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RESEARCH

Modelling of Friction Force at Compact Ejecting From Die in Process of Metal Powder Pressing

In this paper ejecting force of compact from tool - die is initiated, during pressing of metal powder in manufacture of sintered parts as well as friction force is definited. Experimentally, static friction force and sliding friction force are identified as components. Applying experimentally analytic method of multifactor planning of the experiment (central composite plans) for chosen experiment conditions and by varying values of independently changeable variables, aided by developed programme support, on the computer, corresponding mathematical models are obtained by which static friction force and sliding friction force are adequately described. On the base of experimental results the model is formed with multilayer neural network and optimization of model parameters is performed.

Keywords: *modelling, friction force, metal powder*

1. INTRODUCTION

Cold metal powder pressing in the solid die belongs to the discontinual methods of treatment and it is consisted of three phases:

- die filling with powder,
- pressing by axial compression and
- ejecting of the compact from die.

Compacts have designed geometry, formed by a tool and the so – called raw (green) strength, which enables controlled manipulation with them.

Ejecting of the compact from the tool, in other words from die, is delicate task. Tool components and adequate movements of the executive press organs usually provide that. At the simplest shape, as in the case of cylinder roller which has diameter *D* and height *H*, it is achieved either by the lower punch moving up while the die is at the standstill or by the die sliding down while the lower punch and compact are at the standstill.

Ejecting force of compact from die represents the friction force in a tribological sense. Static friction force *Fts* and sliding friction force *Ftk* are differentiated. However, in the great number of the researches these two components of ejecting force are not considered separately. That makes serious shortcomings in discovering the friction influence on the process of the tool wear.

Separate observations of static and sliding friction parameters becomes interesting for the discovering and defining of the wear mechanisms which appear on the die during the time and on the certain characteristic places on the die wall as well.

Static friction force at compact ejecting from the die is the force which is needed to suppress adhesion of the compact with the die wall and the inactivity resistance of the compact which is under the action of tension (caused by the elastic deformation of the compact) which effects as a residual pressure laterally on the die.

Sliding friction force is the force which continues to effect during the already started moving of the compact till the final compact ejecting from the die.

In the conditions of exploitation ejecting force, in other words friction force, is usually roughly measured, directly on the press. in the research work the one – factorial method for examining the influence of the certain factors on the friction force and for analytic determination of the friction coefficient was most often applied [1].

However, universal method of multifactorial planning of experiments [2-4] for given conditions has advantages compared to usual experimental and purely analytic methods. As it is known, the

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essence of the method of the experiments multifactorial planning is consisted of the fact that for chosen conditions an experiment is carried out according in advanced established plan and on the basis of the treatment of the experimental data according to certain algorithm. That way the response function dependence on the influential factors of the input is determined.

The output characteristics were modelled with artificial neural networks, which massive parallelism and multipath structure gave best results.

2. CARRYING OUT OF THE EXPERIMENTS

According to the plan of the experiments and theoretical procedure [3] a task for establishing the mathematical pattern for friction force as a function of the changeable, most influential factors at Fe powder compact ejecting from the die is set. That mathematical pattern is implicitly set by the next relation:

$$Ft = f(\alpha, A, Fp) \quad (1)$$

Ft – friction force at ejecting (kN),

α - quantity of the lubricant in the powder mixture (%),

$A = At/Ap$ – proportion of the friction surface to pressing surface,

Fp – pressing force (kN).

Choice of the given factors which influence the friction force most is done on the basis of the results of the former one – factorial method [1].

Ferric Fe powder (NC 100.24) represents basis of the mixture and it is dependently changeable value.

The classical mathematical analysis equation (1) can be presented as the function of three independent variables, in other words in the following form:

$$Y = f(X_1, X_2, X_3) \quad (2)$$

Y – function which represents friction force *Ft*, and

X_1, X_2, X_3 – represent independently changeable variables α, *A, Fp*, respectively. Varied values of the independently changeable values are formed as it follows:

Number of the factors: $k = 3$

$X_1 = \alpha$ /%/ percentage of lubricant

$X_{1d} = 0.3$ lower level; $X_{1g} = 1.3$ upper level

$X_2 = A = At/Ap$ proportion of the friction surface to pressing surface

$X_{2d} = 3.47$ lower level; $X_{2g} = 12.30$ upper level

$X_3 = Fp$ /kN/ pressing force

$X_{3d} = 34.80$ lower level; $X_{3g} = 67.00$ upper level

The experimental coded plan matrix [3] which is given in Table 1 is defined on the basis of the central composite plan.

Thereby, the entire number of the experimental points amounts:

$$N = n_k + n_1 + n_0 = 2^k + 2k + n_0 \quad (3)$$

k = number of the independently changeable factors,

n_k = number of the points (apexes) of hypercube,

n_1 = number of the points on the central axes,

n_0 = number of the points in the central point of the plan.

Table 1.

Ord. number	Plan of the matrices of the central composite rotatable plan - coded values			
	X_0	X_1	X_2	X_3
1.	1	1	1	1
2.	1	-1	1	1
3.	1	1	-1	1
4.	1	-1	-1	1
5.	1	1	1	-1
6.	1	-1	1	-1
7.	1	1	-1	-1
8.	1	-1	-1	-1
9.	1	1.682	0	0
10.	1	-1.682	0	0
11.	1	0	1.682	0
12.	1	0	-1.682	0
13.	1	0	0	1.682
14.	1	0	0	-1.682
15.	1	0	0	0
16.	1	0	0	0
17.	1	0	0	0
18.	1	0	0	0
19.	1	0	0	0
20.	1	0	0	0

That way the entire number of the experimental points N=20 is determined. After the executed experimental procedure the results of the measuring are shown in Table 2. Ejecting forces marked as static friction force *Fts* (Y_1) and sliding friction force *Ftk* (Y_2) are measured as output values.

Programme of the experimental research is carried out in the laboratory of the enterprise “SINTER” from Uzice by means of:

- special steel tool with the die made of steel C4150 (diameter of the hole ∅12,93 mm), annealed on 62 HRC with average roughness of the surface of the die inner wall Ra = 0,15μm and
- ferric powder NC 100.24 (Hoganas – Sweden) mixed with various percentage of KENALUB, which is used for lubrication of powder, with mixing time of 10 min.

The experiments are carried out according to the set plan (Table 2). First, the mass is measured, and then the samples with set force on set height are formed by the procedure of one-sided pressing. Compact ejecting is done on the mechanical breaking-machine, observing the ejecting process, reading and writing down corresponding values of the friction forces (*Fts* and *Ftk*) in the function of the sliding way, which could be measured as well.

Table 2.

Ord. no.	Plan of the matrices of the central composite rotatable plan - natural values				
	α (%)	A	F_p (kN)	Ejection force (kN)	
	X_1	X_2	X_3	Fts (Y_1)	Ftk (Y_2)
1.	1.1	10.52	60.3	12.3	8.8
2.	0.5	10.52	60.3	28.4	21.0
3.	1.1	5.26	60.3	7.2	4.8
4.	0.5	5.26	60.3	15.8	10.0
5.	1.1	10.52	41.5	13.8	9.6
6.	0.5	10.52	41.5	29.1	14.9
7.	1.1	5.26	41.5	7.9	5.0
8.	0.5	5.26	41.5	12.4	7.2
9.	1.3	7.89	50.9	8.7	6.0
10.	0.3	7.89	50.9	25.3	15.5
11.	0.8	12.30	50.9	19.4	14.6
12.	0.8	3.47	50.9	7.0	4.5
13.	0.8	7.89	67.0	15.1	11.
14.	0.8	7.89	34.8	14.8	8.8
15.	0.8	7.89	50.9	15.0	10.3
16.	0.8	7.89	50.9	13.5	9.5
17.	0.8	7.89	50.9	14.7	9.9
18.	0.8	7.89	50.9	15.1	10.1
19.	0.8	7.89	50.9	14.4	9.6
20.	0.8	7.89	50.9	13.9	9.8

3. TREATMENT OF THE EXPERIMENTAL RESULTS

In the next step, on the basis of the measuring results from plan matrix (Table 2) complex calculation procedure is carried out, by means of programme support. The following results are obtained:

1. Static friction force *Fts*:

The model of the third order is adequate and in the coded form it is:

$$Fts = 14.4084 - 5.9058\cdot\alpha + 5.7763\cdot A + 0.0479\cdot F_p - 2.2875\cdot\alpha\cdot A - 0.6125\cdot\alpha\cdot F_p - 0.6125\cdot A\cdot F_p + 1.0708\cdot\alpha^2 - 2.724\cdot A^2 + 0.3462\cdot F_p^2 + 0.4125\cdot\alpha\cdot A\cdot F_p + 0.3433\cdot\alpha^3 - 0.7388\cdot A^3 + 0.0146\cdot F_p^3 \qquad (4)$$

Area of validity (coded domain):

$-1.682 <= \alpha, A, F_p = <1.682.$

Values of F-test are:

Frlf = 4,81628;   Ft(1,0; 5,0; 0,05) = 6,61;   Frlf < Ft.

2. Sliding friction force *Ftk* – two models are adequate:

a) Multiple linear regression:

$$Ftk = 10.04 - 3.113\cdot\alpha + 3.413\cdot A + 0.987\cdot F_p - 1.2625\cdot\alpha\cdot A - 1.2375\cdot\alpha\cdot F_p + 0.3375\cdot A\cdot F_p - 0.4875\cdot\alpha\cdot A\cdot F_p \qquad (5)$$

Equation is valid for the coded domain:

$-1 <= \alpha, A, F_p <= 1$

Values of F-test are:

Frlf = 3,30948; Ft(1,0; 5,0; 0,05) = 6,61;   Frlf<Ft

Comparison of the results is given in Table 3.

Table 3.

Ord. number	Experiment	Model
1.	12.3	11.99041
2.	28.4	28.09041
3.	7.2	6.89041
4.	15.8	15.49041
5.	13.8	13.49041
6.	29.1	28.79041
7.	7.9	7.59041
8.	12.4	12.09041
9.	25.3	25.73771
10.	8.7	9.13772

11.	7.0	7.43772
12.	19.4	19.83772
13.	14.8	15.23772
14.	15.1	15.53772
15.	15.0	14.40840
16.	13.5	14.40840
17.	14.7	14.40840
18.	15.1	14.40840
19.	13.9	14.40840
20.	14.4	14.40840

b) Model of the third order is adequate and in the coded form it is:

$$Ftk = 9.8640 - 3.2702\cdot\alpha + 3.6367\cdot A + 1.1698\cdot F_p - 1.2625\cdot\alpha\cdot A - 1.2375\cdot\alpha\cdot F_p + 0.3375\cdot A\cdot F_p + 0.3299\cdot\alpha^2 - 0.0943\cdot A^2 + 0.0294\cdot F_p^2 - 0.4875\cdot\alpha\cdot A\cdot F_p + 0.1577\cdot\alpha^3 - 0.2242\cdot A^3 - 0.1823\cdot F_p^3 \quad (6)$$

Area of validity:

$-1.682 <= \alpha, A, F_p = < 1.682$

Values of F-test are:

Frlf = 0,24717;   Ft(1,0; 5,0; 0,05) = 6,61; Frlf<Ft

Comparison of the results is given in Table 4.

Table 4.

Ord. number	Experiment	Model
1.	8.8	8.76665
2.	21.0	20.96665
3.	4.8	4.76665
4.	10.	9.96665
5.	9.6	9.56665
6.	14.9	14.86665
7.	5.0	4.96665
8.	7.2	7.16655
9.	15.5	15.54729
10.	6.0	6.04729
11.	4.5	4.54729
12.	14.6	14.64729
13.	8.8	8.84729
14.	11.	11.04729
15.	10.3	9.86397
16.	9.5	9.86397
17.	9.7	9.86397
18.	10.1	9.86397
19.	9.6	9.86397
20.	9.8	9.86397

4. MODEL

For modelling the output characteristics, a multilayer neural network with backpropagation learning algorithm [5] is used (more about neural networks approach in process modelling in [6] is given). The architecture of multilayered neural net (Fig. 1) consists of an input layer, one (or more) “hidden” layers and an output layer. Each layer is made of a certain number of processing elements, whereas the number of processing elements in input and output layer corresponds to the number of chosen factors of the process and the output characteristics, respectively, however, the number of the processing elements in the hidden layer is arbitrary.

The learning of the network is performed applying the corresponding data set in iterative cycles. At the same time, the learning error (difference between desired, i.e. experimental output and real output of the network) decreases, converging to a value that depends on the system parameters. The testing of the network behavior is performed on the particular data set, at which some greater error than learning error is obtained for the same number of cycles. Testing error, as learning error, for the most cases convergently decreases. Values of the parameters of the neural network model were: learning term 0.6, momentum term 0.9, initial values of weights ±0.3, and number of processing elements in the hidden layer 5.

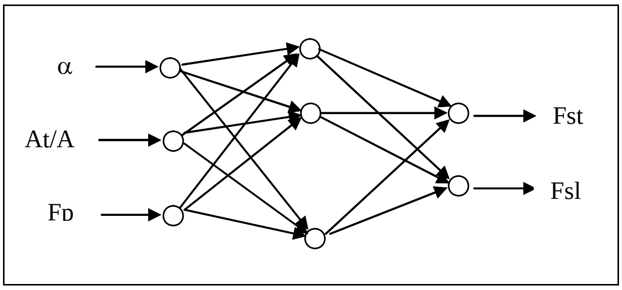
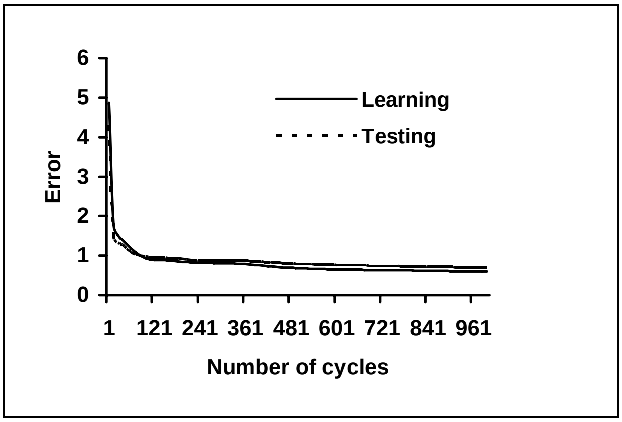


Figure 1. The architecture of the model



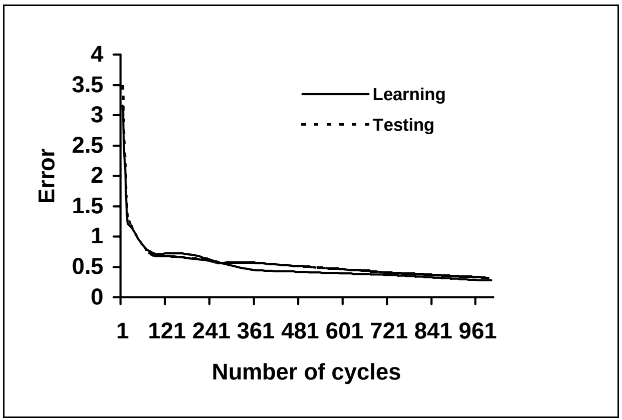


Figure 2. Learning and testing errors of static (a) and sliding (b) friction force

The results as obtained by modelling with the given parameters in the form of the change of errors of the outputs, i. e. errors of learning and testing, with the increased number of the learning cycles, are given in Fig. 2. From the given diagrams it can be seen that after very rapid decrease at the beginning of the learning process, learning and testing errors after approximately 120 cycles enter the area of convergation towards the minimum.

In Table 5. values of the learning and testing errors are given, after 1000 cycles, upon which the change of these errors is practically negligible. Testing errors are greater then learning errors, which represents a normal behavior of the model. The magnitude of the errors of particular characteristics, apart from their absolute values, was also influenced by the noise of the process. The given values of testing errors represent capability of the model with regards to the accuracy.

Table 5.

Outputs	Static friction force	Sliding friction force
Learning error	0.4732	0.1797
Testing error	0.5052	0.1811

5. CONCLUSIONS

Great similarity between experimental and theoretical values (tables 3 and 4) is discerned by comparing them. This enables us to determine and prognosticate corresponding friction forces at compact ejecting from the die by means of mathematical models (4), (5) and (6) within the limits of the varied values of the changeable variables: quantity of lubricant (α), proportion of the friction surface to pressing surface ($a = at/ap$) and compact pressing force (fp).

Fact that the function of the sliding friction force ftk can adequately be described by multiple linear regression as well (5) confirms the estimate about its greater linearity compared to static friction force fts.

Practical significance of the presented procedure and modelling results is that the model will, for some new combination of the input data from the range in which learning was performed or from its surroundings (since the model is capable of extrapolation apart from interpolation), gives values of the outputs, i.e. the friction forces, with an average error from Table 5.

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