Study of V-bending deformation Characteristics of Magnesium alloy sheet in Warm Forming

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Abstract. Magnesium alloys have low elongation at room temperature. Warm forming is a common method used for forming of magnesium alloy sheets. In the V-bending process, the bending deformation of magnesium alloy sheet due to effect of strain rate is different at the room temperature and 250℃. The bending behaviour at 250℃ makes the radius of curvature of sheet larger than the punch radius. The results of V-bending deformation of magnesium alloy sheet in warm forming were investigated both experimentally and numerically. Three-point contact occurred due to effect of strain rate at 250℃

1. Introduction

Magnesium alloys have excellent mechanical properties such as specific strength and specific stiffness. However, magnesium alloys have low formability. There have been numerous studies on the formability and springback characteristics of magnesium alloy sheet. Wang et al. [1] studied the characteristics of neutral axis and springback change with temperature in magnesium alloy sheets. Bruni et al. [2] studied the effect of reducing springback as the punch radius decreases with warm air bending of the magnesium alloy sheet. Hama et al. [3] confirmed that the springback is reduced as the temperature increases in draw bending of the magnesium alloy sheet. Nguyen et al. [4] studied the material constitutive equation for springback prediction at various temperatures in V-bending process of magnesium alloy sheet. In these studies, it was found that the magnesium alloy sheet has maximum formability at 250℃ and the springback was found to be minimum.

Warm forming is a forming method to improve formability and to reduce springback. In warm forming, a small punch radius causes defects such as deflection of the sheet towards inner side during V-bending. The strain rate and temperature [5-7] affect the elongation and bending mechanism of the magnesium alloy sheet. In this study, we analyzed the bending deformation characteristics of the magnesium alloy sheet for temperature and punch radius.

2. FE Model set-up

2.1. Material data

In this study, a magnesium alloy sheet(AZ31B) was used. Experimental material properties were obtained from NUMISHEET 2011 benchmark No.2. [8] Figure 1 shows the graphs for strain-stress relationship at various temperatures and strain rates along the rolling direction of the magnesium alloy sheet. Figure 1(a) indicates that the flow curve of the AZ31B decreases as the temperature increases. As the temperature increases due to dynamic recrystallization, the yield strength of the material decreases with increase in elongation. In addition, as shown in Figure 1(b), the flow curve of the AZ31B decreases...
with strain rate at 250°C. The higher the strain rate, the faster movement of dislocations in AZ31B. By preventing sliding of other potentials, the work hardening takes place earlier compared to lower strain rates [9,10].

2.2. Schematic of V-bending process
In the simulation of V-bending, the commercial finite element software ABAQUS/standard v6.17 was employed. An ABAQUS implicit code was used for V-bending process analysis. The sheet element is set to the shell elements. Integration points of sheet along its thickness is 7. The Element type is quadrilateral. The simulation is assumed to be plane strain. The material properties with respect to the temperature and the strain rate were employed in the finite element analysis.

The punch, die and sheet used in V-bending analysis are shown in Figure 2. The width of the punch is 50mm. The width of the die is 80mm. The length of the material is 200mm and its thickness is 1mm. At forming temperature of 523K, the analysis was carried out for two cases of punch radius as 1mm and 4mm. The stroke of the punch after bottoming process is 25.6mm.

3. Experimental Result
Figure 3 shows the formability and springback change of magnesium alloy sheet according to punch radius (Punch R) with respect to temperature. The springback change (Δθ) is defined as the difference in angle between the bottom dead point of material to the springback.

As shown in Figure 3(a), forming is possible at room temperature when punch radius of 4mm, 6mm dimensions. When punch radius was 2mm, the magnesium alloy sheet cracks before 150°C. For a punch radius 1mm, forming was possible after 200°C. Figure 3(b) is the experimental result showing the springback change of magnesium alloy sheet with respect to various punch radius at 250°C. When the
punch radius is smaller than 4mm and, temperature increases, the springback angle shows negative values.

![Graph](image)

**Figure 3.** Formability and springback change of magnesium alloy sheet [10]

4. Bending characteristics with respect to temperature

Figure 4 shows the analysis and experimental results of the bending deformation distribution of the magnesium alloy sheet. The punch radius was 4mm and deformation distribution according to the temperature were analysed. The stroke of punch is 22.24mm.

![Image](image)

**Figure 4.** Bending deformation characteristics of AZ31B at R.T, 250°C. (a) Simulation result at R.T, (b) Experimental result at R.T, (c) Simulation result at 250°C, and (d) Experimental result at 250°C.

Figure 4(a) and (b) show the bending deformation distribution of the magnesium alloy sheet at room temperature. At the room temperature, the punch contacts with the sheet at the center of the punch (one-point contact) at a punch stroke of 22.24mm. The maximum plastic strain of the magnesium alloy sheet is 0.11 at the center of the material. Figure 4(c) and (d) show the bending deformation characteristics of the magnesium alloy sheet at 250°C. At 250°C, the punch contacts with the sheet at the center of the punch and each edge of the punch (three-point contact) at a punch stroke of 22.24 mm. The maximum plastic strain of the magnesium alloy sheet is 0.091 at the center of punch and material. Up to the stroke
of 21.6mm, contact occurs only at the center of material as like in room temperature. From the stroke of 22.24mm, three-point contact of the punch and material occurs.

The effect of the strain rate makes a difference in bending deformation characteristics of the material at room temperature and 250°C. At room temperature, the yield stress difference of the material due to strain rate is small. Plastic deformation may concentrate at the center of the material. At 250°C, The difference in yield stress of the material in relation to strain rate is large as shown in Figure 1(b). During the bending deformation, the center of the sheet shows higher strain rate than other regions. Because of the high strain rate, the center of the sheet has high yield stress. Plastic deformation is widely distributed as shown in Figure 4(c). Finally, the angle of the bent sheet is smaller than the objective angle (90°).

5. Bending characteristics with respect to punch radius at 250°C

Table 1 and Figure 5 show the bending deformation characteristics and the radius of magnesium alloy sheet at 250°C with respect to punch radius. The punch radius was 1mm and 4mm.

| Table 1. The radius of curvature of the material before and after bottoming process at 250°C |
|---------------------------------------------------------------|
| Before Bottoming process | After Bottoming Process |
| Experiment | Analysis | Experiment | Analysis |
| Rp = 1mm | 4.34mm | 4.26mm | 1.17mm | 1.09mm |
| Rp = 4mm | 5.95mm | 5.87mm | 4.13mm | 4.04mm |

Figure 5. Radius of curvature of material according to punch radius at 250°C before bottoming process. (a) punch radius 1mm and (b) punch radius 4mm

The stroke before bottoming is the distance where the material and punch make three-point contact. When the punch radius is 1mm, the punch and material contacted at three-points at punch stroke of 21.59mm. The radius of curvature of material (Material R) is 4.26mm before bottoming and 1.09mm after it. When the punch radius is 4mm, the punch and material are contacted at three-point at a stroke of 22.44mm. The radius of curvature of material is 5.87mm before bottoming and 4.04mm after bottoming.

Considering the effect of strain rate, the strain rate distribution of the material using the punch radius of 1mm is smaller than the punch radius of 4mm. When the punch radius is 1mm, the strain rate is higher than that of the punch radius of 4mm at the same punch stroke at lower punch radius. The yielding occurs earlier near the center of the material due to effect of strain rate. This yielding makes three-point contact early.
6. Conclusion
In this study, the bending deformation characteristics of magnesium alloy sheet were analysed in warm forming. The deformation characteristics of magnesium alloy sheet in V-bending process are as follow. At room temperature, the punch and the magnesium alloy sheet make one-point contact during V-bending process. At 250°C, additional yielding occurs due to effect of strain rate. Through the experiment and analysis, it was concluded that the contact between the punch and magnesium alloy sheet changed from one-point contact to three-point contact. The bending deformation at 250°C was spread widely due to high sensitivity of strain rate. For smaller punch radius, the strain rate of the center was higher. It causes early three-point contact and increases the ratio of radius of curvature of magnesium alloy sheet to the punch radius when compared to that of large punch radius.

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