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THE INFLUENCE OF VARIOUS PROCESS PARAMETERS ON COEFFICIENT OF FRICTION ON DIE AT IRONING OF AlMg3 SHEET METALS

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Abstract: *Friction coefficient on die side is extremely important in ironing process. Drawing force value, and therefore the power consumed for process performance, will depend on it. That opens up a great number of specific problems, such as: change of friction coefficient on sliding path, significance of tool roughness and its interaction with initial and then varied roughness of material being formed, course of wear process and possible local welding (appearance of "galling"), possibility for lubrication and its quality etc. In the closed system tool-lubricant-material,numerous tribological factors are present, most of which can be varied throughout the process, and during particular interaction, which makes the entire problem extremely complex.*

The obtained results indicate complex influence of selected analysed parameters of ironing process on coefficient of friction on die side.

Key words: *Ironing, Friction coefficient, Dispersion analysis, Aluminium alloys*

1. INTRODUCTION

Friction at cold plastic forming, which occurs on contact surfaces of tool and forming object, is considerably different from sliding friction between different machine elements or other elastically strained couples. Investigation of friction and formulating of particular parameters is of extreme importance, both from the aspect of determining necessary forming forces, forming energy, tool wear intensity and formed parts quality and from the aspect of guiding the process of plastic material flow, distribution of strains which occur, material formability etc. These specific properties mainly arise from the fact that very high working pressures appear on contact surfaces in cold plastic forming processes – much higher pressures than those which occur in hot forming or at relative machine elements travel.

In cold plastic forming, the size of contact surface changes during the process, which means that material parts which were not in contact in the previous phase now come in contact with the tool. This and other circumstances open up a series of specific problems, such as: change of friction coefficient in plastic forming conditions, significance of tool roughness and its interaction with initial and then varied roughness of material being formed, strikingly great differences in mechanical properties of material, course of wear process and possible local welding (appearance of "*galling*"), possibility for lubrication and its quality etc [1,2].

Cold plastic forming processes are characterized by unity of positive and negative influence of outer friction forces; on some areas of contact of tool and material, friction should be intensified (e.g. on movable die surface in indirect extrusion, on punch surface in ironing, etc..), and in some other zones (in general, on almost all surfaces) friction forces must be reduced by lubrication as much as possible. This is possible due to new materials for tools with special coatings of increased hardness and also due to very efficient lubricants.

In the closed system tool-lubricant-material numerous tribological factors are present, most of which are variable during the process and are in a particular interaction, which makes the entire problem extremely complex. These factors can be observed from macro-geometrical, rheological or some other aspect. Some factors which are very important are: properties of tool material and material being formed, thermal problems (temperature, heat transfer, …), micro- and macro-properties of forming process, relation of contact and free surface of the piece, friction properties, lubricant and lubrication method properties, contact surface roughness and its orientation, plasticity, fatigue, adhesion, diffusion, wear, stress and strain distribution, sliding speed, remaining stresses, damages, physical-chemical properties, condition of surface etc [3].

Everything aforesaid indicates that the influence of tribological factors on cold plastic forming process is extremely important and had been the subject of investigations of many researches in the previous period, in both real processes and tribo models [4,5]. Since the investigations in production conditions are considerably more complicated and more expensive in relation to model investigations, they are rarely applied. Modelling of tribological conditions implies satisfying of the minimum of necessary criteria considering the following: similarity of stress-strain properties, temperature-speed conditions, properties of surfaces of tools and forming object and status of their contact during forming, which will be the objective of this paper.

2. EXPERIMENTAL INVESTIGATIONS

The original model of strip ironing device for experimental investigations in this paper has been developed at the Faculty of Mechanical Engineering in Kragujevac. It imitates the zone of contact with die and punch [6] with double-sided symmetry during modelling of ironing. This device enables the realisation of high contact pressures and respects physical and geometrical conditions of real process (material of die and punch, contact surfaces topography, different semi-angle of die cone – α etc). The scheme of strip ironing device, with presentation of forces which act upon the work piece, i.e. die and punch, as well as specimen shape, is shown in Figure 1.

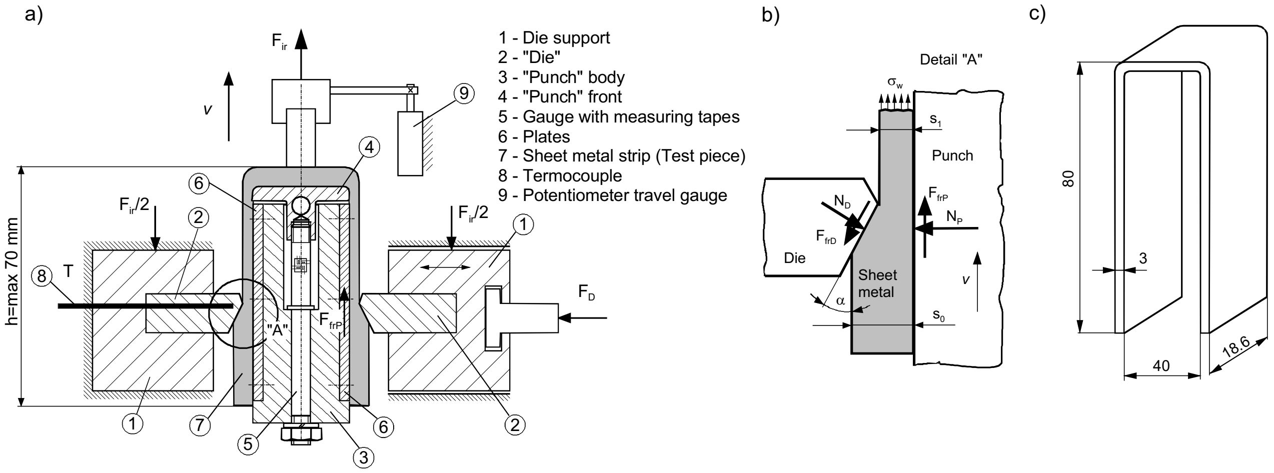

Figure. 1 Scheme of strip ironing device with measuring chain for data acquisition (a), presentation of forces in deformation zone (b) and specimen shape (c)

Strip ironing device is installed on the hydraulic press for investigation of thin sheet metals – ERICHSEN 142/12. The main drive of the machine is used for production of ironing force (force F_{ir}), whereat the second action is the pressure on strip specimen (force F_D). Sheet metal strip 7 is bent (Figure 1c) and placed on the "punch". Dies 2 are placed in supports, whereat the left support is motionless, and the right one is movable together with the die.

The divided punch consists of body 3 and front 4 which are inter-connected by gauge with measuring tapes 5. The strip is ironed between dies due to the effects of force F on the punch front. Throughout ironing, the outer surface of strip slides over die surface, which is skewed at an angle α. The inner surface of strip slides over plates 6, fixed onto the punch body. During the construction of strip ironing device, the main idea was to enable determining of friction coefficient, both on die side and on punch side at various contact conditions.

Total ironing force F_{ir} represents the sum of friction force F_{frP} between punch and work-piece, and force that acts upon the test specimen bottom, F_w (Figure 1), that is:

$$F_{ir} = F_{frP} + F_w \tag{1}$$

Force F_{ir} is measured on the machine, and friction force on punch side F_{frP}, is registered with the gauge with measuring tapes.

Friction coefficients on punch (μ_P) and die (μ_D) sides can be calculated by equations:

$$\mu_P = \frac{F_{frP}}{2 \cdot F_D} \qquad (2)$$

$$\mu_D = \frac{F \cdot \cos\alpha - 2 \cdot F_D \cdot \sin\alpha}{F \cdot \sin\alpha + F_D \cdot \cos\alpha} \qquad (3)$$

The process of pieces manufacturing by ironing is influenced by many factors. They can be divided into four main groups [3]:

- Influential factors which depend on forming object (material, dimensions and piece form),
- Influential factors which depend on tools,
- Influential factors which depend on machine, and
- Influential factors that depend on contact conditions (tribological conditions).

By reviewing the forming process and influential factors for all elements which take active participation in the process, the programming of investigation towards optimisation of the production process is performed, both from the aspect of forming object quality and from the aspect of productivity increase and production cheapening.

Considering the large number of influential factors and their interaction, it is not always possible to perceive clearly the individual influence of each factor on output process properties. In laboratory investigations, especially investigations on models, many influential factors cannot be taken into consideration, which requires extreme caution when making conclusions about the influence of particular influential factors.

Based on analysis of researches and preliminary investigations so far, the following factors, which will be the subject of experimental investigations, were selected:

- Type of investigated material (1 level – AlMg3),
- Die gradient angle, α (4 levels - α=5°; 10°; 15°; 20°),
- Tool material (die/punch), (4 levels - TS/TS; Cr/Cr; TiN/TiN; HM/TS),
- Punch roughness, expressed by mean height of roughnesses R_a (3 levels - Ra=0.01; 0.09; 0.4 μm, which corresponds to surface qualities N1; N3; N5 respectively),
- Type of lubricant on die side (1 level – L5 (paraffin based oil with special additives)),
- Type of lubricant on punch side (1 level - L4 (non-emulsifying mineral oil with mild EP properties)),
- Blank holding force (3 levels - F_D = 8.7 ; 17.4 ; 26.1 kN),
- Forming speed (1 level – v = 20 mm/min).

In addition to specified influential parameters, there is a large number of others such as: polishing zone height, punch radius, thickness of work piece bottom, number of dies for drawing, ratio of inner and outer piece diameter, ratio of dies diameters in multistage tool, ratio of height and diameter of work piece etc. [7]. They were not included in this experiment due to objective reasons.

Mechanical properties of aluminium alloy AlMg3 (DIN: AlMg3 F24) are listed in Table 1.

Table 1. Mechanical properties of strip material

Material - AlMg3
Mechanical properties
R_p = 201.1 MPa, R_m = 251.0 MPa, R_p/R_m = 0.801, A = 12.0 % n = 0.13545, r = 0.40510 E = 0.701×10^5 MPa

3. EXPERIMENTAL RESULTS

Friction coefficient on die side is extremely important in ironing process. Drawing force value, and therefore the power consumed for process performance, will depend on it.

Change of friction coefficient on sliding path can be classified into six characteristic types (figure 2):

I. constant,
II. mildly increasing,
III. mildly decreasing,
IV. unstable (wavy),
V. untypical and
VI. intensively increasing

Such classification is in line with the one given in some papers [8,9,10].

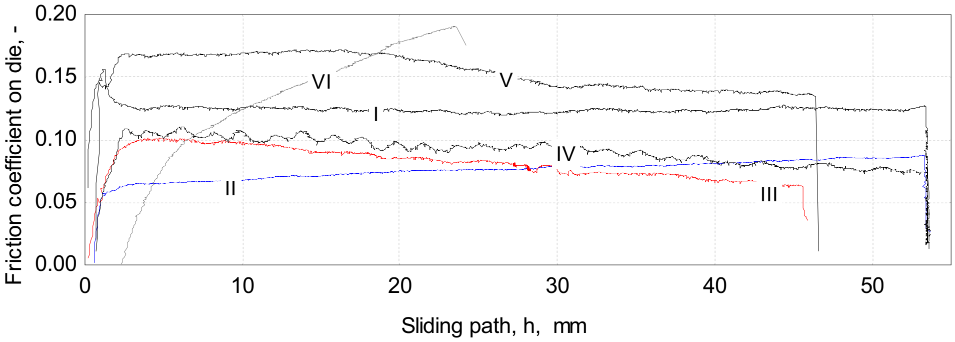

Figure 2. Types of changes of friction coefficient on die

For analysing the influence of all adopted parameters on ironing process, the principle of measuring drawing force and friction force on punch was adopted; therefore, for each investigated sample (test specimen) there is a recorded diagram of change of specified forces in dependence on punch travel (sliding path).

The obtained results were analysed statistically. Since the experiment was performed as multifactor one, dispersion analysis made it possible to determine the influence of particular factors and to determine their interaction towards analysed variable (value). In some cases, further analysis was performed within the very factor in order to determine the best (most favourable) level of that factor for analysed variable (value). The specified additional analysis was performed by comparing mean values by applying Duncan's range test (*Duncan's multiple range test*) [11].

Performed dispersion analysis of the influence of particular factors and their interaction towards friction coefficient on die is given in fig 3. This figure also gives the list of factors whose influence is monitored, as well as the number (in brackets) and mark of the level.

The influence of particular factors and their interaction are estimated based on values of F-test, determined for proper level of credibility (p-level) for which the critical value $\alpha = 0.05$ was taken. This means that one factor or interaction of some factors influences the analysed value of p-level<α=0.05 [11]. The size of influence will be determined by value of F-test, whereat higher value of F-test indicates a stronger influence on analysed value.

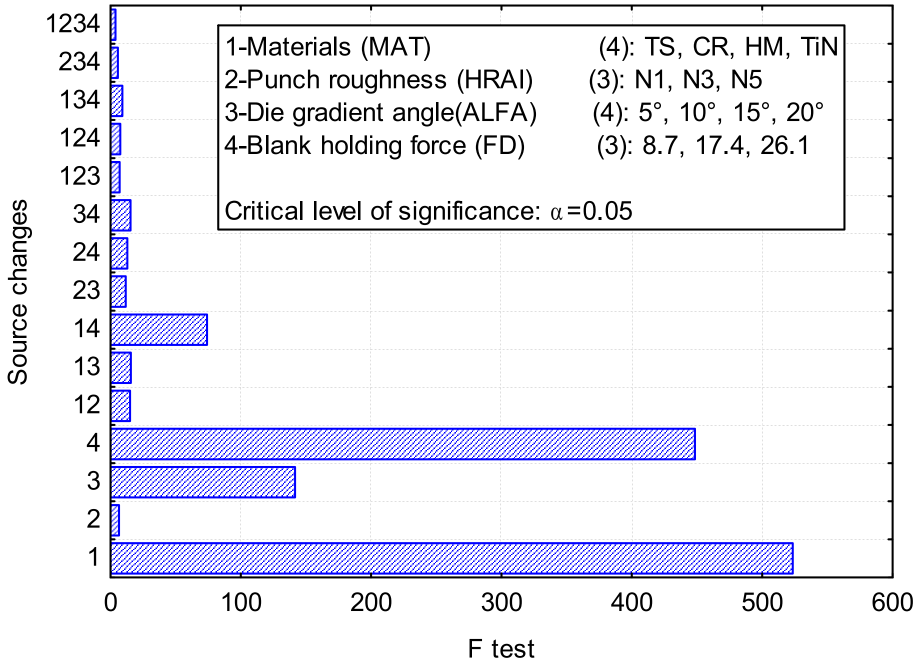

Figure 3. F test

The results of dispersion analysis of factors (tool material, punch roughness, die gradient angle and blank holding force) which influence the friction coefficient on die side (Figure 3), show that the tool material has the biggest influence on friction coefficient on die side (change source 1). The reason for this is the fact that aluminium has a great tendency to adhere to some tool materials. In addition, blank holding force influence is very prominent (change source 4), as well as somewhat smaller influence of die gradient angle (change source 3). Regarding factors interaction, the one between tool material and blank holding force is the most prominent (change source 14). Other interactions are statistically significant, but much smaller. The influence of roughness (change source 2), as shown by dispersion analysis, is very small in comparison with other factors.

The analysis of mean values (table 2) of friction coefficient on die side showed that the smallest value will be obtained by using alloyed tool steel (TS), and the biggest value by using tool with coating TiN. The differences between friction coefficient obtained with hard metal tools (HM) and tools with hard chrome coating (Cr) are statistically insignificant. Considering a very small importance of punch roughness, significant differences were established only between roughnesses N1 (Ra=0.01μm) and N5 (Ra=0.4). In addition to that, Duncan test showed that there are significant differences between all levels of blank holding force and die gradient angle.

Table 2. Analysis of mean values

Duncan test; FRICTION COEFFICIENT ON DIE SIDE - MIM (μ_D)
Mean values analysis
Critical level of significance: $\alpha = 0.05$

MATERIAL: AlMg3

FACTOR: TOOL MATERIAL (MAT)

	{1} .1027846	{2} .1464502	{3} .1499008	{4} .1872871
AC .... {1}		.000009	.000011	.000003
CR .... {2}	.000009		.106364	.000011
TM .... {3}	.000011	.106364		.000009
TIN .... {4}	.000003	.000011	.000009	

FACTOR: PUNCH ROUGHNESS (HRAI)

	{1} .1499408	{2} .1466464	{3} .1432299
.... N1 .... {1}		.075044	.000426
.... N3 .... {2}	.075044		.064870
.... N5 .... {3}	.000426	.064870	

FACTOR: DIE GRADIENT (ALFA)

	{1} .1431109	{2} .1514303	{3} .1675481	{4} .1243334
.... A1 .... {1}		.000106	.000011	.000009
.... A2 .... {2}	.000106		.000009	.000011
.... A3 .... {3}	.000011	.000009		.000003
.... A4 .... {4}	.000009	.000011	.000003	

FACTOR: BLANK HOLDING FORCE (FD)

	{1} .1780849	{2} .1358248	{3} .1259073
.... D1 {1}		.000009	.000011
.... D2 {2}	.000009		.000009
.... D3 {3}	.000011	.000009	

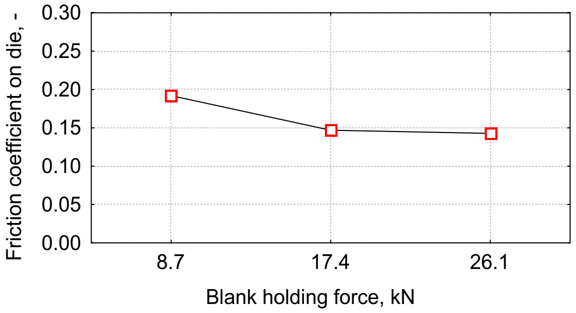

Figure 4. Dependence of friction coefficient on die on blank holding force

The change of mean values of friction coefficient on die side in dependence on blank holding force is shown in figure 4. With the increase of blank holding force, the friction coefficient decreases. That decrease, for bigger blank holding forces, is somewhat less intensive than for smaller blank holding forces.

Dependence of friction coefficient on blank holding force at various levels of analysed factors is shown in figures 5 to 7.

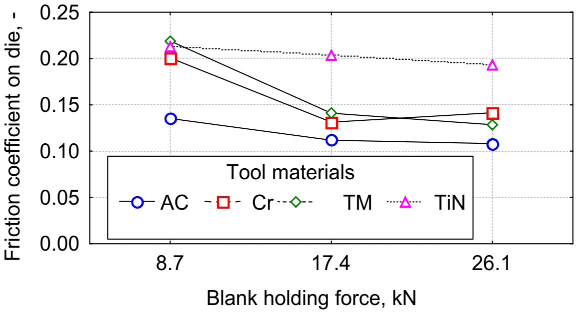

Figure 5. Change of friction coefficient on die in dependence on blank holding force for various tool materials

The change of friction coefficient on die side, in dependence on blank holding force, for different tool materials, is given in figure 5. The smallest friction coefficient was obtained with AC tool, and somewhat higher values were obtained with tools Cr and TM (figure 5). Much higher values were obtained by using TiN tool. It should be mentioned once again that the tool with TiN coating had a partly damaged coating, which could have been the reason for obtaining bigger values of friction coefficient.

As shown previously by Duncan test, significant difference in influence of roughness level on friction coefficient on die (curves in figure 6 for all punch roughnesses almost coincide) was observed only between roughnesses N5 and N1 (figure 6).

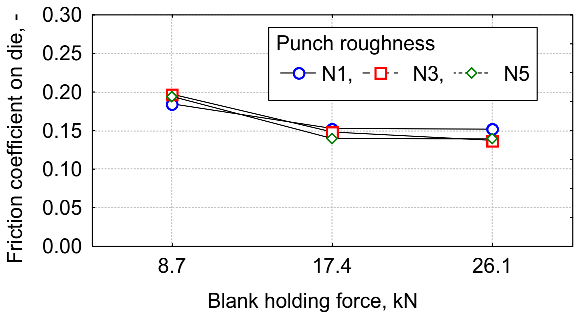

Figure 6. Change of friction coefficient on die in dependence on blank holding force at various punch roughnesses

The smallest friction coefficient, for all blank holding forces, was obtained with die gradient angle of 20° (figure 7).

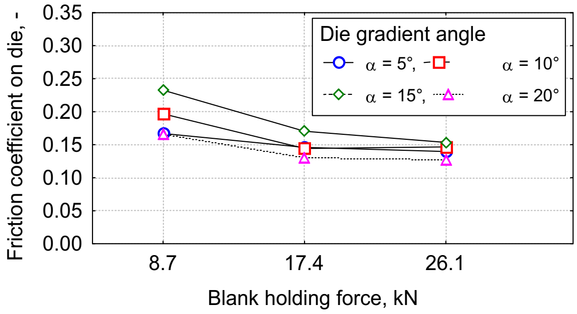

Figure 7. Change of friction coefficient on die in dependence on blank holding force at various die gradient angles

The change of friction coefficient on die, in dependence on die gradient angle, is shown in figure 8. The highest value of friction coefficient is obtained at die gradient angle of 15°.

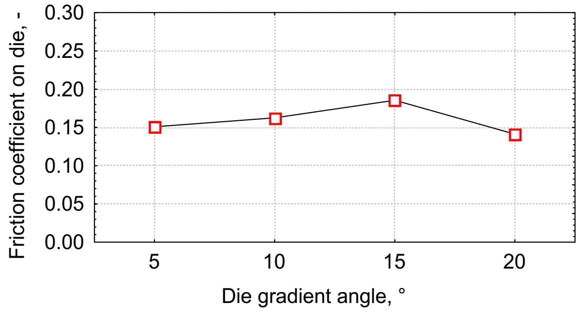

Figure 8. Change of friction coefficient on die by die gradient angle

Figures 9 to 11 show the change of friction coefficient on die in dependence on die gradient angle at various levels of analysed factors.

Out of all die gradient angles, the best results were obtained for alloyed tool steel die, while somewhat higher values of friction coefficient were obtained with tools with chrome coating and hard metal. Out of all die gradient angles, the worst results were obtained for tool with titanium-nitride coating (Figure 9).

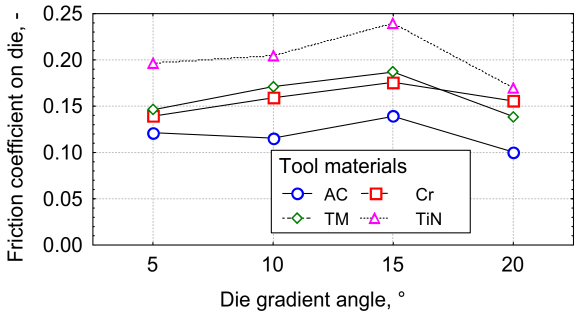

Figure 9. Change of friction coefficient on die in dependence on die gradient angle at various tool materials

The change of friction coefficient in dependence on die gradient angle is shown in figure 10. Here as well, it is obvious that the influence of punch roughness level on friction coefficient is very small.

Diagrams in figure 11 show that higher values of friction coefficient will be obtained at smaller blank holding forces regardless of die gradient angle.

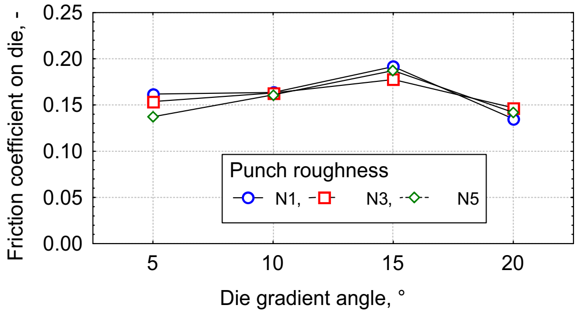

Figure 10. Change of friction coefficient on die in dependence on die gradient angle at various punch roughnesses

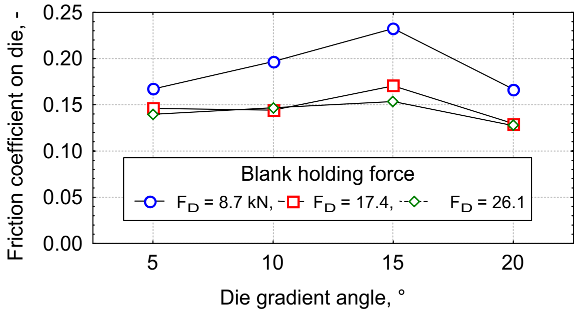

Figure 11. Change of friction coefficient on die in dependence on die gradient angle at various blank holding forces

Friction coefficients for various tool materials are shown in figure 12. The smallest value of friction coefficient was obtained by using tool made of alloyed tool steel. Somewhat higher values of friction coefficient were obtained with alloyed tool steel (TS) and chrome coating (Cr), as well as with hard metal, and the highest values were obtained with tool made of titanium-nitride coating (TiN).

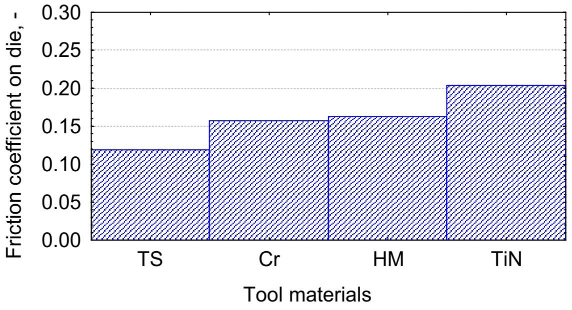

Figure 12. Friction coefficient on die for various tool materials

As established previously by dispersion analysis, friction coefficient will depend on punch roughness very little, which is shown by diagram in figure 13.

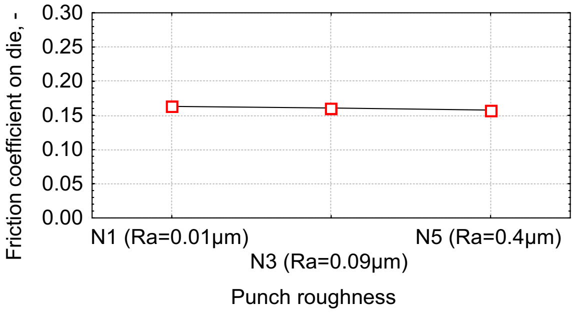

Figure 13. Change of friction coefficient on die in dependence on punch roughness

4. CONCLUSION

Friction coefficient on die side plays an important role in ironing process. Drawing force value, and therefore the power consumed for process performance, will depend on it. The appearance of six different types of change of friction on proper sliding path was observed. Which of those change types will appear depends on the type of tool material, especially type of lubricant and its physical properties.

Performed dispersion analysis shows that tool material has the most prominent influence on friction coefficient on die side. The reason for this is the fact that aluminium has a great tendency to adhere to some tool materials. The influence of blank holding force and die gradient angle is also very prominent here. Regarding factors interaction, the most prominent is the one between tool material and blank holding force. Other interactions are statistically significant but considerably weaker.

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