17th International Conference on Sheet Metal, SHEMET17

Detection of strain localization in Nakazima formability test - experimental research and numerical simulation

Dmytro Lumelskyj[a], Jerzy Rojek[a], Dorel Banabic[b], Lucian Lazarescu[b]*

[a]*Institute of Fundamental Technological Research, Polish Academy of Sciences, Pawinskiego 5B, 02-106 Warsaw, Poland*
[b]*Technical University from Cluj-Napoca, Str. Memorandumului 28, 400114, Cluj Napoca, Romania*

Abstract

This paper presents the investigation on detection of strain localization in experimental research and numerical simulation of sheet metal forming. Experimental tests and numerical simulations of the Nakazima test have been performed for the DC04 grade steel sheet. The onset of localized necking has been determined using the criterion based on analysis of the major principal strain and its first and second time derivatives in the most strained zone. The strain localization has been evaluated by the maximum of strain acceleration which corresponds to the inflection point of the strain velocity vs. time. The limit strains have been calculated numerically and experimentally for specimens undergoing deformation at different strain paths. It has been shown that the numerical model predicts formability limits close to the experimental results. Analyzed criterion can be used as a potential alternative tool to determine formability in standard finite element simulations of sheet forming processes.

1. Introduction

Sheet stamping is one of the most important manufacturing techniques widely used in many industries, the automotive and aerospace sectors being the most important users of this technology. Development of new theoretical models and more accurate methods for prediction of forming process manufacturability is still of great practical importance, especially due to introduction of new materials and a need of process optimization. Therefore, metal

---

* Corresponding author. Tel.: +48-22-826-12-81 int. 289.
  E-mail address: dlumelsk@ippt.pan.pl

forming is a subject of intense experimental and theoretical research [1]. Formability, the ability of the sheet to undergo deformation without defects, belongs to the main fields of investigation in metal forming.

Despite many new concepts of formability prediction, strain based forming limit diagrams (FLD) are used most often in engineering practice to assess the sheet formability. Location of the points representing principal strains with respect to the forming limit curve (FLC) allows us to determine probability of defects in the form of strain localization or material fracture.

FLCs can be determined by different methods, including experimental [2, 3], theoretical [4], as well as hybrid methods combining experimental data with analytical or numerical approaches [5]. Different methods of FLC determination are reviewed in [6].

Theoretical methods are based on criteria of the loss of stability (strain localization) or damage (fracture) of the material. Although a significant progress in theoretical methods has been achieved, the most reliable methods for evaluation of formability are based on the experimental methods. The most commonly used experimental methods are the Erichsen [2], Marciniak and Nakazima [3] tests. The Nakazima testing method consists in bulging of sheet samples with a hemispherical punch. Use of samples of different width allows us to obtain different strain paths from the uniaxial to biaxial tension.

Experimental formability tests are performed with automatic strain measurements using systems such as AutoGrid, ASAME or ARAMIS. The limit strains are evaluated using different methods for the analysis of the strains measured in the critical zone. The most commonly used ones are the methods proposed by Veerman [6], Bragard [6], Kobayashi [6] and Hecker [6]. The Veerman method analyses the circular deformed grid on the fractured blank. The strains in the fractured circles are calculated as the average of the strains of the two circles on the sides of the considered fractured one. The Hecker method consists in measuring strains in three types circles (grids) in the fractured zone: fractured, necked and acceptable (with no failure). The limit curve is traced between the points corresponding to the circles with failure and the acceptable ones. The Bragard method identifies the limit strains from the strain distribution along the cross section perpendicular to the fracture. A curve fitting algorithm is used to obtain the maximum in the major strain as the limit strain. The modified Bragard method is used in the standard ISO 12004 [3]. With the development of strain measuring systems, new methods based on the analysis of time evolution of strains and their time derivatives have been developed. Volk and Hora [7] have presented a method based on the analysis of the first derivative of the strains in the necked zone. The onset of necking is assumed to occur at the point corresponding to a sudden change of the slope of the strain rate vs. time curve. The first and second time derivatives of the principal strains (strain velocities and accelerations) have been postprocessed in [8, 5]. The onset of necking is determined by the peak of the major strain acceleration vs. time curve.

The FLDs are very useful for evaluating the formability in the finite element analyses at the design stage and during the optimization process. Numerical evaluation of the forming operations formability is usually performed by confronting strains estimated in numerical simulation with the FLC obtained using one of the methods described above. In most FE programs, however, no fracture or strain localization criteria are implemented, so simulation can be continued even after a failure conditions are achieved. In consequence, the strains obtained in numerical simulation corresponding to critical zones are often unrealistically high. Forming limit diagrams allow us to determine that the strains are above the FLC assumed for the formed material but we are not able to determine a failure point in the simulation itself.

The main objective of the present work is to compare the criterion of strain localization applied in the numerical and experimental analysis to experimental FLC. Criterion has been implemented in the finite element program for sheet forming analysis and verified its performance by simulation of the Nakazima formability test. Nakazima test was selected because of its popularity as a formability test. The criterion is based on the analysis of the principal strain vs. time curves and their first and second time derivatives. This criterion was proposed in [8, 5] and applied in numerical simulation of sheet forming problems in [9, 10]. Numerical predictions of strain localization in the Nakazima test have been compared with the strain paths, limit strains, and FLC determined experimentally in the laboratory procedure. Two specimens with different strain paths for these comparisons have been chosen.

The outline of this paper is as follows. The experimental results and numerical model of the Nakazima test are briefly described in Section 2 and 3 accordingly. Section 4 contains presentation and discussion of numerical results in comparison to the experimental FLC. Finally, conclusions drawn from the present work are given.