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Investigations of ductile damage in DP600 and DC04 deep drawing steel sheets during punching

Kerim Isik[a,*], Gregory Gerstein[b], Florian Gutknecht[a], Till Clausmeyer[a], Florian Nürnberger[b], Hans Jürgen Maier[b], A. Erman Tekkaya[a]

[a]*Institute of Forming Technology and Lightweight Construction, Technical University of Dortmund, Baroper Str. 303, 44227 Dortmund, Germany*

[b]*Institut für Werkstoffkunde (Materials Science), Leibniz Universität Hannover, An der Universität 2, 30823 Garbsen, Germany*

Abstract

The paper presents numerical and microstructural investigations on a punching process of 2 mm thick steel sheets. The dual phase steel DP600 and the mild steel DC04 exhibit different damage and fracture characteristics. To distinguish the void development and crack initiation for both materials, interrupted tests at varied punch displacements are analyzed. The void volume fractions in the shearing zone are identified by scanning electron microscopy (SEM). The Gurson model family, which is recently extended for shear fracture, is utilized to model the elastoplastic behavior with ductile damage. The effect of the shear governing void growth parameter, introduced by Nahshon and Hutchinson (2008), is discussed.

Keywords: Punching; Gurson model; dual phase steel; mild steel; shear fracture; SEM

1. Introduction

Sheet metal cutting operations such as blanking, fine blanking, trimming, guillotining and punching aim to separate a certain amount of the material from the remaining sheet by using a controlled shearing and fracture at the contour of cut. The properties of the resulting surface of cut depend on the proportion of the sheared and fractured regions. To this proportion, plastic flow, friction and fracture contribute simultaneously (Atkins, 1981). Material properties and process parameters such as sheet thickness, clearance, punch and die radii etc. define the cut surface properties.

* Corresponding author. Tel.: +49-231-755-6918; fax: +49-231-755-2489.
E-mail address: Kerim.Isik@iul.tu-dortmund.de

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For the process design, predictions of the surface characteristics and force requirements are mandatory. Analytical models provide acceptable estimations of the fraction of the sheared region and the maximal shearing force required for the cutting operations, cf. (Atkins, 1980) and (Martins and Atkins, 2013). Numerical modelling of the metal cutting processes using fracture models aims to improve predictions of the same manner as in (Thipprakmas et al., 2008). Hambli (2001) used the Lemaitre damage model (Lemaitre, 1985) and Rachik et al. (2003) applied the Gurson-Tvergard-Needleman (GTN) model (Tvergaard and Needleman, 1984) to simulate the fine blanking and the blanking process, respectively. Using those models, the fracture is mainly performed by removal of those elements, at which the damage has reached a critical threshold value. Main challenges in the numerical models are the requirement of very fine discretization (small mesh size) at the cutting zones and the occurrence of large deformations during the cutting process which follows excessive deformation of finite elements. To remedy those problems, Brokken et al. (1998) applied the Arbitrary-Lagrangian-Eulerian (ALE) method combined with remeshing. For the fractured region, Komori (2014) suggested a node-separation-method instead of element deletion to model fracture.

In this paper, the punching process is modelled using the Gurson model (Tvergaard and Needleman, 1984) which is recently extended for shear fracture (Nahshon and Hutchinson, 2008). In the Gurson model family, the material deterioration is measured by the void volume fraction f. The amount of voids, which may already be included at the initial state, is denoted by the initial void volume fraction f_0. During the deformation, nucleation of new voids and growth of already existing ones decreases the load carrying capacity of the material. Unlike Gurson's original model, which does not account for void evolution under shear stress, the modification in (Nahshon and Hutchinson, 2008) takes additional phenomenological effects of void distortion and void interactions with material rotation into consideration. The threshold values f_c and f_f define the onset of the coalescence and final fracture, respectively. The aim of this investigation is to prove the applicability of this model for a punching process, in which the shear stress states are dominant. A combined experimental and numerical investigation on the void evolution and succeeding fracture of two different sheet materials, namely a dual phase steel DP600 and a mild steel DC04 with the same sheet thickness of 2 mm is conducted. Specimens from interrupted tests at varied levels of punch displacements are used to measure voidage under scanning electron microscope at the intermediate stage of the punching process.

2. Gurson porous plasticity

The Gurson's yield function in general is (Gurson, 1977):

$$\Phi^P = \left(\frac{\sigma_{eq}}{\sigma_y}\right)^2 + 2q_1 f^* \cosh\left[\frac{3}{2}\frac{q_2\sigma_m}{\sigma_y}\right] - (1 - q_3 f^{*2}) = 0 \tag{1}$$

where σ_{eq} is the equivalent stress of von Mises, $\sigma_m = tr[\mathbf{T}]$ with $\mathbf{T}$ denoting the Cauchy stress tensor. q_1, q_2 und q_3 are material parameters (Tvergaard, 1981; Tvergaard, 1982). $\sigma_y = \sigma_y\,[e^p]$ is the flow stress and for the Swift type isotropic hardening with material parameters K, e_0 und n, it reads:

$$\sigma_y[e^p] = K\,(e_0 + e^p)^n \tag{2}$$

The volume void fraction is modified to f^*, due to the accelerating effects of the void coalescence as follows (Tvergaard and Needleman, 1984):

$$f^* = \begin{cases} f & f \le f_c \\ f_c + \dfrac{f_u^* - f_c}{f_f - f_c}\left(f - f_c\right) & f > f_c \end{cases} \tag{3}$$