Microstructure and Mechanical Properties of Extruded Mg-Y-Zn-Ni-Co Alloy

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Abstract: Microstructure and mechanical properties of Mg-2Y-0.5Zn-0.5Ni-0.5Co (MYZNC, at.%) alloy were investigated in the as-cast, homogeneous and extruded states. The as-cast MYZNC alloy mainly consisted of α-Mg matrix, gray lamellar 18R LPSO phase, and white irregular Mg_2Y, $MgY(Co,Zn,Ni)_4$, and granular $Mg_3(Co,Zn,Ni,Y)$ phases. After homogenization treatment, a large number of strip-like 14H LPSO phases precipitated in the grain interior. After hot extrusion, the alloy occured obvious dynamic recrystallization with a significant grain refinement from 46.5 μm in the homogenized state to 2.98 μm in the extruded state, while the second phases were fragmented and distributed along the extrusion direction. The tensile testing results indicated that the extruded MYZNC alloy exhibited the good tensile strengths as compared with the as-cast and homogenized alloys, whose ultimate tensile strength (σ_b), yield strength ($\sigma_{0.2}$) and elongation to failure (ε_f) of were 280 MPa, 225 MPa and 11.7%, respectively. The high tensile properties of the extruded alloy were mainly attributed to the grain refinement and the second-phase strengthening by the high volume fraction of LPSO phase. In addition, the homogenized appeared a more pronounced strain hardening behavior, attributed to its large grain size and higher dislocation density arised from the presence of numerous fine particles and LPSO phases.

1 Introduction

Mg alloys are favored by researchers for their low density and high specific strength, however, low room-temperature strength and poor plasticity limit their development and application in aerospace, automotive and electronic 3C and other fields. How to improve the tensile strengths, room-temperature plasticity and processing performance of Mg alloys has become an urgent problem.

Recently, rare-earth Mg alloys containing a long-period stack-ordered (LPSO) structure phase have exhibited exceptional mechanical properties both at room and high-temperatures [1]. Considering the formation conditions, including structural and chemical order, of the LPSO phase, it is inevitable that the properties of the transition elements therein (atomic radius, melting point, and solid solubility, etc.) will exert a significant influence on the aforementioned properties of the LPSO phase. Consequently, these factors collectively contribute to enhancing the overall mechanical properties of the alloy. Previous studies [2,3] have demonstrated that the solid solubility of Ni or Co in α-Mg matrix is lower than as compared to Zn, indicating a higher propensity for the LPSO phase formation. Therefore, in this paper, the composite addition of the elements of Zn, Ni, and Co in Mg-2Y alloys, the extruded Mg-2Y-0.5Zn-0.5Ni-0.5Co (at.%) alloy (MYZNC) was prepared and the corresponding relation between microstructure and mechanical properties was discussed. The strengthening mechanisms of extruded alloy was also clarified. The experimental results would provide theoretical support for the design and development of high-strength and high-toughness extruded Mg alloys.

2 Experimental procedure

The experimental Mg-2Y-0.5Zn-0.5Ni-0.5Co (at.% , MYZNC) alloy was prepared by pure Mg (99.90 wt.%), Zn (99.95 wt.%) and Mg-15Ni (wt.%), Mg-15Co (wt.%), and Mg-20Y (wt.%) master alloys by a gravity casting under the protection of the molten salt covering agent (NaCl and KCl). The melting in iron crucible located in a resistance furnace was heated up to 750 ºC and held for 60 min. After the pure metal and alloy ingots were was completely melted, the refining agent was added into the melts and stirred slowly for about 5 min until the surface of the melts appeared to a metallic luster, and held for about 10 min. Subsequently, the melts were poured into a water-cooled mold and formed the cylindrical ingot with a diameter of 90 mm and a length of 200 mm. The ingot was homogenized at 400 ºC for 12 h before extrusion. The homogenized ingot was extruded in to extrusion sheet with a thickness of 10 mm and a width of 40 mm. The extrusion temperature and extrusion ratio were 366 ºC and 16:1, respectively.

The microstructures of the alloys were characterized using optical microscopy (OM, LSM800Laser confocal microscope), X-ray diffractometer (XRD, Rigaku D/max 2500 PC), scanning electron microscope (SEM, JEM-2100F), the electron backscatter diffraction (EBSD, HRFESEM, TESCANMAIA3) and transmission electron microscope (TEM, FEI Talos F200X).

3 Result and discussion

Fig. 1 shows the hardness and tensile stress-strain curves of the as-cast, homogenized and extruded MYZNC alloys. it can be concluded that the extruded alloy exhibits a higher hardness value (64.7 HV) compared to both the as-cast alloy (53.4 HV) and the homogenized alloy (56.4 HV). Furthermore. the tensile test results also reveal that the extruded alloy exhibits the higher tensile strengths than as-cast and homogenized alloys, whose ultimate tensile strength (σ_b), yield strength ($\sigma_{0.2}$), and elongation (ε_f) of the extruded alloy are 280 MPa, 225 MPa, and 11.7%, respectively. The σ_b, $\sigma_{0.2}$ and ε_f of extruded alloy increase by 131%, 257% and 154%, respectively as compared with that of as-cast alloy. The σ_b, $\sigma_{0.2}$ and ε_f of extruded alloy increase by 131%, 257% and 154%, respectively as compared with that of as-cast alloy. Combining Figure 2 and Figure 3, It can be seen that the hot extrusion is indeed an effective method to improve the mechanical properties of the alloy through grain size reduction and refinement of the LPSO phase.

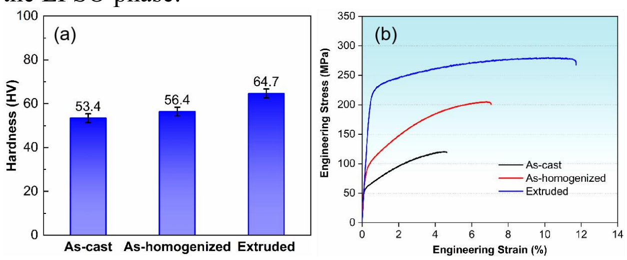

Fig. 1 Hardness (a) and Engineering stress-strain curve (b) of MYZNC alloy as cast, homogenized, and extruded

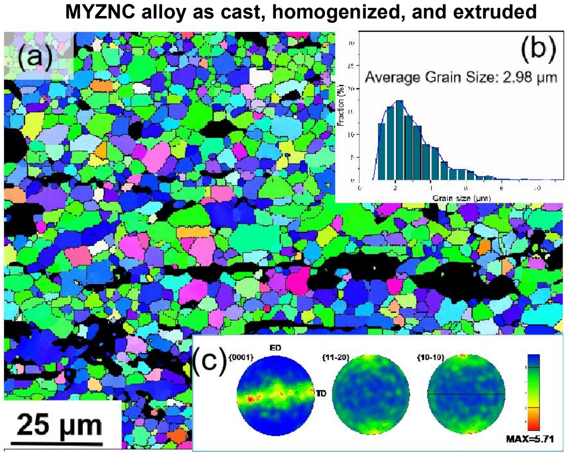

Fig. 2 Inverse pole figure (IPF) (a), (0001) pole figure (b) and average grain size distribution of extruded alloy (c)

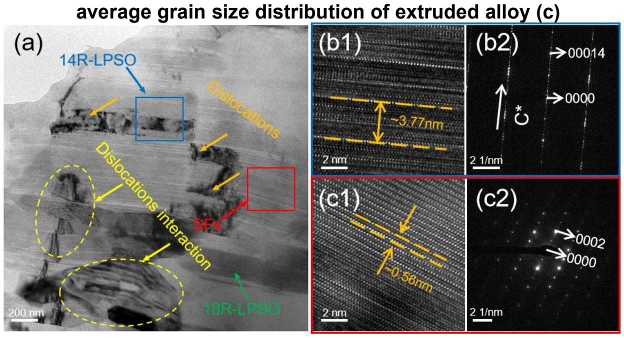

Fig. 3 TEM images of extruded MYZNC alloy; (b1, c1) HR-TEM images; (b2, c2) select the Electron diffraction (SAED) images; Where (b1, b2) corresponds to the blue box area of images(a), and (c1, c2) corresponds to the red box area of images (a)

4 Conclusion

(1) The microstructure of the as-cast MYZNC alloy is composed of $MgY(Co,Zn,Ni)_4$, $Mg_3(Co,Zn,Ni,Y)$, and Mg_2Y granular phases, as well as lamellar 18R LPSO phase. After homogenization, some of the 18R LPSO phases transforms into finely striated 14H LPSO phases parallel to each other and with a slight increase in grain size. After hot extrusion, the grain size of the MYZNC alloy was refined to 2.98 μm, the second phase is fragmented to form extruded bands along the extrusion direction, and the grain occurs to rotate and generate a basal texture with a maximum texture strength of 5.71.

(2) The extruded alloy exhibits a high tensile properties as compared with as-cast and homogenized alloys. The ultimate tensile strength, yield strength, elongation to failure and hardness of the extruded MYZNC alloy are 280 MPa, 225 MPa,11.7% and 64.7 HV at room temperature. The high tensile strengths and hardness of the extruded alloy is mainly related to the grain refinement and second phase strengthening from LPSO phase.

Acknowledgments

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References

[1] X.H. Shao, Z.Q. Yang, X.L. Ma, Strengthening and toughening mechanisms in Mg-Zn-Y alloy with a long period stacking ordered structure, Acta Materialia 58(14) (2010) 4760-4771.

[2] G. Bi, H. Man, J. Jiang, Y. Li, T. Chen, X. Zhang, D. Fang, X. Ding, Effects of Zn addition on microstructure and tensile properties of Mg-Y-Co alloy, Journal of Materials Research and Technology 20 (2022) 590-605.

[3] Q.-Q. Jin, S.-B. Mi, Intermetallic phases in Mg–Co–Y alloys, Journal of Alloys and Compounds 582 (2014) 130-134.