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FEM ANALYSIS OF FRICTION COEFFICIENT IN OPEN DIE COINING PROCESS OF DIFFERENT GRAIN SIZES

Zdenka Keran, Miljenko Math*, Petar Piljek

Faculty of Mechanical Engineering and Naval Architecture, Ivana Lucica 5, Zagreb, Croatia

ABSTRACT

The study concerns the analysis of significant contact friction changes by changing the size of crystal grains in the processes of free axisymmetric workpieces upsetting, initial height of 2 mm. The friction changes result with significant changes in forming force. This phenomenon usually characterizes microforming processes. Using hard experimental data in the creation of numerical FE (finite element) model, a dependence of the changes of contact friction in correlation to the change of the workpiece crystal grain size for three different grain sizes: 39, 47 and 76 μm is presented. It is shown that the friction factor is increased by reducing the size of crystal grains. Physical interpretation of the results is given by theory of Bowden and Tabor.
Keywords: *coining process, numerical simulation, friction coefficient.*

1. INTRODUCTION

Coining is a deformation processing of metallic materials. In its definition it includes production of coins, medals, and some other products that demand very fine surface microgeometry. Although this process seems very simple (the only condition is traceability of surface microgeometry achieved by the deformation of surface layer of the blank), some serious problems take a place [1]:

- Surface damage,
- Insufficient filling,
- Excess lubricant,
- Foreign substance,
- Deformation during unloading caused by residual stresses in the workpiece and/or elastic springback of the material.

Also, one of the major problems that occur in coining processes is a large influence of grain size on amount of forming force.Experimental research work [4] verified solving of springback problems when coining is treated as a microforming process. This approach takes into

[*]*Corresponding author's email: miljenko.math@fsb.hr*

consideration grain size influence on the process parameters. Hypothesis of the research is that blank material, because of the size influence, acts according to microforming postulates [1]. Results confirmed this presumption and showed significantly different forming force for different grain sizes. Aluminium blanks (Al 99.5), initial high 2 mm, initial diameter 20 mm were deformed with different reduction coefficient in open and closed die. Experimental tool is designed with two parallel surfaces and deformation is accomplished by their relative movement. A scheme of the tool is presented at figure 1.
Previous annealing resulted with three different grain sizes: 76 µm, 47 µm and 39 µm – table 1. Measured parameters were: forming force, total deformation, elastic springback and die filling.

Table 1. - Grain sizes achieved by specific heat treatment regime

Heat treatment regime	Grain size
350°C – 2 h / air cooling	39 µm
450°C – ½ h / air cooling	47 µm
450°C – 2 h / air cooling	76 µm

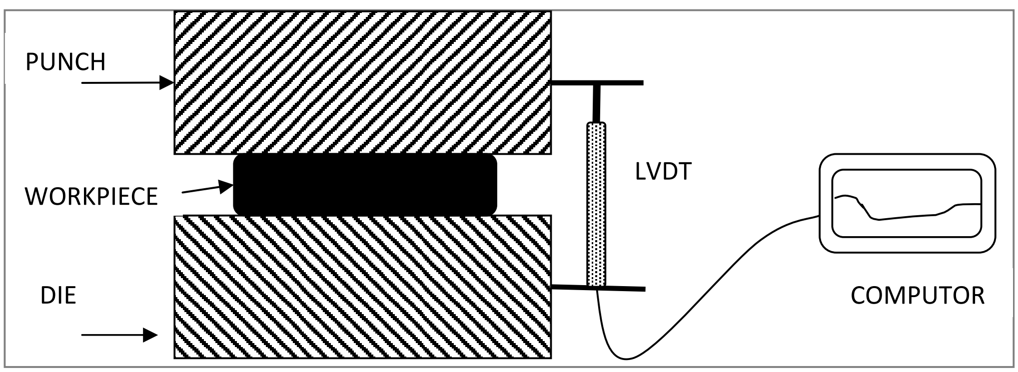

Fig. 1 - Scheme of experimental tool

For the causes of further numerical investigation of friction coefficient, only one pair of measured parameters is observed. That is the relation between total forming force and total deformation. As it was expected (according to hypothesis of the research), the opposite results have been obtained in those two experimental conditions – open and closed die. In open die experiments forming force raises up with smaller grain size – fig.2. On the opposite, in closed die forging, forming force is decreased with decreased grain size – fig. 3.
Although, it would be interesting to make a numerical analyses in both cases – open and closed die coining, in particular case it is not possible because of very small geometry dimensions of gravure details that cannot be digitalized and prepared for the numeric model. That is why numerical simulation has been performed only for the case of open die coining.

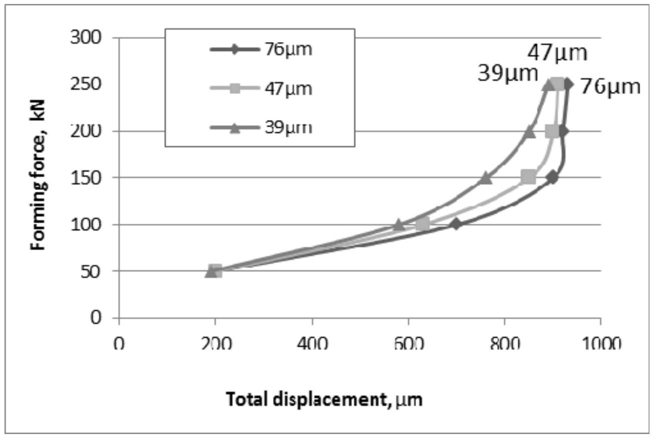

Fig. 2 - Relation between forming force and total displacement - open die coining

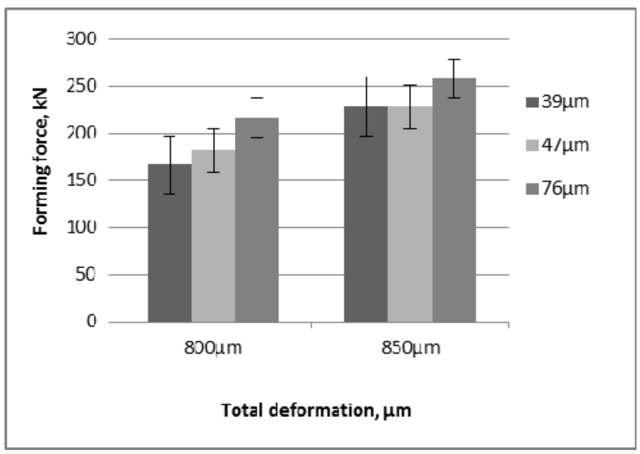

Fig. 3 - Relation between forming force and total displacement - closed die coining

2. NUMERICAL SIMULATION

As it is presented in the introduction, significant changes of contact friction occur with changes in grain size. With intention to explain this phenomenon contact friction has been analyzed using finite element method (FEM) and the purpose of the analyzes is a description of correlation between grain size and friction coefficient in case of open die forging.

Numerical simulation of an open die forging has been supported by MSC Marc Mentat program package. Axisymmetric 2D FEM model has been created. Material is defined as elasto-plastic isotropic. In elastic field constants for Al99,5 are: Young modulus E = 69000 N/mm^2, Poisson coefficient v = 0,33. Isotropic plasticity is modelled using experimentally obtained results – the correlation between true strain and maximal specific stress for three different grain sizes.

Element type 10 is a four-node, isoparametric, arbitrary quadrilateral is used. As this element uses bilinear interpolation functions, the strains tend to be constant throughout the element. This element is preferred over higher-order elements when used in a contact analysis. The stiffness of this element is formed using four-point Gaussian integration [2].
Coulomb friction, that is used, is a highly nonlinear phenomenon dependent upon both the normal force and relative velocity. When the stress based friction model is used, the following steps are taken [2].

1. Extrapolate the physical stress, equivalent stress, and temperature from the integration points to the nodes using the conventional element shape functions.
2. Calculate the normal stress.
3. Calculate the relative sliding velocity. At the beginning of an increment, the previously calculated relative sliding velocity is used as the starting point. When a node first comes into contact, it is assumed that it is first sticking, so the relative sliding velocity is zero.
4. Numerically integrate the friction forces and the stiffness contribution.

The friction calculation is dependent upon the surface normal and tangent. When using the analytical approach, the friction calculation includes the effect of changes in the direction of the normal vector from iteration to iteration. This improves the accuracy and convergence behaviour.
Model has been created from 2000 elements and analyses open die coining up to $\varphi = 0,6$ (true strain). Figures 4 and 5 presents initial mesh and deformed one with its maximum distortion.

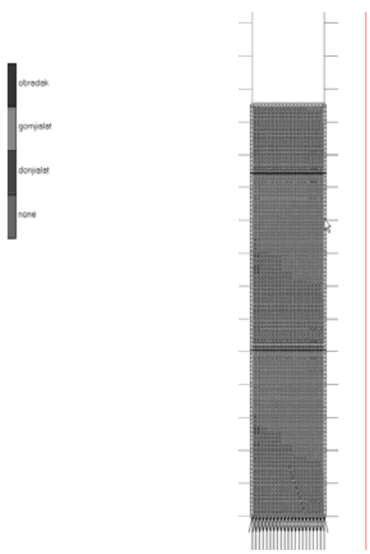

Fig. 4 - 2D Axisymmetric FE model created of 2000 elements

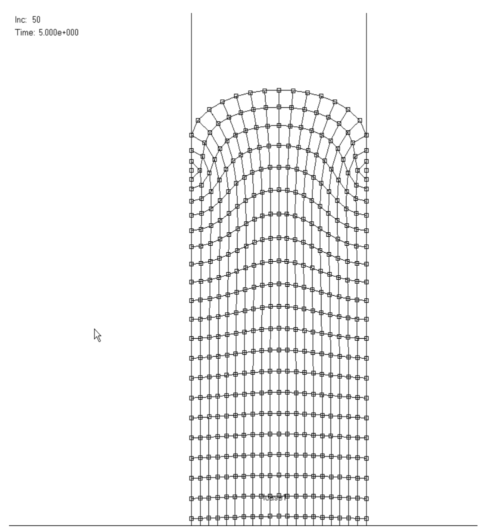

Fig. 5 - Distorted mesh at the end of coining process

3. ALGORITHM FOR DETERMINATION OF FRICTION COEFFICIENT

By using well known constants for defining material properties in elastic field, familiar geometry of axisymmetric 2D model, experimentally defined curves (true strain – flow stress dependence for different grain sizes in plastic area), simple boundary conditions and contact definition, the initial base for algorithm developing is set. This algorithm is presented in figure 6.
Another relevant factor for its development is: experimentally obtained maximal forming forces for different grain sizes. These forces should be achieved using numerical simulation (in a range ±10%), so that numerical model could be relevant, and friction coefficient valid.

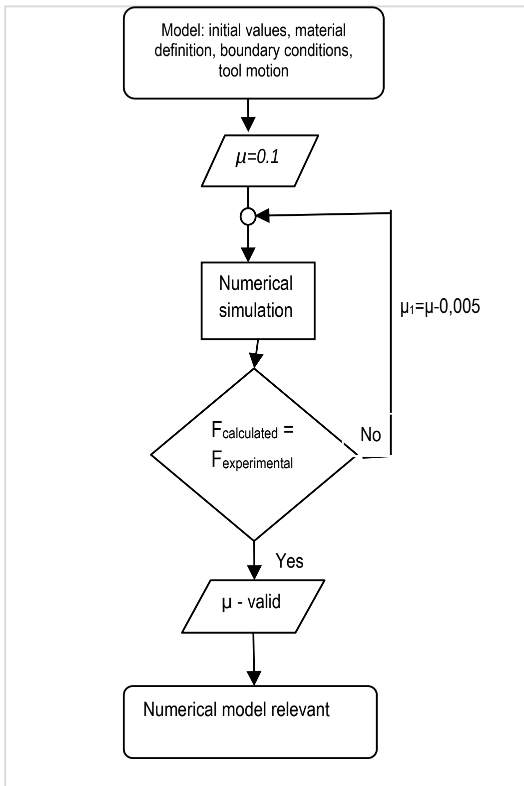

Fig. 6 - Algorithm used for numerical determination of friction coefficient

4. RESULTS OF NUMERICAL SIMULATION

By using a described algorithm a numerical simulation has been performed. In calculation of forming forces, which have been achieved in numerical simulation, confidence interval of ±10% according to experimental values was predicted. Maximal calculated forming forces match different friction coefficients for different grain sizes. Parallel overview of experimental and calculated results together with associated friction coefficient is presented in table 2.

Table 2. - Friction coefficients obtained by numerical simulation

Grain size, μm	Experimental forming force, kN	Calculated forming force, kN	**Friction coefficient**
39	275	293	0.050
47	225	244	0.040
76	155	167	0.025

5. INTERPRETATION OF DIFFERENCE IN FRICTION COEFFICIENT

For physical interpretation of difference in friction coefficient, the Bowden and Tabor adhesion model or plastic junction model is used. This model gives an access into friction nature and into friction coefficient changes in relation to surface roughness and used lubricants. The base of this model (as it is showed in figure 7) is that the real area of contact is made up of a large number of small regions of contact, in the literature called *asperities* or junctions of contact, where atom-to-atom contact takes place. When rough surface slides against a softer surface, in adhesive wear, asperity junctions plastically deform above a critical shear strength, which depends on the adhesive forces of the two surfaces in contact. Assuming during a frictional sliding process a fully plastic flow situation of all asperities, friction is found to change linearly with the applied load. This load regularly reaches 2000-2500 MPa distributed on convex spots. Under such point load micro-welding occurs. In order to achieve sliding, micro welds must be broken. Therefore according to Bowden and Tabor friction force becomes a sum of all shear forces needed for this breaking.

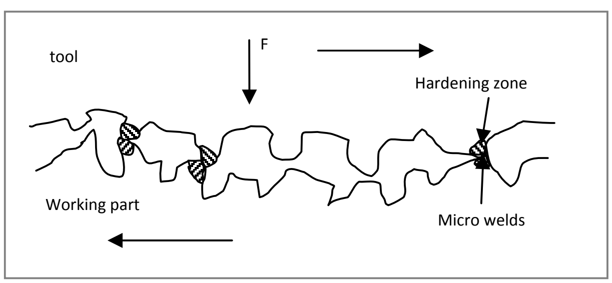

Fig. 7 - Bowden and Tabor adhesion model [3]

According to described model it is possible to make an explanation of friction coefficient increase by decrease of grain size of the material. It can be assumed that smaller grain size makes larger number of critical convex spots. On this way the number of micro-welds is increased, and also a sum of all sheared forces that need to be broken. Increased shear forces indicate increased friction forces.

6. CONCLUSION

As it is presented, some significant changes of process parameters take place when changes of gran size occur. These changes are referred in a first place to the amount of maximal forming force that is needed to achieve a proper deformation of the coin. In a case of open die coining process maximal forming force raises with smaller grain size for the same range of total deformation. Numerical analysis has been performed to describe behaviour of friction (in cases of different grain size) that can also affect the size of forming force.
Analysis showed that calculated friction coefficient grows up when grain size decreases. The physical explanation of this phenomenon is given by Bowden and Tabor adhesion model.
The conclusion leads to recommendation for achieving the optimal process parameters. In order to reduce the level of friction it would be necessary to enlarge the grain size of used material. By enlarging the grain size, forming force will also be reduced. This recommendation is valid only in a case of open die forging.
Further research work should be based in analysis and description of closed die forging and results comparison.

ACKNOWLEDGEMENT

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FEM ANALIZA KOEFICIJENTA TRENJA U PROCESIMA KOVANJA PRI RAZLIČITIM DIMENZIJAMA ZRNA

Zdenka Keran[1], Miljenko Math[1], Petar Piljek[1]

Faculty of Mechanical Engineering and Naval Architecture, Ivana Lucica 5, Zagreb, Croatia

REZIME

U prikazanoj studiji prezentovana je analiza promene kontatktnog trenja promenom veličine kristalnih zrna u procesima slobodnog sabijanja osnosimetričnog obradka, početne visine 2mm. Promene veličine trenja rezultiraju i u promenama daformacione sile. Ovaj fenomen obično karakteriše procese mikroobrade. U ovom radu je prikazano korišćenje eksperimentalnih podataka u kreiranju numeričkog modela, zavisnost i promene kontaktnog trenja u vezi sa promenom veličine zrna pripremka za tri različite veličine: 39, 47, 76 μm. Pokazano je da je koeficijent trenja povećan redukcijom veličine kristalnog zrna. Fizička interpretacija rezultata je data teorijom Bowden-a i Tobir-a. Daje se preporuka za optimizaciju parametara procesa. Da bi se smanjio koeficijent trenja neophodno je povećati veličinu zrna korištenog materijala. Povećanjem veličine zrna, redukuje se i deformaciona sila. Ova preporuka važi samo za kovanje u otvorenom kalupu. Buduća istraživanja bi trebala biti usmerena na analizu i opis kovanja u zatvorenom kalupu i poređenju rezultata sa već postojećim.

Ključne reči: *kovanje, numerička simulacija, koeficijent trenja*