). In the present work, a brief overview of literature on laser forming specifically using some form of coating on the material surface during the laser bending process is presented.

Barletta et al. (2006) defined and investigated a new hybrid forming process consisting of a fluidized bed pre-treatment to coat with Al₂O₃ and pre-curve aluminium thin sheets and of a diode laser forming to perform the proper line bending of fluidized bed pre-treated sheets. They carried out comparison with the diode laser forming of untreated aluminium thin sheets. Their experimental results showed that the bending angles in the range of 0° to 40-45° could be achieved on Al₂O₃ coated aluminium thin sheets employing output power in the range of 150 W to 250 W. The uncoated specimens exhibited maximum bending angles of 20-25° employing output power of about 400 W. Recently, Roohi et al. (2012) studied the effect of external forces assisting the laser bending – known as “External Force Assisted Forming Process”. They used anodised and graphite coated 5 mm thick AL-5005 alloy. It was found that the bending angle increased significantly, by about 30%, in laser assisted bending in comparison to laser bending at same value of the parameters. A numerical simulation using ABAQUS package was also performed which found that the equivalent plastic strain in laser forming process increases in a step wise manner with the increasing the number of scanning passes. Griffiths et al. (2010) employed finite element modelling to ascertain the quantitative contribution of various process parameters such as thermal, geometrical, and variation in coefficient of absorption towards the variation in the bend angle per pass with multiple irradiations. They found that the thermal parameters have lesser influence than the geometrical parameters and coefficient of
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The effect of different coatings, namely lime, graphite and grease, was studied first by Singh (2013). He studied the effect of coatings on the absorption of CO₂ laser beam in line bending of mild steel sheets. The bend quality was compared with mechanically bent sheets. It was observed that all the coatings increased the coefficient of absorption. More than 100 percent increase in the coefficient of absorption for the case of graphite coated sheets was observed. The increase for lime coated sheets was found to be in the range of 400 – 1500 %.

Based on the literature reviewed above it has been observed that use of various form of coatings leads to an increase in the coefficient of absorption. This leads to higher bending angles. However, it is felt that there is a further need to study the effect of some more coatings on the laser forming process. Also, it is seen that the effect of coatings has not been studied in the bending of complex shapes such as bowl (Chakraborty, 2012) or dome (Maji, 2014). It is believed that better results can be obtained not only for simple line bending but also for other complex laser forming processes using coatings on the surface of material.

Hence, the objectives of the present work are
(a) to study the effect of different coatings on the bending behaviour of mild steel sheets at different values of laser power and scan speeds,
(b) to identify a suitable coating which leads to maximum bending angle and,
(c) to apply the best coating to study the deformation process during laser forming of bowl and dome shaped surfaces.

The remainder of this paper is structured as follows: Section 3 lists the factors which affect the laser forming process and 4 presents the details of the experiments and the set-up used in this work, Section 5 presents the results. The discussion is presented next in Section 6. Section 7 concludes this paper.

3. Factors Affecting Laser Forming

In laser forming, the shape and the position of the zone, intended to be deformed into desired shape, is influenced by a number of parameters which can broadly be divided into three groups – energy parameters, material parameters, and work piece related parameters.

(a) Energy based parameters. These parameters are directly related to the laser being used to form the product. The forming process is affected by namely the laser power, scanning speed (or the feed rate), geometry and size of laser beam, number of passes, absorption coefficient of the material, cooling conditions etc.

(b) Material parameters. The material properties of the material being formed have a direct influence on the forming process. Some of these are namely Young’s modulus (E), Poisson’s ratio (v), thermal expansion coefficient (α), thermal conductivity, heat capacity, etc.

(c) Work piece related parameters. The geometric parameters of the sheet being formed also affect the forming process. This includes the sheet thickness, length, and width. The sheet thickness is considered the most important geometric parameter (Singh, 2013).

Further details of the laser forming and process mechanisms can be found elsewhere, see for e.g. Dixit et al., 2013; Steen and Mazumder, 2010.

4. Details of Experiment

Mild steel sheet samples, yield strength 274 MPa and ultimate strength 383 MPa, of thickness 2 mm were prepared from commercially available sheets. Figures (1) – (3) show the typical stress-strain curve for the mild steel sheet along three different directions. The in plane dimensions of the sheet i.e., length and breadth, were varied for different cases and are mentioned in appropriate place in section 4. As reported by Singh (2013), lime coating was found to be performing better than graphite and grease coatings. Hence, in this work, graphite and grease coatings are not considered. For the present study, we selected lime and commercially available cement as coating material.

All the specimens were cut by the 2.5 KW CO₂ laser cutting machine (Model: Orion 3015, Make: LVD). They were subsequently cleaned in acetone to remove any foreign particle from the surface. A CNC controlled 2.5 KW CO₂ laser machine (Model: Orion 3015, Make: LVD) was used to impinge the laser beam on the surface of the specimens. Figure 4 shows the experimental set up used in the present work.
In the laser machine, a circular laser beam of 6 mm diameter (at a stand-off distance of 30 mm) with Gaussian mode was used during all the experiments. Various levels of laser power and scanning speed were used in the experiments. The specific values are mentioned in section 4 at appropriate place. The coatings were applied manually using a brush. After applying the coating the specimens were left to dry to remove moisture. It has already been reported, see Singh (2013), that moisture does not affect the performance of the coatings. The average coating thickness for lime coated specimen along the scan line was 0.1960 mm (maximum: 0.3465 mm and minimum 0.0736 mm). While for cemented coated specimen the coating thickness was 0.2682 mm (maximum: 0.68 mm and minimum 0.0726 mm). However, it should be noted that the sheet thickness itself does not remain 2 mm and varies slightly which in turn changes the coating thickness which is measured using a coordinate measuring machine.

5. Results

The effect of different coatings was studied for laser forming of three different cases. They are: (1) line bending, (2) laser forming of dome shaped part, and (3) laser forming of bowl shaped part. In the following subsections we present the results for each case.

5.1 Effect of different coatings on line bending of mild steel sheet specimens

First, the effect of different coatings is studied for the case of simple line bending. For this, mild steel samples of size 50 mm × 50 mm × 2mm were prepared. The effect on maximum temperature is studied. An infra-red pyrometer (Make: Raytek) was placed at the bottom surface of the plate at a point directly beneath the mid-point to measure the temperature at that point. DATATEMP software recorded the temperature as a function of time.

Figures (5) - (7) shows the variation of maximum temperature of the bottom surface of the sheet with
scan speed for three different laser powers for uncoated, lime, and cement coated specimens. For each data point three specimens were considered. It is evident that higher temperatures are reached for cement coated specimens. Figures (8) – (10) show the variation of bending angle with different laser power and scan speeds for uncoated, lime, and cement coated specimens (size 150 mm × 100 mm × 2 mm) after 10 passes. Figures 11(a) – 11(c) shows the bent sheets for the uncoated, lime coated, and cement coated specimens at 300 W laser power, 5 mm/s scan speed and 10 passes respectively.

Figure 5 Variation of maximum temperature with scan speed for uncoated sheet at different laser power for first pass.

Figure 6 Variation of maximum temperature with scan speed for lime coated sheet at different laser power for first pass.

Figure 7 Variation of maximum temperature with scan speed for cement coated sheet at different laser power for first pass.

Figure 8 Variation of bending angle with laser power for uncoated specimens for three different scan speeds.

Figure 9 Variation of bending angle with laser power for lime coated specimens for three different scan speeds.
5.2 Effect of different coatings on laser forming of dome shaped surface

Next, the effect of cement coating on forming of dome shaped surface is investigated. The dimension of the mild steel sheet specimen is taken as 120 mm × 120 mm × 2 mm. The irradiation strategy described in Yang et al. (2010) is adopted. Table 1 shows the dome height (measured at the centre of the dome) with different laser power. The total number of passes is kept at one and the laser scan speed is kept at 5 mm/s. The last column shows the difference in the dome height between the cement coated and uncoated specimens. The experimentally observed dome shaped surface is shown in Figure 12.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Power (W)</th>
<th>Height ‘a’ (mm) (uncoated)</th>
<th>Height ‘b’ (mm) (cement coated)</th>
<th>b-a (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>200</td>
<td>5</td>
<td>6.1</td>
<td>1.1</td>
</tr>
<tr>
<td>2.</td>
<td>300</td>
<td>5.2</td>
<td>6.3</td>
<td>1.1</td>
</tr>
<tr>
<td>3.</td>
<td>400</td>
<td>5</td>
<td>6.6</td>
<td>1.6</td>
</tr>
<tr>
<td>4.</td>
<td>500</td>
<td>5.2</td>
<td>6.3</td>
<td>1.1</td>
</tr>
</tbody>
</table>

5.3 Effect of different coatings on laser forming of bowl shaped surface

Finally, the effect of cement coating is studied on forming of bowl shaped surface. Circular specimens of diameter 100 mm and thickness 2 mm are cut from mild steel sheets. The irradiation strategy of Chakraborty et al. (2012) is adopted. However, instead of nine passes used by Chakraborty et al. (2012) only five passes are used. The scanning speed is fixed at 10 mm/s. Table 2 shows the height of bowl at the centre for both uncoated and cement coated specimen at different laser powers. The last column shows the difference in the bowl height between the cement coated and uncoated specimens. The experimentally observed bowl shaped surface is shown in Figure 13.
Table 2 Height of bowl at centre for different value of laser power

<table>
<thead>
<tr>
<th>S. No</th>
<th>Laser Power (W)</th>
<th>Height ‘a’ in mm (uncoated)</th>
<th>Height ‘b’ in mm (cement coated)</th>
<th>Difference (b-a) in mm</th>
</tr>
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<tr>
<td>1</td>
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<td>5</td>
<td>6.1</td>
<td>1.1</td>
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<td>5.2</td>
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<td>0.9</td>
</tr>
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<tr>
<td>4</td>
<td>500</td>
<td>6.2</td>
<td>7.3</td>
<td>1.1</td>
</tr>
</tbody>
</table>

6. Discussion

It can be seen from Figures (5) - (7) that the maximum temperature reached at the bottom surface directly under the midpoint of the scanning line is higher in the case of cement coated specimen. This shows that the absorption coefficient of the sheet increases when the coating is applied. The increase is due to trapping of the heat between the coating and the sheet (Griffiths, 2010). Hence, higher bend angles are observed for different laser power and scan speeds for cement coated specimens as compared to uncoated specimens, see Figures (8) - (10).

In forming of other complex shaped surfaces like bowl or dome, it is again observed that the degree of deformation of the cement coated specimen, measured in terms of the height of the centre of the specimen, as compared to uncoated specimen is higher for different values of laser power, see Tables 1 and 2. However, the difference between the heights is not significant.

7. Conclusion

In the present work, the effect of different coatings has been studied on laser forming process. Three specific shapes were formed with and without the application of coatings. It can be seen that the cement coating leads to higher bend angles during the laser bending for all values of laser power and scan speeds. In the forming of dome and bowl shaped surfaces, it was observed that the cement coated specimens gave higher degree of deformation as compared to uncoated specimens. In conclusion, it can be said that the use of coatings significantly enhances the laser forming results as compared to uncoated specimens. In future, the effect of coatings will be studied on more complex shaped surfaces like tubes, ducts, etc.

References