Microstructure evolution of AZ31 magnesium alloy during continuous extrusion and hot rolling processes

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Abstract

The continuous extrusion experiments were conducted by using TLJ400 machine under various processing conditions. As a result, the magnesium sheets in sizes of 160mm×8mm were obtained successfully. Then, the sheets were rolled to approximate 1mm thickness at 350°C and 200°C, respectively. The microstructure and texture evolution of the as-extruded and the rolled sheets were examined by using optical microscope and electron back scattered diffraction (EBSD). As a result, the microstructure in the center area of the continuous extruded sheet exhibited completed dynamic recrystallized grains with an average grain size of 12μm. However, a great number of coarse grains with an average grain size of 47μm were observed in the edge area. The microstructure of the final sheets could be refined and homogenized by rolling at a temperature of 200 °C. On the other hand, macro-texture investigations were conducted by XRD. The results show that the (0002) basal intensity decreases from the center to the edge in the extruded sheet. 86.3° <11-20> twin is a cause of weakening basal texture intensity in the edge region. Tensile strength of the continuous extruded sheet is ranging from 218 MPa to 256 MPa, and the tensile elongation is in 9%~18% due to the inhomogeneous microstructures. However, the final sheet rolled at 200°C temperature exhibits relative excellent tensile properties. The tensile strength reaches to 309MPa and the average elongation is about 18%.

1. Introduction

It is generally known that current available Mg alloy sheet are impractically expensive due to the complicated manufacturing processes. Therefore, the main challenge for application of the Mg sheet is to further reduce cost and improve the mechanical properties simultaneously. A new process, continuous extrusion technology combined with warm rolling, which could be used to produce the AZ31 Magnesium alloy sheets in lower cost was proposed in this study.

The continuous extrusion technique is effective in grain refinement and improving mechanical properties of products. Therefore, this technique has become a well-established processing route for production of copper flat wire and other extruded profiles. Compared to the conventional extrusion, no external heat source is used in the process. Friction force acts as useful work, is converted into driving force and heating source of initial materials in the continuous extrusion process. Severe shear deformation during the continuous extrusion may contribute to dynamic recrystallization (DRX) and enhance grain refinement of productions. These features greatly satisfy the requirement of energy-saving and emission-reduction for productions of magnesium alloys.

Because it is difficult to deform at room temperature in the magnesium alloys without any heating, the most commonly processed metals by using the continuous extrusion are various profiles of aluminum alloys and copper alloys. Therefore, it is a challenge work to form the magnesium alloy sheet with a large width to thickness ratio.

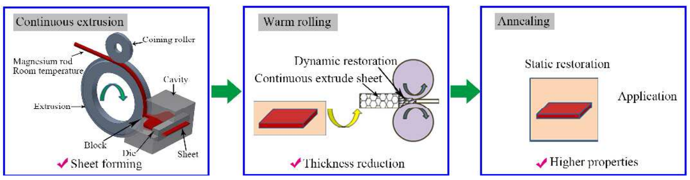

Fig.1 Schematic of continuous extrusion, warm rolling and annealing processes

Fig.1 presents a schematic diagram of the continuous extrusion. A rod is fed into the profiled groove of a conform wheel by means of a driving wheel and a coining roller. The frictional force generates between the wheel and the feedstock. The temperature rises due to the friction and plastic deformation, finally causing the material to exit through the extrusion die after right-angle bending. We have proposed a new process of the continuous extrusion combined with the hot rolling to produce fine grained magnesium alloy sheets with lower cost. Therefore, main purpose of this study is to investigate the microstructure evolution during the continuous extrusion and the rolling processes.

2. Experimental method

The initial material used in the present study was commercial AZ31 magnesium rod in 20mm diameter. The experiment was performed by using the TLJ400 continuous extrusion machine with a single feeding mode (Fig.2).

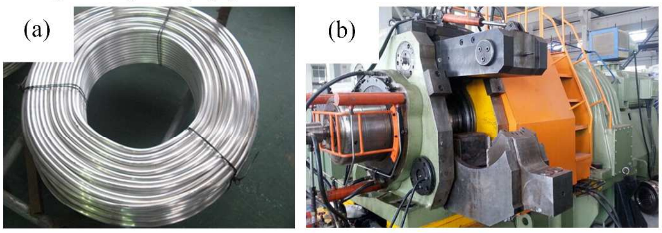

Fig.2 (a) Purchased extruded AZ31 magnesium rod in 20 diameter, (b) TLJ400 continuous extrusion machine

For microstructure analysis, digital microscopes (Keyence) with VHX-900 software were used in this study. The X-ray texture analysis was performed by the Schulz reflection method to obtain an incomplete (0002) pole figure using PANalytical-DY1086. Specimens for EBSD analysis were electro-polished in a solution of HNO3, CH3OH and glycerin.

Measurements were taken at the center locations in the surface normal to the extrude direction (ED) of the extruded sheet. Tensile specimens were sampled along the ED from the extruded sheet (8mm thickness) and after rolled and annealed sheet (2mm thickness).

3. Results and discussion

It can be seen that the continuous extruded sheet has good flatness and appearance quality, Fig 3. No any edge crack and curve bending are found in the sheet surfaces. However, slight edge crack occurs in the rolled sheet.The remnant inside the extension and extrusion dies was taken out and cut along the ED in order to investigate the microstructure evolution in the longitudinal section, as shown in Fig 4.

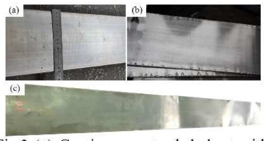

Fig.3 (a) Continuous extruded sheet with 160mm width and 8mm thickness, (b) as rolled sheet with 160mm width and 2mm thickness of AZ31 magnesium alloys, (c) rolled sheet with 140mm width and 1mm thickness of AZ31 magnesium alloys (cut edge).

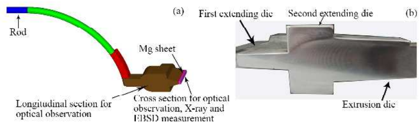

Fig.4 (a) Schematic representation of continuous extrusion and sample preparation for optical observation, EBSD and x-ray measurement, (b) remnant part inside the extending dies and the extrusion die.

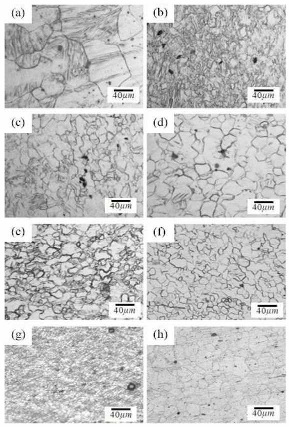

Fig.5 Microstructural evolution in AZ31 magnesium alloys during continuous extrusion, 350°C rolling and annealing processes. Optical microstructure of (a) the extruded rod, (b) near the abutment, (c) extending die entrance, (d) extending die exit, (e) inside the extrusion die, (f) extruded sheet, (g) as-rolled sheet, (h) annealed sheet.

Fig.5 shows the microstructure evolution of the AZ31 magnesium alloy during the continuous extrusion, 350 °C rolling and annealing processes. As a result, refined grains with grain size of 11μm were obtained by the continuous extrusion, hot rolling and annealing processes. As a result, it is obvious that the initial microstructures are greatly refined through the proposed process.

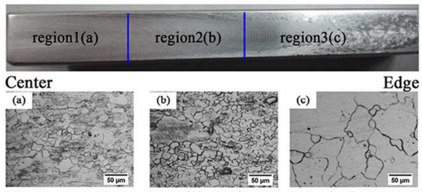

Fig.6 Optical micrographs of the half cross section in the continuous extruded sheet of AZ31 alloys, Optical microstructures in the (a) region1, (b) region 2 and (c) region3.

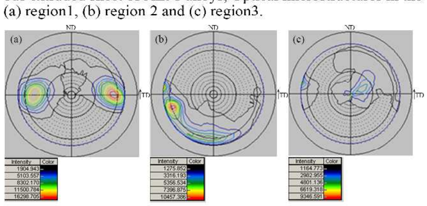

Fig.7 Incomplete (0002) pole figures of the samples in (a) region1, (b) region2 and (c) region3 in the continuous extruded sheet of AZ31 alloys.

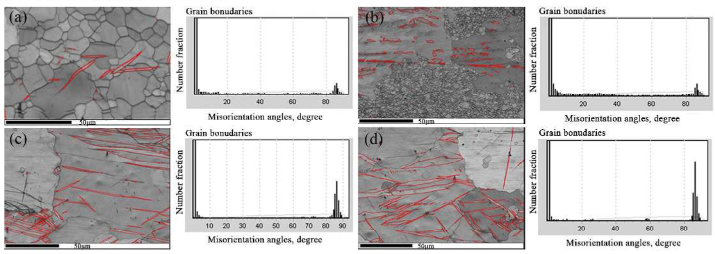

Fig.8 86 °±15° <11-20> twin boundary maps of the continuous extruded sheet of the AZ31 alloy, (a) region1, (b) region2, (c) and (d) region3.

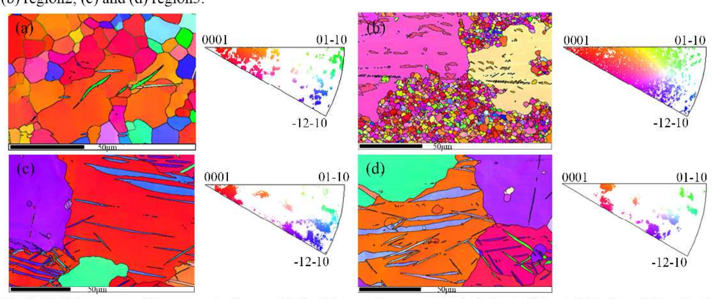

Fig.9 EBSD maps and inverse pole figure (IPF) of the continuous extruded sheet of the AZ31 alloy, (a) region1, (b) region2, (c) and (d) region3.

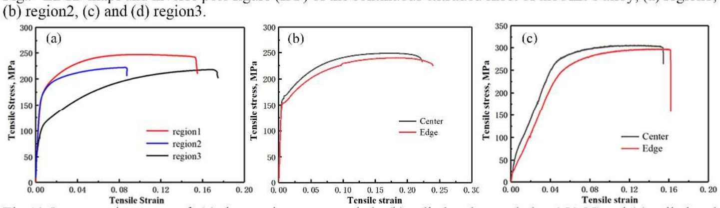

Fig.10 Stress-strain curves of (a) the continuous extruded, (b) rolled and annealed at 350 °C and (c) rolled and annealed at 200°C sheet in AZ31 magnesium alloys.

4. Conclusions

(1) The microstructures of the continuous extruded sheet are inhomogeneous in the cross section. The number of fine grains decreases from the sheet center to the edge.
(2) The (0002) basal intensity decreases from the sheet center to the edge in the continuous extruded sheet of the AZ31 alloys. 86.3°<11-20> twin is a cause of weakening basal texture intensity in the edge region of the extruded sheet.
(3) The tensile properties of the AZ31 alloys after rolling and annealing at 350 °C and 200°C were investigated. The average tensile strength reaches to 245MPa and 309MPa, the elongation is about 23.1% and 18% in the sheet rolled and annealed at 350°C and 200°C, respectively.