

Research on the warm deep drawing of AZ31 magnesium alloy sheet based on DYNAFORM

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Abstract. The effect of forming temperature on the deep drawability (limit drawing ratio (LDR)) of AZ31 magnesium alloy sheet was studied both numerically and experimentally by the use of finite element analysis software DYNAFORM and specially designed warm deep drawing die set. The simulation model was built by SolidWorks 2009, 3-Parameter_Barat model with BT shell unit was adopted as material model. The constitutive relation of the material was provided by uniaxial isothermal tension tests at different temperatures. After being set, all parameters were referred to famous explicit dynamic solver LS-DYNA. The simulation results showed that the LDR of the AZ31 magnesium alloy sheet is increased with the increase of the temperature initially, but after the temperature reached 423K, the LDR reached the maximum, and then decrease with the increase of temperature in the temperature range studied (room temperature–673K). PTEF was used as lubricant in the experiment. Experimental results showed same trend as numerical simulation results in the studied range of temperature, and LDR reached the maximum of 3.0 at 423K. It is shown that the results of numerical simulation have a good agreement with that of the experiment. By analyzing the microstructure of the drawn-cup walls at different temperatures, it is found that grains were stretched along the direction of tension at temperatures lower than 423K. And there appeared a large number of fine recrystallized grains when forming temperature is 423K showing that dynamic recrystallization occurred during forming process. Dynamic recrystallization conducted completely when forming temperature increased higher than 423K, but the material softening would aggravate with the increase of temperature and on the contrary would do harm to the deep drawing of AZ31 magnesium alloy sheet, resulting the decrease of LDR.

Introduction

As the lightest structural metal, magnesium alloys have broad application prospects in the automotive, aerospace and electrical manufacturing industry because of their high specific stiffness and specific strength, good thermal conductivity, electromagnetic shielding and damping properties [1]. Nowadays, the products of magnesium alloys are mainly formed by casting and die-casting. Compared with casting and die-casting, plastic forming technology seems to be more attractive because of its competitive productivity and performance. Among the fabrication processes of plastic forming, stamping of magnesium alloy sheets is especially important for the production of thin-walled structural components [2]. However, magnesium alloy sheets have low ductility at room temperature due to its hexagonal close-packed structure limiting their development and wide application.

Researchers have conducted a lot of useful work to improve the formability of magnesium alloy sheets focusing on the factors influencing the deep drawing performance such as temperature, punch speed, blank holder force, punch and die corner radius, punch and die clearance, lubricant, heat treatment, plate thickness, and so on, among which the most significant is the drawing temperature[3-7]. 523-673K is considered as the suitable temperature range to produce magnesium alloys products by plastic deformation, because when the temperature is above 523K, the plasticity of

magnesium alloy will be improved very much due to new sliding system operated, but if the temperature is over 673K, oxidation will be aggravated. S.H. ZHANG and et al [3] reported that when the forming temperature is between 573-623K and the blank holder force between 6kN -15kN, the magnesium alloy has good formability, and that the LDR of circular cup could exceed 2.0 at the forming temperature of 413K, and can reach 2.6 at the forming temperature of 443K. G. Palumbo and et al [4] reported that a LDR equal to 3.375 is possible when setting the temperature of the blank holder at 503K and the punch speed at 6 mm/min. S. Yoshihara, et al [5] investigated a circular cup deep-drawing process using a magnesium alloy material, and an improvement in the limiting drawing ratio (LDR) from 2.09 to 2.14 at 573K was observed by controlling a variable blank holder force (BHF) during the process, in comparison with the constant BHF conditions. Z.H. Chen and et al [6] discussed the technological parameters including drawing temperature, holder clearance, lubricating method, drawing speed, etc. on formability and found that the formability of the AZ31 magnesium alloy sheet with thickness of 1 mm was better at temperature range 473-548K, and the LDR was 2.14. Most of researchers agree that magnesium alloy sheets usually show good formability above 473K.

There also some researchers making efforts to improve the formability of magnesium alloy sheets at room temperature [8-11]. Even though the formability of magnesium alloy sheets can be improved by the use of special methods, but the LDR is still lower to meet most industrial requirements. When forming temperature is higher than 473K forming dies must be made of high cost antioxidative material and in turn increase the cost of die sets. Further, higher forming temperature will increase the energy consuming. So it is of significant practical meaning to study the deep drawing performance of commercial AZ31 magnesium alloy sheets at temperatures below 473K. In this paper, the deep drawing of AZ31 magnesium alloy sheet was studied both numerically and experimentally by the use of finite element analysis software DYNAFORM and specially designed warm deep drawing die set.

Numerical Simulation

This paper aims to reveal the deep drawing formability of magnesium alloy sheet at temperatures below 473K, but both in simulation and experiment verification the cases where deep drawing is carried out at temperatures higher than 473K are included for comparison. In this study, deep drawing processes were performed at room temperature (RT), 423K, 443K, 473K, 523K, 573K, 623K and 673K. Limit drawing ratio (LDR) was used to evaluate the deep drawability of studied AZ31 magnesium alloy sheets.

Modeling and simulation parameters

The simulation model of deep drawing process was built using SolidWorks 2009, saved as *.igs format, and imported into sheet metal forming FEA software DYNAFORM. The die, punch, blank holder and blank were meshed as shown in Fig. The minimum element size of the blank is 2mm, and that of the punch, die and blank holder are 3mm. 3-Parameter_Barat model with BT shell unit was adopted as material model. After being set, all parameters were referred to the well-known algorithm of explicit dynamic solver LS-DYNA.

In finite element numerical simulation, parameter setting is critical to the validity of the simulation results. The deep drawing process of magnesium alloy sheets can be influenced by many factors, among which the Lankford value r , coefficient of friction and punch speed have obvious effects. The parameters used in the simulation are listed in Table 1. The stress-strain curves were provided by uniaxial tensile tests carried on commercial AZ31B magnesium alloy sheets with a thickness of 1.0mm at different temperatures in [12].

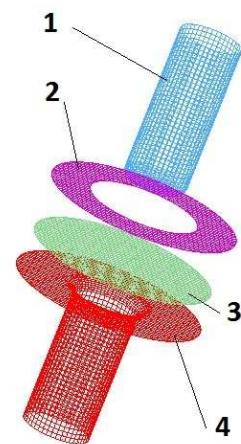


Fig.1 FEA model
(1-punch
2-blank holder 3-blank 4
-die)

Limit Drawing Ratio Tests

Table 1 Parameters used in the simulation

temperautre [K]	RT	423	443	473	523	573	623	673
Young's modulus, E [Gpa]				45				
Poisson's ratio				0.35				
density, ρ [kg.m ⁻³]				1.77				
friction coefficient				0.08				
virtual punch speed				5000				
the Lankford value, r	2.235	2.15	1.85	1.645	1.25	0.9	0.7	0.65

Commercial AZ31 magnesium alloy sheets with a thickness of 1mm, processed into circular specimens with different diameters using wire-cutting were used in the experiments. LDR tests were carried out by the use of a specially designed warm deep drawing die set mounted on a 200kN universal material testing machine at different temperatures. The schematic diagram and geometry dimension of die are shown in Fig. 2 and Table 2 respectively. Before deep drawing, all circular specimens should be polished by the abrasive paper in order to avoid crack in them. Special positioning ring was adopted to fix the specimens. A rigid blank holder was used on the molds, which can offer sufficient blank holder force to press the blank tightly. The blank holder and die were uniformly lubricated with PTEF. The punch was not lubricated.

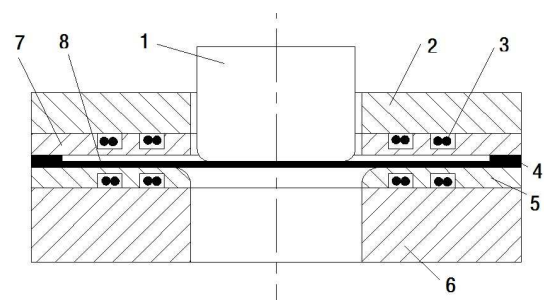


Fig.2 Schematic diagram of the die (1-punch, 2,8-blank holder, 3-heating coils, 4-gasket, 5,6-die, 7-sheet meta)

Table 2 Parameters used in the experiment [mm]

Punch diameter, d_p	Punch corner radius, r_p			Die clearance, Z		Die corner radius, r_d	
40	7			2		9	
Temperature [K]	RT	373	383	403	423	443	473

Microsturcture Observation of Drawn Cylindrical Wall

In order to study the effects of the forming temperature on the microstructure of formed parts, samples are cut from the cylinder wall of drawn cups at different temperatures. The samples are grinded, polished, etched, and observed using optical microscope (OM).

Results and Analysis

The effect of drawing temperature on the LDR of AZ31 magnesium alloy sheet

Fig.3 shows the relations between the LDR of studied AZ31 magnesium alloy sheets and the temperature at which deep drawings were carried out. The results from experiment and numerical simulation were illustrated in Fig.3. It can be seen obviously that the optimum drawing temperature at which the maximum LDR obtained were 423K both in simulation and experiment. When the temperature was lower than 423K, the LDR was improved gradually with the increase of temperature and reached the climax at 423K. In the contrary, when the temperature was over 423K, the LDR would drop with the increase of temperature. Fig.4 gave a 80mm high cylindrical cup drawn from AZ31 magnesium alloy sheet.

It is known that the plasticity of AZ31 magnesium alloy sheet increases with the incese of temperature in uniaxial tensile test, but when the temperature is over a certain value, oxidation will lead to the decrease of the plasticity, so 473-523K is usually considered as a proper temperature range

for AZ31 magnesium alloy sheet forming with the combination of plasticity, energy consumption and die cost. But in our study, a high LDR value of 3.0 was obtained when the temperature is at 423K which is much lower than the conventional forming temperature of AZ31 magnesium alloy sheets. This results can be explained by the real stress and strain relation at different temperatures. When the specimen was tensiled at room temperature, the elongation was only around 15%, when it was tensiled at temperatures of 423-473K, the elongations were all around 50%, but the ultimate tensile strength decreased from 250MPa to 150MPa[12], this will result in the premature fracture in risk point at the transit of cup corner radius and the cup wall due to lower strength when the sheet was drawn at elevated temperatures.

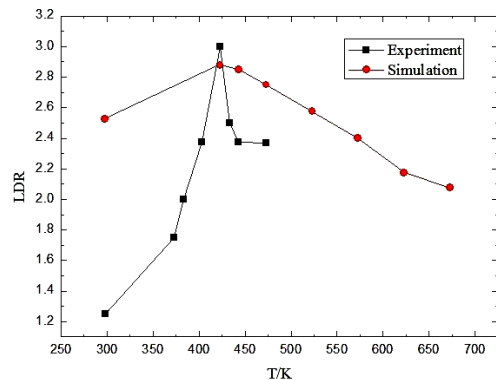


Fig.3 The effects of temperature on LDR Fig.4 The cylindrical cup of 80mm in height
The effect of drawing temperature on the microstructure of drawn cup walls
 The microstructures of drawn cup walls at 403K, 423K, 443K and 473K were shown in Fig.5.

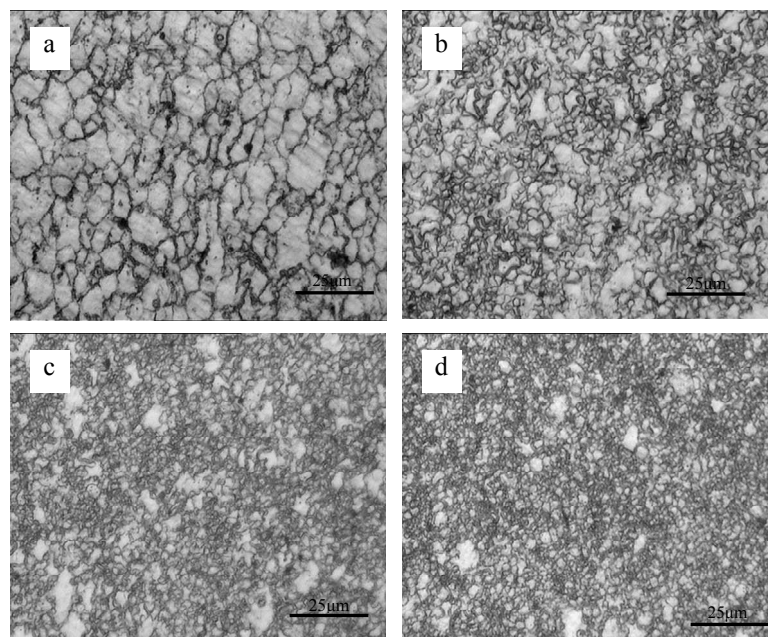


Fig.5 The microstructure of drawn cup walls at different temperatures a) 403K b) 423K c) 443K d) 473K

It can be seen from Fig.5a that, due to the presence of the intragranular slip, the size of the grain has been stretched along the direction of deep drawing during the deformation at 403K, but when the temperature is elevated, it can be observed clearly that the dynamic recrystallization occurred resulting in a large number of the small recrystallized grains, meanwhile the microstructure were refined, but there were still a number of large size of grains in most part of the microstructure at 423K. The occurrence of dynamic recrystallization is also observed in successfully deep-drawn AZ31 cups in literature [7]. Although the microstructure became finer and more homogeneity at temperatures of 443K and 473K in our study, this leads to the hardening rate of the material is less than the rate of dynamic recovery and recrystallization, and results in the drop of LDR.

In Table 3 the LDR of AZ31 magnesium alloy sheets obtained in our study are compared with the results obtained by other researchers under different situations. It can be concluded from the comparison that forming at 423K for AZ31 magnesium alloy sheets in our study is competitive if it is used in the manufacture industry in future.

Table 3 LDR of AZ31 magnesium alloy sheets in different situation

temperature[K]	RT	RT	RT	RT	423	423	423	403
processing way	ECAP	O-773K	O-723K	RUB	DSR	No	No	No
LDR	1.6	1.75	1.72	1.5	1.5	3.0	2.0	2.4
literature	[8]	[11]	[9]	[10]	[14]	this study	[13]	this study

RT-room temperature; ECAP-equal channel angular pressing; RUB-repeated unidirectional bending; DSR-differential speed rolling; O-annealing

Summary

In our study a cylindrical cup of commercial AZ31 magnesium alloy sheet was successfully obtained with the LDR of 3.0 at the drawing temperature of 423K. The simulation results have a good agreement with the experimental results showing that 423K is the optimum temperature for commercial AZ31 magnesium alloy sheets forming.

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