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FRICTION FACTOR OPTIMIZATION AT THE BULK DEFORMATION PROCESS

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ABSTRACT
Friction determination is of special importance in bulk deformation processes. Friction influence is expressed through material flow, operating force, deformation, tool wear, so knowing friction factors is of great importance for projecting technological procedures by numerical simulation of Finite Elements Method - FEM. In the recent years, the development of computer techniques and software have enabled process simulation of bulk metal forming and opened wide possibilities in determining friction factors. The paper deals with problem of determining friction factor, where the techno-economic process optimization is done, by using Box-Wilson's gradient method. Experimental points of determining friction factor, by compress ring method (Ring Test), for alloy AlMgSi0,5 on specified temperatures and numerical simulations have been done, by using software package DEFORM 2D, are given. A great improvement has been done, referring to classical friction factor determining, by using this package.
Key-words: *Friction factor, Finite Element Method - FEM, Deviation function, Numeric simulation, Box-Wilson's method, Ring Test, DEFORM 2D.*

1. INTRODUCTION

One of the most significant parameters at deformation process is contact friction. There are several laws used for mathematical description of contact friction, one of most frequently used among them is: constant friction law (adhering law).
Constant friction law presupposes a constant tangentional friction stress and is expressed by *friction factor m*. [5]

$$\tau = mk\,,\ 0 \le m \le 1 \qquad \text{... (1)}$$

To determine friction factor as an input within numerical FEM deformation process systems, a ring compression process of AlMgSi0,5 alloy is optimized, in relation to deviation function. Influence factors to be observed are: temperature $T=x_1$, friction factor $m=x_2$ and height reduction degree in function of deviation degree of inner radius of $\varepsilon_h = x_3$, ($\varepsilon_h=\varepsilon_h(\varepsilon_d)$). [3,4]
Box-Wilson's method as used for optimization. An operative procedure of gradient method consist of a number of successive cycles, namely moving along a gradient line up to optimum process (M_0). Within the cycles, a description of a smaller reaction area is done by polynome function of first degree based on the realized matrix plan of first order. The number of cycles depends on the size of noise field. The cycles continue to the moment when all the linear model regression coefficients become insignificant, namely when an optimal forming process field is entered, for which the linear model is mostly inadequate one, thus a further, more precise determination of optimum position in this field is done by virtue of plans and models of the second or higher order. [3,4]

2. INDIRECT RING COMPRESSION METHOD FOR FRICTION FACTOR DETERMINATION

There is a number of test for friction factor determination. On of the most widely applied indirect methods is the ring compression method - Burgdorf's method (Ring Test). The method is based on rings compressed between plane flat surfaces, whose dimensions are in ration: $\phi D_0:\phi d_0:h_0$= 6:3:2. Working-piece dimensions are given in Fig. 1.

Working-piece is compress up different height h and deformation height and inner diameter in percentages are determined according to formulas:

$$\varepsilon_h = \frac{h_0 - h}{h_0} \times 100\% \qquad \ldots (2)$$

$$\varepsilon_d = \frac{d_0 - d}{d_0} \times 100\%$$

Several points obtained in the way are input into corresponding caliber diagrams (etalon diagram) for friction factor determination. There is a larger number of diagrams, obtained by various authors, for ring test with dimensions ratio $\phi D_0:\phi d_0:h_0$=6:3:2. Etalon diagram obtained by numerical simulation, using DEFORM-2D software package will be used. [1,2]

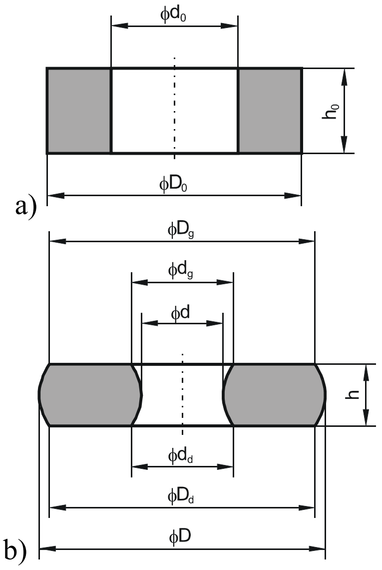

Figure 1. Ring working-piece for friction factor determination (a) before, (b) during deformation process

3. RING COMPRESSION

To determine friction factor it is necessary to set the following parameters:

- Experimental material is AlMgSi0,5 alloy.
- Hot forming temperatures of AlMgSi0,5: T_{min}=420 [°C], T_{min}=440 [°C], T_{min}=460 [°C].
- Lubricated with graphite grease.
- Velocity deformation conditions: v=10 [mm/min].

Ring geometry measuring in the course of cold deformation is simple as the process is discreeted per steps and continued after measurement. Measurements are carried out at the end of five deformation steps for all the research conditions, thus, taking it into account, it was necessary to make a working-piece whose dimensions were D_0=36 [mm], d_0=18 [mm] and h_0=12 [mm]. [1,2] After compression in single steps, height and inner diameter were measured. The values measured are given in Table 1. Based on them, height reduction degree values are calculated ε_h [%] and inner diameter change degree ε_d [%] and they are given in Table 2.

Table 1.

Material	T [°C]	Ring height measured per compression steps						Inner ring diameters measured per compression steps					
		h_0 [mm]	h_1 [mm]	h_2 [mm]	h_3 [mm]	h_4 [mm]	h_5 [mm]	d_0 [mm]	d_1 [mm]	d_2 [mm]	d_3 [mm]	d_4 [mm]	d_5 [mm]
AlMgSi0,5	420	12	9.54	8.00	6.70	5.60	5	18	19.15	19.53	19.76	19.70	19.60
AlMgSi0,5	440	12	8.10	7.80	6.70	5.80	4.54	18	19.42	19.44	19.55	19.46	19.13
AlMgSi0,5	460	12	10.10	8	7.10	5.90	4.91	18	18.75	19.25	19.15	19.10	18.85

Table 2.

Material	T [°C]	Ring height reduction degrees per compression steps						Inner ring diameter change degrees per compression steps					
		ε_{h0} [%]	ε_{h1} [%]	ε_{h2} [%]	ε_{h3} [%]	ε_{h4} [%]	ε_{h5} [%]	ε_{d0} [%]	ε_{d1} [%]	ε_{d2} [%]	ε_{d3} [%]	ε_{d4} [%]	ε_{d5} [%]
AlMgSi0,5	420	0	20.50	33.33	44.17	53.33	58.33	0	-6.40	-8.50	-9.80	-9.44	-8.89
AlMgSi0,5	440	0	32.50	35	44.17	51.67	62.17	0	-7.90	-8.00	-8.60	-8.10	-6.30
AlMgSi0,5	460	0	15.83	33.33	40.83	50.83	59.08	0	-4.17	-6.94	-6.39	-6.11	-4.72

4. NUMERICAL SIMULATION OF RING COMPRESSION

DEFORM-2D software package is used for determining friction factor by numerical simulation. Ring compression process is simulated for the given conditions, friction factor has the following values: m=0; 0.5; 0.10; 0.15; 0.20; 0.25; 0.30; 0.40; 0.50; 0.60; 0.80; 1. The curve obtained by a simplified method is used as a hardening strengthening curve. For the mentioned friction factor values m, geometry change during compression process by numerical simulation is obtained for AlMgSi0,5 alloy, at temperature of: T_{min}=420 [°C], T_{min}=440 [°C], T_{min}=460 [°C], for some values of tool stroke. By direct height and inner diameter determination, reduction degrees are calculated in percents and caliber diagram curves for AlMgSi0,5 alloy are obtained. [1,2]. From DEFORM caliber diagrams it is possible to compute m friction factor value. This value is obtained for minimum deviation value of experimentally got deformation degree dependences on DEFORM caliber curves in function of friction factor. Deviation function is given by Expression 3:

$$E(m) = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{\varepsilon_d^e(\varepsilon_h) - \varepsilon_d^{Ds(m)}(\varepsilon_h)}{\varepsilon_d^e(\varepsilon_h)}\right)^2 \quad ... (3)$$

where: $\varepsilon_d^e(\varepsilon_h)$ - is inner diameter change degree in function of height reduction degree measured experimentally, and $\varepsilon_d^{Ds(m)}(\varepsilon_h)$ - is inner diameter change degree in function of height reduction degree obtained by DEFORM simulation for different m friction factor values. Deviation function change of E(m) deformation degrees in dependence on m friction factor at 440 [°C] is shown in Fig. 2, whereas E(m, ε_h) deviation function with lubrication is given in Fig. 3.

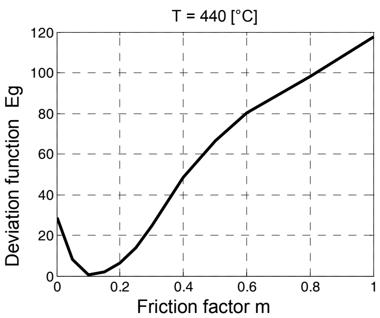

Figure 2. Deviation function of deformation degrees for AlMgSi0,5 alloy with lubrication at 440 [°C]

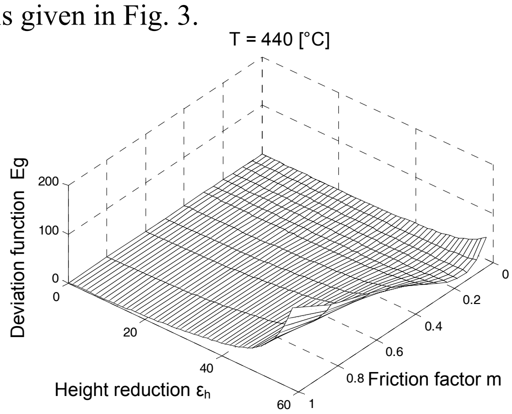

Figure 3. Deviation function in dependence on m and ε_h for T=440 [°C] with lubrication, friction factor and height reduction

5. EXPERIMENT PLAN - REGRESSION AND DISPERSION ANALYSES

When processing data, it is suitable to use normal factors and form a mathematical model. A complete orthogonal plan with a repeated experiment in the central point of the plan four times is taken as an experimental one. The mathematical model of optimizing process being used, is described by polynome function and mutual-factor influences are taken into account: [3]

$$\hat{y} = a_0 + \sum_{i=1}^{3} a_i x_i + \sum_{i<j}^{3} a_{ij} x_i y_j + a_{123} x_1 x_2 x_3 \quad ... (4)$$

where: x_i - are coded coordinates; a_0, a_i and a_{ij} - are regression coefficients:

$$x_i = \frac{X_i - X_{oi}}{w_i};\; a_0 = \frac{1}{12}\sum_{i=1}^{12} y_i,\; a_i = \frac{1}{8}\sum_{j=1}^{8} x_j y_j,\; i = 1,2,3 \;\; a_{ij} = \frac{1}{8}\sum_{k=1}^{8} x_i x_j y_k,\; (i<j) = 1,2,3 \quad ... (5)$$

The square sum related to model adequacy is given by Expression 6.

$$S_{AD} = S_R - S_E = \sum_{i=1}^{N}(y_i - \hat{\bar{y}}_i)^2 - \sum_{i=1}^{N_0}(y_{0i} - \bar{y}_0)^2 \quad ... (6)$$

A programme for a complete analysis is written with in the MATLAB programme package and it is meant to have initial input data, such as: varying factors (temperature, friction factor and height reduction) and values ε_d^e - experimental and ε_d^n - numerical ones. The programme then, computes regression coefficient, estimates their significance, gives a model and checks its adequacy, it also computes model values.

Table dispersion relation values according to Fisher's criteria taken here are:

- for estimating coefficient significance $F_T(5\%,1.3) = 10.13$ [3]
- for checking model adequacy $F_T(5\%,5.3) = 9.01$ [3]

6. OPTIMIZATION CYCLES

In the first cycle, after regression and dispersion analyses, step values per gradient line and experimental point are determined. Deviation function E on its model value in gradient value points are computed. The fourth point is the most appropriate one representing a basic level for the second cycle. Deviation function E in the second cycle is the falling function, thus taken as the most snitable is the second point (T=420 [°C], m=0.2 and ε_h=38.33 [%]). The best point in the third cycle is the third point (T=420 [°C], m=0.125 and ε_h=35.83 [%]). The fourth cycle has three experiment points where model is not adequate either, deviation function E is also falling one, so the most suitable is second point (T=420 [°C], m=0.12 and ε_h=33.83 [%]). In the firth cycle, after regression and dispersion analyses are done, the model is proved to be adequate, step values per gradient line and experimental points, four of them being in this cycle, are determined. It can be noted that deviation function E has its minimum in this cycle, thus the third point is taken as the best one, (T=420 [°C], m=0.11 i ε_h=33.83 [%]). At the end of programme, output varying factor data ore obtained and given in Fig. 4., over the reaction plane surface in function ε_h and m for T = 420 [°C].

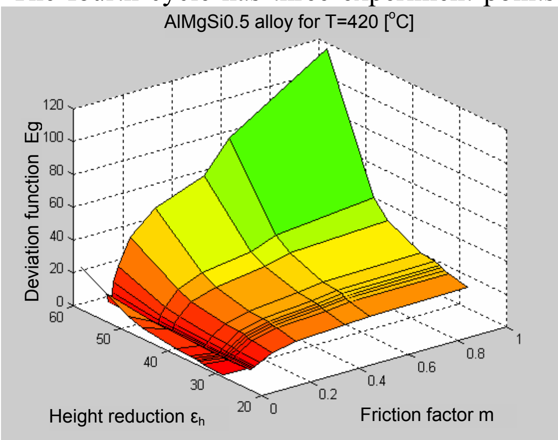

Figure 4. Reaction plane in friction ε_h and m for T=420 [°C]

7. CONCLUSION

The procedure of applying Box-Wilson's gradient method for fiction factor determination in concrete deformation conditions is given in this paper. Experimentally obtained results of AlMgSi0,5 alloy ring compression at given temperatures and the results achieved by numerical simulation using DEFORM-2D programme package are presented in the paper. Optimization is carried out according to standard procedure. Mathematical model of optimization process is formed; namely mode coefficients (regression coefficients) are determined by regression analysis, dispersion is calculated, model adequacy and regression coefficient significance estimation are checked. Gradient line is important to reach friction factor m=0.11 value to define initial deformation conditions. The procedure of determining friction factor m can be applied to all the deformation condition, i.e. to different materials and temperatures.

8. REFERENCES

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