FRICITION STIR LAP JOINING OF PURE TITANIUM

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INTRODUCTION
Since the appearance of friction stir welding (FSW), it has gained considerable interests due to the avoidance of solidification problems associated with the conventional fusion welding techniques, and it has been successfully applied to the low-melting metals such as Al alloys and Mg alloys. With the continuous development of the FSW technique, a great deal of attention has been recently paid to the FSW of high-melting metals, especially titanium and its alloys because of their wide application in the industrial field. However, it is extraordinarily arduous to friction-stir weld titanium and its alloys owing to their high activity, high melting point, low heat diffusivity, and α/β phase transformation. Fortunately, a large number of researches have been done to overcome these problems [1-5], including the microstructure characteristics, the mechanical properties, the material flow, and the grain structure evolution. All of the previous researches have mainly been concentrated on the butt joint of titanium and its alloys, but little work has reported the FSW of lap joint. In the present study, the effect of welding parameter on defect type was investigated, and the microstructure and tensile properties of the sound joint were examined.

EXPERIMENTAL
The material used in this research was the commercially pure titanium with dimensions of 300mm×100mm×2mm. The friction stir lap joining was carried out under position control by using a WC-Co tool, consisting of a shoulder of 15mm in diameter and a probe with diameter of 6mm and length of 2.0mm. Rotation speeds from 150 to 300rpm and welding speeds from 50 to 125mm/min were used. The water cooling and argon shielding systems were utilized during FSW. The cross-sections of the joints were mechanically polished using water abrasive paper followed by the 1µm diamond paste as the final polishing, and then the polished cross-sections were etched in a solution of hydrofluoric acid, nitric acid and distilled water at a volume ratio of 1:1:8.

RESULTS AND DISCUSSION
The relationship between welding parameter and defect type in FSW lap joints is shown in Fig. 1. The groove-like defect was found in the joints when welded at fast welding speed (or low rotation speed) due to the shortage of heat input. With the decrease of the welding speed at the same rotation speed (or increase of the rotation speed at the same welding speed), the groove-like defect disappeared and the inner cavity defect appeared gradually. Moreover, the joint without defect was obtained when welded at 250rpm - 75mm/min and 200rpm - 50mm/min, as can be seen from Table 1. With the further decrease of the welding speed (or increase of the rotation speed), the overheating rough surface formed because of the excess of heat input. It can be seen from Table 1 that the lap interface lengths were about 4.5mm, and the joints had the high failure load and the tensile specimens broke in the base metal. The sufficient length of lap interface supplied the enough bonding strength in the lap interface, which led to the fracture in the base metal. The microstructures at various regions in the sound lap joint welded at 250rpm - 75mm/min are shown in Fig. 2. A low magnification overview of the transversal cross-section is also displayed in the Fig. 2. It can be found from the overview of the cross-section that the lap joint was composed of the thermo-mechanically affected zone (TMAZ), stir zone (SZ) and lap interface zone. Fig. 2a shows the microstructure of the base metal of pure titanium. It can be clearly seen that the base metal consisted of the equiaxed α phase grains. The microstructures of the TMAZ, SZ and lap interface zone were obviously different from that in the base metal. A mix structure of fine and coarse grains was
observed in the TMAZ, and fine-grain structure was found in SZ and lap interface zone. The average grain sizes in thermo-mechanically affected zone, stir zone and lap interface zone were remarkably smaller than that in the base metal. It can also be seen from Fig. 2b to Fig.2c that the microstructures of TMAZs at advancing side (AS) and retreating side (RS) were similar, and both of them resulted from the friction heat between the metal and FSW tool and the plastic deformation generated by the FSW tool.

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**Fig. 1** Relationship between welding parameter and defect type in FSW lap joints

**Fig. 2** Microstructures in the joint welded at 250rpm and 75mm/min: (a) BM; (b) TMAZ-AS; (c) TMAZ-RS; (d) Lap interface zone

**Table 1** Welding parameter, interface length, failure load and fracture position of the sound lap joints

<table>
<thead>
<tr>
<th>Rotation speed (rpm)</th>
<th>Welding speed (mm/min)</th>
<th>Macrostructure of the joints</th>
<th>Interface length (mm)</th>
<th>Failure load (N)</th>
<th>Fracture position</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>50</td>
<td></td>
<td>4.6</td>
<td>14500</td>
<td>Base metal</td>
</tr>
<tr>
<td>250</td>
<td>75</td>
<td></td>
<td>4.5</td>
<td>14400</td>
<td>Base metal</td>
</tr>
</tbody>
</table>

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**REFERENCES**