AmirKabir University of Technology
(Tehran Polytechnic)

AmirKabir Jounrnal of Science & Research
Mechanical Engineering
(ASJR-ME)
Vol. 48, No. 4, Winter 2017, pp. 141-144

Determination of Forming Limit Diagram Using Two Modified Finite Element Models

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(Received 24 June, 2015, Accepted 9 November, 2015)

ABSTRACT

In sheet forming processes, using forming limit diagrams (FLDs) in study of formability and designing die is very important. One method to achieve the curves of FLDs that has appropriate results is Marciniak–Kuczynski model. This model is a way to predict local necking. In the present study, FLDs were achieved by imposing the theoretical Marciniak–Kuczynski model in two different finite element models and using ABAQUS. In the first model, the theory of Marciniak–Kuczynski was imposed to finite element of Nakazima test and in second one (Flat), the theory of Marciniak–Kuczynski was simulated. The input data for these simulations was obtained from tension tests in three different directions. After comparing the results of Flat and Nakazima finite element model with empirical results, the FLD obtained from the finite element of Nakazima test was valid and less than 10 percent below the empirical FLD. Bending is the reason of difference between FLD obtained from Flat model and empirical one.

KEYWORDS:

Forming Limit Diagram, Marciniak–Kuczynski model, Finite Element Simulation, Nakazima Test, Sheet St14.

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1- Introduction

Using forming limit diagram (FLD) is conventional method for determining localized necking in sheet metal forming process. The typical FLD is shown in Figure 1. As long as the sheet metal measured major and minor strains are lower than forming limit curve, necking and rupture would not happen, but if it placed above the FLD, the rupture might happen [1]. Marciniak and Kuczynski [2] presented a criterion based on an inconsistency in sheet metal. The inconsistency was introduced with factor "*f*" (e.g., a geometrical inhomogeneity). They presented their numerical model for biaxial stretching mode.

In this study, the FLD obtained through the inclusion of the M-K model in the Nakazima's out-of-plane test's finite element model and also a flat model. The results of the simulations were compared with experimental test results. After this comparison, the obtained results indicated that the finite element model of Nakazima's test (e.g., for obtaining FLD) was more accurate than the flat model.

2- The research method

2-1- Experiment of tension test

In this work, a uniaxial tension test accomplished on two samples shown in Figure 1. The right sample in the figure was used to obtain mechanical properties and the left sample was used to obtain uniaxial tension mode of limit strains.

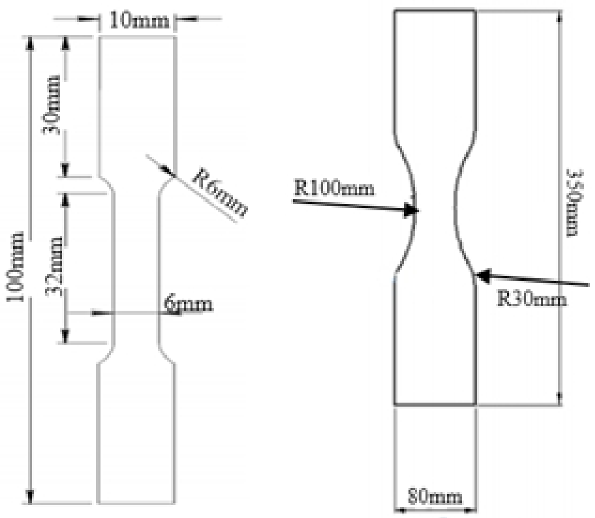

Figure 1. Dimensions of the tensile tests

The forming parameters are listed in are shown in Table 1.

Table 1. Forming parameters

Material	Strain hardening exponent	Strength coefficient K (MPa)	R_0	R_{45}	R_{90}
ST14	0.315	600	2.45	1.13	2.68

2-2- Experimental Nakazima Tests

The experimental tests were done according to Nakazima's standard method using a spherical punch with diameter of 100 mm and a 3ton hydraulic press. The electrochemical etching was used to draw circles with a diameter of 2.5 mm. The sheet was gridded by the electrochemical etching process to measure the strains after deformation. These specimens' dimensions were prepared according to reference [3]. The specimens are presented in Figure 2.

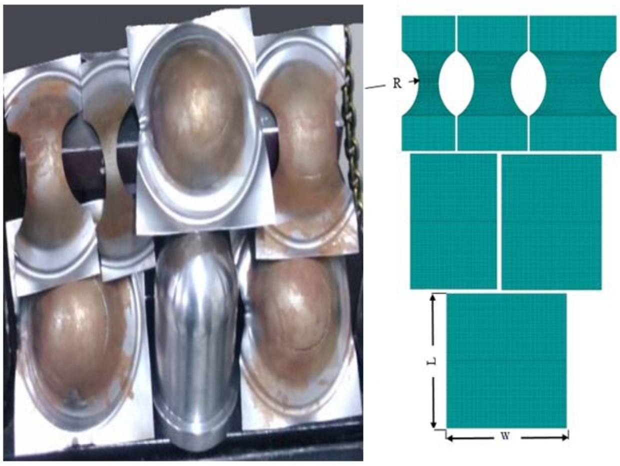

Figure 2. Specimens after the test

2-3- Finite Element Simulation

2-3-1- Finite Element Simulation of Nakazima Test and Flat Model

A numerical study of stretch forming process was done using the ABAQUS/Explicit software. Nakazima model consists of a spherical punch, blank holder, die and sheet. In the flat model, a square sheet with 180 x 180 mm dimensions was placed under various loading paths according to Figure 3.

2-3-2- Material Modeling

Hill's 48 yield criterion [4] was applied to model the material properties in finite element simulation as follows:

$$f(\sigma) = \sqrt{\begin{array}{c} F(\sigma_{22}-\sigma_{33})^2 + G(\sigma_{33}-\sigma_{11})^2 \\ +H(\sigma_{11}-\sigma_{22})^2 \\ +2L\sigma_{23}^2 + 2M\sigma_{13}^2 + 2N\sigma_{12}^2 \end{array}} \qquad (1)$$

Holloman's Hardening law was applied to describe work-hardening as follows [5]:

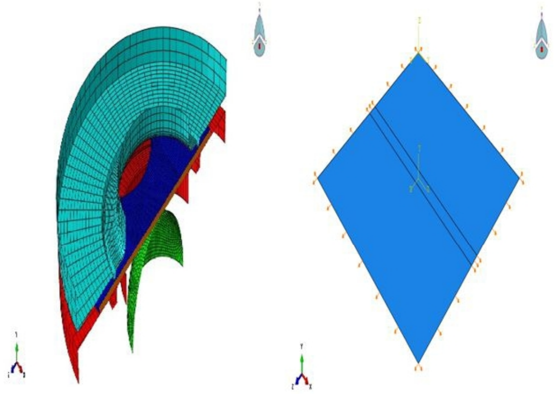

Figure 3. Fainant element models

$$\sigma_e = K(\varepsilon_e)^n \quad (2)$$

3- Results

Forming limit diagrams were computed by using the different finite element simulations (e.g., the Nakazima's model and the flat model) compared with the experimental test results in Figure 4.

Figure 4 shows that the FLD predicted by Nakazima's finite element simulations had almost good results, the differences between the simulations' results and experimental tests were less than ten percent.

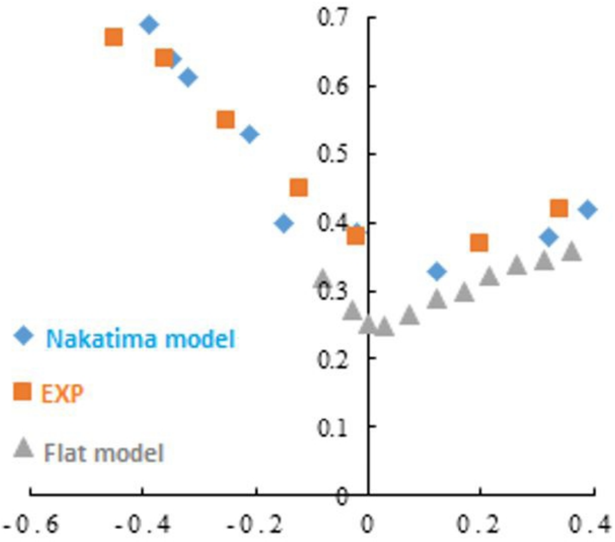

Figure 4. Comparison FLD of the flat and Nakazima models with experimental

4- Conclusion

In this research, the forming limit diagram with two finite element models have been predicted and the results have been compared with experimental data. The analytical M-K model was incorporated into the finite element simulation to predict the FLDs. To verify the results of simulations and investigate the effect of bending on the FLDs, Nakazima out plane stretch test was used. After comparing the results of the flat and Nakazima finite element models with experimental results, the FLD obtained by Nakazima finite element model, was more accurate with less than ten percent at the lower level of the experimental FLD. Moreover, it was observed that the width of the groove had a little effect on the right side of the FLD but a significant effect on the left side. The results of the flat model simulation were quite similar to those of the M-K method and it could be concluded that if the effect of bending had not been considered in the simulations, the obtained results would have had a large difference with the test results.

5- References

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