Texture and its effect on mechanical properties in fiber laser weld of a fine-grained Mg alloy

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A fine-grained Mg alloy was fiber-laser welded, and microstructures and texture in the welds were extensively examined, together with the effect on mechanical properties. Fusion zone, which has lower hardness than BM and HAZ, consists of columnar grain zone and equiaxed grain zone with coarser grains. Strong texture with the same orientation as base metal forms at columnar grain zone. With decreasing welding heat input, yield strength of the welded joint increases due to the finer microstructures; however, ultimate tensile strength as well as elongation decreases because of the deterioration in deformation capacity induced by the diminishment of the width of equiaxed grain zone.

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1. Introduction

Excellent specific mechanical properties of fine-grained magnesium alloys, comparable with steel, predestine them for applications in the automobile and aircraft industry [1,2]. With their increasing demand of industrial application, it’s necessary to develop effective welding techniques for the joining of fine-grained Mg alloys. However, some investigations on the fine-grained materials have shown that the grain coarsening in heat-affected zone (HAZ) may cause the performance mismatch between HAZ and base metal (BM), which inevitably deteriorates the mechanical performance of welded joint dramatically [3,4]. Therefore the grain coarsening is the crucial problem for the welding of the fine-grained materials. After comparing the laser welding with plasma arc welding and gas metal arc welding of ultra-fine grained steel, Peng et [5,6] have found that laser welding can decrease the width of softening zone and avoid the mechanical performance deterioration of welded joint resulted from the coarsening grain because of its high energy density and rapid cooling speed. Besides, as a new laser welding method, high power fiber laser beam welding (FBLW) also has some other advantages, such as high efficiency and good beam quality [7]. Until now, there are few reports about the laser welding of fine-grained Mg alloy. In the present work, a fine-grained Mg alloy was welded by using FBLW, and the effect of welding condition on the microstructure, texture and mechanical properties of fiber laser welds was discussed.

2. Experimental

A fine-grained Mg alloy (Mg-3.19Al-1.05Zn-0.39Mn-0.01Cu, mass%) with the average grain size of 1.9μm, produced by hot extrusion, was used in present work, with 250 mm × 150 mm × 4 mm in specimen size. The samples were bead-on-plate welded perpendicular to the extrusion direction by FBLW with beam diameter of 0.2 mm on the specimen surface with double sides' Ar shielding gas of 30 l/min. The laser power was ranged as 4, 6 and 8 kW, while the welding speed was changed as 4, 8 and 16 m/min. After welding, the metallurgical inspections were performed on the cross-section of the welded joints. The specimens for metallurgical inspection were polished and etched with standard solution containing 1 g picric acid, 2.5 g acetic acid, 2.5 ml distilled water and 17.5 ml alcohol. The microstructures of the welded joint were observed with optical microscope, and the hardness measurement was performed on the metallographic specimens crossing the joints. The tensile sample with the thickness of 3 mm was cut across the joints eliminated the top and bottom surfaces, and the tensile data are the average data of 3 measurements. Furthermore, the crystallographic texture in welded joints was analyzed with the help of Electron Back-Scattered Diffraction (EBSD).

3. Results and discussion

Fig. 1 shows the microstructure of the welded joint of the fine-grained Mg alloy. The grain size of HAZ is obviously bigger than that of BM, which is similar to the former results [3–6]. Fusion zone (FZ) consists of two parts: the equiaxed grain zone in the middle part and the columnar grain zone on the left and right sides, which both contains coarser grains than BM. The hardness was measured at mid-thickness across the welded joint at different welding conditions. Because of the coarser grains in FZ, the
hardness of FZ is evidently lower than that of BM, and the hardness of HAZ is between FZ and BM. This indicates that the grain coarsening in FZ and HAZ both results in hardness decrease. Furthermore, the average hardness in FZ increases slightly with increasing welding speed at a constant laser power or decreasing laser power at a constant welding speed, i.e. with decreasing welding heat input.

EBSD was performed to analyze the crystallographic texture in the welds, as illustrated in Fig. 2. From the pole figures, it can be found that the magnesium alloy plate used in present study has a strong texture structure, and the basal plane (0001) is aligned with its normal direction perpendicular to the plate surface and also the extrusion direction, i.e. the tensile direction. The columnar grain zone also exhibits a comparatively strong texture, having almost the same orientation as BM. The grain orientation in the equiaxed grain zone in the center of FZ is random. It should be noted that the texture at columnar grain zone is affected by welding heat input. With increasing welding heat input, the texture becomes weak.

The mechanical properties of welded joints at different welding conditions are shown in Table 1. All tensile samples fracture in FZ, as shown in Fig. 3. This is caused by

![Fig. 1. Microstructure of the cross section of weld joint with 4 kW laser power and 8 m/min welding speed.](image)

![Fig. 2. EBSD analysis near fusion zone of the fine-grained Mg alloy welded with 4 kW laser power and 4 m/min and 16 m/min welding speed (a) 4 m/min; (b) 16 m/min.](image)

![Fig. 3. Stress-strain curves at different welding conditions and fracture position.](image)

<table>
<thead>
<tr>
<th>No.</th>
<th>Welding condition</th>
<th>Tensile strength (MPa)</th>
<th>Elongation (%)</th>
<th>Yield strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4 kW–4 m/min</td>
<td>260</td>
<td>6.0</td>
<td>183</td>
</tr>
<tr>
<td>2</td>
<td>4 kW–8 m/min</td>
<td>239</td>
<td>3.9</td>
<td>187</td>
</tr>
<tr>
<td>3</td>
<td>4 kW–16 m/min</td>
<td>226</td>
<td>2.1</td>
<td>196</td>
</tr>
<tr>
<td>4</td>
<td>6 kW–16 m/min</td>
<td>227</td>
<td>2.1</td>
<td>193</td>
</tr>
<tr>
<td>5</td>
<td>8 kW–16 m/min*</td>
<td>177</td>
<td>0.7</td>
<td>168</td>
</tr>
</tbody>
</table>

*aWeld defect.
the lowest hardness of FZ. From Table 1, it can be seen that yield strength increases with increasing welding speed or decreasing laser power, which is similar to the trend of the average hardness of FZ, caused by the decrease of mean dendrite arm spacing (DAS) in FZ. However, both tensile strength and elongation of welded joints decrease with increasing the welding speed at a constant laser power, quite different from the yield strength. It’s noted that because there are many porosity in the welded joint at 8 kW laser power and 16 m/min welding speed, all the mechanical properties reach the lowest point.

For many metals and their welded joints, tensile strength of metals always has the similar change tendency with yield strength, i.e. they both increase with decreasing grain size or mean DAS. In present work, however, the tensile strength of welded joint has the contrary tendency with the yield strength, which is quite different from the previous results. This phenomenon is discussed as follows.

Generally, during tensile test, the stress reaches a maximum value after elastic deformation and the subsequent plastic deformation, and followed by necking and fracture. In present tensile test, all the samples fracture prior to obvious necking, as shown in Fig. 3. That is to say, the deformation capacity of the samples is insufficient. Therefore the tensile strength of sample is greatly affected by the deformation capacity of sample. This also explains that the tensile strength in present test always has the similar change tendency with elongation. In fact, the tensile strength increases with elongation.

The crystalline structure of Mg alloy is hexagonal close-packed. The formability of Mg alloys is restricted due to a limited number of independent and readily activated slip systems [8]. Texture has a great influence on yielding and deformation of Mg alloys. When basal plane of texture structure aligned 45° to tensile direction, low yielding strength and tremendously large strain to failure were found [9]. That is to say, to obtain high deformation capacity, a random structure where many grains have basal plane inclined 45° to tensile direction is favored [9–13]. From Fig. 2, it can be seen that strong texture exists at BM, HAZ and columnar grain zone of FZ. The angle between basal plane inclined 45° to tensile direction is favored [9].

In conclusion, grain coarsening occurs in HAZ of the laser-welded fine-grained Mg alloy. FZ consists of the outer columnar grain zone and the center equiaxed grain zone with coarser grains. Because of larger grain size, the hardness of FZ is lower than those of BM and HAZ. With increasing welding speed or decreasing laser power, yield strength of welded joint increases due to finer microstructures; however, ultimate tensile strength as well as elongation decreases, exhibiting quite different changing tendency from yield strength. Strong texture with the same orientation as BM is generated at columnar grain zone, which makes the equiaxed grain zone of FZ to be the main deformation zone. The width of equiaxed grain zone reduces with increasing welding speed or decreasing laser power, which lead to the decrease of tensile strength.

4. Conclusion

In conclusion, grain coarsening occurs in HAZ of the laser-welded fine-grained Mg alloy. FZ consists of the outer columnar grain zone and the center equiaxed grain zone with coarser grains. Because of larger grain size, the hardness of FZ is lower than those of BM and HAZ. With increasing welding speed or decreasing laser power, yield strength of welded joint increases due to finer microstructures; however, ultimate tensile strength as well as elongation decreases, exhibiting quite different changing tendency from yield strength. Strong texture with the same orientation as BM is generated at columnar grain zone, which makes the equiaxed grain zone of FZ to be the main deformation zone. The width of equiaxed grain zone reduces with increasing welding speed or decreasing laser power, which lead to the decrease of tensile strength.

References