Influence of Grain Refinement and Texture Evolution on the Yield Strength of Mg Alloy Processed by Cyclic Extrusion and Compression

Jinbao Lin1,*, Qudong Wang2, Yanxia Chen1 and Xiaochao Cui1

1School of Applied Science, Taiyuan University of Science and Technology, Taiyuan 030024, China
2National Engineering Research Center for Light Alloy Net Forming, Shanghai Jiao Tong University, Shanghai 200240, China

The microstructure, texture and room temperature tensile property of an extruded GW102K alloy processed by cyclic extrusion and compression (CEC) at 350°C were investigated. Results show that the microstructure was effectively refined and the initial fiber texture changed to a new texture. The strength and ductility were simultaneously increased obviously. In particular, yield strength increases with decreasing grain size and high speciﬁc densities under the CEC process.

Keywords: magnesium alloy, cyclic extrusion and compression (CEC), texture, grain size, yield strength

1. Introduction

Mg alloys are energy-efﬁcient materials due to their low density and high speciﬁc strength, but its application was greatly limited for its relatively low strength and plasticity. An effective way to improve the mechanical properties of Mg alloy is to reﬁne the grains.1,2) In recent years, severe plastic deformation (SPD) has widely been used to fabricate ultraﬁne grained Mg alloys.3,4) Among the various SPD techniques, cyclic extrusion and compression (CEC) is attractive due to its continuous process. It has been widely proved that the microstructures of Mg alloys can be dramatically reﬁned by CEC5-10) Nevertheless, the CEC-processed Mg alloys often showed a decrease in yield strength even though grain size is reduced effectively.5-8) But still have researchers report an increase in yield strength of ﬁne-grained CECed Mg alloys9) These discrepancies indicate that the effects of CEC process on the mechanical properties of Mg alloy are complicated, and the mechanism is still under debate. In the present study, the microstructure, texture and tensile property of an extruded GW102K alloy processed by CEC at 350°C were investigated. And the effects of grain size and texture on the yield strength were studied.

2. Experimental Procedure

The extruded GW102K (Mg–9.95 mass%Gd–2.3 mass%Y–0.46 mass%Zr) alloy with a diameter of 29.5 mm was subjected to CEC process up to 8 cycles at 350°C. The CEC procedure was described elsewhere.5,6) The CEC processing was carried out by pushing a specimen from one cylindrical chamber with a diameter D = 30 mm, into the second chamber with the same dimensions, through a die having a smaller diameter d = 20 mm. This will form one ‘cycle’ of extrusion and compression resulting.

The longitudinal microstructure and texture of the sample were analyzed using a Zeiss 55VP FEG-SEM equipped with a Nordif EBSE detector and the TSL OIM EBSS software. EBSS samples were prepared by electropolishing with an AC2 solution at a voltage of 15 V for 10–20 s at −30°C. Tensile tests were carried out using the flat tensile specimens with a gauge section of 10 mm × 3 mm × 1.5 mm at room temperature and strain rate of 5 × 10−3 s−1.

3. Experimental Results

Figure 1 shows the EBSD mapping in form of an inverse pole ﬁgure (IPF) map of the GW102K alloy before and after CEC process. The different colors represent different orientations of the grains. The stereographic triangle in the lower left corner of the maps gives color-code employed in these maps. It can be seen that CEC is efﬁcient grain reﬁnement method for GW102K alloy. The average grain sizes are determined to be 18, 2.3 and 1.3 µm, respectively. Most grains in Fig. 1(a) exhibit red color, which means that the {0001} basal planes of these grains are nearly parallel to the paper. After CEC processing (Figs. 1(b)–1(c)), the grains are dramatically reﬁned and uniformly distributed. The much more randomly distributed grains colors indicate the grains orientations are changed.

The {0002} and {1010} pole ﬁgures are shown in Fig. 2. It can be seen that the extruded GW102K alloy exhibited an ED // {1010} ﬁber texture (Fig. 2(a)). After 4 cycles CEC, the initial ﬁber texture became disintegrated and changed to a new {1013}(3032) + {1011}(1543) type texture. The new texture is similar with that of CECed ZK60,5,6) AZ3110) and AZ9110) alloys, but the texture intensity of the CECed GW102K alloy is much lower than that of the latter’s. So, it can be concluded that the texture type of the CECed Mg alloy is determined by the CEC process and the CEC die structure. The texture intensity of the CECed Mg alloy is mainly depends on the alloy composition, at the same time, would be affected by the CEC processing parameters, such as deformation temperature.

*Corresponding author, E-mail: linjinbao@qq.com
Figure 3 shows the tensile engineering stress–strain curves at room temperature before and after CEC processed at 350°C. The obtained yield strength ($\sigma_{0.2}$), ultimate tensile strength ($\sigma_{UTS}$) and elongation-to-failure ($\delta$) are summarized in Table 1. It shows that both the strength and elongation-to-failure are increased with the increasing number of the CEC cycles. After 8 cycles CEC, the $\sigma_{0.2}$, $\sigma_{UTS}$ and $\delta$ are increased by 41.3, 16.1 and 162.5%, respectively. Despite the presence of similar texture component and grain refinement, the CECed ZK60 and AZ31 exhibit an opposite trend in yield strength.

4. Discussion

Figure 4 summarizes the grain size of Mg alloys as a function of the accumulated strain of CEC. As shown in Table 1 and Fig. 3, the 8-cycle CECed GW102K alloy exhibited a large tensile elongation of $\delta \approx 17\%$, which is almost three times as high as that before CEC. It can be concluded that the grain refinement and texture softening by the CEC process combined to give rise to the remarkable improvement in the uniform elongation. On the one hand, with the texture changing, the maximum Schmid factor in the basal slip systems increased, thus, basal slip is much more easily activated. In addition, the decreased texture intensity should help to promote uniform plastic deformation. On the
systems due to the grain-boundary compatibility effect.\textsuperscript{11)}

basal slip systems can be activated as well as basal slip

Fig. 5 Grain size dependencies of yield strength of Mg alloys before and

after CEC.

other hand, with the grain refinement of Mg alloy, the non-

basal slip systems can be activated as well as basal slip systems due to the grain-boundary compatibility effect.\textsuperscript{11)}

An interesting result obtained in the present study is that the yield strength of the GW102K alloy dramatically increased by CEC process, i.e., the yield strength increases with decreasing grain sizes, and exhibiting clear grain size dependency according to Hall–Petch relation, in spite of the existence of same texture with CECed ZK60 and AZ31 alloys, as shown in Fig. 5. In addition, the increase in Hall–Petch slope of the GW102K CECed at 350°C compared with that CECed at 450°C is likely related to the higher dislocation density in the sample due to the lower deformation temperature.

The opposite relationships between grain size and yield strength of the CECed GW102K, ZK60 and AZ31 alloys can be ascribed to the different texture intensity. As shown in Fig. 2, the maximum texture intensity of [0002] pole figure of the GW102K alloy before and after CEC 4-cycle are 3.6 and 2.7, respectively. By contrast, the maximum intensities for the ZK60 alloy before and after CEC 4-cycle are as high as 10.1 and 6.0, respectively.\textsuperscript{3)} Lower texture intensity indicates that more random grain orientation, and then weaker effect of texture on the yield strength. So, it can be concluded that the yield strength of the CECed Mg alloys is dominated by combined effects of grain size strengthening and texture softening. For the GW102K alloy, the grain refines strengthening is the largest contributor to the yield strength and the texture play relatively minor roles on the yield strength.

5. Conclusions

(1) The microstructure of GW102K alloy can be obviously refined by CEC. A homogeneous structure of refined grains with a size of $\sim$1.3 µm is obtained after 8 cycles CEC processing.

(2) After CEC, the initial fiber texture of extruded GW102K became disintegrated and changed to a new texture, which type is same with that of CECed ZK60, AZ31 and AZ91 Mg alloys, but the maximum texture intensity of CECed GW102K alloy is much lower than that of the latter’s.

(3) The combined effect of grain refinement and texture modification caused by CEC can improve the strength and ductility of the GW102K alloy simultaneously. After 8-cycle CEC, the elongation increased significantly from 6.4 to 16.8% and the yield strength increased from 225 to 318 MPa, respectively.

(4) The yield strength of the CECed Mg alloys is determined by the competition of grain size strengthening effect and texture softening effect, and the texture softening effect depends on the texture type and intensity. For the GW102K alloy, the grain refines strengthening is the largest contributor to the yield strength and the texture play relatively minor roles on the yield strength.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (51204117, 51074106, 50674067); Natural Science Foundation of Shanxi (20122012182-2); Shanxi Scholarship Council of China (2011-079); Program for the Top Young Academic Leaders of Higher Learning Institutions of Shanxi.

REFERENCES