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Original Research Article

Detection of strain localization in numerical simulation of sheet metal forming

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ABSTRACT

This paper presents an investigation on the detection of strain localization in numerical simulation of sheet metal forming. Two methods to determine the onset of localized necking have been compared. The first criterion, newly implemented in this work, is based on the analysis of the through-thickness thinning (through-thickness strain) and its first time derivative in the most strained zone. The limit strain in the second method, studied in the authors' earlier works, is determined by the maximum of the strain acceleration. The limit strains have been determined for different specimens undergoing deformation at different strain paths covering the whole range of the strain paths typical for sheet forming processes. This has allowed to construct numerical forming limit curves (FLCs). The numerical FLCs have been compared with the experimental one. Mesh sensitivity analysis for these criteria has been performed for the selected specimens. It has been shown that the numerical FLC obtained with the new criterion predicts formability limits close to the experimental results so this method can be used as a potential alternative tool to determine formability in standard finite element simulations of sheet forming processes.

Introduction

Sheet stamping is one of the most important manufacturing techniques widely used in many industries, the automotive and aerospace sectors being the most notable users of this technology. Development of new theoretical models and more accurate methods for prediction of sheet metal behavior in a forming process is still of high practical importance, especially due to an introduction of new materials and a need for process optimization. Therefore, metal forming is a subject of intense experimental and theoretical research [1–3]. Formability, i.e. 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 a probability of defects in the form of strain localization or material fracture.

Different methods, including experimental [4–6] and theoretical [7–9] ones, as well as hybrid methods combining experimental data with analytical or numerical approaches

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[3,10], can be used to determine FLCs. Different methods of FLC determination are reviewed in [11].

Theoretical methods are based on criteria of the loss of stability (strain localization) or damage (fracture) of the material. The most widely used theoretical formability models are those proposed by Swift [7], Hill [8], and by Marciniak and Kuczyński [9,12]. 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 [4], Marciniak [5] and Nakazima [5] 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 spatial distribution of the strains over fractured specimens is used to determine the limit strains [13–16]. 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 [17] 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 thinning rate curve. The first and second time derivatives of the principal strains (strain velocities and accelerations) have been postprocessed by Situ et al. [10,18] to detect strain localization. The peak of the major strain acceleration vs. time curve has been taken as the indicator of the strain localization.

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 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. A possible solution to this problem can be provided by adaptation of the above mentioned experimental procedures based on the analysis of time evolution of strains and their time derivatives. The criterion based on the analysis of the second time derivatives proposed in [10,18,19] has been used in the numerical simulation of sheet forming problems in [20–23]. The limit strains estimated numerically in [21] for selected complex strain paths were close to the experimental results. A more comprehensive investigation of this criterion performed in [22] for different strain paths covering a whole range of the strain paths typical for sheet forming processes has shown that the numerical FLC obtained in this way predicts significantly higher formability limits than the experimental FLC. Similar observations have been made in [23].

The main objective of the present work is to implement in the finite element program and validate the other criterion of strain localization mentioned above, that introduced by Volk and Hora [17], which is based on the study of the first derivative of the through-thickness (thinning) strain in the necked zone. Numerical studies will be performed for the Nakazima formability tests.

The formability limits obtained with the newly implemented criterion will be compared to those predicted by the previously studied criterion in [22,23]. Numerical predictions of strain localization in the Nakazima test will be confronted with the FLC determined experimentally in the laboratory procedure. The influence of the friction and finite element mesh size on the formability predictions will be investigated for selected cases.

Numerical model

A schematic of the Nakazima test which was studied numerically is shown in Fig. 1. The laboratory formability tests have been carried out for the DC04 steel sheet 1 mm thick. The experimental results used for validation have been widely presented in [22,24].

Simulation of the Nakazima test has been performed using the authors' own explicit dynamic finite element program [25,26]. A numerical model for the whole process associated with the Nakazima formability test has been developed in [21]. Simulations using a model representing the complete geometry of the Nakazima test performed in [21] have shown that the drawbead nearly completely blocks the flow of the sheet. Therefore the simulations in this work have been carried out using a simplified model, taking into account a part of the sheet within the drawbead line, only, and assuming the restrictions of the sheet motion on the drawbead. This has allowed us to reduce considerably the number of elements and to avoid very small elements limiting the time step length. The finite element model at the initial and deformed configuration is shown in Fig. 2.

The sheet has been discretized with the so-called BST (Basic Shell Triangle) elements [27]. Equal-spaced structured mesh

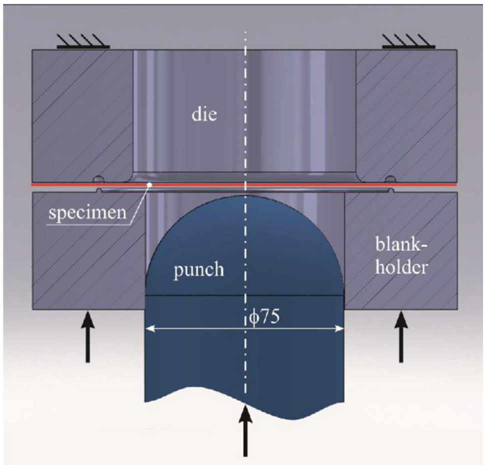

Fig. 1 – Schematic of the Nakazima test setup [24].