Stress Based Forming Limit

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Abstract— Metal forming processes is finding increasing acceptance as a manufacturing process for various engineering components. In need of higher performance and due to economic and ecological reasons, lightweight construction is the key factor to success, mainly not only in the transportation sector, but also in general engineering, machine tools and architecture. This seminar is deals with the stress based forming limit diagram. With the use of forming limit diagram one can predict the ability of metal to form in various shapes. Here in this seminar comparison between strain and stress based diagram is done. And in addition with this, finding the advantage of stress based FLD to Strain based FLD. In processes like Hydroforming and flanging or multistage processes the stress based forming limit diagram is given better prediction of onset of necking compare to strain based forming limit diagram. In case of tube Hydroforming of the square cross section extended stress based forming limit diagram is introduced.

Index Terms— Failure Criterion, Finite Element Analysis, Forming Limit Diagram, Forming Limit Stress Diagram.

1 Introduction

DIE engineers mostly use finite element analyses in the metal forming industry to find the formability of sheet-metal products prior before the dies are built in order to save money in die build and tryout costs, as well as to address manufacturability issues early in the product design cycle. One of the most important objectives in this assessment is to avoid necking and fracture of the sheet metal. Although the finite element method FEM does not directly predict whether or not the sheet metal will neck or tear during the forming of the product, it does predict the metal flow and the development of stress and strains throughout the forming process. The engineer determines the forming severity by comparing the predictions of the FEM to a forming limit criterion, which is a function of the sheet-metal properties and the forming history. Obviously, a critical factor in the success of FEM analysis is the reliability of this forming limit criterion.

The most commonly used method of gauging forming severity with respect to necking is based on the forming limit diagram FLD developed by Keeler and Goodwin. The diagram is composed of a curve in strain-space defined to characterize the forming limit of the material. As long as all strains on the part fall below this forming limit curve FLC, that part will be free from necks. The forming limit is determined by forcing the material to follow linear strain paths, and measure the strain on the material just before a neck appears.

As the application of the FEM was extended to analysis of hydro-forming, redraws and flanging operations, where the total strain path is significantly nonlinear, the limitations of the conventional FLD could no longer be ignored. Furthermore, nonlinear strain paths have been found to be much more common in the first draw die than first believed, resulting in costly errors in the assessment of forming severity [1]. Stoughton proposed a method through which, under a suitable set of constitutive assumptions, the strain-based FLC can be transferred to principal stress space [2]. It is also shown that within the scope of the constitutive assumptions, there exists a single curve in principal stress space that represents the formability limit of the sheet. Therefore, the stress-based FLC appears to be attractive to predict the onset of necking when the sheet is subjected to nonlinear load paths [3].

2 Determination of FLD

The FLD is based upon the work of KEELER and GOODWIN where the plane strain limit is given as follows:

$$FLD_0 = \frac{n}{0.21}(23.3 + 14.1t) \qquad (1)$$

Where n is the strain hardening coefficient, and n<0.21, t is the metal thickness in mm.
The key feature of the FLD is an experimentally determined forming limit curve (FLC). The shape and location of the FLC, which define the boundary between strain states that are always free of necks from those states that are prone to necking, are a characteristic of the metal that is independent of the forming process or work piece shape. Therefore, the distance between the FLC and all of the measured or predicted strain. The material properties and stress strain diagram is shown below.

Table 1 Material parameters of 3A21 aluminum

Lankford parameter	Strength/ MPa	Hardening rule	Blank thickness/ mm
0.58	519	0.18	2

The strain states used to determine the strain limit are commonly obtained via the dome test procedure, where grid markings are etched onto the surface of specimens. In these tests, various strain states are achieved by adjusting different parameters like the lubrication conditions between the sheet metal and the specimen width. The width varies at 180, 160, 140, 120, 100, 80, 60, 40 and 20 mm. Length of all specimens is

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180 mm. For all the specimens, the length is along the rolling direction, while the width is along the transverse direction. The velocity of punch is 10 mm/min, and the binder force is 20 kN. The stamped specimens are shown in Fig.2. After the desired deformation is achieved, the geometry of the markings near a neck or fracture is analyzed in order to calculate and record various strain states associated with the strain limit. By altering the strain ratio within the principal strain coordinates, from uni-axial tension to equi-biaxial tension, a theoretical FLD with damage consideration can be determined (see Fig.3).

3 Transformation between Stress and Strain States

The strain-path dependent nature of the FLD causes the method to become ineffective in the analysis of complex forming process such as restrikes, flanging operations and hydro forming. The stress-based forming limit diagram (FLSD) established with limit stress is independent of the strain paths. Compared with traditional strain-based FLD, it is more convenient and practical to use as the criterion of forming limit under complex strain path

Using the formula of Stoughton for transformation between stress and strain states, and omitting the thickness stress of sheet ($\sigma_3=0$), the state is plane-stress condition, then the ratio of the minor true stress, σ_2, to the major true stress, σ_1, is defined by the parameter.

$$\alpha=\sigma_2/\sigma_1 \tag{2}$$

The plasticity theory defines an effective stress, σ, which is a function of the stress tensor components and a set of material parameters. In this case, the definition of the effective stress can be expressed in terms of the principal stresses:

$$\overline{\sigma} = \overline{\sigma}(\sigma_1, \sigma_2) \tag{3}$$

This relation can also be expressed as follows:

$$\overline{\sigma} = \sigma_1 \varphi(\alpha) \tag{4}$$

Where φ (α) is a function of material parameters.

Similarly, the ratio of the minor true strain increment, $d_{\varepsilon 2}$, to the major true strain increment, $d_{\varepsilon 1}$, is defined by the paramter

$$\rho=d\varepsilon_2/d\varepsilon_1 \tag{5}$$

The effective strain is defined by the time integral of the effective strain increment:

$$\overline{\varepsilon} = \int d\overline{\varepsilon} = \int \lambda(\rho) d\varepsilon_1 \tag{6}$$

Where λ (ρ) is a function of the material parameters.

The relation between the effective stress and effective strain can be written formally as:

$$\overline{\sigma} = \overline{\sigma\,\varepsilon} \tag{7}$$

Then, the relation between α and ρ can be expressed as:

$$\alpha=\alpha(\rho) \tag{8}$$

The transformation from the strain states to the stress states can be defined using the above equations. If the prestrain results in a strain state (ε_{1i}, ε_{2i}), the secondary stage results in a final strain state (ε_{1f}, ε_{2f}), then the principal stresses at the end of the secondary stage are given by

$$\sigma_1 = \frac{\overline{\sigma}[\overline{\varepsilon}(\varepsilon_{1i}, \varepsilon_{2i}) + \overline{\varepsilon}(\varepsilon_{1f} - \varepsilon_{1i}, \varepsilon_{2f} - \varepsilon_{2i})]}{\varphi[\alpha(\varepsilon_{2f} - \varepsilon_{2i})/(\varepsilon_{1f} - \varepsilon_{1i})]} \tag{9}$$

$$\sigma_2 = \alpha\left(\frac{\varepsilon_{2f} - \varepsilon_{2i}}{\varepsilon_{1f} - \varepsilon_{1i}}\right)\sigma_1 \tag{10}$$

The above two relations allow us to map each point on the strain-based forming limit curves into stress space for each of the prestrained conditions, as well as for the as-received material ($\varepsilon_{1i}=\varepsilon_{2i}=0$). Fig.4 shown below is the FLSD of 3A21 transformed form FLD using the above transformation formulas.[3]

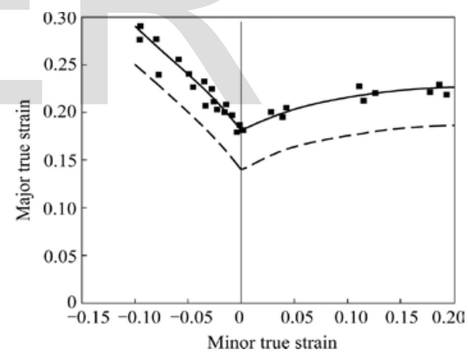

Fig: 3 FLD of 3A21 aluminum[3]

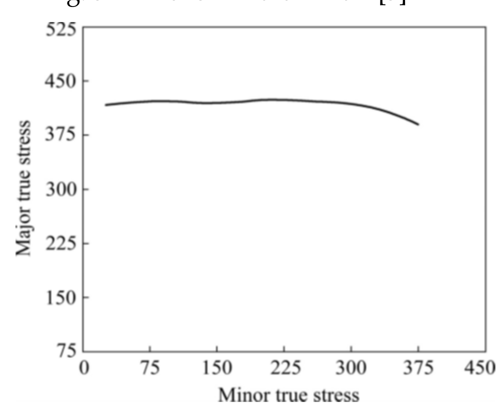

Fig: 4 Forming limit stress diagram (FLSD) of 3A21 aluminum[3]

4 Theoretical Computation of the Forming Limit Stress Diagrams

To predict the sheet metal forming stress and strain limits, the well-known ''Marciniak and Kuczynski" (M–K) model has been used. In this model, it has been assumed that there is a narrow groove in the surface. Thus the sheet is composed of safe zone and a groove zone which are denoted by ''a" and ''b", respectively. This groove leads to localized necking in the sheet shown in below fig.5 For modeling the groove, an imperfection factor is introduced which represents the thickness ratio $f = t_b/t_a$, where, ''t" denotes material thickness. The safe area is subjected to proportional strains. Also it is assumed that strains at groove direction in two areas are equal. [4]

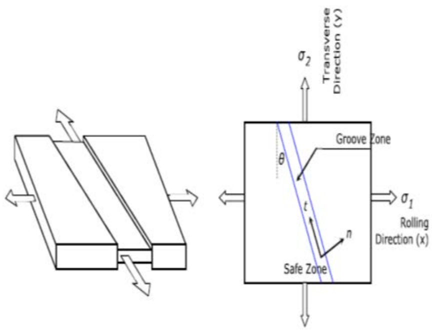

Fig: 5 Schematic of the Marciniak and Kuczynski model on prediction of the FLD and FLSD [4]

In deformation process, strain ratio (minimum strain to maximum strain) outside the groove is constant. This ratio decreases in groove zone. In fact deformation in groove area is close to plane strain. In practice, this type of groove can be caused by surface roughness or local thickness variation which could be formed before the process. Because of plane stress assumption, strain and stress increments in groove can directly be solved with respect to the safe zone strain increments. In the M–K model, the system of equations basically consists of equilibrium, compatibility and energy balance equations. The steps of computations in this procedure are summarized as the following:

•Step 1: Apply the external loads in the safe region.

•Step 2: Apply the boundary conditions at interface between the safe and groove region (strain compatibility equation and force equilibrium equations)

•Step 3: Use the energy relation equation [4].

5. Conclusion:

It can be argued that a stress-based criterion will lead to overly safe designs for materials with weak strain hardening where large changes in strain are accompanied by small changes in stress. This might be a problem if it were necessary to actually measure stresses and compare them to a stress-based forming limit curve. In fact, we cannot measure forming stresses in any but the simplest cases. Consequently, the use of a stress-based criterion is only practical through the calculationof the state of stress using strain measurements and accounting for the strain path.

In addition to that it is feasible and effective to analyze the multi-step sheet metal formability utilizing the FLSD as a criterion and it was validated that FLSD is reliable and effective through actual the multi-step forming experiments. It is beneficial to improving forming limit predict precise that FLSD be applied in multi-step stamping forming FEM simulations.

When comparing the strain based FLD to stress based FLD (FSLD). The FSLD is not strain path dependent, when we go through simple drawing, stretching and hydro forming like processes its analysis easily done with FLD. But when prestraining effect are there , after the processes like bending in hydroforming or sheet forming in multistage at that time strain based data is converted in to stress based data and the curve we found is uniform then FLD. In addition to that analysis of formation of neck under three dimensional stresses the XFLD is also useful.

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