Cold Deep Drawing of Commercial Magnesium Alloy Sheets

K. Mori[1] (2), H. Tsuji[1]
[1]Department of Production Systems Engineering, Toyohashi University of Technology,
Toyohashi, 441-8580, Japan

Abstract
A cold deep drawing process for commercial AZ31 magnesium alloy sheets was developed. The commercial sheets were successfully formed into circular cups at room temperature by optimising the annealing temperature of the sheets, i.e. a limiting drawing ratio of 1.75 was attained for an annealing temperature of 500 ºC. The increases in elongation, n-value and r-value, and the decrease in flow stress effective in the improvement of drawability were obtained for the annealing. The apparatus for cold deep drawing without heating becomes much simpler than that for the conventional warm deep drawing. The effects of the lubricant, the clearance between the die and the punch and the corner radius of the punch on the drawability were examined. The limiting drawing ratio was increased by applying force onto the edge of a blank through the die corner. In addition, cold deep drawing of magnesium alloy square cups was performed. It was found that comparatively shallow magnesium alloy cups are satisfactorily formed at room temperature without heating.

Keywords:
Magnesium, Sheet, Cold Deep Drawing

1 INTRODUCTION

The application of magnesium alloy to electrical and automobile products tends to increase because of high specific strength. Although magnesium alloy products are mainly produced by die casting and thixomoulding, stamping processes are attractive due to high productivity, small wall thickness, high strength, etc. [1,2]. The magnesium alloy has low ductility at room temperature due to small number of slip systems, whereas the ductility is largely heightened by heating between 200 and 300 ºC [3-5]. Warm and hot stamping is common for the magnesium alloy sheet. In the warm and hot stamping, the formability is improved by local heating of the flange portion by means of a die and blank holder with a built-in heater due to the decrease in flow stress and increase in ductility in the flange portion [6].

Cold forming of magnesium alloy sheets is limited to small deformation processes such as bending, and large deformation processes such as deep drawing and bulging are generally difficult. Although the warm deep drawing has high formability, the apparatus becomes complex due to the build-in of heaters, and thus it is desirable in the stamping industry to develop a cold deep drawing process without heaters. It was reported that the limiting drawing ratio for the cold deep drawing of commercial magnesium alloy sheets is considerably low, 1.2-1.4 [7]. On the other hand, Yamashita et al. [8] have carried out cold deep drawing of magnesium alloy sheets with a rubber ring, and the sandwiching of the magnesium sheet between two aluminium sheets is not practical. Although the temperature in the warm forming is decreased by grain refinements of the sheets, room temperature is not attained yet.

In the present study, a cold deep drawing process of commercial magnesium alloy sheets without heating was developed. The effects of the annealing temperature, lubrication and tool geometry on the drawability were examined from a deep drawing experiment. In addition, prevention of fracture occurrence and deep drawing of square cups were carried out.

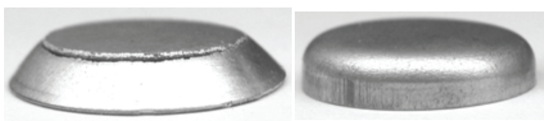
2 COLD DEEP DRAWING PROCEDURE

Cold deep drawing of commercial AZ31 magnesium alloy sheets having 0.5 mm in thickness was performed. The formability of the magnesium sheets at room temperature was improved. In the deep drawing, the die set was installed in a 250 kN screw driven type universal testing instrument. The blank holder force was set at 1 kN by adjusting clamps consisting of a bolt and disk spring. The diameter of the die was 20 mm, the radius of the punch corner was r=2 and 5 mm and the clearance between the die and punch was set at c=0.5, 0.6 and 0.7 mm by changing the diameter of the punch. The lubricants were an oil-based lubricant for deep drawing of aluminium sheets, molybdenum disulfide, Teflon sheets and Teflon spray, and both sides of the sheet except for the interface with the punch were lubricated.

3 COLD DEEP DRAWING OF COMMERCIAL MAGNESIUM ALLOY SHEETS

3.1 Annealing conditions

Since the commercial sheets undergo large deformation during rolling, the fracture occurs even for a low drawing ratio of α=1.32 as shown in Figure 1(a). The magnesium alloy sheet is deeply drawn by annealing the sheet for 500 ºC in temperature and 1 h in holding time as shown in Figure 1 (b). The magnesium alloy blanks were annealed by wrapping the blanks in aluminium foil because of the protection against oxidation.



(a) No annealing (b) Annealing

Figure 1: Cold deep drawing of commercial AZ31 magnesium alloy sheets without and with annealing for α=1.32.

The annealing is effective in improving the cold drawability of the magnesium alloy sheets. The relationship between the limiting drawing ratio and the annealing temperature is given in Figure 2. As the temperature increases, the limiting drawing ratio increases, whereas the annealing temperature was limited up to 500 ºC because of severe oxidation. The following results were obtained for an annealing temperature of 500 ºC.

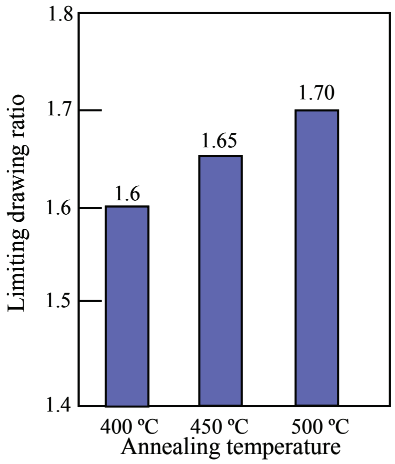
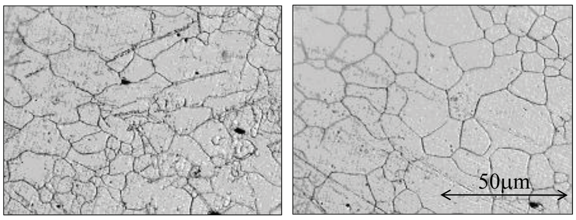


Figure 2: Limiting drawing ratios for different annealing temperatures.

The microstructure of the AZ31 magnesium alloy sheet is changed by the annealing as shown in Figure 3. The grains become round due to the recrystallisation in the annealing.



(a) No annealing (b) Annealing

Figure 3: Microstructures in AZ31 magnesium alloy sheet without and with annealing.

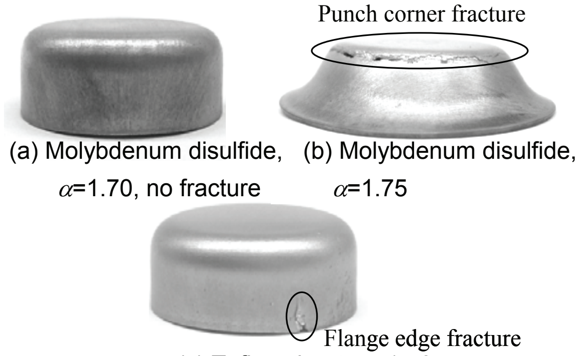
The changes in mechanical properties by the annealing are given in Table 1. The yield stress, tensile strength and hardness are decreased by the annealing, and the elongation, reduction in area, n-value and r-value are increased. This leads to the improvement in drawability.

	No annealing	Annealing
Yield stress [MPa]	213	156
Tensile strength [MPa]	273	246
Vickers hardness [HV]	61.6	54.6
Elongation [%]	18.1	22.2
Reduction in area [%]	20.8	23.3
n-value	0.14	0.27
r-value	1.34	1.70

Table 1: Mechanical properties of commercial AZ31 magnesium alloy sheets without and with annealing.

3.2 Lubrication

The formation of fractures is changed by the lubricants as shown in Figure 4. The fracture occurred around the corner of the punch for the oil-based lubricant, molybdenum disulfide and Teflon spray, whereas the fracture occurred around the edge of the flange for the Teflon sheets.



(a) Molybdenum disulfide, α=1.70, no fracture (b) Molybdenum disulfide, α=1.75

(c) Teflon sheet, α=1.70

Figure 4: Drawn cups without and with fracture for *c*=0.6 mm and *r*=2 mm.

The limiting drawing ratios for the different lubricants, *c*=0.6 mm and *r*=2 mm are shown in Figure 5. The limiting drawing ratio for the molybdenum disulfide is 1.7, whereas those for the oil-based lubricant, Teflon sheets and Teflon spray are 1.65.

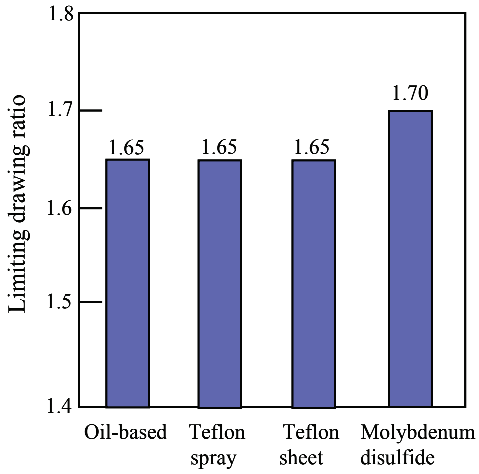


Figure 5: Limiting drawing ratios for *c*=0.6 mm and *r*=2 mm.

The forming load-stroke curves for the different lubricants, *c*=0.6 mm, *r*=2 mm and α=1.65 are shown in Figure 6. The forming load has the two peaks for the drawing of the sheet and for the ironing of the side wall. In the Teflon sheets having good lubrication, the drawing load is small, whereas the ironing load becomes large due to the increase in the amount of ironing by the Teflon sheet thickness, and thus the fracture occurs around the edge of the flange as shown in Figure 4. The following results were obtained for the molybdenum disulfide.

3.3 Effects of clearance between die and punch and radius of punch corner

The defects for the different clearances and punch corner radii are illustrated in Figure 7. For *c*=0.5 mm, the edge of the side wall was torn by the large ironing, and the fractures occurred around the corner of the punch for *c*=0.6 and 0.7 mm and *r*=2 mm, and around the edge of the flange for *c*=0.6 and 0.7 mm and *r*=5 mm, respectively. The fractures around the edge of the flange are special to the magnesium alloy sheets.