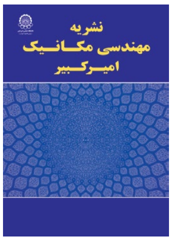

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(3) (2020) 135-138
DOI: 10.22060/mej.2019.15298.6087

Predicting Sheets Forming Limit Diagrams by Numerical Simulation of Nakazima and Modified Marciniak Tests

V. Talebsafa and M. Aghaie-Khafri*

Faculty of Materials Science and Engineering, K. N. Toosi University of Technology, Tehran, Iran

ABSTRACT: Forming limit diagram is a useful tool for investigation of sheet's formability for designing industrial products. Experimentally extracting forming limit diagram requires exact experimental tests, and is time consuming, and expensive. Therefore, several studies have been carried out on the usage of theoretical methods and finite element software for determining these diagrams. In this study, forming limit diagram for AA3105 aluminum alloy sheet were obtained by simulating the Nakazima and modified Marciniak tests in ABAQUS software. In order to numerically determine forming limit diagram of AA3105, Hill yield criterion, Hosford yield criterion and Gurson, Tvergaad and Needleman damage model based on the Hosford criterion and Voce and power law hardening rules were investigated. Due to the lack of the Hosford yield criterion and the Gurson, Tvergaad and Needleman damage model based on Hosford criterion in the ABAQUS software, VUMAT subroutines has been developed and used to determine the behavior of the AA3105 aluminum alloy. The results showed that the predicted forming limit diagram based on the Hill criterion, shows large deviation from experimental results. The usage of the Hosford criterion and Gurson, Tvergaad and Needleman damage model for aluminum alloys showed a better correlation with experimental results. Also, due to the presence of voids in metals, the Gurson, Tvergaad and Needleman damage model which is based on the void volume fraction has a greater physical justification than the other yield criterions. Furthermore, by comparing numerical forming limit diagrams that obtained from Nakazima and modified Marciniak tests, it was concluded that the limit strains in modified Marciniak test is lower than the Nakazima test.

Review History:

Received: 11/17/2018
Revised: 1/11/2019
Accepted: 3/11/2019
Available Online: 4/3/2019

Keywords:

Forming limit diagram
Anisotropic yield criteria
Gurson
Tvergaad and Needleman damage model
Nakazima test
Modified Marciniak test

1. Introduction

Metal forming is one of the most important production methods in various industries. In the metal forming, the raw material is plastically deformed by the tool into a complex product with the desired engineering properties. The forming limits in the sheets is mostly determined by the onset of localization of the deformation and the formation of a neck. The Forming Limit Diagram (FLD), indicates the formability of a sheet in different strain states [1]. Killer and Backofen in 1964, for the first time, experimentally examined the limit strains of the sheet metal. They constructed the right hand side of the FLD [2]. Subsequently, Goodwin in 1968, by drawing sheets with different widths, obtained the left hand side of the FLD, and presented a complete forming limit diagram [3]. There are many factors affecting the simulation and predicting FLD, some of the most important of which are the yield criteria and the hardening rules. Results of different researches show that during the deformation of ductile alloys porosity occurs during the plastic deformation due to the presence of secondary phase particles and impurities [4]. Nucleation of the voids and subsequent growth and interconnection of them during plastic deformation can cause fracture in the metal sheet. In this situation, the effect of the hydrostatic stress and the void volume fraction should be considered in the plastic deformation. With this in mind, different models of void and defect are presented by the researchers to predict the yield behavior of a ductile metal. The most well-known void-based criterion is the Gurson model that has been modified by Tvergaad and Needleman, and is now known as the Gurson–Tvergaard–Needleman (GTN) model [5]. Aluminum alloys are characterized by good formability, high mechanical strength, low density, high thermal and electrical conductivity, and relatively high resistance to corrosion. These alloys are widely used in the metal forming industry. formability of aluminum sheets is important in product design and production process.

In this paper, sheet forming limit diagrams have been predicted by numerical simulation of Nakazima and modified Marciniak tests by GTN damage model based on the Hill 1948 and the Hosford yield criterions. Furthermore, a comparison between these criteria have been made.

2. Methodology

In the present study, a GTN damage model based on the Hosford criterion has been developed to determine the numerical forming limit curve for AA3105 aluminum sheet by simulating the Nakazima and modified Marciniak tests in Abaqus software. This simulation used the VUMAT subroutine in Abaqus software 2014. Also, the numerical prediction of the forming limit curve was made using the 1948 Hill yield criterion and the Hosford yield criterion. The

*Corresponding author's email: maghaei@kntu.ac.ir

results obtained were compared with each other. In addition, the effect of the Voce and power law hardening rules on the FLD for the AA3105 aluminum sheet was investigated based on the simulation results.

Details of the implementation of the GTN damage model in Abaqus finite element software was based on the works of Chen and Dong in reference [6].

3. Results and Discussion

Simulation results obtained by different yield criteria and hardening rules are presented and discussed in this section. The main results are as follows:

- Comparison of FLDs obtained based on the Voce and power law hardening rules:

Comparison of predicted FLD based on power and voce laws using the Hosford criterion with experimental results is shown in Fig. 1. The results of this investigation show that the flow curve resulting from the Voce relationship is more consistent with experimental results. The application of the Voce equation is superior than the power low equation in predicting FLD, so the predicted data is very close to the experimental data.

- Evaluation of the Nakazima test by the GTN model:

The GTN model was used to evaluate the limit strains obtained in Nakazima test. Simulation results for maximum strain contour of Nakazima test based on the GTN-Hosford criterion for AA3105 sheets of 45 mm widths is shown in Fig. 2. It is evident that when a porous sheet is under tensile stress,

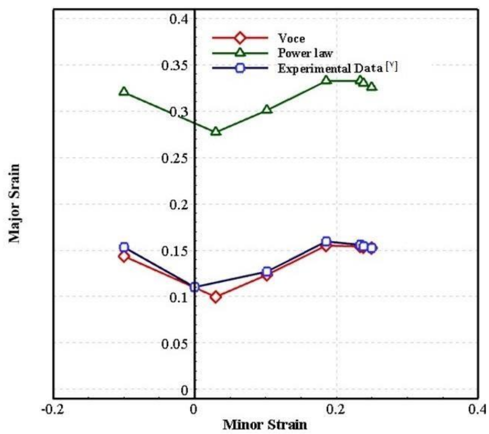

Fig. 1. Comparison of predicted FLD based on power and Voce laws using the Hosford criterion with experimental results.

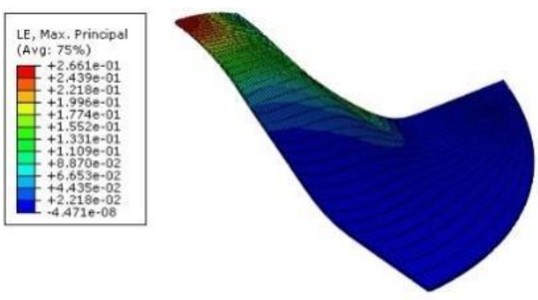

Fig. 2. Strain distribution at the necking time resulting from the simulation of the Nakazima test for the AA3105 alloy using the GTN model and Hosford criterion for 45 mm width sheet.

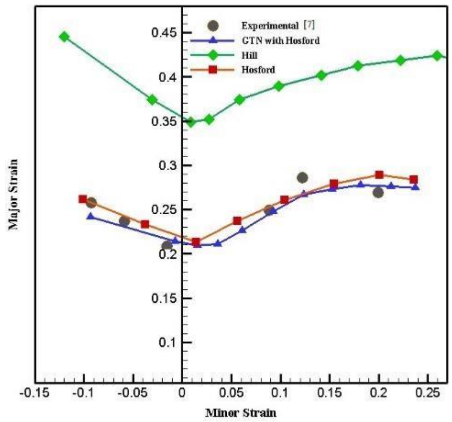

Fig. 3. Comparison of the forming limit diagram obtained from Hill's 1948, Hosford yield criterion and GTN model with experimental results.

the amount of the free volume or voids grows and increases. Subsequently, with increasing tension stress and strain, the voids join each other resulting in cracks, and finally cause material rupture. According to the simulation results based on the Hosford criterion, the void volume fraction reaches to a critical volume fraction (f_c =0.1) at the time of the neck formation. Furthermore, the void volume fraction reaches to the amount of, f_c=0.15, at the time of rupture and failure in the material. The results obtained are in good agreement with the results of other reported investigations [6].

- Comparison of the forming limit curves based on the Hill 1948, Hosford criterions and GTN model:

Comparison of the forming limit diagram obtained from Hill's 1948, Hosford yield criterion and GTN model with experimental results is shown in Fig. 3.

The simulation results indicate that the predicted FLD based on the Hill criterion, shows large deviation from the experimental results of Aghaie-Khafri and Mahmudi [7]. However, the usage of the Hosford criterion and GTN damage model for aluminum alloys showed a better correlation with experimental results. Furthermore, due to the presence of voids in metals, the GTN damage model which is based on the void volume fraction has a greater physical justification than other yield criterions.

-Comparison of FLDs obtained from both the Nakazima and Marciniak tests:

Both the Nakazima and Marciniak tests are used for construction of FLD [1]. Simulation results indicate that the FLD curve of AA3105 in Nakazima test is higher than the Marciniak test. This result is in good agreement with the experimental results of Moshksar and Mansourzadeh [8].

4. Conclusions

In this research, Hill 1948, the Hosford yield criterion and the GTN model based on the Hosford criterion were used for predicting forming limit curve of the sheet metal by finite element simulation. The results obtained can be summarized as follows:

- The Hosford and GTN model predictions of the FLD of AA3105 alloy are more accurate and are close to the experimental results.
- Comparison of the experimental FLD of the AA3105 alloy

with the numerical FLD obtained from the hardening relationships shows that the power law predicts the limit strains above the experimental values, and the Voce relationship is suitable for the aluminum alloys.

- Despite of the conventional hardening rules such as power laws, by using the GTN model it is possible to detect the softening of the material during the deformation and necking.
- Based on the numerical FLDs that obtained from Nakazima and modified Marciniak tests, it was concluded that the limit strains in the modified Marciniak test is lower than the Nakazima test.

References

[1] M. Aghaie-Khafri, Formability of Metals, K.N. Toosi University of Technology 2015,(in Persion).

[2] S.P. Keeler, W.A. Backhofen, Plastic instability and fracture in sheet stretched over rigid punches, ASM Transactions Quarterly, 56 (1964) 25-48. [3] G. Goodwin, Application of strain analysis to sheet metal forming in the press shop, (1968) 1-12.

[4] J.Samei, D.E.Green, J.Cheng, M.Lima, Influence of strain path on nucleation and growth of voids in dual phase steel sheets, Materials and Design, 92 (2016) 1028–1037.

[5] V. .Tvergaard, A. Needleman, Analysis of the cupcone fracture in a round tensile bar, Acta metallurgica, 32 (1984) 157-169.

[6] Z. Chen, X. Dong, The GTN damage model based on Hill'48 anisotropic yield criterion and its application in sheet metal forming, Computational Materials Science, 44 (2009) 1013–1021.

[7] M. Aghaie-Khafri, R. Mahmudi, Predicting of plastic instability and forming limit diagrams, International Journal of Mechanical Sciences 46 (2004) 1289–1306.

[8] M. Moshksar, S. Mansorzadeh, Determination of the forming limit diagram for Al 3105 sheet, Journal of Materials Processing Technology, 141 (2003) 138-142.