Recent Research and Developments of LS-DYNA®'s user subroutine in JSTAMP/NV®

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Abstract

Sheet metal forming simulation has been widely used in die design process, in order to make lightweight products and shorten production lead time. JSOL Corporation has been developing JSTAMP/NV® since 1996 and continuously supplying the best stamping simulation environment for users. One of the most competitive advantages of JSTAMP/NV is its accuracy on the evaluation of formability when using explicit and implicit solutions in LS-DYNA®. In this paper, new material model and user subroutine of anisotropic plasticity with temperature dependency were developed for hot forming simulation by authors. Using the developed material model, the formability of deep drawing of a magnesium alloy was estimated with the high accuracy compared with experimental results.

Introduction

In the industries such as automotive, appliance, and electronics, much effort is taken to develop lightweight products, to reduce the costs and to shorten the lead time. Because of this situation, a press simulation software package JSTAMP/NV has been receiving a lot of demands from customers, and has met many of the demands by offering advanced capabilities [1-2]. A hot forming analysis is the one of the capability [3].

In this paper, a benchmark problem of hot forming 'Simulation of the Cross-Shaped Cup Deep-drawing Process' supplied by conference committee of NUMISHEET2011 was taken as an example [4]. The conference is characterized by several opening benchmark problems.

One of the benchmark problems is to simulate the formability of magnesium alloys. Magnesium alloys usually exhibit poor formability at room temperature because of their micro structure, but the forming limit can be increased at high temperature. The practicability and the accuracy of JSTAMP/NV were validated by this benchmark problem.

Tooling Specification and its numerical modeling

The tool geometry is shown in the following figure. This model is opened in NUMISEET2011[4]. Only one fourth of geometry is modeled due to their symmetry conditions.

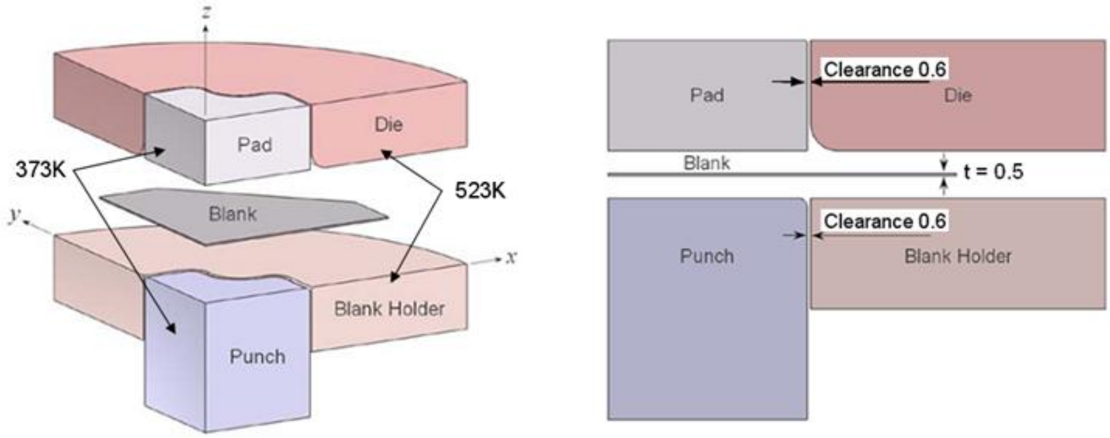


Fig.1 Tool geometry

We state the tool specification as following.

- Clearance between the pad and the die: 0.6 mm
- Clearance between the punch and the blank holder: 0.6 mm
- Thickness of the blank: 0.5 mm
- Surface temperature of tool
  - Die : 523K, Blank holder : 523K, Punch : 373K, Pad : 373K
- Punch velocity: 0.15mm/s
- Drawing depth: 18mm
- Blank holding force and Pad force: shown following Figure 2.

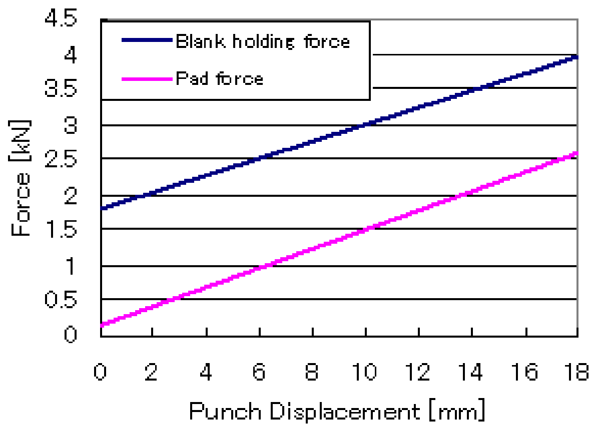


Fig.2.Blank holding and Pad force

Numerical modeling of tools and blank and their temperature conditions are shown in Fig.3. At the beginning in the forming process, the blank is contacting with all tools. It is assumed that the temperature distribution of the blank have reached a steady state when the punch start to move up.

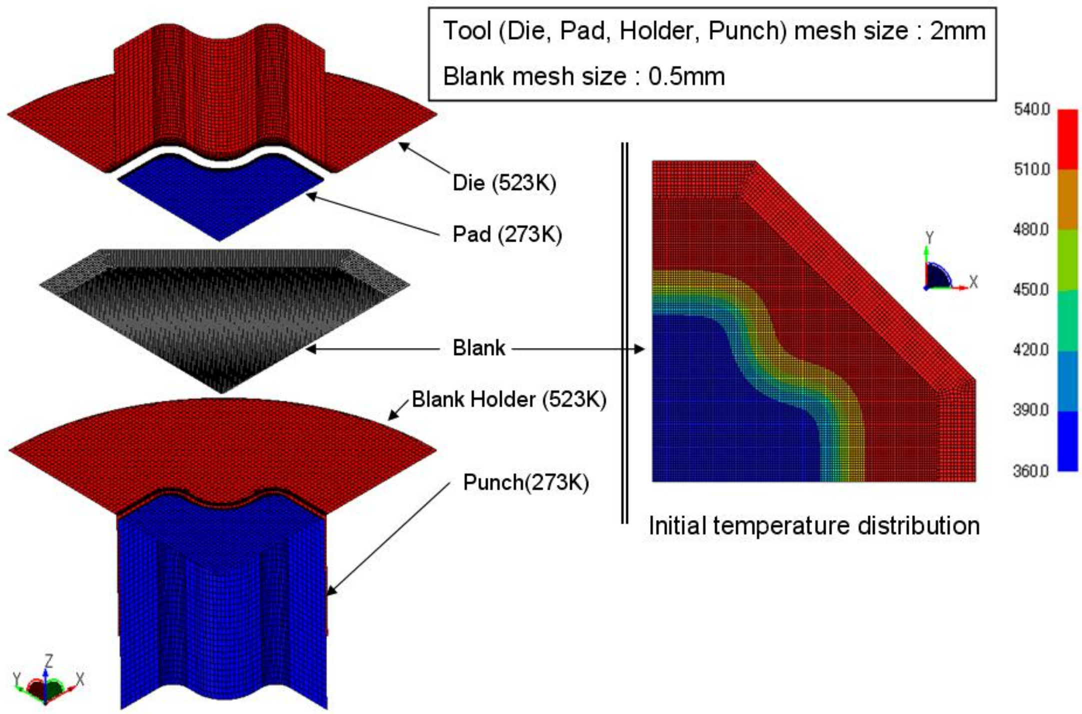


Fig.3 Numerical modeling and thermal condition

Properties of Magnesium alloy sheet and its numerical modeling

The mechanical and thermal properties of magnesium alloy sheet are shown in Table 1 as described in the definition of the benchmark problem of NUMISHEET2011 [4].

Table 1. Mechanical and thermal property of magnesium alloy

Young's modulus	45GPa
Poisson's ratio	0.35
Density	1770kg/ m^3
Thermal conductivity	96W/(m・℃)
Heat Capacity	1000J/(kg・℃)
Interface heat transfer coefficient	4500W/(m^2 ・℃)
Coulomb friction coefficient	0.1

Stress-Strain relations with temperature dependency are shown in Fig.4. The figure shows that the maximum load decreases with increasing temperature. In this study, The stress-strain relations at strain rate 0.0016/s from provided data are used in the simulation.

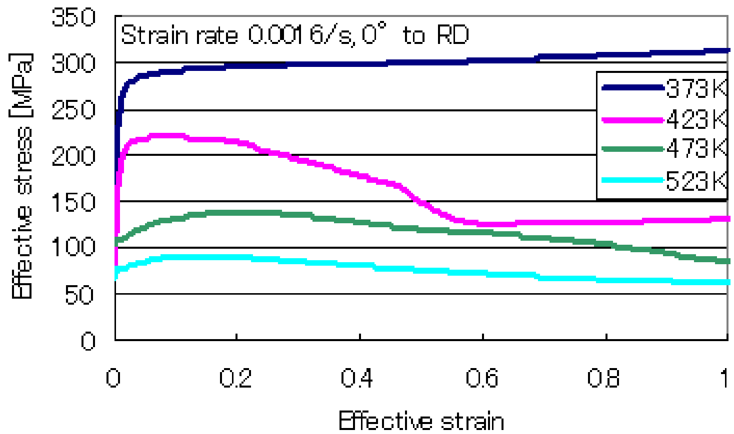


Fig.4 Stress – Strain relation at different temperature

The anisotropic r-values with temperature dependency are shown in Table 2.

Table 2. Anisotropic r-values

Test direction	Strain rate : 0.016 /s					
	Temperature [℃]					
	RT	100	150	200	250	300
0°	1.347	2.006	1.291	1.621	1.344	1.374
45°	2.793	2.412	1.976	2.118	1.532	1.477
90°	4.109	4.406	3.189	2.672	1.799	1.881
Mean	2.760	2.809	2.108	2.132	1.552	1.552

A difficulty of this bench mark problem is considering anisotropy which depends on temperature. Usually, a material model for hot stamping does not consider its anisotropy. If the temperature is high enough, it may be possible to neglect the anisotropy. However, the change of anisotropic r-values in this problem is quite large as shown in Table 2. To improve the simulation accuracy, we need to consider the anisotropic r-values.

To consider the anisotropy, in hot forming process, we developed a material model of anisotropic plasticity with temperature dependency and its user-material subroutine. We show the formulation of the material model as following. The yield function is Hill'48 type [5].

$$F(T)\cdot(\sigma_y-\sigma_z)^2+G(T)\cdot(\sigma_z-\sigma_x)^2+H(T)\cdot(\sigma_x-\sigma_y)^2+2N(T)\cdot\sigma_{xy}^2+2L(T)\cdot\sigma_{yz}^2+2M(T)\cdot\sigma_{zx}^2=\sigma_Y^2(\bar{\varepsilon}^p,T) \tag{1}$$

where T implies temperature, $F(T), G(T), H(T), N(T), L(T), M(T)$ are anisotropic parameters which depend on temperature T, and $\sigma_Y(\bar{\varepsilon}^p,T)$ is yield stress which depends on effective strain $\bar{\varepsilon}^p$ and temperature T. The anisotropic parameters can be simple calculated from the r-values as following.

$$\begin{cases} H(T) = \dfrac{R_{00}(T)}{1+R_{00}(T)} \\ \mathrm{G(T)} = \dfrac{1}{1+R_{00}(T)} \\ F(T) = \dfrac{R_{00}(T)}{[1+R_{00}(T)]R_{90}(T)} \\ N(T) = \dfrac{[1+2R_{45}(T)][R_{00}(T)+R_{90}(T)]}{2[1+R_{00}(T)]R_{90}(T)} \\ L(T) = 1.5 \\ M(T) = 1.5 \end{cases} \tag{2}$$

The hardening modulus with strain H' and the hardening modulus with temperature H^T are given by following equations [6].

$$H' = \frac{\partial \sigma_Y(\bar{\varepsilon}^p, T)}{\partial \bar{\varepsilon}^p}, \quad H^T = \frac{\partial \sigma_Y(\bar{\varepsilon}^p, T)}{\partial T} \tag{3}$$

Then we have yield stress increment of rolling direction as following.

$$d\sigma_Y(\bar{\varepsilon}^p, T) = H' d\bar{\varepsilon}^p + H^T dT \tag{4}$$

When we consider the thermal expansion, the total strain increment $\Delta\varepsilon$ is given by the sum of the elastic strain increment $\Delta\varepsilon^e$, the plastic strain increment $\Delta\varepsilon^p$ and the thermal strain increment $\Delta\varepsilon^T$ [6].

$$\{\Delta\varepsilon\} = \{\Delta\varepsilon^e\} + \{\Delta\varepsilon^p\} + \{\Delta\varepsilon^T\} \tag{5}$$

The case where we assume Young's modulus depends on temperature, the stress increment is computed as following [6].

$$\{\Delta\sigma\} = [D^e](\{\Delta\varepsilon\} - \{\Delta\varepsilon^p\} - \{\Delta\varepsilon^T\}) + \frac{\partial E}{\partial T}\frac{1}{E}\{\sigma\}\Delta T \tag{6}$$

FEA results and discussion

In this section we show some simulation results. To discuss the effect of anisotropy, we computed two cases. One is the case where Mises type yield function is used. Using Mises yield function implies that r-value parameters R00, R45, R90 are 1.0. The other is the case where Hill'48 type yield function is used. The formulation of Hill'48 type is stated in the previous section. By using Hill'48 type yield function we can consider the anisotropic property in Table 2.

First we show simulation results of Punch load – Punch stroke relations with experimental result in Fig.5. This experimental data is opened in the proceedings of NUMISHEET2011. The figure shows that both the case Mises type and the case Hill'48 type predict maximum load accurately.

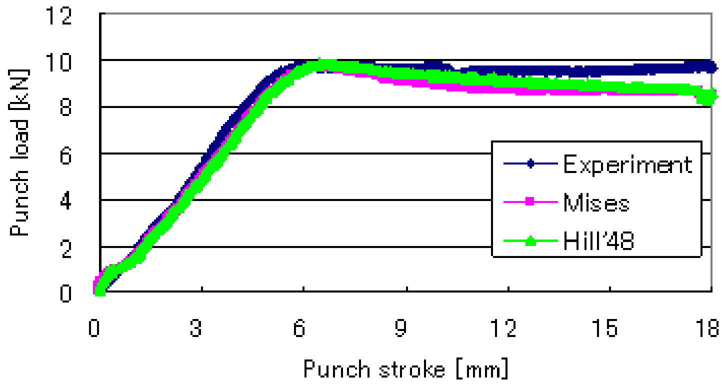
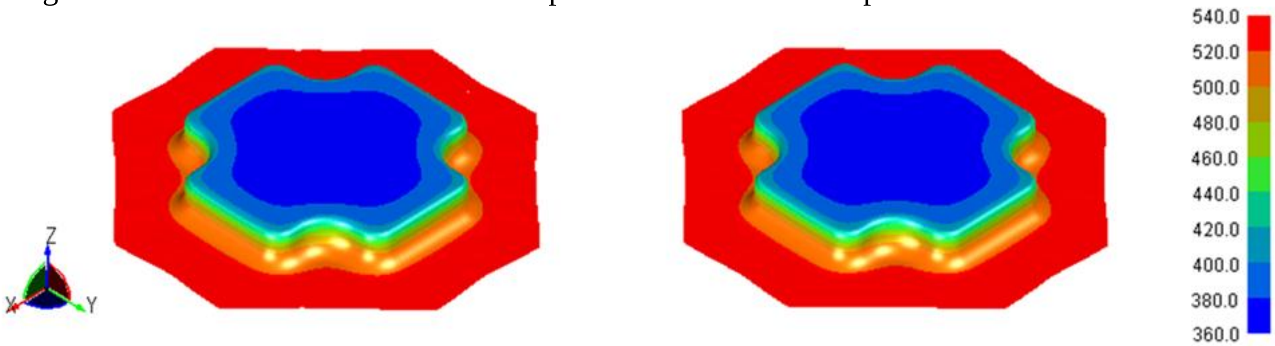


Fig.5 Punch load vs Displacement

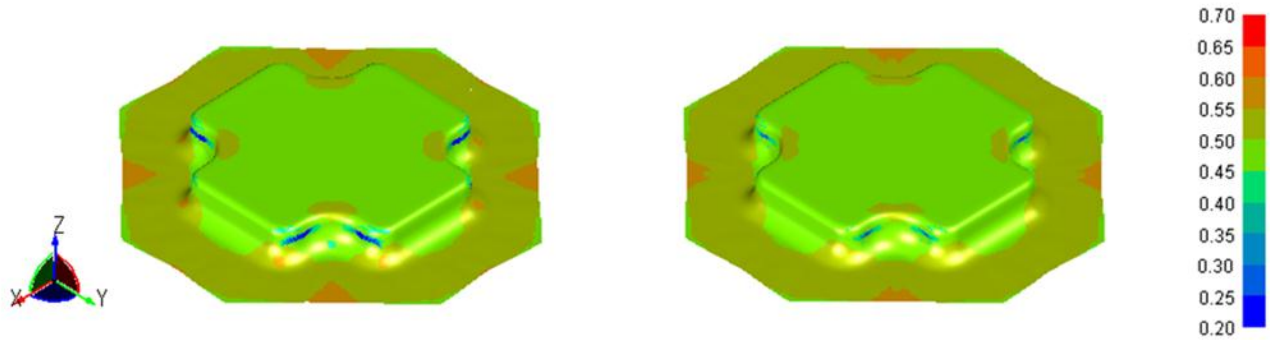
We show the temperature distribution on the blank at the punch stroke 10mm in Fig.6. There are no significant differences between the isotropic case and the anisotropic case.



(a) Mises (b) Hill'48

Fig.6 Temperature Distribution

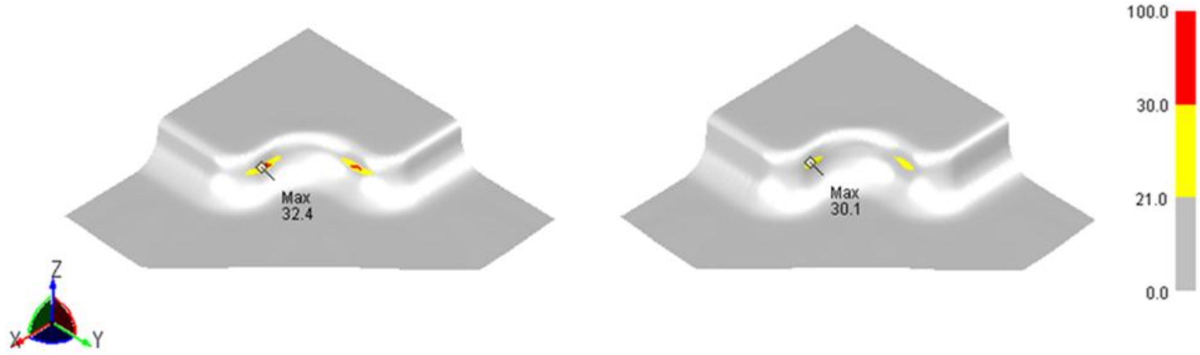
Fig.7 shows the thickness distribution of the blank at punch stroke 10mm. In this figure, we can see that the result of Hill'48 show less thickness decreasing.



(a) Mises (b) Hill'48

Fig.7 Thickness Distribution

We predict the forming limit and the failure location. First, we show the failure prediction which is based on thinning. Let criterion value be 30%. We usually use this criterion value in the case where the blank material is a normal steel sheet. Fig .8 shows the failure prediction.



(a) Mises (Stroke: 8.39mm) (b) Hill'48(Stroke: 10.32mm)

Fig.8 Failure Prediction by Thinning

We state the computational result of the limit punch stroke and the coordinate of failure location with experimental results in Table 3.

Table 3 Failure location

	Punch stroke [mm]	Failure location (x,y,z) [mm]
Experiment	10.00	(31.00, 18.00, 6.61)
Simulation (Hill)	10.32	(29.98, 18.39, 7.09)
Simulation (Mises)	8.39	(30.05, 18.39, 5.04)

As we have showed above figures, there are no significant differences in terms of failure location of the blank. However, by the effect of anisotropy, the forming limit based on Hill'48 type is higher than that based on Mises type. Moreover, table 3 shows that the result of Hill'48 type is closer to experimental results than that of Mises type.

We discuss the results given by the criterion of thinning. Following figure.9 shows the forming limit diagram at various temperatures, which is provided data. By the temperature of the failure location that is based on thinning, we choice the curve with 473K to make an estimate based on FLD [5].

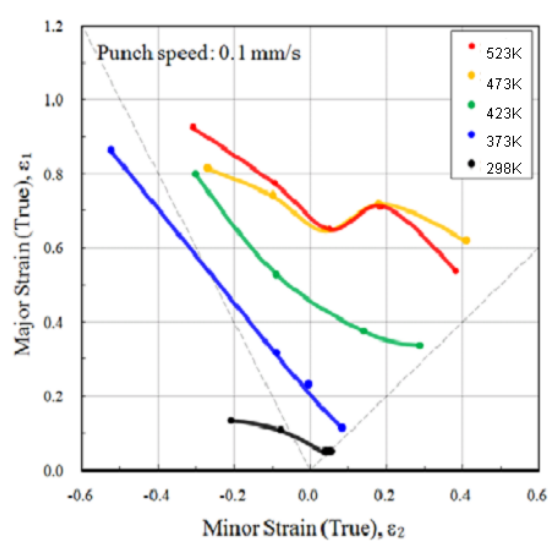
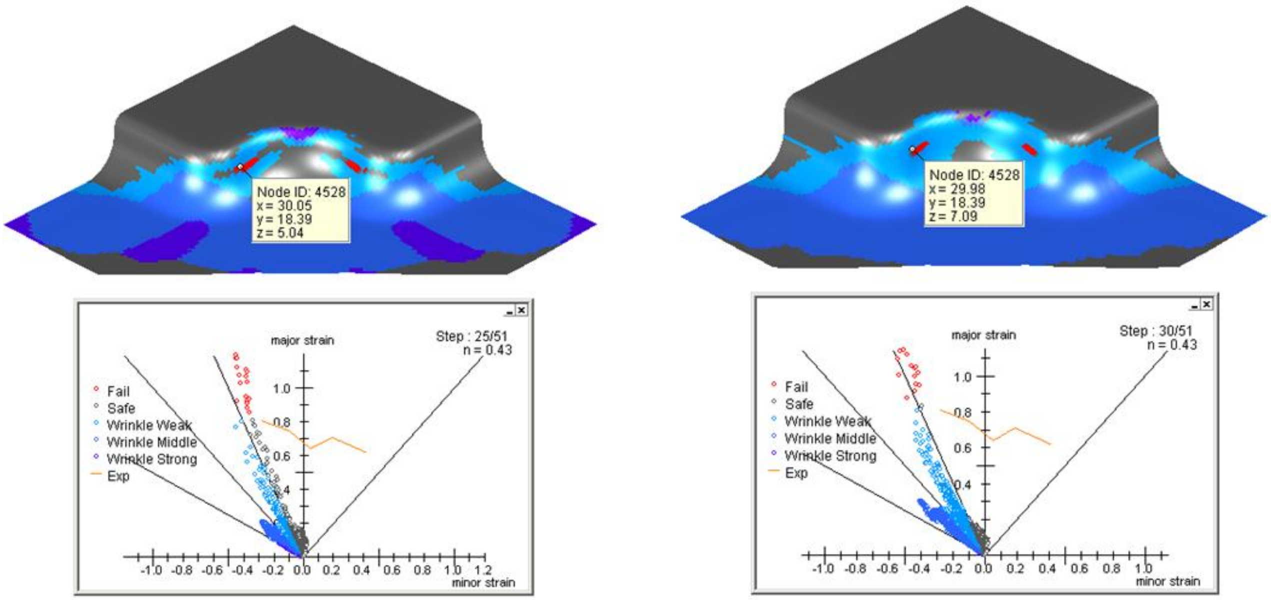


Fig.9 FLD at various temperature

Figure.10 shows the failure prediction based on FLD at the limit punch stroke. These figures verify the validity of the estimation which is given by thinning.



(a) Mises   (b) Hill'48

Fig.10 Failure Prediction by FLD

Summary

(1) To consider the anisotropic plasticity with temperature dependency, a new material model and its user subroutine were developed for hot forming simulation.
(2) The formability of deep drawing of a magnesium alloy is evaluated using the developed new material model.

References

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