Materials Letters 63 (2009) 870–872

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/matlet

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

L. Yu [a,*], K. Nakata [a], N. Yamamoto [b], J. Liao [b]

[a] Joining and Welding Research Institute, Osaka University, Osaka, Japan
[b] Kurimoto, Ltd., Osaka, Japan

ARTICLE INFO

*Article history:*
Received 4 December 2008
Accepted 10 January 2009
Available online 25 January 2009

*Keywords:*
Fine-grained Mg alloy
Fiber laser welding
Texture
Microstructure
Mechanical properties

ABSTRACT

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.



## 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 al.[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.

* Corresponding author. Tel./fax: +81 6 6879 8668.
*E-mail address:* yuxueer33@hotmail.com (L. Yu).

0167-577X/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.matlet.2009.01.050

## 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

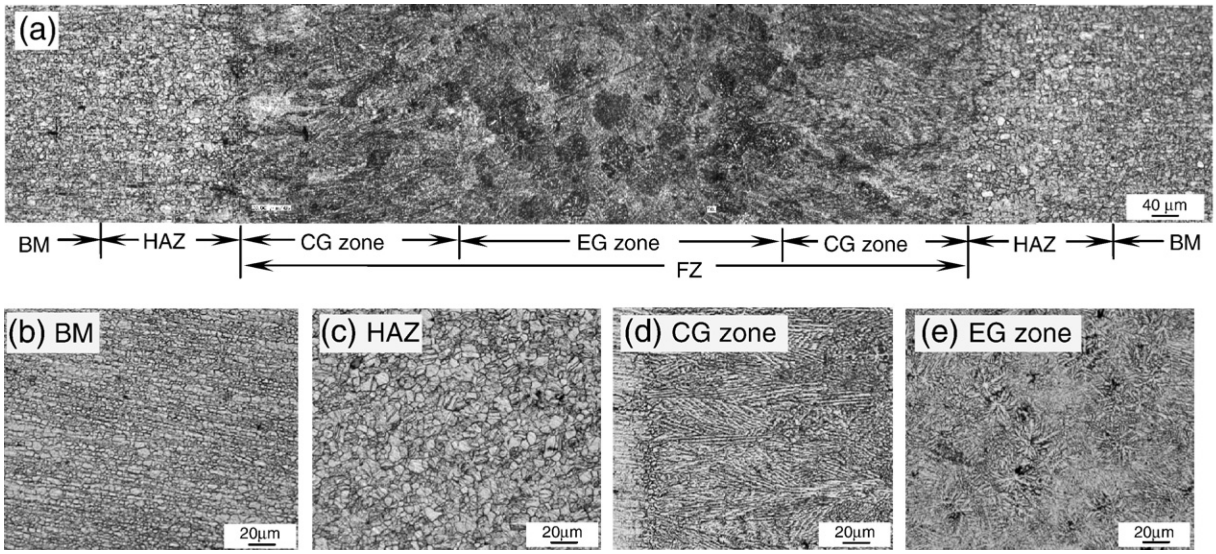


**Fig. 1.** Microstructure of the cross section of weld joint with 4 kW laser power and 8 m/min welding speed.

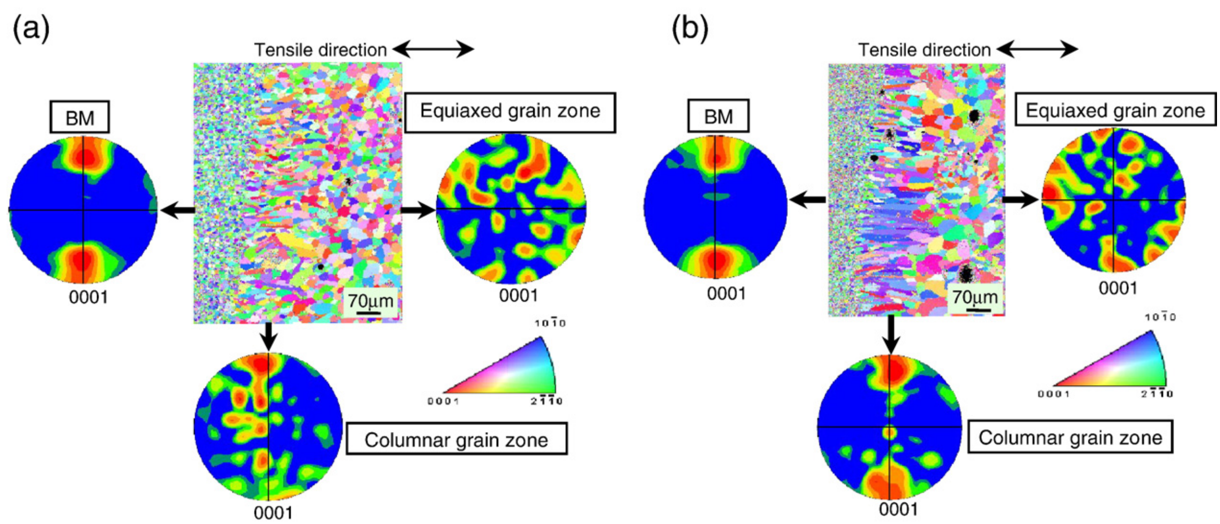


**Fig. 2.** EBSD analysis near fusion zone of the fine-grained Mg alloy welded with 4 kW laser power and 4 m/min and 16 m/min welding speed (a) 4 m/min; (b) 16 m/min.

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

**Table 1**
Mechanical properties of the fine-grained Mg alloy after welding

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

*Weld defect.

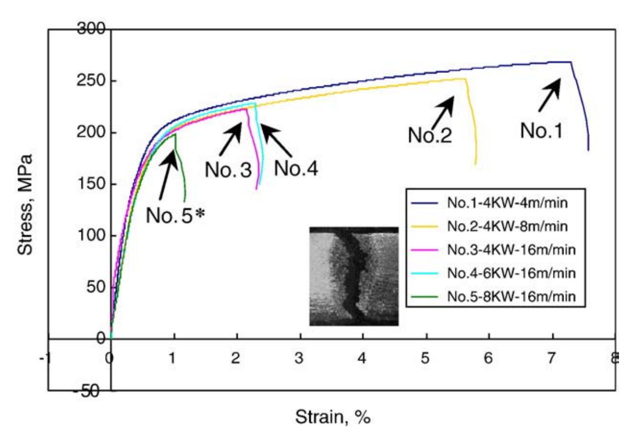


**Fig. 3.** Stress-strain curves at different welding conditions and fracture position.

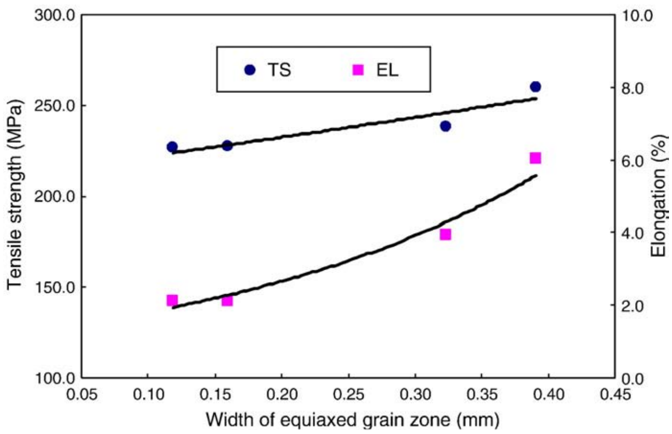


**Fig. 4.** Relation between tensile strength/elongation and and fracture position width of equiaxed grain zone of FZ.

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 capability 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 (0001) of the texture structure and tensile direction is nearly 0°, i.e. the basal plane is approximately parallel to the tensile direction. In contrast, the grain orientation at equiaxed grain zone in the center of FZ is random. Hence, it can be believed that yielding and deformation occurred mainly at the equiaxed grain zone during tensile test. For this, the deformation capacity of the equiaxed grain zone is the key factor to the elongation and ultimate tensile strength. The relation between the tensile strength as well as elongation and the width of equiaxed grain zone in FZ was examined. As shown in Fig. 4, both the tensile strength and elongation increase monotonically with increasing the width of equiaxed grain zone, which supports the above discussion.

The columnar grain zone of FZ has a strong texture with the same orientation as BM and HAZ, as mentioned above. This is another interesting phenomenon worth to be discussed. During the rapid solidification process in FZ of laser welds, grains likely grow epitaxially from the fusion line regions of HAZ into FZ [14,15]. Texture formation in FZ is determined by the speed of grain growing from fusion line of HAZ to FZ, i.e. the growing speed of old grains, and the nucleating and growing speeds of new grains in the molten FZ. At columnar grain zone, the growing speed of old grains is higher than the nucleating and growing speeds of new grains, thus texture with the same orientation as HAZ is generated. When welding heat input increases, the cooling speed is not so fast, so that some new grains may nucleate and grow at columnar grain zone of FZ. As the result, the texture structure at the columnar grain zone becomes weak. At equiaxed grain zone, almost all grains are those newly nucleated and grown, hence the grain orientation is random.

In the fine-grained materials, decreasing the width of softened zone is common method for improving the tensile strength [3,4]. However, in present study, the tensile strength increased with increasing the width of equiaxed grain zone (Fig. 4), which is the main deformation zone during tensile test. When the width of equiaxed grain zone is bigger, there is more deformation capability, which can result in more plastic deformation. Therefore, in order to keep the high tensile strength in fine-grained Mg alloy, the width of FZ (especially the equiaxed grain zone) cannot be too narrow.

## 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

[1] Afrin N, Chen DL, Cao X, Jahazi M. Scripta Mater 2007;57:1004–7.
[2] Mordike BL, Ebert T. Mater Sci Eng A 2001;302:37–45.
[3] Hrivnak I. ISIJ Int 1995;35:1148–56.
[4] Qui H, Ohmori A, Hagiwara Y. ISIJ Int 2003;43:2046–53.
[5] Peng Y, Tian ZL, He CH, Ma CY. Trans China Weld Inst 2003;24:21–4.
[6] Peng Y, Tian ZL, Chen WZ, Wang C, Bao G. J Iron Res Int 2003;10:32–6.
[7] Quintino L, Costa A, Miranda R, Yapp D, Kumar V, Kong CJ. Mater Design 2007;28:1231–7.
[8] Barnett MR, Keshaverz Z, Beer AG, Atwell D. Acta Mater 2004;52:5093–103.
[9] Agnew SR, Horton JA, Lillo TM, Brown DW. Script Mater 2004;50:377–81.
[10] Muransky O, Carr DG, Barnett MR, Oliver EC, Sittner P. Mater Sci Eng A 2008;496:14–24.
[11] Styczynski A, Hatig C, Bohlen J, Letzig D. Script Mater 2004;50:943–7.
[12] Lou XY, Li M, Boger RK, Agnew SR, Wagoner RH. Int J Plast 2007;23:44–86.
[13] Coelho RS, Kostka A, Pinto H, Riekehr S, Kocak M, Pyzalla AR. Mater Sci Eng A 2008;485:20–30.
[14] Cahn RW. Acta Mater 1953;1:50–74.
[15] Karkhin VA, Plochikhine VV, Ilyin AS, Bergmann HW. Weld World 2002;46:11–2.