An Effective Jig for Friction Stir Welding of Pipe Butt Joint

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Abstract. A dedicated or specialized friction stir welding (FSW) machine is quite costly especially for pipe joining. Therefore, not many institutions manage to conduct their research on FSW at their facilities. Besides that, the difficulty to design a jig that can hold the complex shape such as pipe section tightly and easily to be removed during and after the FSW process respectively will nullify the intentions. In many institutions, there was either conventional or CNC milling machine available in their workshops. Thus, a jig called orbital clamping unit (OCU) was designed to suit this milling machine. It acts as an additional device to enable this milling machine to run as FSW machine at a lower cost, hence fully utilized the available facility in the workshop. Several good samples were successfully produced by using this jig and milling machine.

Introduction

The friction stir welding is a solid state joining process which was first invented by Sir Wayne Thomas from The Welding Institute, UK in 1991 [1]. This process uses frictional heat from the tool shoulder to soften the adjoining sections and the pin tool stirred these sections together to become a quality joint. This FSW is used to weld ferrous and non-ferrous materials in the form of flat panels and tubular sections for various industry applications such as shipbuilding, aerospace, and land transport. As it involves mechanical contact between the tool and the work-piece, a proper design of jig is vitally required.

Lammlein et al [1] had successfully built a jig for 4.2" diameter of pipe butt joint with the thickness of 0.2". This tubular section of pipe with small radius presents unique challenges as it requires the use of special techniques and equipment as shown in Fig. 1. Several good samples were produced for further testing with the superb quality joint.

Fig. 1 Jig and pipe setup by Lammlein [1]

Besides that, the collaboration between Advanced Metal Product Inc, Oak Ridge National Lab, and Megastir Technology had produced an orbital welding fixture to joint 12" diameter of X65 steel pipe with the thickness of 0.25". The fixture utilizes a rotating tool about the stationary pipe and hydraulic internal support jig inside the pipe as shown in Fig. 2. Both designs ensure tight holding of pipes during the welding and easy removal of pipes after welding with the sound quality of welded joints.
Gerçekçioglu et al [3] and Qasim et al [4] approach were about the same design of jig for AA6063-T6 and AA6061-T6 pipe respectively. This jig was attached to the conventional milling machine which ensure tight holding during welding and require a hydraulic press to remove the pipe after the welding process. The design is shown in Fig. 3.

These jigs were applied to hold the pipe during the FSW process. The difference is the method to remove the pipe piece after the welding process [1-5]. Internal mandrel such as an expendable internal mandrel, hydraulic support and solid rod were utilized respectively. As there are not many studies done on FSW for pipe application, the implementation on the pipe would extend its application for petroleum, petrochemical and natural gas industries.

**Fixture Design and Setup**

Based on the literature review done previously, a simple fixture was designed accordingly to cater for 3.5" AA6063-T6 pipe with a thickness of 0.2". This is called as an orbital clamping unit (OCU). The design includes a customized main shaft unit, two steel-made capping for both sides, a customized internal mandrel, two units of pillow blocks, two steel base flat bars, sprocket gear, chain and motorized pipe cutter. The main intention is to hold the pipe tightly during the welding process and ensure easy removal of pipe after welding. This orbital clamp will also prevent distortion during and after welding. This OCU was then attached to CNC Bridgeport 2216 milling machine as shown in Fig. 4.
For butt joint, the pipe must be rotated and maintain contact between surface and tool. This can be done by offsetting the tool about 6mm from its centerline [1, 5]. This will eliminate the possibility of wormhole to occur in the weld joint made by FSW process. Several work-piece with certain welding parameters had been tested in order to verify the functionality of OCU, as shown in Table 1.

<table>
<thead>
<tr>
<th>FSW sample</th>
<th>Welding parameters</th>
<th>Dwell time (s)</th>
<th>Plunge depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rotation speed (rpm)</td>
<td>Travel speed (mm/s)</td>
<td></td>
</tr>
<tr>
<td>FSW#1</td>
<td>900</td>
<td>1.2</td>
<td>30</td>
</tr>
<tr>
<td>FSW#2</td>
<td>1200</td>
<td>1.2</td>
<td>30</td>
</tr>
<tr>
<td>FSW#3</td>
<td>1500</td>
<td>1.2</td>
<td>30</td>
</tr>
<tr>
<td>FSW#4</td>
<td>1500</td>
<td>1.8</td>
<td>30</td>
</tr>
<tr>
<td>FSW#5</td>
<td>1500</td>
<td>2.4</td>
<td>30</td>
</tr>
</tbody>
</table>

**Results and Discussion**

Visual inspection was conducted according to AWS D17.3 for five tested samples produced by FSW which utilizing this OCU. The results can be seen in Table 2.
Based on the findings as stated in Table 1, the plastic deformation occurred depending on welding parameters. The lateral flash found on the weld surface of FSW#1 and FSW#2 were due to pipe eccentricity. However, by offsetting the tool, there was no weld defect found in the welded joint. FSW#3 and FSW#4 gave good surface and cross section condition except for FSW#5, which contained a small crack line on the cross section. This may be caused by the mismatch of welding parameters (i.e. rotational and travel speed) [3].

**Conclusion**

The results showed that all welded samples produced by utilizing this OCU were in good surface and joint condition except for FSW#5 which contained a small crack line detected on the cross section. Both rotation speed and travel speed must be suitably chosen in order to get better weld joint and this proved that OCU is in correct condition and well-functioned in order to produce reliable weld joint with suitably selected welding parameters.

The internal mandrel is still required for this OCU which cater for one specific size of pipe. The flexibility to cater for various sizes may need to be explored for future use to accommodate the requirement for on-site pipeline application.

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