마그네슘 판재의 사각 컵 점진성형 공정의 변수영향 평가

Parametric studies for rectangular cup forming of magnesium alloy sheet at room temperature by using incremental forming

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1. Introduction

In the recently years, many sheet metal forming techniques have been under study in order to develop novel forming processes, such as laser forming, water assisted forming and incremental forming, characterized by high flexibility.[1-2]

Incremental forming (negative or positive) is a recently developed dieless sheet metal forming technique that is gradually evolving towards industrial applicability. In this process a sheet metal part is formed in a stepwise fashion by a CNC controlled rotating spherical tool without the need for a supporting (partial) die. This technique allows a relatively fast and cheap production of small series of sheet metal parts. This process is very well suited to the small volume, varied and complex production of plate [4-6].

From literature [3] magnesium has HCP crystal structure and low ductility at room temperature. Recently Park et al.[4] have successfully applied this forming technique to circular cup forming of magnesium alloy sheet at room temperature. They have revealed that rotating spherical tool in high speed generated naturally temperature rise induced from severe plastic work and friction (between rotating tool and blank) up to 200°C and this assisted plastic deformation of magnesium alloy sheet in room temperature without any heat addition from outside.

In this study, the effect of forming parameters such spindle speed, pitch size, cup wall angle on temperature rise and thickness distribution of the specimen are experimentally investigated for rectangular cup forming of magnesium alloy sheet. Also finite element simulations are conducted and compared with experimental results.

2. Theoretical background

The heat energy of plastic deforming process is defined by.

$$Q=cmdT \tag{1}$$

Where Q is the heat energy, C is the specific heat of material, m is the mass of material, which contact with tool. dT is the volume of temperature change. Also Q is expressed by plastic work W in incremental forming.

$$Q=\eta W=F\cdot S\ ,\quad S=v\cdot t_i\ ,\quad F=\tau\cdot A \tag{2}$$

Where the factor η is a user specified factor which determines which part of the frictional energy loss is transformed into heat (η is between 0 and 1), S is the movement of tool on the material, v $(=r\cdot\omega+v_l)$ is the tangential speed, ω is the angular speed, r is the radius of tool. The key to design of an incremental tool, v_l is the traveling speed of tool, t_i is time of movement. $\tau\ (=\sigma_Y/\sqrt{3})$ is the mean shear yield stress, A is the surface by the limit of contact between tool and blank as shown in Fig. 1.

$$\sigma_Y=\frac{1}{\varepsilon}\int_0^{\varepsilon}\sigma d\varepsilon\ ,\qquad A=\frac{1}{2}\int_0^{\theta}rd\theta\times(2\pi r\sin\theta) \tag{3}$$

Where σ_Y is the yield stress, θ is the interior half-angle of the cone formed by the limit of contact between tool and blank as shown in Fig. 1.

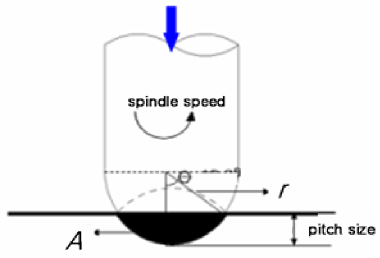


Fig. 1 Schematic view of plastic deforming area

3. Experiment and results

In this study, the material used was a magnesium AZ31B sheet of 1.0mm in thickness. Yield stress of the specimen is 290MPa. The chemical components of the specimen are listed in the Table 1 [3].

Table 1 Standard chemical composition of test material (mass %)

Elements	Al	Zn	Mn	Ni	Fe	Cu	C	Mg
Mass (%)	3	1	0.2	0.2	0.2	0.2	0.2	Bal

A bolt fixture is used to prevent the specimen's draw-in into the die cavity area. The spherical tool diameter is 12mm. As a parameter study we choose the incremental depths (pitch) as 0.5mm and 0.4mm, the wall angles of rectangular cup tested as 45°, 60° and 75°, and also the rotation speed of tool as 1500 rpm and 2200rpm respectively. All specimens are deformed up to a cup height of 12.5mm.

Tool motions are controlled by G-code. Traveling speed of tool is fixed at 600mm/min in all experiments. The concept and tested sample of incremental forming is shown in Fig. 2.

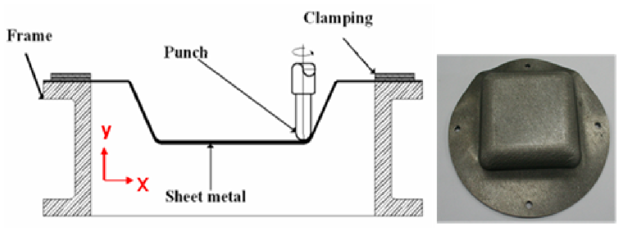


Fig. 2 (a) Configurations of negative incremental forming process and (b) Sample shape formed at room temperature

Figure 3 shows the deformed shape of magnesium alloy sheets without any failure even though the incremental forming was conducted at room temperature.

Figure 4 shows the temperature rise of tested specimen due to plastic work induced from rotating tool with high speed in the case of rectangular cup forming with 2,200rpm, 0.5mm pitch and 45°

cup wall angle. Experiment shows that steady temperature rise observed and maximum temperature is about 135°C when the punch depth reaches at 12.5mm. The comparisons of temperature revealed that theoretical results overestimated the temperature as the forming depth increases.

Figure 5 shows the thickness variation for different cup wall angle. For the cup geometry and forming condition of this study the thickness of specimen becomes thinner as the cup wall angle increases. Specially, minimum thickness are 0.828mm, 0.570mm, and 0.531mm at cup wall angle of 45°, 60° and 75° respectively.

Also maximum temperature and minimum thickness are 155.3°C, 134.4°C and 0.531mm, 0.407mm at the spindle speed of 2200rpm and 1500rpm respectively.

Fig. 3 Deformed shapes of rectangular cups (half cut) for (left) 2,000rpm and 45° and (right) 1,500rpmn and 75°

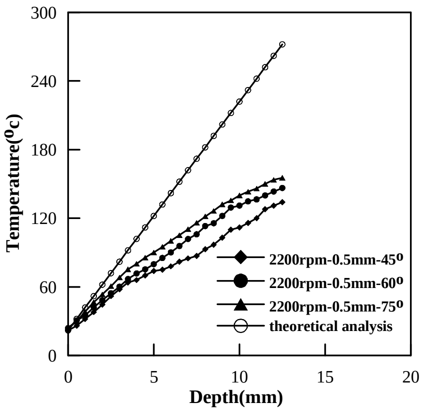


Fig. 4 Comparisons of temperatures of sheet metal between theoretical and experimental results

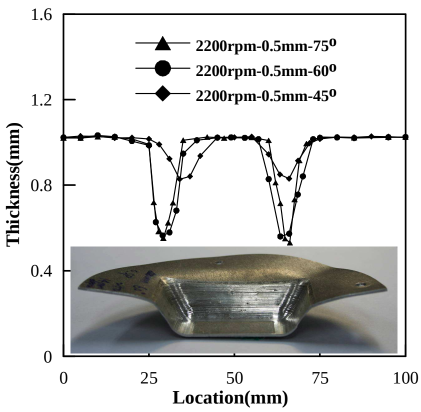
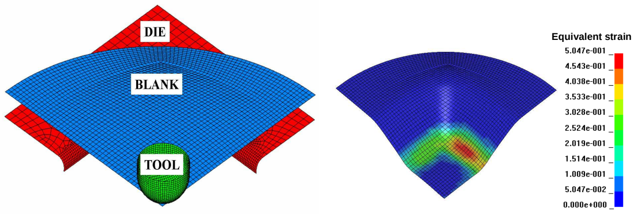


Fig. 5 Thickness variation of specimens at different cup wall angle (inside photo is for 2,000rpm and 60°)

4. FEM simulation

Finite element simulation for the incremental forming process of magnesium alloy sheet was performed using the LS-Dyna 970, dynamic explicit code. Due to the symmetric geometry, a 1/4 model was adopted with proper boundary conditions along the edges and modeled with shell elements.

Figure 6 shows a FEM model and deformed mesh shape for the 12.5mm cup height of 45° cup wall angle. In Figure 7 thickness variation between simulation and experiment is compared.



(a) (b)

Fig. 6 (a) FEM model for incremental forming simulation
(b) Deformed mesh shape with equivalent strain contour

From Fig.7 the thickness variations of FE simulation results are compared with the experimental results and both are well coincide.

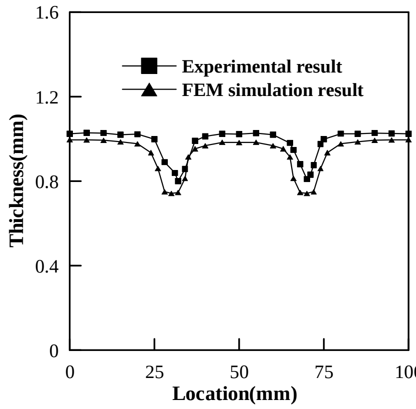


Fig. 7 Comparisons of thickness variation between FE simulation and experimental results

5. Conclusions

In this study, the effect of forming parameters for incremental forming of rectangular cups haves been clarified.

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