Finite Element Analyses of Conventional Single Point Incremental Forming and Friction Stir Incremental Forming of Aluminum Alloy Sheets

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FINITE ELEMENT ANALYSES OF CONVENTIONAL SINGLE POINT INCREMENTAL FORMING AND FRICTION STIR INCREMENTAL FORMING OF ALUMINUM ALLOY SHEETS

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ABSTRACT

Friction stir incremental forming process for forming A5083 aluminum alloy sheets was calculated by finite element method. Conventional incremental forming process was also calculated and the both calculated results about distributions of temperature, plastic strain and deformation after springback were compared each other. Metallurgical change was not taken into account in the calculation. The maximum temperatures of sheet during forming in friction stir incremental forming and conventional incremental forming were 380 ^{o}C and 60 ^{o}C, respectively. Both distributions of equivalent strain in friction stir incremental forming and conventional incremental forming were almost uniform, however, absolute value in friction stir incremental forming was greater due to the shear strain introduced by tool rotation. Displacement in Z-direction by conventional incremental forming was uniform, however, that by friction stir incremental forming was not uniform since the temperature difference between during and after forming was large.

INTRODUCTION

Development of technology for small lot production is required in industry. Die less forming is one of the candidates for the solutions. Incremental forming process is a kind of die less forming methods for sheet metals. Incremental forming can form pure aluminum sheets into three-dimensional shape with large deformation, however, it is difficult to form high strength aluminum alloy sheets. To improve formability of high strength aluminum alloy sheets by incremental forming method, the authors developed friction stir incremental forming method (1, 2 and 3). In this study, to clarify the mechanism of formability improvement by friction stir incremental forming method, finite element analyses for both conventional incremental forming method and friction stir incremental method were carried out and the results were compared with.

COMPUTATIONAL METHOD

The commercial FEM code Simufact.Forming 11.0 was used for the calculation. Three-dimensional model shown in Figure 1 was used. Dimension of both the die and blank holder is 100 mm x 100 mm x 5 mm and they have a square hole of 50mm x 50mm in the center. Length and diameter of a forming tool are 70 mm and 6 mm, respectively. The top shape of the forming tool is hemispherical. A5083 aluminum alloy sheets were used in the calculation. The material properties of A5083 in the library of Siumufact.Forming 11.0 was used. Tool feed rate was fixed to v = 2000 mm/min. Tool rotation rate were ω = 0 and 7000 rpm. Shear friction coefficient between the sheet and forming tool was 0.4. The sheet was divided into tetrahedral elements of 1 mm and finer elements were used at the plastically deformed area. The total number of elements

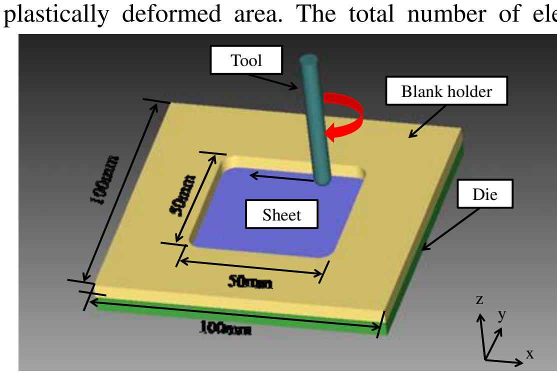


FIGURE 1 - FE MODEL

were 16398. Forming path was a 40 mm x 40 mm square and the corners were quarter arc of 10 mm in radius. The forming tool was moved first for one side of square with gradually push into the sheet for 0.5mm and then, moved in horizontal direction for other 3 sides. For the sake of simplicity, effects of microstructure changes such as dynamic recrystallization were not taken into account in the computation. The computational conditions and flow stress stored in the library of the simulator, and the working conditions are shown in Table 1 and Figure 2.

CALCULATED RESULTS AND DISCUSSIONS

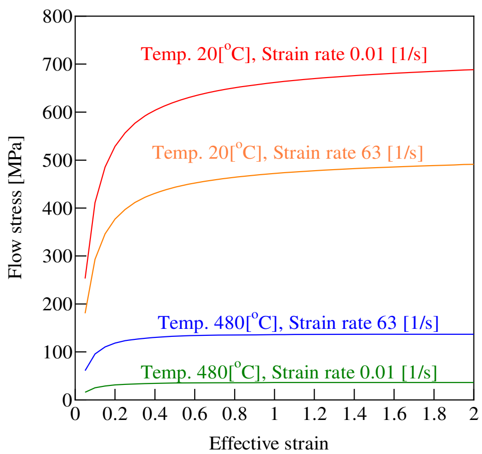


FIGURE 2 - FLOW STRESS CURVES

Temperature

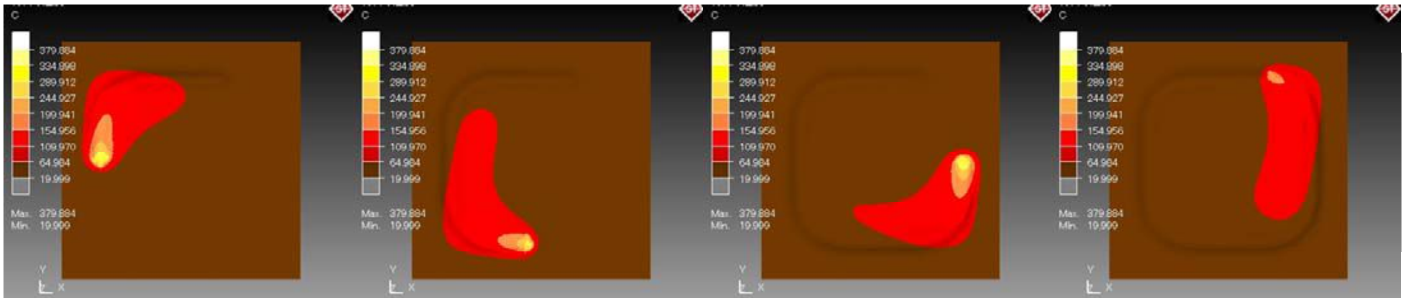
Temperature distributions are illustrated in Figure 3. When the tool rotation rate was $\omega = 0$, this means the conventional incremental forming, the maximum temperature was 60 °C. In the case of ω = 7000 rpm, this means friction stir incremental forming, that was 380 °C. This temperature is higher than the static recrystallization temperature of 5000 series aluminum alloys of about 330 °C. Since temperature of sheet at deformation area is elevated, elongation of the material at deformation area improved and formability is also improved.

Equivalent strain

After forming, the tool and blank holder were removed and formed sheet shows springback. Distributions of equivalent

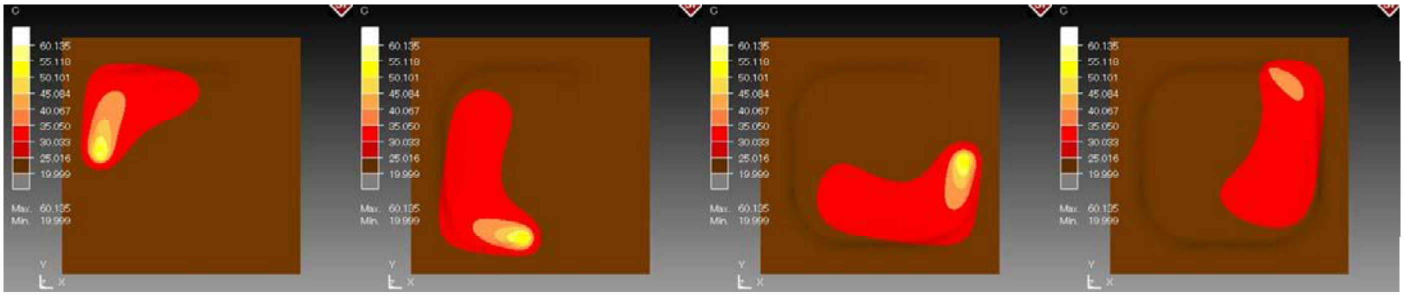
TABLE 1 - COMPUTATIONAL CONDITIONS

Sheet	Poisson's ratio	0.25
	Density [Mg/m^3]	2655
	Number of elements	16398
	Initial sheet temperature [°C]	20
	Heat transfer coefficient to ambient [W/m^2·K]	50
	Emissivity for heat radiation to ambient	0.25
Blank holder Die Tool	Blank holder, die and tool temperature [°C]	20
	Heat transfer coefficient to ambient [W/m^2·K]	50
	Thermal conductivity [W/m^2·K]	20000
	Emissivity for heat radiation to ambient	0.25
Working conditions	Tool feed rate [mm/min]	2000
	Tool rotation rate [rpm]	0, 7000
	Shear friction coefficient	0.4



(a) 1.40 s **(b) 2.44 s** **(c) 3.55 s** **(d) 4.36 s**

(i) ω = 7000 rpm



(a) 1.40 s **(b) 2.44 s** **(c) 3.55 s** **(d) 4.36 s**

(ii) ω = 0 rpm

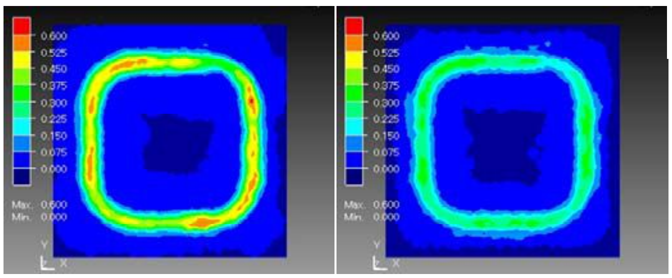
FIGURE 3 - TEMPERATURE DISTRIBUTION

plastic strain after springback is shown in Figure 4. Both distributions of equivalent strain in friction stir incremental forming and conventional incremental forming were almost uniform, however, absolute value in friction stir incremental forming was greater due to the shear strain introduced by tool rotation. This reason is the effect of additional shear strain by tool rotation.

It is considerable that in case of friction stir incremental forming, dynamic recrystallization may occur due to introducing large strain with large strain rate and becoming temperature at deforming area higher than static recrystallization temperature, and super plasticity may appear.

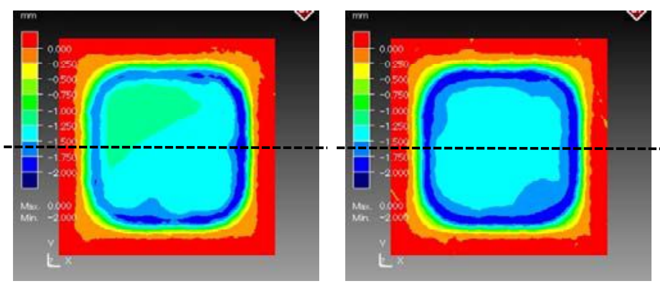
Formed shape

Displacement distributions in z direction and cross-sectional shapes after springback are shown in Figures 5 and 6, respectively. Displacement in Z-direction by conventional incremental forming was uniform, however, that by friction stir incremental forming was not uniform since the temperature difference between during and after forming was large. This reason was the thermal expansion due to temperature difference between during forming and after cooling down to room temperature. Distortion of formed sheet by friction stir incremental forming is smaller than that by conventional incremental forming in experiment. The calculated results does not meet the experimental one. So the effects of microstructure change during forming should be taken into account in the computation.



(a) ω = 7000 rpm (b) ω = 0 rpm

FIGURE 4 - DISTRIBUTIONS OF EQUIVALENT PLASTIC STRAIN AFTER SPRINGBACK



(a) ω = 7000 rpm (b) ω = 0 rpm

FIGURE 5 - DISTRIBUTIONS OF DISPLACEMENT IN Z DIRECTION AFTER SPRINGBACK

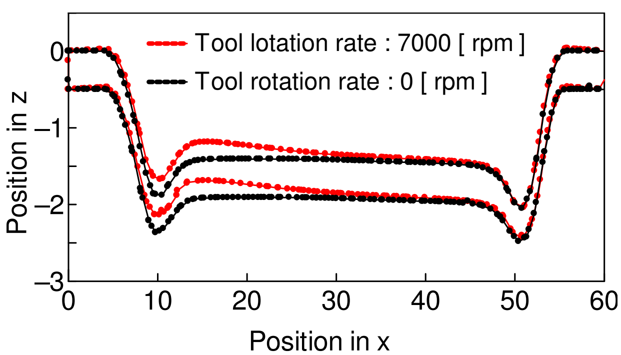


FIGURE 6 - CROSS-SECTIONAL SHAPE OF FORMED PARTS AFTER SPRINGBACK

CONCLUSIONS

The commercial FEM code Simufact.Forming 11.0 was used for analysis of both friction stir incremental forming and conventional single point incremental forming processes. It is considerable that reason of formability improvement is not only elongation enhancement dependent on temperature but also occurrence of dynamic recrystallization and super plasticity resulted from the introduction of equivalent strain and temperature elevation, improvement. Springback by friction stir incremental forming was greater than that by conventional incremental forming, and this tendency is different from experimental results. It is necessary that microstructure change of sheet metal such as dynamic recrystallization during forming is taken into account in the analysis in the future.

NOMENCLATURE

ω : Tool rotation rate

v : Tool feed rate

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REFERENCES

[1] M. Otsu, H. Matsuo, M. Matsuda, K. Takashima (2010). "Friction Stir Incremental Forming of Aluminum Alloy Sheets." *Steel Res. Int.*, 81(9), pp. 942-945.

[2] M. Otsu, T. Ichikawa, M. Matsuda, K. Takashima (2011). "Improvement of Formability of Magnesium Alloy Sheets by Friction Stir Incremental Forming." *Steel Res. Int.*, Special Edition, pp. 537-541.

[3] M. Otsu, H. Arai, M. Matsuda, K. Takashima (2012). "Friction Stir Incremental Forming of Titanium Sheets.", *Steel Res. Int.*, Special Edition, pp. 419-422.