Research on Correlation between Weld Concavity and Weld Process Parameters in Tailored Blank Laser Welding

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Abstract. Weld quality control is of great importance in tailored blank laser welding for the purpose of making products at a high quality and high productivity. In general, the controllable parameters are only indirect data on features of the final weld to be made. In this paper, direct correlation between weld concavity and weld process parameters including weld gap and torch offset are discussed based on theoretical analyses and experiments. A direct control model is established according to the analysis of reasons causing weld concavity. This model will improve the quality of laser welding process by accurately controlling the weld geometry in real time.

Introduction

At present, tailored blank laser welding is widely used in several industrial sectors particularly automotive industry [1,2]. Tailored blank is known as a process where various materials are welded together before the forming process. Tailored blank has many advantages including weight reduction due to combining specific material at particular parts of the components, scrap reduction and high dimensional accuracy [3,4]. Weld quality control of tailored blank is of great importance for the purpose of making products at a high quality and high productivity.

Techniques for laser weld process control have been under development for many years and some systems have been commercialized. The most common techniques are based on monitoring of the plasma plume and weld pool, as well as acoustic from the weld process [5-7]. However, the controllable parameters are only indirect data on features of the final weld to be made. So the correlation between weld defects and weld process parameters should be studied for direct control of weld quality. As one of the major weld defects of tailored blanks, weld concavity will be studied in detail in this paper. Firstly, origins of weld concavity are analyzed based on theoretical analyses and experiments. Secondly, a direct control model is built according to the correlation between the weld concavity and weld process parameters. This model will improve the quality of laser welding process by accurately controlling the weld geometry in real time.

Origins of weld concavity

A. Definition

Weld concavity is defined as the under fill of metal in the weld causing the weld surface to be below flush with the parent metal surface. This condition may exist on either root or face surfaces as shown in Fig. 1.

![Weld concavity figure][1]

Figure 1. Weld concavity [8]
Overall concavity should not exceed 10 percent of the governing metal thickness or 0.5mm according to ISO 13919-1 B grade.

B. Analysis of the reasons causing weld concavity
Weld gap and torch offset are the main reasons causing weld concavity.

1) Weld gap
The sheets to be welded will be sheared first and edge straightness errors $\Delta_1$ and $\Delta_2$ will be caused after this procedure as shown in Fig. 2. When butt welding, sheared sheets will be center shifted which is correlated to the presence of weld gap. The accuracy of the shearing machine is 0.1mm/m in general, so the gap of two sheets will fluctuate randomly between 0 ~ 0.2mm.

![Figure 2. Weld gap](image)

Figure 2. Weld gap

Weld gap is the direct reason for weld concavity. When sheets of different thickness were used for welding, molten metal of the thicker sheet will flow to the thinner one as shown in Fig. 3. If weld gap is not small enough, the laser beam will leak and molten metal will not be sufficient for filling the weld gap and weld concavity will occur.

2) Torch offset
Positive torch offset is defined as the laser spot move to the thicker steel sheet from the center of the weld seam. The weld seam width of thicker steel sheet and volume of molten metal will be increased by positive offset, so positive offset can compensate the negative influence of the gap and avoiding the presence of weld concavity.

Experiments and analyses

A. Equipments and materials
Experiments are done on automatic tailored blank laser welding equipment as shown in Fig. 4 developed by Shenyang Institute of Automation, Chinese Academy of Science. The equipment consists of several units, including load unit, positioning unit, welding unit, ejector unit, unload unit and control unit. The test equipments include metallurgical microscope, hardness tester, micrometer, quality inspection system of Servo Robot and coordinate measuring machines, etc. Materials for welding are cold rolled steel sheet (DC06) and type of weld joint is straight butt joint.

![Figure 4. The laser welding equipment](image)

B. Weld gap
Welding experiments are carried out to study the correlation between the weld gap and weld
concavity. High precision shearing machine and manual positioning method is adopted to ensure the edge straightness accuracy of sheets. The welding parameters are shown in Table 1 except weld gap.

<table>
<thead>
<tr>
<th>Thickness of sheets [mm]</th>
<th>Laser power [kW]</th>
<th>Welding speed [m/min]</th>
<th>Defocus [mm]</th>
<th>Offset [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6-2.5</td>
<td>4.0</td>
<td>5</td>
<td>0.7</td>
<td>0</td>
</tr>
</tbody>
</table>

The gap value is measured with proof stick. The weld seam is smooth when the gap is 0. The weld concavity occurred when the gap is 0.2 mm as shown in Fig. 5. Fig. 6 shows the weld concavity detected by Servo Robot Inspection System based on laser vision when the gap is 0. The detected value is in allowed band, so the inspection result of weld concavity is good.

The maximum allowable gap is related to the thicknesses of sheets and the offset of laser spot. The experimental analysis shows that the allowable gap value is 0.08 mm when there is no offset and the sheets thicknesses combination is 1.6 mm and 2.5 mm.

C. Torch offset

Welding experiments are carried out to study the correlation between torch offset and weld concavity. The welding parameters are shown in Table 2 except torch offset. Fig. 7 shows the cross-section of weld seam in different offset. When the offset is -0.2 mm, the molten metal is insufficient to fill in weld gap to form a smooth weld seam, and weld concavity occurs; when the offset is zero, a slight sag appears on the weld seam surface; when the offset is +0.2 mm, the molten metal increased and the weld is smoother.

<table>
<thead>
<tr>
<th>Thickness of sheets [mm]</th>
<th>Laser power [kW]</th>
<th>Welding speed [m/min]</th>
<th>Defocus [mm]</th>
<th>Gap [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6-2.5</td>
<td>3.5</td>
<td>3.5</td>
<td>-1</td>
<td>0.06</td>
</tr>
</tbody>
</table>

When width of weld seam is fixed, the width of weld seam in thicker sheet will be increased and
the width of weld seam in thinner sheet will be decreased by positive offset. However, if the width in thinner sheet is too small, it will cause undercut defect, or even influence the formation of weld seam. So the maximum positive offset depends on the minimum width of weld seam in thinner sheet. Welding experiments are carried out to study the minimum width of weld seam in thinner sheet. The welding parameters are shown in Table 3.

Table 3. The parameters of laser welding

<table>
<thead>
<tr>
<th>Thickness of sheets [mm]</th>
<th>Laser power [kW]</th>
<th>Welding speed [m/min]</th>
<th>Defocus [mm]</th>
<th>Offset [mm]</th>
<th>Gap [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9-1.5</td>
<td>4</td>
<td>5.5</td>
<td>0</td>
<td>0.27, 0.32, 0.37, 0.42, 0.47</td>
<td>0.06</td>
</tr>
</tbody>
</table>

As shown in Fig. 8, serious undercut occurred when the offset is 0.47mm, and there is a slight one when the offset is 0.42mm. In consideration of the maximum offset, the different thickness of sheets and the total width of weld seam, the minimum allowable width of weld seam in thinner sheet is about 0.1mm.

Figure 8. Cross-section of weld seam (offset=0.47mm)

**Direct control model for weld concavity**

A direct control model is established according to the analysis of origins producing weld concavity. The major elements of this model are quality inspection sensor, tracking sensor, welding torch and welding control system based on knowledge base system shown as Fig. 9. Quality inspection sensor is used for inspecting the weld concavity and tracking sensor is for inspecting weld gap and torch offset. Knowledge base system is found through a large number of experiments like above. In tailored blank laser welding, tracking sensor transmits the weld gap and torch offset to knowledge base system, and then the proper weld gap and modified torch offset will be given for controlling the position of weld torch. The model could be used for improving the quality of laser welding process by accurately controlling the weld geometry in real time.

![Figure 9. Direct control model for weld concavity](image)

**Conclusions**

Correlation between weld concavity and weld process parameters are discussed in this paper. The conclusions are as follows:

1) Analyses and experiments suggest that weld gap and torch offset are the main reasons causing weld concavity in tailored blank laser welding.

2) The allowable size of gap is related to the different thickness of sheets and the maximum limit of offset is required in tailored blank laser welding.
3) A direct control model is established according to the analysis of reasons causing weld concavity and could be used for improving the quality of laser welding process by accurately controlling the weld geometry in real time.

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References