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Procedia Technology 24 (2016) 386 – 393

Procedia Technology

International Conference on Emerging Trends in Engineering, Science and Technology (ICETEST - 2015)

Forming Limit Diagram Generation of Aluminum Alloy AA2014 Using Nakazima Test Simulation Tool

Sreenath D Kumar[a], Amjith T.R[a], C. Anjaneyulu[b]

[a]*Sree Buddha College of Engineering, Alappuzha, India*
[b]*Indian Space Research Organisation, Trivandrum, India*

Abstract

Plastic instability is a commonly observed problem, in sheet metal forming operation, which leads to defective products. Forming Limit Diagram (FLD) is an important parameter to be considered in the manufacturing process of non-defective sheet products. This paper focuses on FLD prediction based on simulation of Nakazima test using finite element software Pam-Stamp 2G. Finite Element Model (FEM) for Nakazima test is established in this work. Then the experimental values are compared with the simulation results in order to establish the credibility of Nakazima test simulation tool. Then the simulation is extended to predict the FLD of AA2014 aluminium alloy.

Peer-review under responsibility of the organizing committee of ICETEST – 2015

Keywords: Forming Limit Diagram (FLD); Nakazima test; Pam-stamp 2G; Finite Element Model (FEM); Material Hardening Law

1. Introduction

Sheet metal forming process must be done with excessive care in order to avoid fracture and excessive localized thinning, since it has many delicate applications [9]. The sheet metal forming operation is widely used in aerospace industry, automotive industry, household equipment's and many other industrial applications that requires fine and accurate forming process. Forming Limit Diagram (FLD) is used during the design stage of any new sheet metal component for tooling shape & optimizing variables. In sheet metal industry and studies, it is widely used and considered as one of the important tool to determine the formability of sheet metals. Every sheet metal has its own forming limit diagram which determines its formability, strain limit and forming regions.

* Corresponding author. Tel.:+919447786119.
E-mail address: sreenathdkumar@gmail.com

Peer-review under responsibility of the organizing committee of ICETEST – 2015
doi:10.1016/j.protcy.2016.05.053

Forming limit diagram is a representation of the critical combination of the two principal surface strains major and minor above which localized necking instability is observed, as illustrated in Fig. 1 [2]. The forming limit curve is plotted, for varying strain ratios, from pure shear to equibiaxial tension. One can conclude that drawing has happened in the case of negative minor strain or negative strain ratio. Stretching is observed, when minor strain is obtained as positive or the strain ratio is positive. It must be ensured that the strains plotted are true strains [1].

In order to construct the FLD and to analyze the instabilities in sheet metal, various experimental and mathematical approaches have been developed [6][7]. Results obtained from theoretical and experimental approaches can be compared to establish the validity of theoretical and mathematical approaches [4]. Uniaxial tensile test, hydraulic bulge test, punch stretching test, Hecker test, Marciniak test, Keeler test, Nakazima test are some of the experimental procedures [1][2].

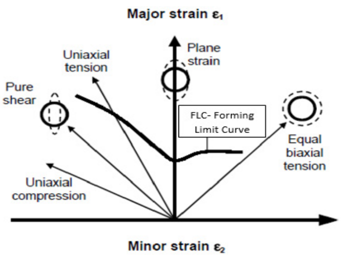

Fig. 1. Forming Limit Diagram

Literature survey conducted revealed various experimental methods used for obtaining FLDs which can be summarised as follows. Keeler test uses punches of different radius to obtain the positive ($\varepsilon_2 > 0$) range of FLDs [2]. High amount of experimental work is required for the Keeler test which is its major drawback. The positive range of FLD can also be obtained by Hecker test. The frictional effects are eliminated and only the negative range of FLD ($\varepsilon_2 < 0$) are obtained, by using uniaxial tension test. The Hydraulic Bulge Test is performed to determine only the positive range of FLD ($\varepsilon_2 > 0$) and in this test the frictional effects are eliminated. FLD can also be obtained by using Punch Stretching Test, in which the specimen is stretched by a hemispherical or elliptical punch and which is clamped between a die and a blank holder and. To obtain different strain paths, the specimen geometries are varied. Marciniak test uses a hollow punch. An intermediate part which has a circular hole in it is placed between the punch and the work piece. The aim is to obtain the tearing at the planar bottom section of the cup, otherwise cracks occurs between the cylindrical wall and the bottom. By using different specimen geometries and intermediate parts, full range of FLD can be obtained. Complex geometries of punches and dies are required for Marciniak test and major drawback is a limitation for the positive range of the FLD. Finally, Nakazima test can be used to obtain the full range of FLD. By drawing the specimens with hemispherical punch and a circular die for varying widths, different strain paths can be obtained.

From the aforementioned tests, Nakazima test seems to be the most powerful and advantageous because of the following reasons:

- The tools used for the test is simple
- The geometries of the specimens are not complex
- Full range of the FLD can be determined.

Today, Nakazima test is widely used in industry and sheet metal testing laboratories in order to evaluate the forming limits of the sheet metals [2].

In this paper, the development of Nakazima test simulation tool is explained initially, then the FLD of aluminium alloy AA2024 sheet metal is predicted by the simulation tool developed. The simulation results obtained are compared with the actual experimental results to validate the simulation tool and the study is extended to predict the