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FEM-based assessment of wear of stamping die

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Abstract. In sheet metal forming industry, surface damage and wear such as adhesion and ploughing of metallic sheet, is a well-known problem which reduces the tool life and quality of drawn elements. Surface defects are the consequences of wear and they accelerate the galling process. The knowledge of places particularly endanger wear allows appropriate design of tools. In this paper, an investigation that focused on the finite element-based analysis of wear of stamping tool for forming an axisymmetric drawpiece has been reported. The analyses were carried out for deep-drawing quality steel sheet with a sheet thickness of 2 mm. The basic mechanical parameters of the sheet tested are determined in uniaxial tensile tests. The analyses performed using Marc/Mentat program for nonlinear analyses take into account the strain hardening phenomenon of sheet material and different values of friction coefficient. The implementation of an Archard's wear model in the numerical simulation proved the possibility of tool wear simulation in sheet metal forming. As a result of the conducted tests, the places of the stamping die potentially exposed to quick wear were determined. It was found that the most exposed region on accelerated wear is the upper part of the die radius.

1. Introduction

Tool wear is an indispensable process in the exploitation of tools in metal forming. The term wear is understood as the loss of material from the surface of tools, which occurred under the influence of friction and the accompanying physical or chemical phenomena [1, 2]. Worn-out tools are often regenerated. Tool surface damage occurs due to faulty construction, wrong manufacturing technology or improper operation. Inappropriate design of tools can be a source of stress accumulation, which under the influence of dynamic loads are sources of cracks. Another parameter determining the tool wear is an inappropriate selection of material with insufficient hardness and, in the case of heat treatment, low heat resistance. Scratches and too much surface roughness of the tools reduce the strength of the material and are also sources of cracks. The basic types of wear include abrasive wear, fatigue and thermal adhesive wear. Abrasive wear is characterized by a set of phenomena occurring in the contact areas of two moving elements relative to each other. Abrasive wear occurs at relative speed and unit pressures resulting in only a slight increase in tool temperature. According to the literature [3], there exist many approaches of wear modeling based on contact mechanics and failure mechanics. The most known is the Archard's model [4] which is based on the motion and interaction of opposing asperities on either contacting body. Archard assumed that the deformation occurring was of a plastic type and that the material property of greatest importance was the "flow pressure" of the softer metal



[5]. Savio et al. [6] analysed the polishing of glass moulds and the inherent material removal process. This is a very complex process because the element will be a polished with the polishing tool and an abrasive action due to the slurry used to help to remove material.

This paper presents the results of numerical investigations of the prediction of places of wear of stamping tool based on the Archard wear model. The wear analyses were carried out during forming of the axisymmetric drawpiece from deep-drawing quality (DDQ) steel sheet. The wear value was determined in the FE-based Marc/Mentat program.

2. Material

The sheet forming tests of axisymmetric drawpiece were conducted on deep drawing quality steel sheet with a sheet thickness of 2 mm. The chemical compositions of steel used are listed in Table 1. The mechanical properties of the sheet metals (Table 2) have been determined through uniaxial tensile test. Five samples were tested and average values of mechanical parameters were determined. The values of the strain hardening parameters K and n in Hollomon law ($\sigma = K \cdot \varepsilon^n$) are determined from the logarithmic true stress – true strain plot by linear regression.

Table 1. Chemical composition of steel sheet (wt. %)

C	Mn	Mo	Ni	Cr	Nb	S	P
0.09	0.18	0.02	0.05	0.05	0.006	0.018	0.04

Table 2. The selected mechanical properties of the tested DDQ sheet*

Material	E (GPa)	$R_{p0.2}$ (MPa)	R_m (MPa)	A_{50} (%)	K (MPa)	n
DDQ	189.4	182.5	304.9	43.1	583.6	0.230

* E – Young's modulus, $R_{p0.2}$, yield stress, R_m – ultimate tensile stress, A_{50} – elongation, K – strain hardening coefficient, n – strain hardening exponent

3. Numerical modeling

FE-modeling of stamping process was carried for the axisymmetric drawpiece. Due to symmetry of the forming process of axisymmetric drawpiece, the model of the forming process has been simplified to 2D (Fig. 1). In real forming conditions, the sheet flange has tendency to loss the stability. To protect the sheet against wrinkling in the blankholder contact region, the force of value $PB = 3$ kN is applied (Fig. 1). The punch and blank diameters were equal to 95 and 220 mm, respectively. Edges of tools were rounded by the radius of 10 mm. All parts of the stamping die are assumed as deformable.

Due to the fact that the strength of tools is much higher than the strength of the drawpiece, the tools are considered as perfectly elastic with the values of elastic parameters Young's modulus and Poisson's ratio assumed according to the literature [7]: $E = 2.07$ GPa and $\nu = 0.3$, respectively. The workpiece is considered as elastic-plastic strain strengthenable material with parameters of strain hardening K and n listed in Table 2. The elastic properties of the sheet material are as follows $E = 2.045$ GPa and $\nu = 0.3$. The blank and tools were modeled with a four-node, isoparametric, arbitrary quadrilateral elements. The mesh is concentrated in the vicinity of surfaces of tools which are in contact with workpiece. The workpiece consists of 880 elements, while tools consist 14020 elements.

The contact phenomena were described by two bilinear Coulomb's and shear friction models. The coefficients of friction between the tools and workpiece were assumed to be $\mu = 0.1$, $\mu = 0.2$ and $\mu = 0.3$ [8]. According to this study, the analysed values of friction coefficients in contact of deep-drawing quality steel sheets correspond to the real values [9].

In order to determine the tool wear, the Archard's abrasive wear model [4] based on the stress in contact and the rate of displacement of the material at workpiece-tools contact was applied. The total volume of wear debris produced w according to Archard's model can be determined from the formulae:

$$w = KF \frac{G}{H} \quad (1)$$

where K is the wear coefficient, F is a normal load, G is the sliding distance and H is the hardness.

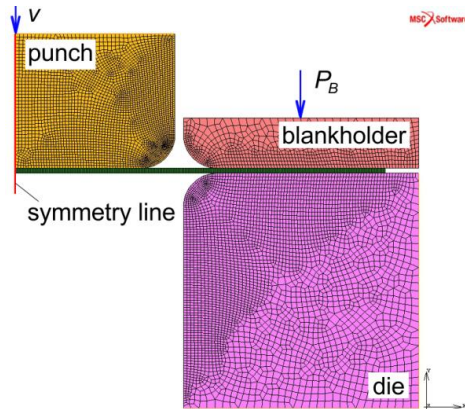


Figure 1. Schematic illustration of the tools and blank for the FE model

After converting Eq. 1 into an incremental form and upon assuming that wear is calculated as a local quantity, the normal force can be replaced by normal stress, and wear rate \dot{w} takes the form:

$$\dot{w} = \sigma \frac{K}{H} v_r \quad (2)$$

where \dot{w} is the rate of change of wear in the direction normal to the surface, σ is the normal stress, v_r is the relative sliding velocity.

The incremental wear is calculated as $\dot{w}\Delta t$ and the wear is accumulated as

$$w_{n+1} = w_n + \dot{w}\Delta t \quad (3)$$

where w_{n+1} is the actual value of wear depth, w_n is the value of wear in previous step of computation, Δt is the time step of computation.

The wear coefficient value and hardness are assumed to be 52 HRC and 0.0178 [8].

4. Results

The prediction of tool wear in the numerical model was analyzed in the area of blankholder action and on the rounded edge of the die. These regions of the stamping die are the most expose to the wear phenomenon. The conditions in the die radius are crucial to the overall tool wear. It is in consistence with the results of Pereira et al. [10]. The wear prediction in both analysed friction conditions is similar. It was found that there are two areas of accelerated wear (Fig. 2). The first region is located on the upper part of the rounded edge of the die. The second region is located at the entrance of the sheet from the blankholder area. For the results to be readable, the distribution of wear presented in Figs 2 and 3 omitted the areas with very little wear below $10^{-5} \mu\text{m}$.

Wear in the flat region of the contact zone of sheet with blankholder is relatively small. The force imposed by blankholder is distributed on the very big area of contact of the sheet with blankholder. So, the normal pressures are relatively small.

The change in the curvature of the sheet in region A (Fig. 2) produces an increasing plastic strain of the material and increases the pressure of the sheet material on the tool surface. At rounded edge of the die, the wear is very uniform. The increase in the value of friction coefficient slightly influences the tool wear (Figs. 2, 3). Examination of the wear indices and local stress concentrations for the other radiuses of the tools indicated similar results, i.e. the region of extensive wear and stress concentration is on the rounded edge of the die. According to the FE-based numerical results, the predicted wear locations were consistent with the trend of experimental results available in the literature [10, 11].

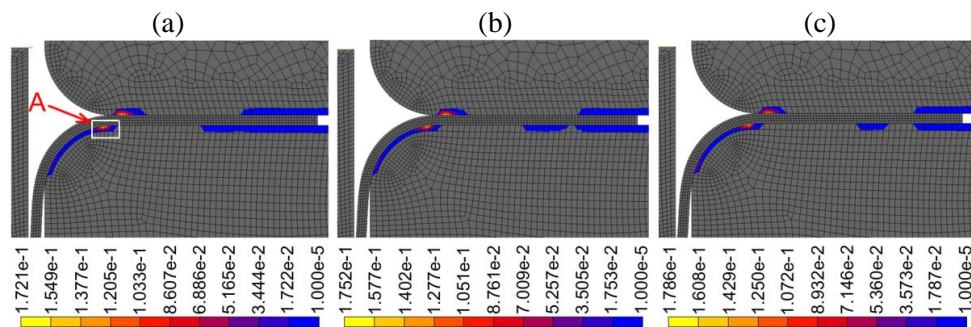


Figure 2. Wear (μm) in the blankholder area for the Coulomb friction conditions at punch depth of 30 mm: (a) $\mu = 0.1$, (b) $\mu = 0.2$ and (c) $\mu = 0.3$.

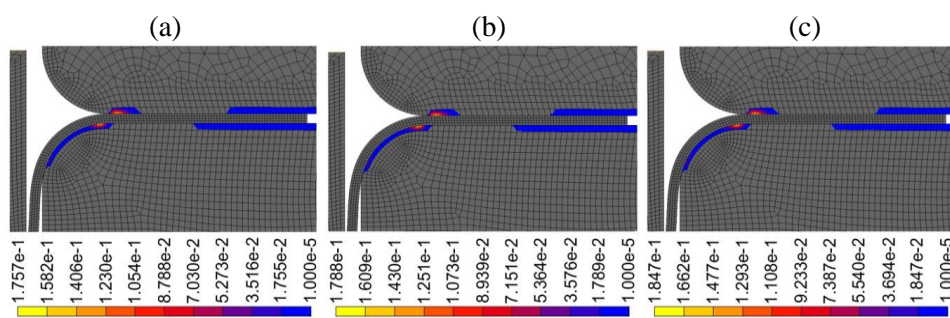


Figure 3. Wear (μm) in the blankholder area for the shear friction conditions at punch depth of 30 mm: (a) $\mu = 0.1$, (b) $\mu = 0.2$ and (c) $\mu = 0.3$.

5. Summary

The implementation of the Archard's wear model in the finite element-based numerical modeling proved the possibility of tool wear simulation in the sheet forming. The possibility of numerically predicting tool wear is helpful in determining the period of reliable work of the stamping die. The methodology presented in the work can be used at the design stage of the tool to determine the places of accelerated wear. In this way, it is possible to use the removable inserts only in places where wear rate is crucial. The results obtained indicate that the upper region of the rounded edge of the die is the most exposed to wear. Furthermore, the change in friction conditions slightly influences the friction coefficient value.

6. References

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