MATERIAL PROPERTIES OF AN AZ31 MAGNESIUM ALLOY SHEET AT ROOM TEMPERATURE

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ABSTRACT

Magnesium alloys near room temperature are difficult to mold owing to their strong texture and limited surface slip, necessary basic data is scarce regarding plate pressing with such deformation characteristics, and a press-working process for this sheet material has not be established. In materials development, research aims to improve formability by enhancing the slip system and randomizing the bottom texture. However, this has not led to the forming at room temperature for a complex product shape using deep-drawing or overhang. In this research, material properties in the room temperature zone were assessed using commercially available AZ31 magnesium O sheets as a test material in order to acquire basic data needed for sheet molding at room temperature. We examined the influence of heat treatment conditions on mechanical properties of a magnesium alloy plate. The following results were found: (1) When strengthened Strain-hardened was annealed, its structure was spheroidized and its deformation resistance was reduced. If it was annealed at a temperature of 450°C or higher, its crystal grain size was coarsened and it softened, making it unsuitable for deep drawing formation. (2) The fracture locations of the flange fractures were constant close to 30° if the rolling direction is considered to be 0°. The occurrence of the fractures at the same location is presumably closely related to the gradient of the hexagonal densely-packed structure. Its fracture surface was shaped with glossiness but without irregularities, because simple compressive deformation occurred on the edges, causing sideways slipping of the flanges. (3) The ultimate ductility did not fall up to 400°C at each retention time, then beginning at 450°C, it was less scattered than the fracture extension, but tended to fall. (4) If the annealing process seriously coarsens the crystal grain size, the *r* value does not tend to increase, and the Δr value inclines towards a negative value.

1. INTRODUCTION

In recent years, magnesium alloys have attracted attention in the endeavor to address various requirements such as global environment considerations and reduction of energy consumption; extensive research has been conducted - (Kohzu, 2004). Recently, research has focused on plate molding in the room temperature range, keeping in mind mass production as an advantage of press working - (Hama, 2015). However, because magnesium alloys near room temperature are difficult to mold owing to their strong texture and limited surface slip, necessary basic data is scarce regarding plate pressing with such deformation characteristics, and a press-working process for this sheet material has not be established - (Suzuki, et al.,2009) and (Kohzu, et al., 2010).

In materials development, research aims to improve formability by enhancing the slip system and randomizing the bottom texture. However, this has not led to the forming at room temperature for a complex product shape using deep-drawing or overhang. In this research, material properties in the room temperature zone were assessed using commercially available AZ31 magnesium O sheets as a test material in order to acquire basic data needed for sheet molding at room temperature.

2. MATERIAL AND EXPERIMENT

2.1 Material and annealing method

Commercially available AZ31-O magnesium alloy sheet (Mg-3%, Al – 1%Zn) was used as the test material. The sheet thickness is 0.8 mm. Its chemical composition is shown in Table 1. It was AZ31-O annealed at 360°C for 1 hour when it was received to improve the formability of the hardened Strain-hardened and eliminate its internal stress. Fig.1 shows the crystalline structure of the Strain-hardened before heating and the annealed AZ31-O. The crystal structure is, in the Strain-hardened, a structure with its crystal grains deformed by strengthening by rolling, and in the AZ31-O, is nearly spherical, but the crystal grain sizes are duplex grains distributed in a range from 3 µm to 20 µm on the photograph.

Table 1 Chemical composition [wt. %]

Material	Al	Zn	Mn	Si	Fe	Mg
AZ31	2.96	1.03	0.41	0.01	0.001	Bal.

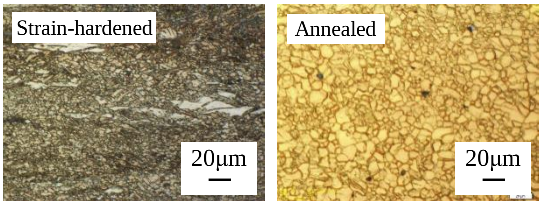

Fig.1 Crystal structure of the commercially available AZ31Mg alloy sheet

The specimens were placed in a stainless steel case which was wrapped in aluminum foil and suspended in a furnace with wire to prevent non-uniform heating. Next, based on a heat treatment time chart, it was heated to the stipulated temperature for 1.5 hours in a 5ℓ/min nitrogen atmosphere, then after retention for the stipulated time, was furnace cooled for 7.5 hours. The heat treatment conditions were 360, 400, 450, and 500°C in an electric furnace and the retention times were 1h, 2h, and 3h.

2.2 Observing the structure and the tensile test

To observe the structure after annealing, a horizontal slice was cut out in the rolling direction for use as the observation slice, it was embedded in resin and polished, then it was etched and observed using a metallographic microscope. The composition of the etchant was acetic acid 10 ml, picric acid 4.2 g, distilled water 10 ml, and ethanol 70 ml. To perform the tensile test, sampling was done at 0°, 45°, and 90° to the rolling direction to prepare 9 JIS-13B specimens—3 for each angle—then using a 10kN Instron tensile testing machine to perform the test at tensile rate of 5 mm/min. To obtain the *r* value, the test was stopped temporarily to measure the W10% sheet width at nominal strain of 10%.

3. TEST RESULTS AND CONSIDERATION

3.1 Annealing and crystal structure

Fig.2 shows photos of the structures of the centers of the sheet thicknesses after annealing of the commercially available AZ31-O under varied conditions. The crystalline grain sizes reveal variation according to annealing temperature and retention time. The average grain size was obtained from the structure photos by the line-segment method. Fig.3 shows the effect of annealing temperature on the average grain size. The average grain size does not change from that of the AZ31-O at delivery time up to annealing temperature of 400°C, but at annealing temperature of 450°C, under the effect of retention time, coarsening is conspicuous, and extremely remarkable coarsening occurs at 500°C.

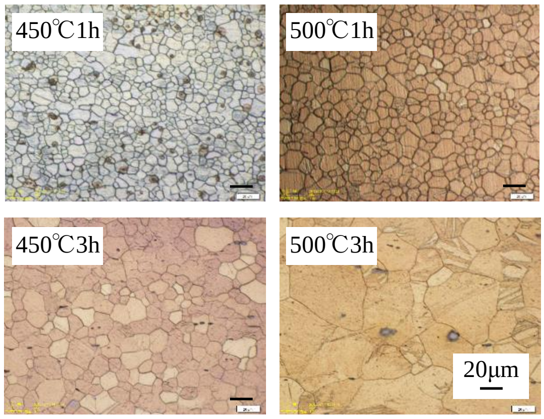

Fig.2 Crystal structure after annealing

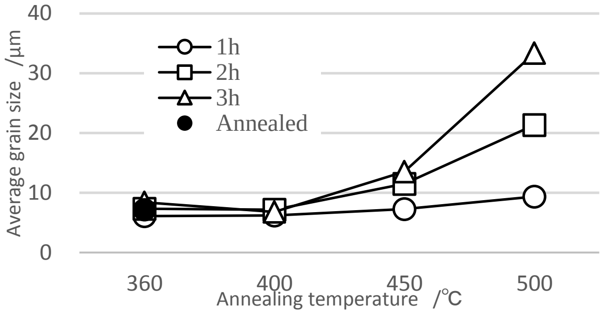

Fig.3 Effect of annealing temperature on average grain size

3.2 Effect of annealing on tensile strength

Tensile tests of the un-annealed material and AZ31-O were performed. Fig.4 shows the stress-strain curve at rolling direction of 0° under each set of conditions. Annealing reduced deformation resistance and increased extension. Fig.5 shows the effect of annealing temperature on the tensile strength. It reveals that from annealing temperature of 450°C, the tensile strength declined remarkably.

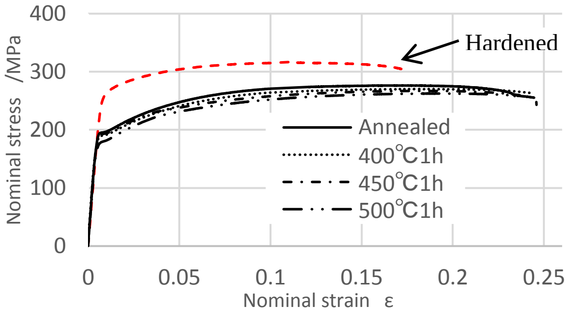

Fig.4 Stress – strain curve

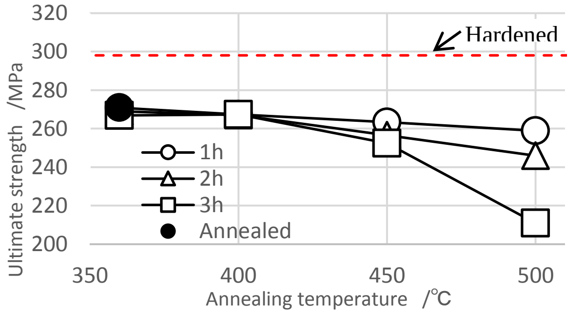

Fig.5 Effect of annealing temperature on tensile strength

3.3 Fracture locations and observing the fracture surface

The cylindrical deep drawing test was done, confirming the locations and shapes of the fractures. A cylindrical deep drawing test was done by preparing specimens made of 2 materials—the commercially available AZ31-O and this material annealed at 450°C for 1 hour—then performing the text using a toshi-type universal deep drawing test machine. The test conditions were a fixed drawing ratio of 2 and BHF under two conditions: 2kN and 10kN in order to investigate the effect of blank holding force (BHF). Fig.6 shows external views of the fracture locations of the cylindrical deep drawing test of two kinds of material: the commercially available AZ31-O material and the same material annealed at 450°C for 1 hour. As shown in Fig.6 (a), the fracture locations of AZ31-O was fracture from the edge of the flange even though its BHF was strengthened. In the material annealed at 450°C for 1 hour, as shown by Fig. (b), fractures occurred from the punch corner if the BHF is strengthened. The reason cited for the difference between the fracture locations is, as shown in Fig.5, insufficient tensile strength at the punch corners as a result of the fall of the tensile strength caused by annealing.

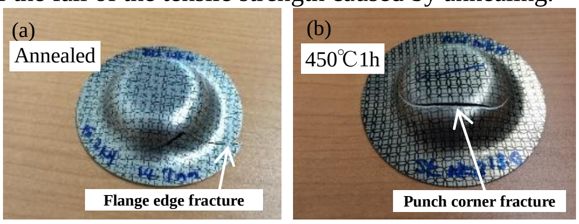

Fig.6 External view of fracture locations caused by cylindrical deep drawing test

Fig.7 shows photos of fracture surfaces of flange fractures and punch corner fractures taken with a 150X 3D profile measuring device. The fracture surface of the flange fracture in Fig.7 (a) is glossy without irregularities. Magnesium is difficult to increase in the sheet thickness direction because of its hexagonal close-packed structure. It is, therefore, assumed that in-plane compressive deformation rotates crystals, causing sideways slipping. The glossiness is presumably caused by slipping to the side at that time. The fracture surface of the corner fracture in Fig.7 (b) features irregularities and is not glossy. It is thought that the punch corners lacked sufficient tensile strength and were pulled apart as a result of the decline of the tensile strength caused by annealing.

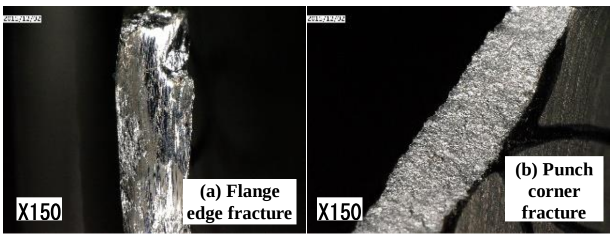

Fig.7 Fracture surface photos (flange fracture (a) and corner fracture (b))

The fracture locations of the flange fractures were, as shown in Fig.8, always constant near 30° if the rolling direction is considered to be 0°. The drawing process, which is deformation of the shrink flange, causes simple compressive deformation on the edges, but this starts side slipping. It is thought that side slipping is a result of low energy side slipping that occurs because magnesium does not easily increase in the sheet thickness direction as a result of its hexagonal close-packed structure. The fact that the fractures occur at the same location is considered to be strongly related to the gradient of the hexagonal close-packed structure, as a result of an aggregate structure of a hexagonal close-packed structure having formed on the sheet material surface.

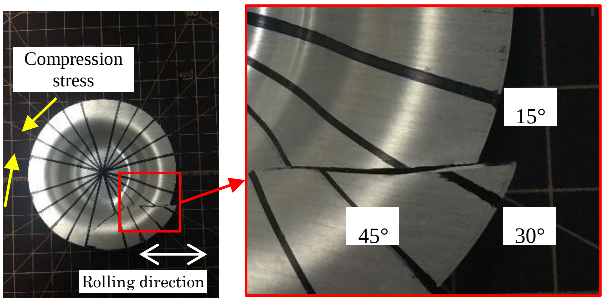

Fig.8 Enlarged view of the part with the fracture location

3.4 Fracture extension and limit deformability

Fig.9 shows the effect of annealing temperature on the fracture extension. In the case of the Strain-hardened, strengthening deformed its structure, lowering its fracture extension. It also shows that in the AZ31-O case, if re-crystalizing the structure, levels its structure, increasing fracture extension, and annealing temperature rises during retention time, the fracture extension falls and is scattered. Annealing at 500°C for 3 hours caused fracture outside the gauge length, so it was omitted from the measurement, but it was about 6.5%.

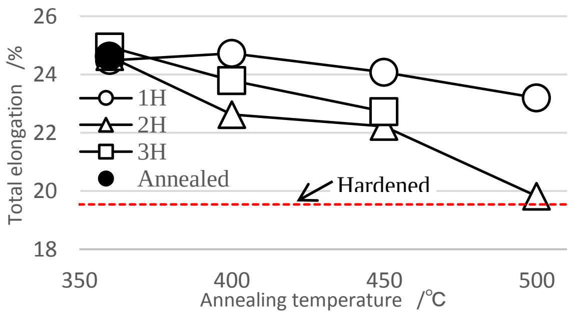

Fig.9 Effect of the annealing temperature on the fracture extension

Next, the ultimate ductility was obtained because near the fractures on the specimens, the strain gradient increases and the length of fracture extension is impacted by the gauge length. The limit deformability permits the unlimited reduction of the gauge length to obtain the true fracture strain of the material in order to avoid the effect of the gauge length, and it can be considered to be a ductility index. Fig.10 shows the effect of annealing temperature on ultimate ductility. It shows that the limit deformability does not decline until 400°C during each retention time, and that at 450°C, its scattering is smaller than that of the fracture extension, but it tends to fall.

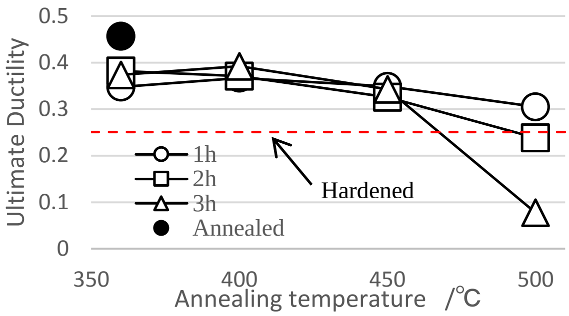

Fig.10 Effect of the annealing temperature on the ultimate ductility

3.5 *r* value and planar anisotropy

Fig. 11 shows the effect of the annealing temperature on the *r* value. It is said that as the *r* value, which represents the sheet thickness anisotropy of the material, increases during deep drawing formation, the formability improves. Within the range of the test conditions of this study, the annealing temperature did not appear to increase the *r* value. As a result of annealing at a temperature of 500°C for 3 hours, the material became fragile and lost its ductility, so it was not possible to measure the *r* value. The ⊿*r* value shown in Fig. 12 greatly effects the formability at anisotropy in each rolling direction, but it reveals that if the annealing temperature exceeds 400°C and retention time is 3 hours, it inclines remarkably to a negative value.

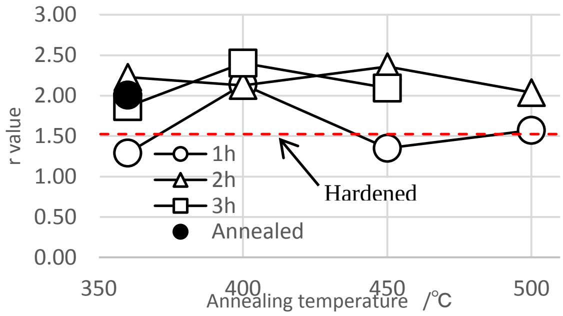

Fig.11 Effect of the annealing temperature on the *r* value

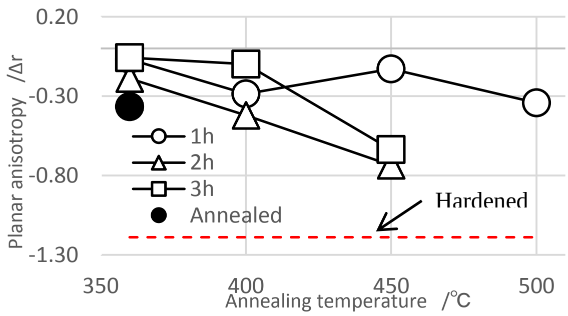

Fig.12 Effect of annealing temperature on the ⊿*r* value

4. CONCLUSION

(1) When strengthened Strain-hardened was annealed, its structure was spheroidized and its deformation resistance was reduced. If it was annealed at a temperature of 450°C or higher, its crystal grain size was coarsened and it softened, making it unsuitable for deep drawing formation.
(2) The fracture locations of the flange fractures were constant close to 30° if the rolling direction is considered to be 0°. The occurrence of the fractures at the same location is presumably closely related to the gradient of the hexagonal densely-packed structure, so in the future, a detailed clarification will be necessary. Its fracture surface was shaped with glossiness but without irregularities, because simple compressive deformation occurred on the edges, causing sideways slipping of the flanges.
(3) The ultimate ductility did not fall up to 400°C at each retention time, then beginning at 450°C, it was less scattered than the fracture extension, but tended to fall.
(4) If the annealing process seriously coarsens the crystal grain size, the *r* value does not tend to increase, and the ⊿*r* value inclines towards a negative value.

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