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Prediction of abrasive punch wear in copper alloy thin sheet blanking

E. Falconnet [a,b,c], J. Chambert [a,c,d,*], H. Makich [a,b,c], G. Monteil [a,b,c]

[a] FEMTO-ST Institute, CNRS UMR 6174, Department of Applied Mechanics, 24 rue de l'Epitaphe, 25000 Besançon, France
[b] ENSMM, 26 rue de l'Epitaphe, 25030 Besançon Cedex, France
[c] University Bourgogne Franche-Comté (UBFC), France
[d] University of Franche-Comté, 1 rue Claude Goudimel, 25030 Besançon Cedex, France

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ABSTRACT

This work presents a combination of finite element simulations of copper alloy thin sheet blanking and a wear algorithm based on Archard formulation for abrasive wear of the punch. Firstly, a tribometer has been specifically designed to measure wear coefficient, and punch worn profiles have been extracted by means of a double-print method. Secondly, the blanking process has been simulated through the finite element method by using an elasto-plastic constitutive model and the shear failure model. Thirdly, a wear algorithm has been programmed using experimental wear data and mechanical fields computed from blanking simulation. Then, a damage criterion, namely the shear failure model, has been calibrated by an original method based on stress triaxiality analysis and shear height value measured from blanked edge profile. Finally, punch wear predictions have been discussed and compared to experimental results.

1. Introduction

Blanking process has been employed for decades in metal industry to obtain quality shaped parts for various applications. The reliability and capability of mass production of this forming process have been used to produce metal supports for electronic components, called leadframes. The manufacturing industries of leadframes have followed the trend in downscaling of electronic components, and thus they have produced smaller parts with high controlled geometry. Gréban et al. [1] have analysed the influence of blanked materials microstructure on leadframes quality with copper alloy thin sheets, a material chosen for its electrical properties. The authors have found that the mechanical characteristics and microstructure of copper alloys have a strong influence on parts blanking profile. Burr formation on sheared parts remains a critical parameter to control in order to insure leadframes electrical efficiency. For the last decades, the wear of shearing tool has been the locus of several experimental studies to understand its influence on sheared edge quality. Maeda and Matsuno [2] have highlighted the relationship between tool wear and burr height, among other process parameters, in conventional blanking. Cheung et al. [3] have studied the effects of several process parameters on dam-bar (integrated circuit component) cutting tools wear, and have established relationships between punch flank wear, burr height and cutting force. Monteil et al. [4] have developed a direct method to measure wear on cylindrical punch, based on selective activation technique, which allows real time quantification of process parameters influence like blanked material nature or lubrication.

Hence, the versatility of numerical methods has been combined to experimental investigations to predict tool wear for a variety of forming processes. Jensen et al. [5] have applied finite element method (FEM) to determine tool wear in conventional deep-drawing. Behrens and Schaefer [6] have performed hot forging process simulation by means of finite element modelling to predict tool wear. More recently, Torres et al. [7] have used FEM to simulate hot metal shearing process and have found good correlation between stress distributions within the tool and wear location observed on tool real shape. However, tool wear prediction has been less investigated in blanking process. Hambli [8] has proposed a theoretical approach to predict tool wear according to the evolution of punch edge radius, which has been implemented in industrial software called Blanksoft to optimize sheet metal blanking processes. Moreover, Hambli [9] has implemented a wear prediction model within finite element (FE) code to predict punch wear during steel metal sheet blanking, and has also investigated the effect of tool wear on burr formation. More recently, Falconnet et al. [10] have combined experimental and numerical analyses to study punch wear in the blanking of copper alloy thin sheet used to produce leadframes. In this study, the material behaviour has been modelled with an elasto-plastic law without considering material damage. Several authors have emphasized the fact that accurate representation of metal shearing processes implies to

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[*] Corresponding author. Tel.: +33 3 81 66 60 25; fax: +33 3 81 66 67 00.
E-mail address: jerome.chambert@univ-fcomte.fr (J. Chambert).

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take account of crack initiation and propagation mechanism within finite element simulation.

In this paper, investigations on punch wear prediction presented in Falconnet et al. [10] have been extended by introducing a finite element blanking model including crack initiation and propagation within blanked sheet by means of shear failure model. Data of the studied blanking configuration and wear measurements have been determined from experimental results. Then, the finite element modelling of blanking process has been established and punch wear calculation has been performed. Results concerning damage parameter calibration and punch worn profile are presented and discussed in the last section of this paper.

2. Experimental set-up

2.1. Material data

The blanked material is a copper–iron alloy with chemical composition listed in Table 1.

Samples have been taken from a copper–iron alloy strip of 15 mm width and 0.254 mm nominal thickness to perform conventional tensile tests, at strain rate of $10^{-3}\ \mathrm{s}^{-1}$.

The rational (true-stress and true-strain) tensile test curve has been described by the following piecewise power hardening law:

$$\sigma = \begin{cases} \sigma_0 + k_0(\bar{\varepsilon}^p)^{n_0} & \text{where} \quad \sigma_0 \le \sigma < \sigma_1 \\ \sigma_1\left(\bar{\varepsilon}^p/\varepsilon_1\right)^{n_1} & \text{where} \quad \sigma > \sigma_1 \end{cases} \tag{1}$$

where σ is the flow stress, $\bar{\varepsilon}^p$ is the equivalent plastic strain, k_0 is a material constant, σ_0 is the initial yield stress, $(\sigma_1, \varepsilon_1)$ is the yield point at incipient necking, and n_0 and n_1 are the strain hardening exponents. As long as a homogeneous uniaxial stress state exists, i.e. until incipient necking occurs, the tensile test curve (Fig. 1) has been interpolated by the first part of Eq. (1).

Beyond this point, an extrapolation of the tensile test curve has been performed according to the second part of Eq. (1) to take into account large deformation plasticity within FE modelling. Poisson's ratio ν has been provided by metal sheet supplier. The mechanical properties are listed in Table 2.

2.2. Blanking test description

The studied blanking process consists in a cylindrical punch passing through a metal sheet maintained between a die and a sheet-holder (Fig. 2).

During downstroke travel, the punch plastically deforms the sheet to create local shear stresses which lead to ductile damage and then complete separation of the cut part. The sheet-holder prevents elastic springback and movement of the sheet during punch travel, thus increasing the quality of the blanked edge. In this study, the punch radius R_p measures 1.85 mm and the clearance j_{pm} between the punch and die equals 10 μm, or 4% relative to sheet thickness. The blanked material is a copper–iron alloy sheet of 254 μm nominal thickness e, and 15 mm width. The punch has been made of H20S tungsten carbide, a tool material commonly used in leadframes manufacturing, and it has been obtained by spark machining. The blanking tests have been performed on a mechanical press with a speed of 500 strokes/min.

Table 1
Chemical composition of the blanked material.

Element	Cu	Fe	*P*	Others
wt%	> 99.61	0.05–0.15	0.025–0.04	< 0.2

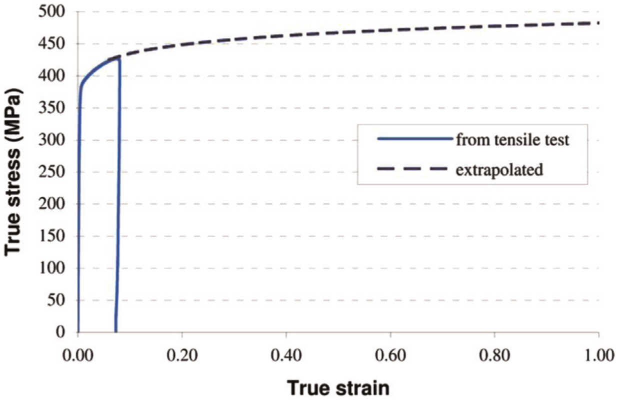

Fig. 1. Uniaxial true-stress – true-strain curve of the blanked material.

Table 2
Mechanical properties of the blanked material.

Parameter	**Symbol**	**Value**
Young's modulus	E	121 GPa
Poisson's ratio	ν	0.34
Initial yield strength	σ_0	371 MPa
Yield strength at incipient necking	σ_1	422 MPa
Equivalent plastic strain at incipient necking	ε_1	0.055
Material constant	k_0	215 MPa
Strain hardening exponent of interpolated curve	n_0	0.490
Strain hardening exponent of extrapolated curve	n_1	0.045

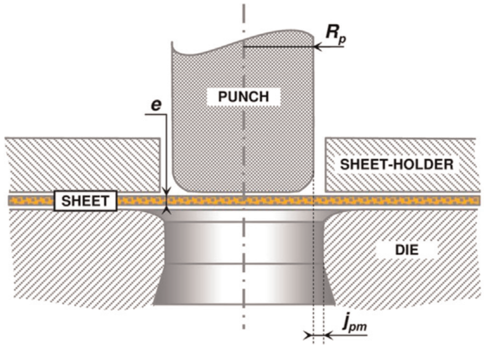

Fig. 2. Blanking test configuration.

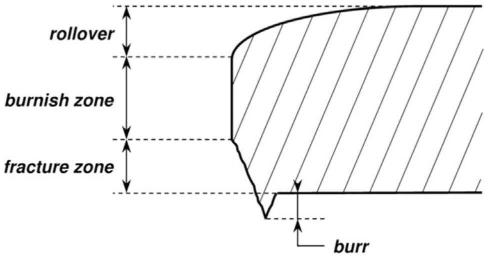

Fig. 3. Blanking edge profile scheme.

Fig. 3 represents typical cut edge profile generated during the blanking process.

According to Johnson and Slater [11], rollover results from bending of the sheet which occurs during the initial plastic indentation stage by the punch. As the tool further penetrates the sheet, cracks initiate at the cutting edge of the tool and propagate inside the sheet. Complete fracture occurs before the punch totally passes through the sheet. The burr and fracture zone are formed