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Formability of sheet metal flowing through drawbead–an experimental investigation

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ABSTRACT

A phenomenon that when the sheet metal flows through drawbead, the limit strains of sheet metal lie above the forming limit diagram indicating fracture in theory, while it is safe in practice, violates the normal forming limit curve has been found. In order to explain the phenomenon, a series of tests were conducted. In the first part, the conventional uniaxial tensile test was employed as a reference. In the second part, specimens were pulled through various drawbead inserts several times, and then cut to the uniaxial tensile test specimens and tested by the conventional uniaxial tensile test. In the third part, specimens were pulled through drawbead inserts many times until the fracture occurs. The results indicate that the percentage of elongation of pre-strained specimens with several times are smaller than that of the conventional uniaxial tensile test. The transition process from the plane strain path to the uniaxial tensile strain path leading to the additional strain hardening is the main reason for the reducing formability of sheet metal. While the percentage of elongation of specimens pulled through drawbead inserts many times until the fracture occurs are evidently higher than that of the conventional uniaxial tensile test and could reach close to 100%. Bending and unbending under tension has a significant effect on the increased percentage of elongation.

1. Introduction

The formability of sheet metal is the capability which undergoes plastic deformation to a given shape without defects (Banabic et al., 2010). The most commonly used tool in assessing the formability of sheet metal is the forming limit diagram (FLD) developed by Keeler and Backofen (1963) and Goodwin (1968), which is composed of the maximum values of the principal strains determined by measuring the strains at failure, widely used in factories and research laboratories (Stoughton and Zhu, 2004). The forming limit curve (FLC) is the line consisting of limit principal strains separating the FLD into two regions. The deformed sheet metal is defined as failure if strain combinations lie above the FLC, otherwise the deformed sheet metal is treated as safe (Nurcheshmeh and Green, 2016), as shown in Fig. 1.

However, a phenomenon that when the sheet metal flows through drawbead, the limit strains of sheet metal lie above the forming limit diagram indicating fracture in theory, while it is safe in practice, violates the normal forming limit curve has been found after testing a large number of automobile panels. The test was done by stamping engineers in Faw Mould Manufacturing co.LTD. The mostly used material of the test is BH180 and the percentage of elongation is 29%. One of the test pieces is the A-side of Audi A6 fender. When the test piece was stamped especially during the process of passing through the drawbead set, the major strains on the A surface of the piece were bigger than areas where the material has not passed through drawbead, such as the flatter part of the test piece shown in Fig. 2. The final thinning in thickness direction in that area where the sheet metal flows through drawbead inserts is close to 50%, which means the thinning in thickness direction is very serious, but the sheet metal is very safe in practice. By numerical simulating the forming process of the sheet metal, the forming limit strains of that area is also very high, above the normal FLC.

As we know, the FLC is only valid under following conditions: (1) straight or proportional strain path; (2) absence of bending; (3) without through-thickness shear; (4) no normal stress or through-thickness stress (Emmens and van den Boogaard, 2009). When the conditions above are not satisfied, the FLC is not always effective (Stoughton, 2000).

In terms of strain paths, Laukonis and Ghosh (1978) conducted an experiment on aluminum-killed steel and 2036-T4 aluminum by pre-straining in balanced biaxial tension. The FLC of aluminum-killed steel decreased while the position of FLC of 2036-T4 aluminum just moved horizontally with the pre-strain increasing. Graf and Hosford (1993)

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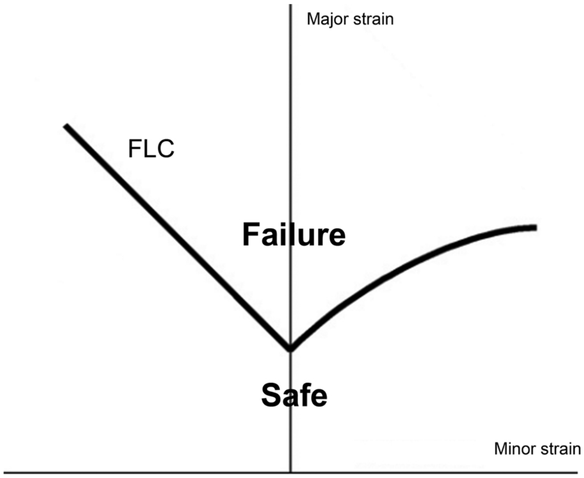

Fig. 1. Schematic diagram of the forming limit curve.

carried out an experiment on Al 2008-T4 pre-strained in uniaxial, biaxial and plane-strain tension parallel and perpendicular to the rolling direction and demonstrated that pre-straining in biaxial tension lowered the entire FLC, while pre-straining in uniaxial tension raised the right side of FLC. Pre-straining in plane strain tension raised both sides away from the minimum of the FLC. Then Graf and Hosford (1994) continued an experiment on Al 6111-T4 and found that if the directions of the principal strains were rotated, pre-straining in uniaxial or plane strain tension lowered the FLC besides the aforementioned. That is to say, changing strain paths has an influence on the formability of sheet metal.

The most commonly used method in experiment determination of the FLD is Nakazima test (out-of-plane) and Marciniak test (in-plane), acquiring strains from uniaxial tensile test to plane strain and then to biaxial tension by testing specimens with different widths (Panich et al., 2013). However, the bending effect is ignored to meet the condition of membrane forces in the tests. Ghosh and Hecker (1974) compared the in-plane stretching with the out-of-plane stretching and found that the out of plane stretching produced larger limiting strains under identical degree of biaxial tension. Charpentier (1975) investigated the effect of punch curvature on the stretching limit of AKQD steel and the limit strains increased with the increasing punch curvature at constant material thickness. Tharrett and Stoughton (2003) conducted a series of stretch bending tests with various curvature punches and the limit strains of small radius were larger and the position of FLC was higher. Kitting et al. (2009) determined the forming limit of H340LAD, CP800, and DP800 under a range of punch radius and deduced that bending had an influence on the forming limit. With the decreasing of punch radius, the forming limit became higher, especially when the punch radius was below 10 mm. Emmens and van den Boogaard (2008) introduced the bending into the conventional tensile test on DC04 and DC06 with different thicknesses and discovered the percentage of elongation was increased greatly. Fictorie et al. (2010) conducted the Nakazima test with four kinds of radii of punches on DC06 and AA5051, and the forming limit increased with decreasing of radius of punch, especially in the plane strain region. The effect of bending on forming limit of sheet metal cannot be neglected.

In addition, the forming limit can be increased if the through-thickness stress or through-thickness shear involves. Smith et al. (2003) put forward a new sheet metal formability model considering the through-thickness stress and proved that the formability increased with the through-thickness stress. Assempour et al. (2010) predicted the forming limit diagram taking into account the normal stress and verified that the FLD shifted up when the normal stress increased. Zhang et al. (2014) established constitutive models with M-K methods and different yield criterions to predict the effect of through-thickness stress on the FLC and the FLC enhanced with increased through-thickness stress. Allwood and Shouler (2009) proposed a new generalized forming limit diagram allowing for the normal stress and through-thickness shear stress and demonstrated that the forming limits can be increased significantly by both normal compressive stress and through-thickness shear. What's more, Eyckens et al. (2009) established a model considering the effect of through-thickness shear with M-K method by investigating the incremental forming, and the results showed that formability was increased for all in-plane strain modes if through-thickness shear was present.

On the other hand, the drawbead has been widely used in sheet metal forming processes, especially in automotive industry and electrical appliances (Kim et al., 1997). By setting appropriate geometric

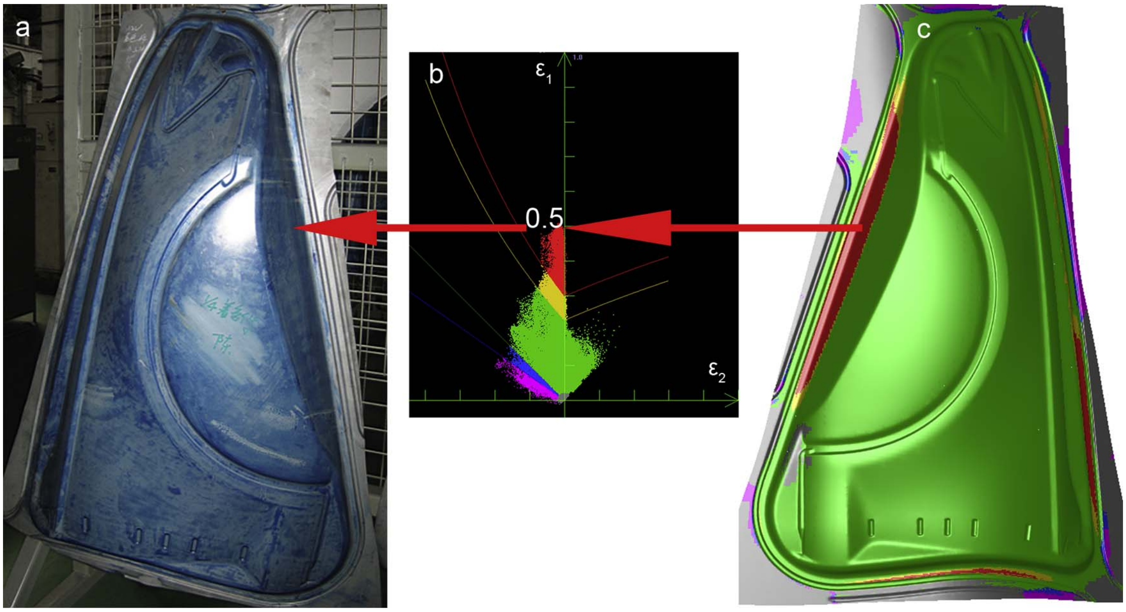

Fig. 2. The phenomenon that when the sheet metal flows through drawbead, the forming limit strains of the sheet metal are above the FLC, which illustrates serious fracture in theory, while it is very safe in practice. (a) the test piece (A-side of Audi A6 fender) in practice. (b) the forming limit strains of the test piece are above the normal forming limit curve. (c) the simulation result of the stamping process of the test piece (A-side of Audi A6 fender).