Extrusion Forming Process and Microstructure of Mg-3Al-1Zn Alloy

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Abstract. In this paper, extrusion treatment of Mg-3Al-1Zn alloy treated with casting and homogenizing was carried out, the effects of extrusion temperature and extrusion ratio on the strength and ductility of the alloy were investigated, and the action mechanism was discussed. The results show that both before extrusion or after, the tensile strength of Mg-3Al-1Zn alloy after the treatment are reduced to some extent, while the elongation increases significantly. At the same extrusion ratio, when the extrusion temperature rises from 250°C to 450°C, the tensile strength of cast alloy is higher than that of uniform state. At lower temperature and larger extrusion ratio, Mg-3Al-1Zn alloy has better plasticity. With the increase of extrusion ratio, the tensile strength and elongation of Mg-3Al-1Zn alloy show a rising trend.

1. Introduction
Magnesium alloy is composed of magnesium-based addition of other elements. The main alloying elements are Al, Zn, Mn, Ce and Zr, which have the advantages of low density, high specific strength, high elastic modulus and good heat dissipation. Mg-3Al-1Zn alloy is widely used in aerospace, transportation, automobile, electronics and other fields [1]. Mg-3Al-1Zn alloy is a typical representative of magnesium alloy, which is widely used at present, because of its higher impact load capacity than aluminum alloy, and has been widely used in many fields such as aerospace, transportation, automobile, and electronics and so on. For its own dense hexagonal lattice characteristics, the alloy has poor plasticity and difficult forming process, which make it possible to roll or extrude magnesium alloy bar or sheet. So that the price of rolling or squeezing magnesium alloy bar or plate is higher, which hinders the application of Mg-3Al-1Zn alloy to a certain extent, and the new process of plastic deformation adapted to it is the key to develop and expand its application [2, 3]. In order to find out the rule and mechanism of improving the strength and plasticity of the alloy, the influence of the process parameters on the microstructure and properties of the alloy during the extrusion and deformation of the Mg-3Al-1Zn alloy is studied.

2. Materials and methods
The diameter of the Mg-3Al-1Zn alloy ingot used in the test is quasi-88mm, and the specific chemical composition W (%): 2.98 Al, 0.92 Zn, 0.28 Mn, 0.02 Si, 0.001 Fe, the residual is Mg. After the surface oil removal and cleaning, drying, uniform annealing treatment was carried out to alloy ingot in the
Cabollette box resistance furnace with temperature of 400°C, homogenization time of 15 hours and air cooling. The Mg-3Al-1Zn alloy was squeezed by rapid prototyping hydraulic press, with the extrusion temperatures of 250~450°C, the ratios of 20, 35 and 50, and the speeds of 4.5~12 m/min. Using positive extrusion mold structure, mold preheating temperature was set to 310°C, and the hot plates with temperature of 275°C are installed on the upper and lower surface of workbench, to ensure the mold temperature within a certain range [4], lubricant used for extrusion is the mixture of cylinder oil and graphite powder.

The alloy samples corroded by 4% nitric acid alcohol was placed under OLYM-PLUS metallographic microscope after cutting, grinding and polishing. Tensile mechanical properties was tested in the WEW-E100D type Electronic Universal Tensile Testing machine with tensile rate of 2mm/min according to GB T228.1-2010 "Indoor Temperature Test Method in Metal Material Tensile Test ", meanwhile the tensile fracture morphology is observed by the Japanese electronic IT-300 tungsten filament scanning electron microscope.

3. Results and Analysis

The metallographic structure of the Mg-3Al-1Zn alloy treated with casting and homogenizing were shown as Fig.1. It can be seen that there are α-Mg solid solution and the coarse branches distributed on the substrate of original Mg-3Al-1Zn alloy ingot, while the granular second phase is distributed between the dendrite and grain boundary. After homogenization treatment of 400°C /15h, the coarse dendrite is basically fused to the α-Mg matrix, while the number and size of the second phase decreases obviously. Thus, the homogenization treatment can be used to help achieving the goal of eliminating the internal segregation of crystals and improving the inhomogeneity of component tissue.

![Figure 1. Microstructure of Mg-3Al-1Zn alloy](image)

The extrusion forces of Mg-3Al-1Zn alloy in condition of cast and homogenizing have been acquired with temperature of 300°C and extrusion ratio of 20, the former is 25 000 KN, while the latter is 2375KN. It can be seen that the extrusion pressure of the alloy ingot after homogenization treatment is reduced and the extrusion performance is improved. The mechanical properties of Mg-3Al-1Zn alloy obtained from as-cast extrusion and homogenized extrusion are listed in Table 1. The test results show that the tensile strength and elongation at break of as-cast samples before extrusion are 255MPa and 7%, respectively. The tensile strength of as-cast alloy decreases and the plasticity increases after homogenization treatment. The tensile strength and elongation at break of as-cast Mg-3Al-1Zn alloy after extrusion were 350 MPa and 15.5%, respectively. While the data of Mg-3Al-1Zn alloy after homogenization were 305 MPa and 18.5%, respectively. It is clear that both before and after compression, the tensile strength of Mg-3Al-1Zn alloy after homogenization treatment decreased to a certain extent, while the elongation at break increased obviously.
Table 1. Mechanical Properties of Mg-3Al-1Zn alloy before and after extrusion

| condition          | As-cast extrusion | Homogenized post extrusion |
|--------------------|-------------------|-----------------------------|
|                    | tensile strength  | elongation at break         | tensile strength  | elongation at break |
|                    | /MPa              | %                           | /MPa              | %                           |
| Before extrusion   | 255               | 7.0                         | 200               | 14.0                        |
| After extrusion    | 350               | 15.5                        | 305               | 18.5                        |

The influence curves of extrusion temperature on tensile strength of Mg-3Al-1Zn alloy are shown as Fig.2. It can be seen that the tensile strength of as-cast and homogeneous samples decreases first and then rises at the extrusion ratio of 20. When the extrusion ratio reach to 35, the strength variation is similar to the trend of 20, and the tensile strength of as-cast and homogeneous alloys both increased. When the extrusion temperature increased from 250°C to 450°C with the same extrusion ratio, the tensile strength of as-cast alloy specimen is higher than that of homogeneous state.

![Figure 2. Effect of extrusion temperature on the tensile strength of Mg-3Al-1Zn](image)

![Figure 3. Effect of extrusion temperature on the elongation of Mg-3Al-1Zn](image)

The influence curves of extrusion temperature on elongation at break of Mg-3Al-1Zn alloy are shown as Fig.3. It can be seen that with the increase of extrusion temperature, the change trend of elongation at break of as-cast and homogeneous Mg-3Al-1Zn alloys is completely different from that of tensile strength, and the elongation at break of Mg-3Al-1Zn alloy decreased with the increase of extrusion temperature. In addition, the elongation at break of Mg-3Al-1Zn alloy can reach 25% when the extrusion ratio is 35 and the extrusion temperature is 250°C. It is known that the plasticity of Mg-3Al-1Zn alloy can be improved at lower temperatures and higher extrusion ratios.

The influence curves of extrusion ratio on tensile strength and elongation at break of Mg-3Al-1Zn alloy are shown as Fig. 4 with the extrusion temperature of 350°C. It can be seen that the tensile strength and elongation at break of Mg-3Al-1Zn alloy increase gradually with the increase of extrusion ratio. The main reason is that with the increase of extrusion ratio, the grain structure of Mg-3Al-1Zn alloy will be fully refined. According to Holpec formula [5], the strength of the alloy will be improved when the grain size is smaller. Grain refinement can also improve the plasticity of the alloy.
Figure 4. Effect of extrusion ratio on the mechanical properties of Mg-3Al-1Zn

The tensile fracture morphology at indoor temperature are shown in Fig. 5 under the conditions of as-cast and extrusion temperature of 300°C and extrusion ratio of 20. It can be seen that there are only a few dimples and more cleavage surfaces in the fracture surface of as-cast alloy, which is characterized by brittle fracture. However, after extrusion deformation, the fracture surfaces of Mg-3Al-1Zn alloy are almost composed of elongated dimples, and the brittle fracture characteristics of as-cast alloy have been completely transformed into ductile fracture characteristics. It can be seen that after extrusion deformation, the plasticity of Mg-3Al-1Zn alloy will be obviously improved. This is mainly due to the dynamic recrystallization of Mg-3Al-1Zn alloy during extrusion [6], the formation of fine equiaxed crystals will make the alloy have high strength and good plasticity at the same time.

Figure 5. Tensile fracture morphology of Mg-3Al-1Zn

4. Conclusion

(1) The homogenization annealing of Mg-3Al-1Zn alloy ingot at 400°C / 15 h can eliminate the intracrystalline segregation and improve the inhomogeneity of composition and microstructure.

(2) Both before and after extrusion, the tensile strength of Mg-3Al-1Zn alloy after homogenization treatment decreased to a certain extent, while the elongation at break increased obviously.

(3) At lower temperature and higher extrusion ratio, the plasticity of Mg-3Al-1Zn alloy can be improved. With the increase of extrusion ratio, the tensile strength and elongation at break of Mg-3Al-1Zn alloy increase gradually.

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