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NUMERICAL ANALYSIS OF THE EFFECT OF BACKPULL ON TOOL WEAR IN THE PROCESS OF WIRE DRAWING

ANALIZA NUMERYCZNA WPŁYWU PRZECIWCIĄGU NA ZUŻYCIE NARZĘDZIA W PROCESIE CIĄGNIENIA

Key words:

wear, drawing, round wire, drawing die, FEM

Słowa kluczowe:

zużycie, ciągnienie, drut okrągły, ciągadło, MES

Summary

The paper presents a comparative numerical analysis of the tool wear in wire drawing process without and with backpull. The study was performed for the copper wire drawing cone by drawing die made of sintered carbide diameter of 3 mm mesh. A constant figure of 30% relative deformation ratio and the angle of pull of 9^o was initially assumed. An axially symmetric numerical model of drawing process was created utilising a commercial program for nonlinear problems and contact MARC / Mentat. Numerical analysis was performed for the case of drawing without backpull, as well

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as application backpull with different rates. The influence of the backpull rate of wire drawing on wear of the die has been determined.

INTRODUCTION

Drawing is an operation in which the cross sectional area of a bar is reduced by pulling it through a converging die **[L. 1]**. Drawing is a manufacturing process used in the industry due to its versatility and good mechanical properties (as good surface finish and dimensional accuracy) of the produced wire **[L. 2]**. Successful drawing operations require proper selection of process parameters and consideration of many factors. The principal variables are the die semiangle, the reduction ratio in cross-sectional area, and the friction at the die-workpiece interface **[L. 3]**.

Wear of drawing dies is a fundamental limitation in the wire drawing process. Replacement of worn dies causes direct costs in money and time for replacement and reconditioning. Die wear has been detected after relatively short time of operation **[L. 4]**.

The die wear can be divided into three zones. The first wear zone is close to the entry plane where the wire first gets in contact with the die. The second wear zone is the drawing cone and the third is the bearing at the die exit. According to Wistreich **[L. 5]** the wear is most severe at the entry plane of the die. He assumed that a "wear ring" occurs as a result of fatigue in the first contact point between the wire and the die. According to Shatynski, this assumption cannot be correct because the fracture surface is usually perpendicular to the direction of the principal tensile stress **[L. 6]**. Kim et al. **[L. 7]** assumed that the wear is not constant in the die because of the variation in pressure. FEM-simulations (finite element method) made by Kim et al. and independently by Overstam **[L. 8]** have shown pressure variations in the die. A peak pressure at the entry plane and a lower pressure peak at the exit of the drawing cone were shown. These pressure peaks may explain some of the irregularities of wear of the die, as a wear ring. If the wear ring occurred because of oscillation from the produced wire, the wear ring would not be uniform and largest in the direction of oscillation. Pirso et al. **[L. 9]** found the wear of cemented carbides during dry conditions is caused mainly by the removal of the cobalt binder followed by fracture of intergranular boundaries and fragmentation of carbide grains. When loosening and separation of carbide particles take place in the entry plane, abrasive wear will appear in the drawing cone and the bearing, if the lubricant film is not thicker than the free carbide grains **[L. 4].** Backpull significantly changes the conditions of deformation and affect the conditions of power and technology drawing process. Some studies have shown that with increasing pressure decreases backpull metal die **[L. 3, 10]**. Reduction in pressure force has a significant influence of the wear intensity of tools (drawing dies).

The paper presents a comparative numerical analyses of the tool wear in wire drawing process without and with backpull.

NUMERICAL SIMULATION

Numerical modeling of drawing is a process that requires consideration of non--linear phenomena and contact parameters. A typical numerical model of the drawing process consists of three bodies being in contact with each other. The first body is the drawn wire, the second and third one are the drawing die and die case, respectively. The drawn material is always modelled as an elastic body, whereas the drawing die is assumed to be a perfectly rigid one. This simplified model does not take into account phenomena of the elastic deformation of the tool and its wear during operation, these phenomena requires the drawing die to be modelled as an elastic body.

The modelled process of drawing presented in **Figure 1**. It consists of a drawn wire 1, deformable drawing die 2 and rigid abutment surface 3. The drawing process is carried out through force Fc (drawing force). Force F_0 acting in the direction opposite to the drawing force is called backpull force. In the case of drawing without backpull value of the force $F_0 = 0$.

The axially symmetric numerical model of drawing process was created in a commercial program for non-linear problems and contact MARC/Mentat. Geometric shapes and dimensions of modelled the tools are shown in **Figure 2.**

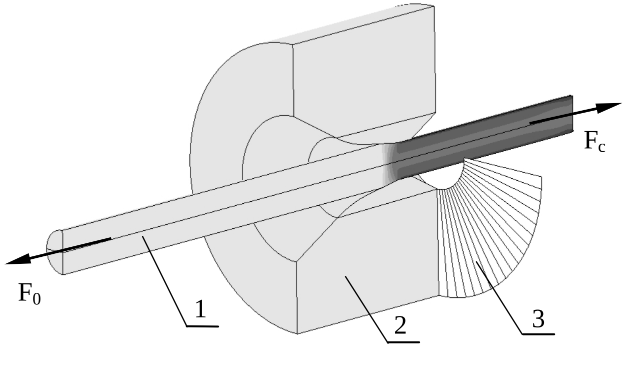

Fig. 1. Scheme of drawing process modelled: 1 – drawn wire, 2 – drawing die, 3 – abutment surface, F_c – drawing force, F_0 – backpull force

Rys. 1. Schemat modelowanego procesu ciągnienia: 1 – ciągniony drut, 2 – ciągadło, 3 – powierzchnia oporowa, F_c – siła ciągnienia, F_0 – siła przeciwciągu

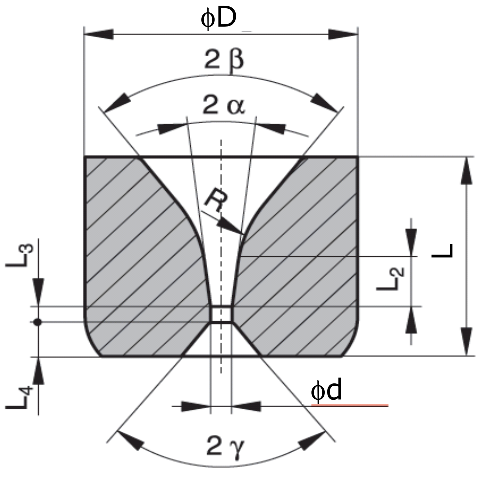

Fig. 2. Dimensions of drawing die for investigations: ϕd = 3 mm, ϕD = 20.45 mm, R = 10 mm, 2β = 2 γ = 60^o, 2α = 18^o, L = 17 mm, L_2 = 5.2 mm, L_3 = 1.5 mm, L_4 = 3.2 mm
Rys. 2. Wymiary ciągadła do badań: ϕd = 3 mm, ϕD = 20,45 mm, R = 10 mm, 2β = 2, γ = 60^o, 2α = 18^o, L = 17 mm, L_2 = 5,2 mm, L_3 = 1,5 mm, L_4 = 3,2 mm

Using a drawing die with a diameter of 3 mm copper wire with a diameter of 3.6 mm was produced. There was approximately 30% relative reduction in cross section. For generating the finite element mesh of tool and wire elements a quad 4 type 10 - arbitrary quadrilateral axial-symmetric ring has been used **[L. 11].** The model of tool had two grids of finite elements **(Fig. 3)**. The average size of the grid in the concentrated area was 0.05 mm and 0.35 mm in the less loaded area. The initial size of mesh of the drawn wire was 0.05 mm. Overall, the numerical model consisted of approximately 24 000 finite elements. Features of tools made of cemented carbide are described with the model assumption of perfectly elastic material, assuming Young's modulus E = 620 000 MPa and Poisson's ratio ν = 0.22 **[L. 12]**. To describe the properties of deformed copper wire assumed elastic-plastic material model with non-linear strengthening has been taken into consideration. Stress-strain dependence of the plastic deformation is described by the equation Hollomon power law. The material parameters of wire used for modeling are given in **Table 1.**

Coulomb's model was used to describe the friction between deformable materials. The coefficient of friction between the drawn rod, and drawing die was assumed to be equal μ = 0.07 **[L. 12]**. The modeling process carried out with the assumption of a constant speed of drawing v = 0.7 m/s.

Table 1. Mechanical properties of drawn material
Tabela 1. Właściwości mechaniczne materiału ciągnionego

Drawn material	Young's modulus E MPa	Poisson's ratio ν	Yeld stress Re MPa	Ultimete strength Rm MPa	Strain hardening coefficient K MPa	Strain hardening exponent n
Cu (M1E)	127 000	0.35	57	227	368	0.3

Archard's model was used to determine of the wear of drawing die as follows:

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

where: k – dimensionless coefficient of wear
dV – volumetric wear
dF – normal force
dL – friction distance
H – tool surface hardness

Archard's model was implemented in the MARC program in the following form:

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

where: $\overset{o}{w}$ – speed of wear
σ – pressure contact
v_{rel} – relative sliding velocity

The wear value, which was the determined wear indicator is calculated from the following dependence:

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

where: w_{n+1} – actual value of the depth of wear
w_n – wear value in the previous step calculation
$\overset{o}{w}$ – speed of wear
Δt – computational time step

Calculated volume of wear enabled determining the lifetime of die. In order to estimate the wear for the modelled cases, quantitative relationship (2) was modified to the following form:

$$\overset{o}{w} = \frac{k}{H}\frac{m}{m_{FEM}}\sigma v_{rel} \tag{4}$$

where: m – the real weight of wire dragged by the drawing die,
m_{FEM} – weight of the wire dragged by the drawing die during FEM modeling.

In this study, value of wear coefficient of drawing die k was assumed to be $k = 3x10^{-7}$ (mm^3 / (m mm^2)), this is the conversion of units and equal $k = 3x10^{-10}$ **[L. 3].** In this work, the wear coefficient was based on the experimental results of drawing of wires with diameters from 2.6 mm to 5.6 mm. The coefficient was calculated from the reduction of volume of the drawing die after drawing a specified mass of wire. A constant surface hardness of the tool during the process of its wear has been assumed with hardness HV_{30} = 1700 kp/mm^2 **[L. 4]**. After the conversion of units H = 17 000 MPa. Wear depth of drawing die was calculated after drawing m = 6.35 Mg of wire. The mass of the drawn wire, for which modelling was done is m_{FEM} = 4.45 g.

Numerical modelling of the drawing process was performed for 14 variants of drawing. The variant of the first drawing was carried out without backpull (F_0 = 0). Thirteen other variants were carried out for different values of the strength of succession backpull in succession F_0 = 10, 20, 30, 40, 50, 60, 100, 150, 200, 250, 300, 350 and 400 N. Other modelling parameters are the same for all variants. As performed simulations allowed determining the size of tool wear in relation to the rate of backpull.

RESULTS AND DISCUSSION

Based on the results of numerical modelling of the influence of backpull on the course and size of tool wear in the process of drawing, the measurement of wear on the numerical model was analyzed in the area of length of the die from 9 mm to 13 mm, as shown in **Figure 3**. The numerical values of the calculated wear depth were recorded for nodes at a distance from each other of 0.05 mm.

The calculated depths of wear of the die for a number of parameters of the backpulling are presented in **Figure 4.** It has been demonstrated that there are two areas of accelerated wear wire drawing dies. Analysis of the results obtained leads to of the conclusion that the specific die show various wear rates elements. The start of wear has been observed in the cone crushing in the contact area of the surface of drawing die with the metal (the first area of high wear). In this place wear of drawing die is large and is manifested in the form of a groove called a ring draw. Figure 4 shows that the depth of the groove and its position on the length of the die depends on the size backpull forces. For example, when drawing without backpull the groove is located at L = 9.643 mm.

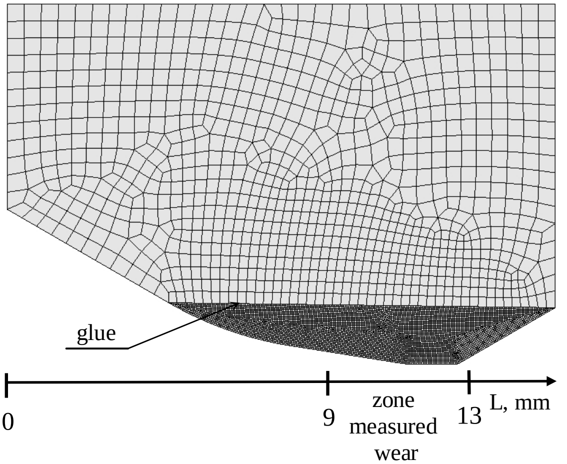

Fig. 3. FEM Model of tool and zone of the measurement his wear
Rys. 3. Model MES narzędzia oraz strefa pomiaru jego zużycia

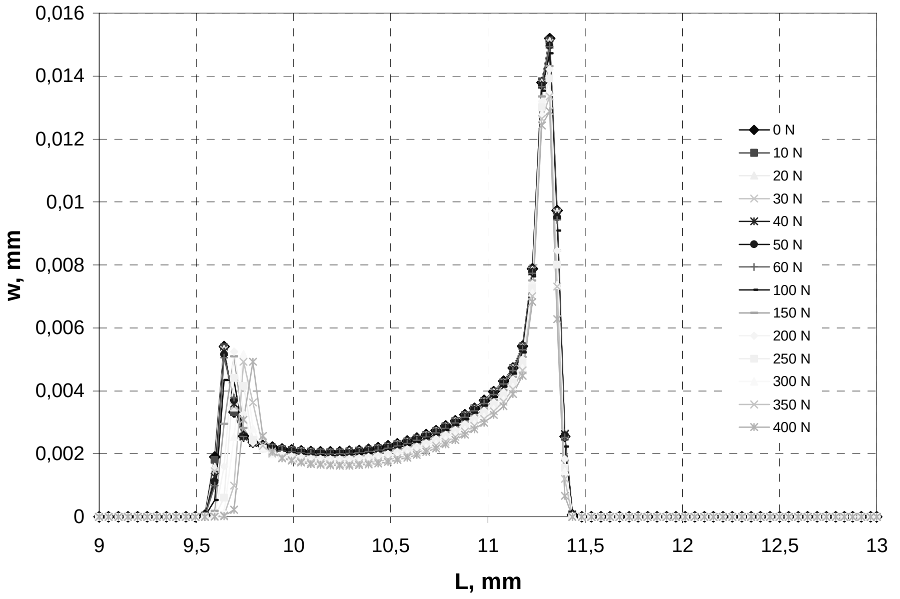

Fig. 4. Change of wear of drawing dies on their length
Rys. 4. Zmiana zużycia ciągadeł na ich długości

Introduction and sequentially increasing the force backpull causes moves its position towards the opening of the calibration. The greatest value backpull force F_0 = 400 N corresponds to the position of the groove L = 9.792 mm. For increasing backpull force, the wear depth decreases. The second area of increased wear is in the area of transition cone crush the calibration opening. In this area, the depth of the projected wear is the largest and also decreases with increasing backpull force. Wear values obtained when there is no backpull on the wire, where it touches the work surface, reach the value of w = 0.0051 mm, while in the transition area of the cone of the working part of sizing the value of wear is equal to w = 0.015 mm.

In case such a backpull drawing the highest wear rate (that is the greatest increase in diameter) occurs at the end of the drawing die and is 0.0128 mm. For comparison, in the entry zone the wear figure is 0.0049 mm. The least interaction of backpull force has been recorded for its figure of 10 N. In this case increase in diameter of drawing in the end zone of drawing die was 0.0302 mm, wheras the increase of diameter of the drawing die in the entry zone has figure of 0.0106 mm. Increasing the backpull force 40 times results in serious reduction of wear of the drawing die to 0.0004 mm. In the entry zone the figure of 0.0023 mm has been estimated.

CONCLUSIONS

Dimensional accuracy of the finished product depends on the geometry of the drawing die, which is worn during operation. The possibility of a quantitative calculation of wear rates for drawing dies will enable determining the life drawing dies or mass of the final product that meets certain requirements specified in the standards. A methodology of the determining wear of drawing dies in the process of drawing has been presented that can be used for preliminary and approximate determination of the wear and life of a drawing die during design. It has been shown that stability can be increased effectively by the use of drawings on backpull. In engineering practice it is defined as a an “optimal value of backpull force”, that is, one that does not cause a significant increase in drawing force compared to the drawing without backpull. Then the influence of this force can be successfully taken into account in determining the lifetime of drawing die at the design stage.

REFERENCES

1. Kalpakjian S.: Manufacturing Processes for Engineering Materials, Addison Wesley, Massachusetts, 1997.
2. Szota P., Mróz S., Stefanik A.: Numeryczne modelowanie zużycia ciągadeł podczas ciągnienia drutu okrągłego, Hutnik – Wiadomości Hutnicze, 1/2001, 138–141.

3. Camacho A.M., Domingo R., Rubio E., Gonzalez C.: Analysis of the influence of back-pull in drawing process by the finite element method, Journal of Materials Processing Technology 164–165 (2005), 1167–1174.
4. Gillstrom P., Jarl M.: Wear of die after drawing of pickled or reverse bent wire rod, Wear 262 (2007) 858–86.
5. Wistreich J.G.: The fundamentals of wire drawing, Metals Rev.3 (1958) 97–142.
6. Shatynski S.R., Wright R.N.: Die wear during wire drawing operations, Wire Technol. 7 (4) (1979) 59–62, 64, 66–69.
7. Kim B.M., Kim T.H., Kim J.C.: Prediction of die wear in the wire-drawing process, Journal of Materials Processing Technology, 61 (1–3) (1997) 11–17.
8. Overstam H.: The interdependence of plastic behavior and final properties of steel wire, analysed by the finite element method, Doctoral thesis, Orebro University, Orebro, 2004.
9. Pirso J., Letunovits S., Viljus M.: Friction and wear behavior of cemented carbides, Wear 257 (2004) 257–265.
10. Skolyszewski A., Paćko M.: Back tension value in the fine wire drawing process, Journal of Materials Processing Technology, 80-81(1998), 380–387.
11. MSC Software: MSC.Marc Volume B: Element Library, Version 2010.
12. Łuksza J.: Elementy ciągarstwa, Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Kraków 2001.

Streszczenie

W pracy przedstawiono numeryczną analizę porównawczą zużycia narzędzia w procesie ciągnienia drutu bez i z przeciwciągiem. Badania przeprowadzono dla przypadku ciągnienia drutu miedzianego przez ciągadło stożkowe wykonane z węglika spiekanego o średnicy oczka równej 3 mm. Założono stałą wartość zgniotu wynoszącą 30% względnego ubytku przekroju oraz kąt ciągnienia wynoszący 9^o. Osiowo-symetryczny model numeryczny procesu ciągnienia zbudowano i modelowano w komercyjnym programie do zagadnień nieliniowych i kontaktowych MARC/Mentat. Analizy numeryczne przeprowadzono dla przypadku ciągnienia bez zastosowania przeciwciągu, jak również z zastosowaniem przeciwciągu o różnych wartościach siły. W wyniku przeprowadzonych badań określono wpływ zastosowania przeciwciągu na wielkość zużycia ciągadła.