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TECHNIKA TRANSPORTU SZYNOWEGO

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WEAR OF TOOL DURING EXTRUSION OF MATERIALS WITH DIFFERENT PROPERTIES – COMPARATIVE NUMERICAL ANALYSIS

Abstract

In this paper comparative numerical simulation of wear die during extrusion of metals with different properties was presented. Description of working condition, geometry and material of tools has been given. Simulation of tool wear during extrusion with using MSC MARC program based Finite Element Method has been carried out. As a result of such studies was determined dies at the depth of their wear of various metals.

INTRODUCTION

In recent years, there has been a growing need in the metal forming industry to improve not only dimensional accuracy and surface finish, but also to reduce production cost. Because of advantages of cold extrusion such as high production rates, costs that are competitive with those of conventional methods, excellent dimensional tolerance, surface finish and mechanical properties, elimination of the need for billet heating, cold extrusion is being exploited increasingly for producing components with complex shapes. Cold extrusion is characterized by various process parameters including the geometry of the initial billet, final product and tools or dies, forming sequence, friction and material property of the work-piece and those of the tools.

In this technology outside giving the shape of the product, it is necessary to take into account the economically feasible tool life. The durability of the tools used in the extrusion process is influenced by many factors that sometimes antagonistic character. The life of dies depends on the proper design and implementation, including appropriate treatment of thermo-chemical and mechanical appropriate to the material chosen, the sequence of the individual performing the thermal treatment, as well as the conditions under which the extrusion process itself (temperature tool, the geometry of the billet material, the speed of the process, the type and amount of lubricant ensuring optimum tribological conditions). Another important parameter is the kind of tool material. It should be taken into account that steel producers use their own procedures, and the chemical composition of for the same material may differ significantly. It all has a significant impact on the cost of production of extruded products and their quality. Due to the high pressure unit, straining of the die material is often so high that it results in the premature wear or even destruction. Information on tool life is of particular importance when considering the issues associated with an increased efficiency of the extrusion process. In practice, it is important to decide how many cycles and the number of produced items which appear unacceptable wear die as well as the knowledge that it is a repeatable phenomenon. In view of the sustainability tools take into account the wear of tribological, causing changes in the structure and properties of the surface layers of the contact areas. Furthermore, the cause of non-uniform friction stress state and the uneven deformation plastically shaped volume of material, which causes an increase in the force required to deform, the increase in tool wear and worsens the surface state of the product.

The first attempt to relate wear to the mechanical properties of materials was made by Tonn [8] in 1937, who proposed an empirical equation for abrasive wear. In 1940, Holm calculated the worn-out volume of a substance over a unit sliding path. General Archard's [2] wear model has been applied to predict die wear. The amounts of wear are proportional to the wear coefficient between the die and the workpiece, the surface pressure of the die, the relative length movement between the die and the workpiece and inverse to the hardness of the die. Altan et al., Geiger et al., and others [3,5,11,17] have estimated the die wear during upsetting and hot forging based on finite-element analyses and have investigated the friction mechanism in metal forming processes [16]. Sobis et al. [19] studied the real contact areas for wear prediction that is the limits of the Archard's model. Painter et al. [13] analyzed the die wear in the hot extrusion using the finite element code DEFORM to simulate the process and WEAR program to predict the wear condition. Lee and Im [9] also used the finite element method to investigate the wear and elastic deformation of die. Recently, Kang et al. [7,8] proposed a new wear model considering thermal softening and used it to calculate the wear profile of a rotor pole for automobile warm forging die. Wibom et al. and Iwama et al. [18] have studied the rise of temperature due to friction and examined how the lubrication condition affected die wear and life. Also, Altan and Knoerr [1] conducted finite-element analyses using a commercial program DEFORM in order to obtain information of metal flow, temperature, strain, and stress for more effective die and process design. They found that the stress concentration in dies was related directly to its life and determined that inducing stress relaxation by changes in the die geometry can improve die life. Modern computational techniques to enable an accurate calculation and hence a more thorough analysis of material flow in the different phases of the process of the device, as well as to determine the wear of the tool [10,11,14,19].

Some tools are used during exploitation extrusion sometimes several species of materials with different properties, which has a significant impact on the size wear and significantly impedes the prediction of tool life on the stage of their designing. Conducted analysis aims at comparing the size of die wear depending on the type and properties of the extruded material. This will allow for better decision-making tools regarding the design designed to reduce wear intensity and an extension of time tools they use.

1. NUMERICAL MODELLING OF EXTRUSION PROCESS

Numerical calculations were performed using the commercial software MARC / Mentat 2010 MSC Software. Extrusion process geometrical model was built based on the experimental model by carrying out the process of extrusion of lead Pb1. During the course of the trial were recorded extrusion force, and then drawn force process characteristics. Verification of the numerical model was performed by comparing the forces and the conduct of the experiment. The extrusion process was modeled for the dies with working cone angle of $\alpha = 90^o$.

Numerical calculations were performed using the commercial software MARC / Mentat 2010 MSC Software. Extrusion process geometrical model was built based on the experimental model. This enabled the determination places and the size of its consumption depending on the extruded metal. Die diagram shown in figure 1 and the basic dimensions of die used in the extrusion tests are shown in Table 1. When modeling to test for specific materials only change their properties and friction conditions. Other conditions for the implementation the extrusion process were analyzed for all cases the same.

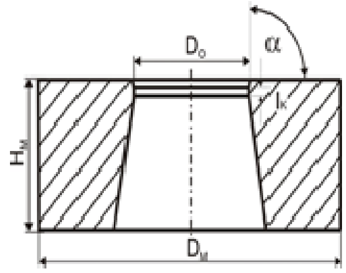

Fig. 1. Scheme of die

Tab.1. Basing dimensions of the investigated die

Parameter	Value
Working angle of the die cone α, degrees	90
Die diameter D_M, mm	36
Die height H_M, mm	20
Die hole diameter D_O, mm	20,78
Bearing length l_k, mm	2

Built numerical model is a model of two-dimensional (flat model), which analyzed assuming axisymmetric state of stress. Geometries made contact with the conditions models and meshes elements of deformable bodies are shown in figure 3. The mechanical properties of the elastic deformable die (made of stainless NC10) described assuming E = 210 000 MPa and ν= 0.3. However, the properties of extruded materials described assuming perfectly plastic body model of the nonlinear strain hardening.

The strain hardening curve curves were determined experimentally from upsetting tests and then approximated by the equation Hollomona. The values determined for the analyzed material constants of materials are given in the table 2. Friction model described by Coulomb's law. The coefficients of friction between materials and tool extruded determined using the tester T-01M and included in the Table 3.

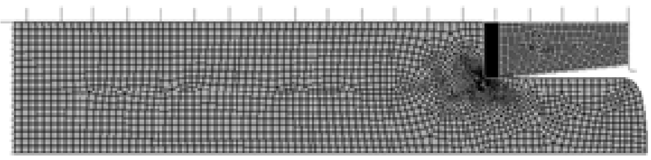

Fig. 3. Two- dimensional geometrical model to FEM simulation of extrusion process

Tab. 2. Values of mechanical test materials

Material	**Re MPa**	**C MPa**	**n**
Soft lead Pb1	5	35	0,45
Hard lead OT3	10	40	0,23
Aluminum Al1	30	115	0,23
Copper M1E	57	368	0,3

Tab. 3. Friction coefficients used in modeling

Material - Material	Friction coefficient
Pb1-steel	0,35
OT3-steel	0,30
Al1-steel	0,20
M1E-steel	0,15

For the construction of the finite element mesh used elements of deformed material type 10 class 4 - axisymmetric quadrilateral ring [12]. Numerical simulation was performed using the global remeshing.

The adhesive wear may be extracted from the equation proposed by Archard [4]:

$$dV = k\frac{dFdL}{H} \tag{1}$$

where:
k — wear coefficient
dV — volume wear
dF — normal force
dL — friction path
H — hardness

In performed researches, the die wear profile during the extrusion was calculated by implementing Archard FEM based wear model in MARC software as presented below:

$$\overset{o}{w} = \frac{k}{H}\sigma_n v_{rel} \tag{2}$$

where:
$\overset{o}{w}$ — wear speed
σ_n — normal stress in contact
v_{rel} — relative slip speed

The wear amount indicated as the wear coefficient was calculated using the equation as follows:

$$w_{n+1} = w_n + \overset{o}{w}\Delta t \tag{3}$$

where:
w_{n+1} — current wear depth
w_n — wear amount in the previous computation step
$\overset{o}{w}$ — wear speed
Δt — time in the computation step

Tool wear indicator (3) can be used as a criterion to evaluate the durability of the tools and, in the present case to analyze the effect of the material type and the size of the wear of die. In performed researches, the wear coefficient k equaled 10-4 [9] and hardness HB = 502.

2. ANALYSIS OF THE RESULTS OF NUMERICAL CALCULATIONS

The size of tool wear depends on many parameters, such as the normal stress, friction, and temperature of the process. Tool wear the most intense zone, expressed as a wear indicator which corresponds to the depth of wear (adhesion) as a result of movement of the material on the tool surface. The highest values of wear index were found in the area of the radius of the die. Increased wear the of the die in this the area with consequent caused failure to meet specified sizes and surface deterioration in the quality of the material extruded.

While numerical modeling was used tool geometry update procedure. It consists in updating the current position of the nodes depending on the size of wear. This approach is very useful, because the update tool geometry at each step computing causes that the course of their use is more similar to the real. Example of wear profile created by the use of this procedure is shown for extrusion of copper (fig. 4).

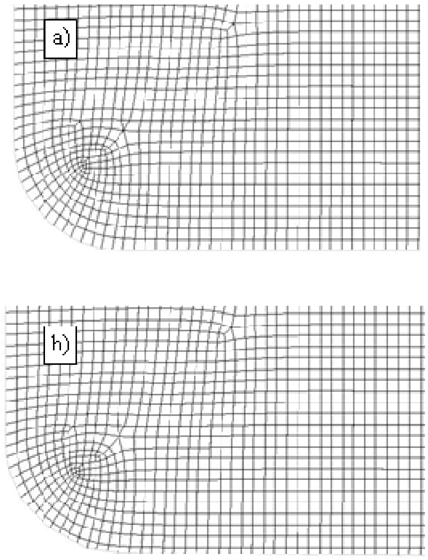

Fig. 4. Profile tools in the area of greatest wear designated by the application tool geometry update procedure: a) unused tool, tool after the extrusion process

In order to determine influence of the type of material the size of the extruded wear in specific areas on the surface of tool depth measurements made wear several different locations in the die. Measurements were made at 55 points of measurement for all the extruded material, for example, as shown in figure 5.

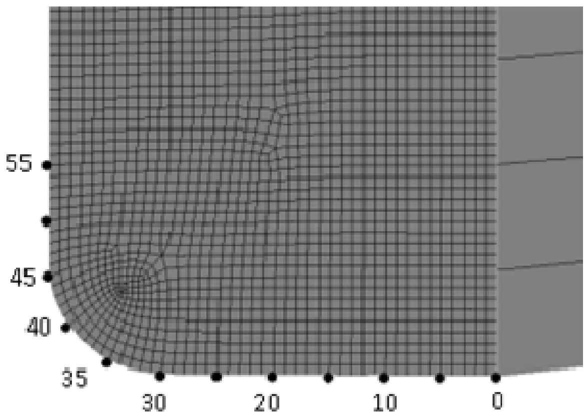

Fig. 5. The location and depth measurement points of wear die

The calculated depth of wear for different die materials extruded shown in figure 6. As the results of tool wear was greatest during the extrusion of copper. The results indicate that wear is accumulated along the inner surface of the die reached a maximum value at the entrance of the hole die. The maximum values for each material are achieved between 30 and 40 measuring point. In the case of copper extrusion the maximum value was recorded for 36 measuring point for aluminum wear was recorded for a maximum of 38 measuring points, while in the case of lead extrusion the maximum value observed for the 35 point. Aluminum extrusion reduced maximum value of the wear of die over 65% and over 90% of lead as compared with the extrusion of copper.

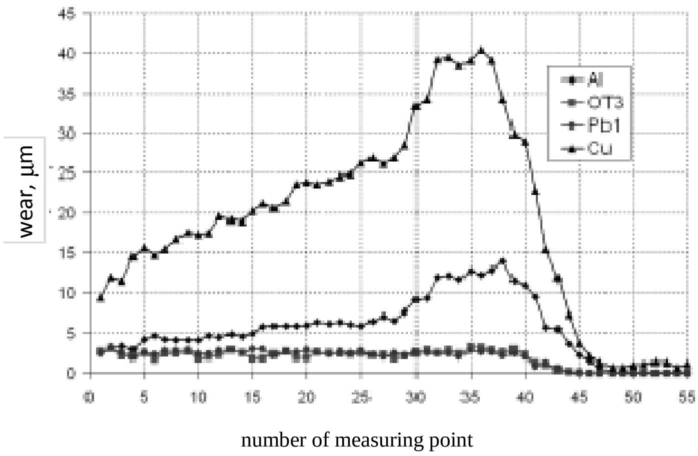

Fig. 6. Depth of wear in particular areas of corner of die

Numerically designated areas of heaviest wear are associated with changes in the direction of flow, while high-intensity gradient of deformation. The size of the wear is directly related to the mechanical properties of extruded materials and the ability to strain hardening.

SUMMARY

Tool wear determined using numerical calculations. This allowed comparison of the impact of kind of extruded material wear without the need to calibrate the model to the actual size of the wear. By using numerical modeling in industrial practice can predict the lifetime of tools for extrusion of different materials, and choose the best variant of the process, to ensure the longest possible service life and repeatable dimensionally-shaped products, while reducing costly experiments. Such as presented in this paper an approach without calibration constant wear model does not provide true compatibility largest in conditions of actual wear, however, is sufficient for this type of comparative analysis.

ZUŻYCIE NARZĘDZIA PODCZAS WYCISKANIA METALI O RÓŻNYCH WŁAŚCIWOŚCIACH - NUMERYCZNA ANALIZA PORÓWNAWCZA

Streszczenie

W pracy zaprezentowano numeryczną analizę porównawczą zużycia matrycy podczas wyciskania współbieżnego różnych metali. Podano warunki pracy, geometrię oraz materiał, z którego wykonano badane narzędzie. Symulację zużycia narzędzia w procesie wyciskania współbieżnego przeprowadzono przy użyciu programu MARC/Mentat, bazującego na Metodzie Elementów Skończonych. W wyniku przeprowadzonych badań wyznaczono m.in. głębokości zużycia matrycy podczas wyciskania różnych metali.

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