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ANALYSIS OF CHANGE OF TOTAL IRONING FORCE AND FRICTION FORCE ON PUNCH AT IRONING

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ABSTRACT

Processes of cold plastic forming are characterised by unity of positive and negative influence of outer friction forces; on some contact surfaces of material and tool the friction should be intensified, and in other zones the friction forces must be reduced by lubrication as much as possible. In ironing process, tribological conditions, i.e. realized friction forces, play a significant part. The main factors at ironing are: forming speed, strain ratio (depends on load and semi-angle of the die cone), condition of materials in contact (surface topography, physical and chemical properties of materials), type of lubricant and geometry of tool and work piece. By proper selection of influential process parameters it is possible to obtain work piece of satisfactory quality with minimal energy consumption.

In this paper, a detailed analysis of influence of specified parameters on total ironing force and friction force on punch will be shown on adequate tribo-model of sheet-metal test-piece sliding between pairs with skewed contact surfaces.

The obtained results indicate the complex effects of selected analysed parameters of ironing process (tool geometry, roughness of contact surfaces, material of tool and formed piece, high contact pressures, lubricant on contact surfaces, forming speed etc) on ironing force.

The results of detailed researches show that ironing force and friction force on punch, on sliding path, can be constant, can increase, decrease or even be of a combined character.

Keywords: *Ironing, Ironing force, Friction force*

1. INTRODUCTION

Ironing is applied for manufacture of cylindrical parts whose depth is larger than diameter, and bottom thickness larger than wall thickness, such as bushes, thin-wall pipes, damper casings, fire extinguishers, gas balloons, oil filters casings, piston engine cylinders liners and especially food and drink cans, whose annual production in the world comes up to billions of pieces. The specified parts are made out of materials which have sufficiently high plasticity in cold condition, such as low-carbon steels, austenitic stainless steels, aluminium, brass and others. Figure 1 shows some parts obtained by this procedure.

Figure 1 - Examples of some parts manufactured by ironing.

The influence of tribological factors at ironing is extremely important and has been the subject of study of many researchers in the last few years, both in real processes and on tribo-models. Investigation of tribological conditions in real processes is considerably longer and more expensive, so investigations on tribo-models are performed more often.

Ironing force represents a very important value in the ironing process, because the consumed power (energy) for process execution depends on it. Because of that, the ironing force is a very frequently analysed value. On the other hand, ironing force represents output value of the process, together with piece quality. Ironing force depends, more or less, on all relevant process parameters.

At ironing, as well as in other metal forming processes, sliding path is usually limited and the conditions keep changing from the beginning until the end. First of all, on that path the temperature of contact pairs and contact pressure can increase, and then there is the influence of realised wear products, change of relative sliding speed etc.

Various dependences of friction force, and thus ironing forces, starting with the sliding path, can be classified in the following way [1]:

- friction force does not depend on sliding path (it is constant all the way) (Figure 2a),
- the force is constant on one part of the path, after which it starts increasing (Figure 2b),
- friction force increases continuously (Figure 2c) and
- friction force decreases continuously (Figure 2d).

The first case relates to the application of active lubricants. It can be assumed that the lubricant layers are steady and they do not get disturbed in the friction process, and thus micro-welding of roughnesses peaks does not occur. Friction coefficients obtained in this case can be both very low and very high, which depends primarily on the type of lubricant.

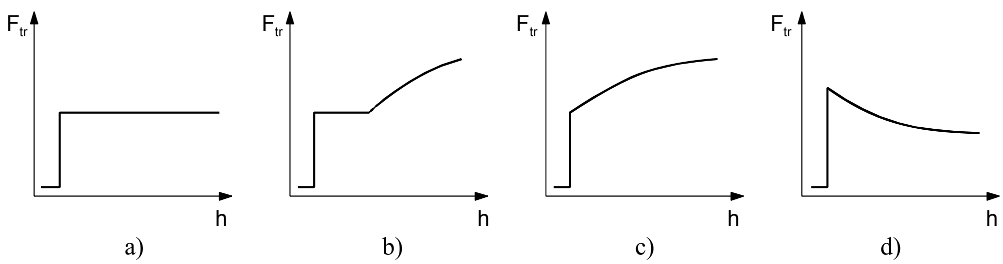


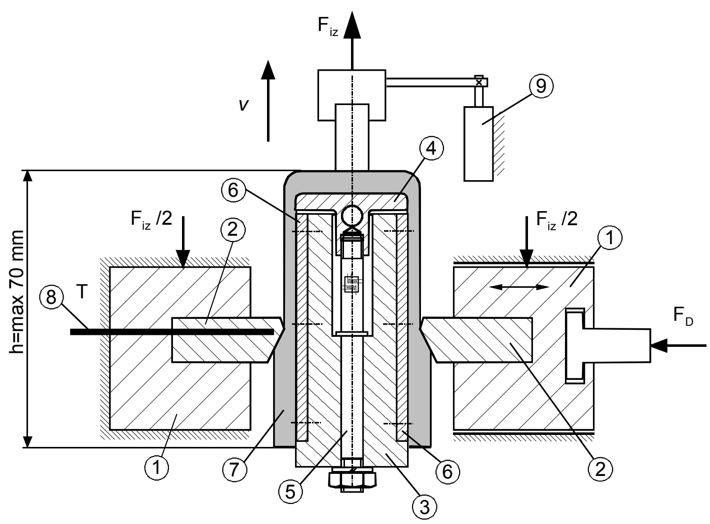
*Figure 2 - Typical cases of friction force **Ftr** dependence on sliding path **h**, [1]*

The second case most often occurs when applying bad or inadequate lubricants, whereat, after certain time, they get extruded out of the contacts, which causes the direct contact of metals, and in that way micro-welding of roughnesses peaks or the intrusion of roughnesses peaks of harder tool into the softer forming material. Increase of friction force is, also, closely connected to specific contact pressure. For example, with one and the same lubricant at small contact pressure the first case of dependency occurs, while at higher pressures the second case occurs. This indicates that such a lubricant is not suitable for high contact pressures.
The third case is connected to the application of high-effective lubricants. Very often all of the lubricants form relatively thick layers. Although it can be assumed that, in that case, the reason for increase of friction force is the appearance of micro-welding and intrusion, it is still hardly probable if the absolute values of friction coefficients are small. Temperature changes in lubricant layer, which influence its properties, are more likely the reason.
The fourth case appears most often when applying MoS_2 as a lubricant which forms thick lubricant films. During the relative sliding of surfaces, lubricant extrusion, i.e. reduction of its thickness, appears which leads to decrease of friction coefficient.

Considerations of dependence of friction force (friction coefficient) on sliding path, show that at constant speed of relative sliding and pressure, the most general dependence corresponds to a horizontal line, which then continues to rise (Figure 2b). That increase confirms the sharp quality change of friction conditions and transition from stable to unstable process. Thereat, that transition is followed by development of micro-welding. Disruption of stability also leads to heating, lubricant rupture and further increase of friction force up until total welding (galling). The existence of surface-active substances in the lubricant makes easier breaking of micro-welding points and enables the elimination of their catastrophic rise and disruption of process stability. In the stable process, the number of new micro-welding points should be equal to the number of broken points. If point-to-point micro-welding does not occur, friction coefficient value will depend only on structural and mechanical properties of the lubricant, whereat at thick lubricant layer both increase and decrease of friction coefficient are possible with the path elongation and reduction of lubricant film thickness.

2. EXPERIMENTAL RESEARCHES

Investigations which were carried out on the original tribo-model of ironing, which with one plane symmetry imitates the zone of contact with die and punch [2]. This model enables realization of high contacting pressures and takes into consideration physical and geometrical conditions of the real process (material of die and punch, topography of contact surfaces, die cone angle - α etc.). The scheme of specified tribo-model is given in Figure 3a, and appearance of device in Figure 3b.



1. Die support
2. “Die”
3. “Punch” body
4. “Punch” front
5. Gauge with measuring bands
6. Plates
7. Sheet metal band (test piece)
8. Thermocouple
9. Potentiometer travel gauge

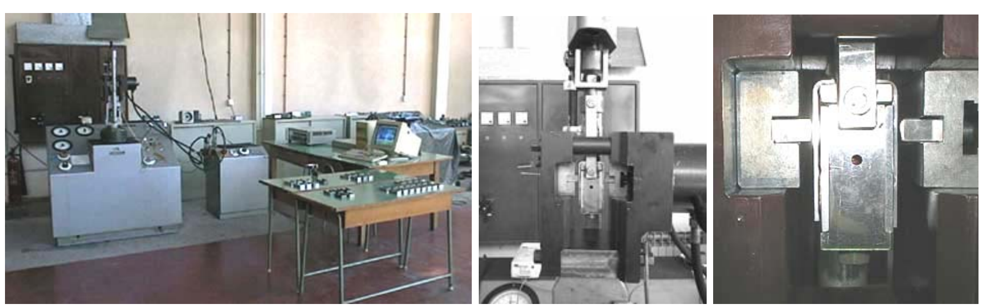
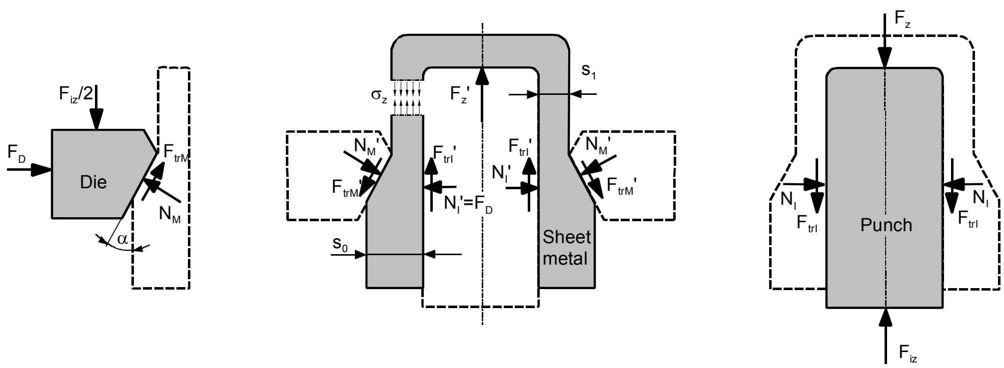


Figure 3 - Scheme and appearance of model used in this paper

Bent sheet metal 7 band, shaped like letter U, (test-piece), is placed on the “punch”. It is acted upon by “dies” 2 with force F_D. Dies are placed in supports, whereat the left support is fixed, and the right one is movable together with the die. The punch consists of body 3 and front 4 which are inter-connected by gauge with measuring bands 5.The test-piece is ironed (it slides) between dies due to the effects of force F_{iz} on the punch front, in the course of which the test-piece is ironed. Throughout ironing, the outer surface of test-piece slides over die surface (inclined at an angle α), and inner surface of test-piece slides over plates 6 fixed onto the punch body.
The device is made with possibility for simple modification of contact – pressing elements (die 2 and plate 6), easy cleaning of contact zones and convenient placing of test piece.Plates 6 and dies 2 can be made of various materials, and with different roughness, and dies can be made with different cone semi-angle α.
On the specified device, it is also possible to simulate successive (multistage) drawing, whereat one and the same test-piece is ironed between contact pairs several times.
Device for ironing is installed on the special machine for investigation of sheet metals ERICHSEN 142/12.
Total ironing force Fiz represents the sum of friction force between punch and work-piece, F_{trI}, and force that acts upon the test-piece bottom, F_z (Figure 4), that is:

$$F = F + F \tag{1}$$

Force F_{iz} is measured on the machine itself, and friction force on punch side F_{trI}, is registered with the gauge with measuring bands.



a) b) c)

Figure 4 - Scheme of forces effects: a) on die, b) on sheet metal, c) on punch.

The process of pieces manufacture by ironing is influenced by many factors. They can all be divided into four main groups:

- influential factors which depend on the object of forming (material, dimensions and shape of the piece),
- influential factors which depend on the tool,
- influential factors which depend on the machine, and
- influential factors which depend on contact conditions (tribological conditions).

Considering a large number of influential factors, as well as their mutual interaction, it is not always possible to examine the individual effects of each factor onto the output properties of the process with certainty. In laboratory investigations, especially in investigations performed on models, many influential factors cannot be taken into consideration which requires some caution when making a conclusion on effects of particular influential factors.
Investigations were performed on steel sheet metal samples (Č0148P3 - low carbon steel) and aluminium alloy sheet metal samples (AlMg3). Different strain ratio was realised by combination of suitable die cone semi-angle, α (α=5°; 10°; 15°; 20°) and blank holding force F_D (F_D = 8.7; 17.4; 26.1 kN).
As tool material (of die and punch), tool steel (AC) and hard metal (TM) were used. Some contact pairs were coated with chrome (Cr), by hard chromium-plating, and with titan nitride (TiN). Punch roughness was varied, expressed by average roughness height R_a (Ra=0.01; 0.09; 0.4 μm, which corresponds to quality of surfaces N1; N3; N5 respectively). As lubricants on contact surfaces, Li + MoS_2 – grease (M1), then mineral emulsifying water-soluble oil with EP additives (M2), as well as non-emulsifying means – paste (M3) and non-emulsifying mineral oil with mild EP properties were used (M4).
Besides specified influential parameters, there is a whole other line of others, such as: polishing zone height, punch radius, work-piece bottom thickness, number of dies for drawing, ratio of inner and outer diameter of piece, ratio of dies diameters in multistage tool, ratio of piece height and diameter etc [3], which have not been taken into consideration in this paper, due to objective reasons.
The device for ironing is installed on a special machine for investigation of sheet metals ERICHSEN 142/12 (Figure 4). Due to a constructive solution, this device is placed into the casing of equipment for investigation by tension, whereat the main machine drive is used for generation of ironing force (force F_{iz}).
Block diagram of data acquisition is given in Figure 5.

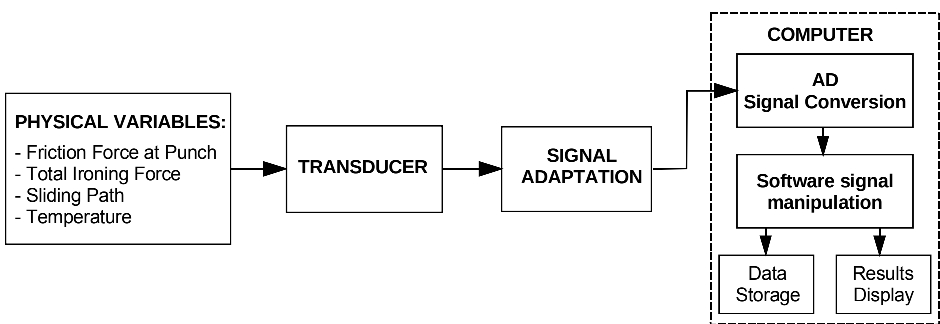


Figure 5 - Block diagram of data acquisition

The device for simulation of ironing process which is performed should be used for measuring (registering) the following physical values: friction force on punch (F_{trI}), total ironing force (F_{iz}) and temperature (T), and all that in the function of sliding path (punch travel - h). Practically speaking, one should convert all those physical values into analogue signals (stress), then carry out their adjustment (intensification and filtering), and then convert that signal into a digital one by using AD converter. With digital signal obtained in such a way, it is possible to continue software manipulations on the computer.

3. EXPERIMENTAL RESULTS

3.1 Trends of ironing force and friction force change on punch side

For analysing the influence of all accepted parameters on the ironing process, the principle of measuring the ironing force, as well as friction force on punch, was adopted; therefore, for every investigated sample (test-piece) there is a recorded diagram of specified forces change from punch travel (sliding path). Only characteristic trends of specified forces change on sliding path will be shown here.

It is characteristic that the ironing forces, on sliding path, can be constant (Figure 5a), increase (Figure 5c), or decrease (Figure 5b), which depends on contact conditions. Friction force on punch, also, can be decreasing (Figure 6a), constant (Figure 6b) or increasing (Figure 6c).

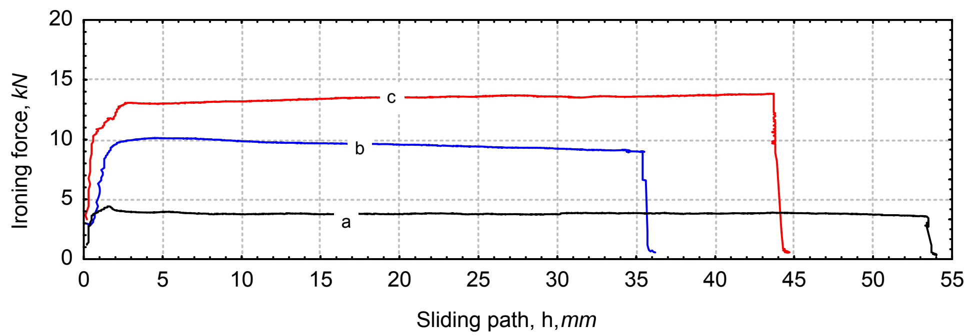


Figure 5 - Example of constant (a), decreasing (b) and increasing (c) ironing force

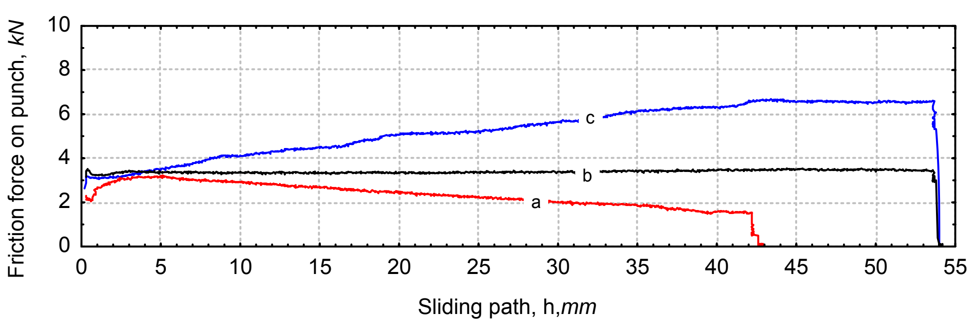


Figure 6 - Example of decreasing (a), constant (b) and increasing (c) friction force on punch

The force is constant when the selected lubricant is of a good quality. Inadequate lubricant with high viscosity most often leads to increase of force on sliding path, while lubricants with EP additives will lead to reduction of forces, i.e. friction, because these forces depend on friction on contact surfaces [4].

For some samples of aluminium alloy, another characteristic case of change of ironing force and friction force on punch has appeared (Figure 7), and that is the oscillatory character of forces. This case appears only at appropriate combination of lubricants on die side and on punch side and does not represent the well known appearance of "*stick-slip*" [5].

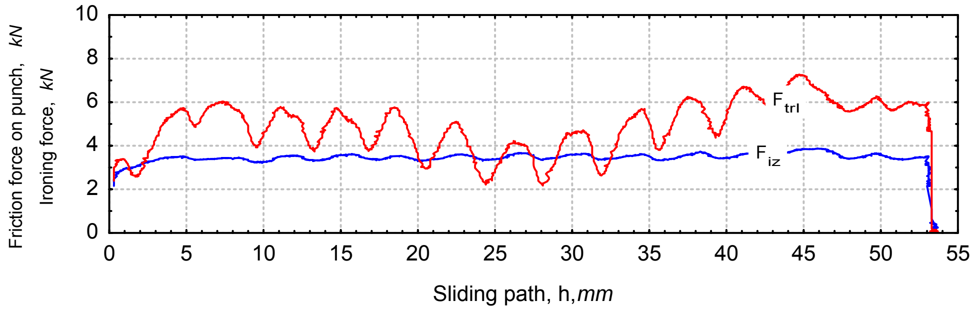


Figure 7 - Example of oscillating friction force on punch (F_{trl}) and ironing force (F_{iz}).

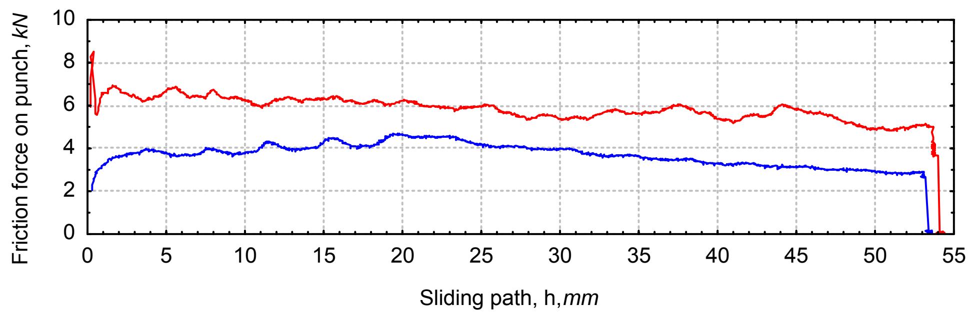


Figure 8 - Example of unstable friction force on punch (F_{trl}).

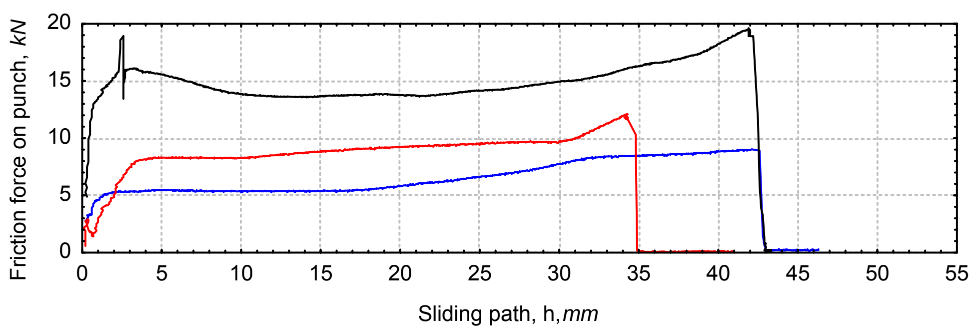


Figure 9 - Example of unstable friction force on punch (F_{trl}) when using inadequate lubricants.

In addition to specified trends of ironing force and friction force change on punch, instability of specified forces on sliding path was also observed (Figure 8 and Figure 9). Instability most often occurs due to inadequate lubricant or due to periodical creation of glued particles and their occasional breaking off.

3.2 Analysis of influence of different parameters on ironing force change

For analyzing the influence of all adopted parameters on the ironing process, a principle for measuring ironing force, as well as friction force on punch, was adopted, so that for each investigated test specimen there is a recorded diagram of specified forces change in the function of punch travel (sliding path) [6].

Since the experiment was carried out as a multi-factor experiment, dispersion analysis made it possible to determine the effects of particular factors, as well as their interaction on analysed variable. In some cases, further analysis within the factor itself was performed in order to determine the best (the most favourable) level of that factor for the analysed variable. The specified additional analysis was carried out by comparison of mean values by using Duncan's multiple range test.

The influence of particular factors and their interaction are estimated on the basis of F-test value which is determined for a particular level of reliability (p-level) for which the critical value α = 0.05 is taken. That means that a certain factor or interaction of particular factors influence the analysed value if p-level<α = 0.05. The extent of influence is determined by value of F -test, whereat the higher value of F-test indicates stronger influence on analysed value.

On the basis of performed dispersion analysis, the influence of all observed factors (lubricant, tool material, punch roughness, die gradient angle and blank holding force) was determined, as well as influence of their interactions on ironing force. Blank holding force and die gradient angle have shown the strongest influence on ironing force. The influence of these two factors could have been observed as a single factor, whereat all other influences would remain unchanged. That was determined in the preliminary analysis which will not be shown here due to its extent. Such approach would make sense from that aspect, meaning that strain ratio depends on die gradient angle and blank holding force. The difference between this test and the real process is also that in real process, strain depends on die gradient angle, and blank holding force represents only radial force which acts upon die. However, it was decided to carry out a separate analysis of factors (die inclination angle and blank holding force) even though it could have been performed in the other way, as mentioned previously. The analysis also showed a large influence of tool material and lubricant on ironing force. Regarding individual effects of factors on ironing force, punch roughness showed the smallest influence, but regardless of it minor influence, it is still significant.

The largest influence of interactions was established for blank holding force and die gradient angle. Somewhat smaller influence was shown by material-die gradient angle, lubricant-material, lubricant-roughness, material-roughness and lubricant-die gradient angle. Other interactions are even smaller, but they exist.

The analysis of mean values of ironing force, developed using Duncan's test, showed the existence of necessary difference between the selected levels of particular factors. Critical reliability factor-α = 0.05 was used as a criterion. Only the punch roughness N5 showed no significant difference in comparison with roughness N1 and N3.

A performed analysis shows the validity of experimental approach, that is the selection of main factors and their level.

Performed dispersion analysis for AlMg3 alloy sheet metal indicated that there is a prominent effect of all analysed factors and their interactions on ironing force. As in the case of steel sheet metal, blank holding force and die gradient angle have the strongest influence. The influence of interaction for these two factors is also very important. In AlMg3 alloy, the effects of tool material are much more prominent, as well as interactions of tool material and blank holding force, than in the case of steel samples. The reason for this is a high tendency for creating glued particles of aluminium alloy. The influence of punch roughness is significant, but much smaller than other factors.

The analysis of mean values of ironing force showed significant statistical differences between the sizes of observed factors levels. The difference was not prominent only between material of tool made of hard metal and hard chrome-plated metal, and also between punch roughness N5 and N3.

Typical diagrams of ironing force change in dependence on punch travel, e.g. at various blank holding forces (F_D = 8.7, 17.4 i 26.1 kN) are shown in Figure 11. The increase of blank holding force leads to increase of ironing force, because larger strain ratios are realised thereat.

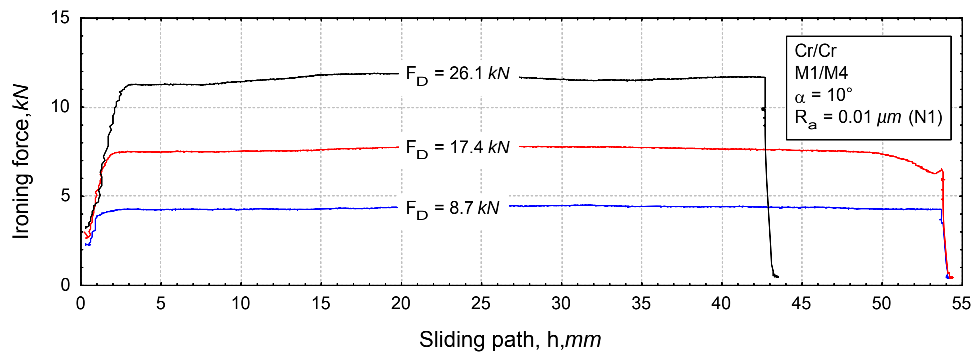


Figure 11 - Change of ironing force dependence on travel at different blank holding forces

The change of mean value of ironing force in the function of blank holding force for Č0148P3 and AlMg3 samples is shown in Figure 12. Trend of increase is almost the same for both materials. Considering the fact that the forces were obtained by investigating specimens of different cross-sections, it makes no sense to compare their values [7].

The influence of various factors (lubricant on die, tool material, punch roughness and die gradient angle) on mean values of ironing forces at different blank holding forces is shown in Figures 13 to 19. These diagrams confirm what had previously been established by dispersion analysis. Trends of changes in specified diagrams, which are given comparatively for steel samples and aluminium alloys, do not differ significantly.

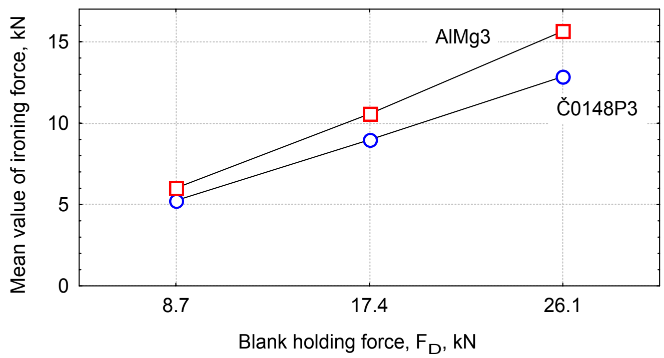


Figure 12 - Change of mean value of drawing force dependence on blank holding force

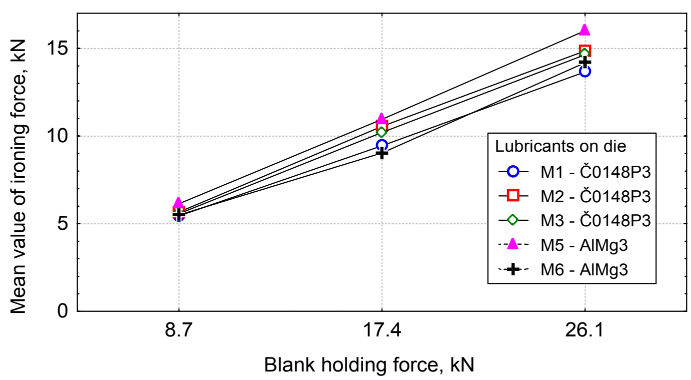


Figure 13 - Change of mean value of drawing force dependence on blank holding force for different lubricants on die

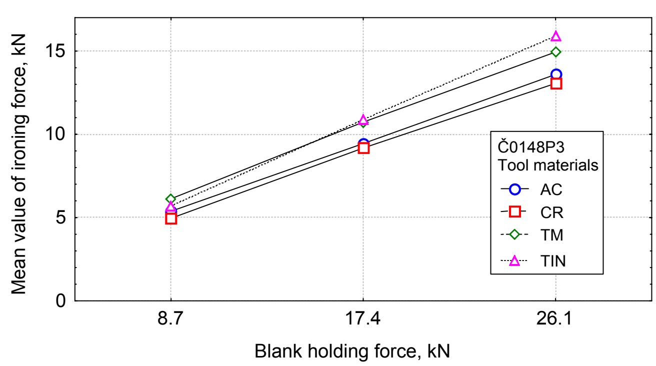


Figure 14 - Change of mean value of ironing force dependence on blank holding force for different tool materials (Č0148P3)

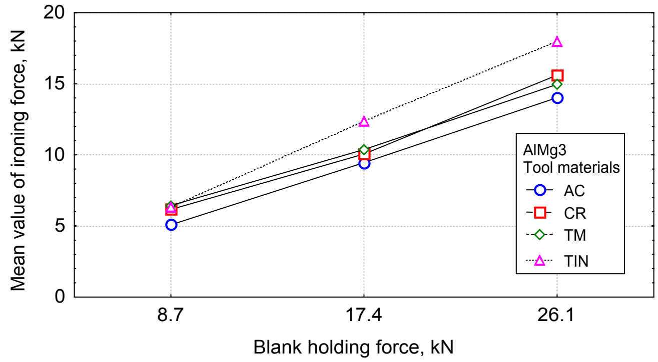


Figure 15 - Change of mean value of ironing force dependence on blank holding force for different tool materials (AlMg3)

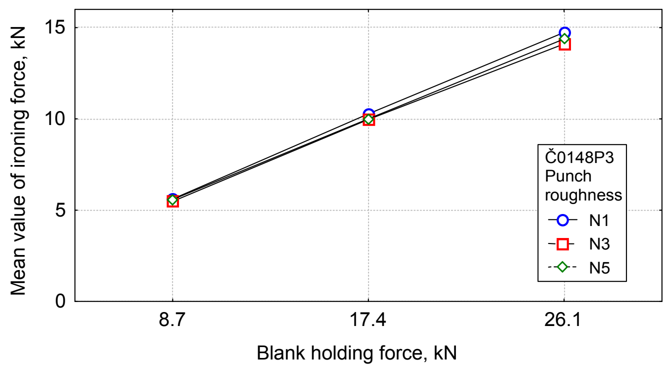


Figure 16 - Change of mean value of ironing force dependence on blank holding force for different punch roughness (Č0148P3)

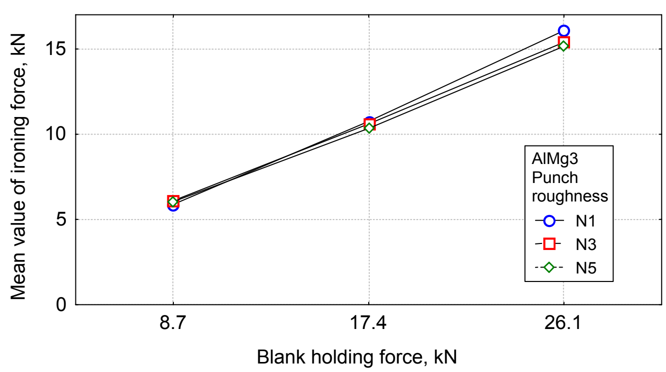


Figure 17 - Change of mean value of ironing force dependence on blank holding force for different punch roughness (AlMg3)

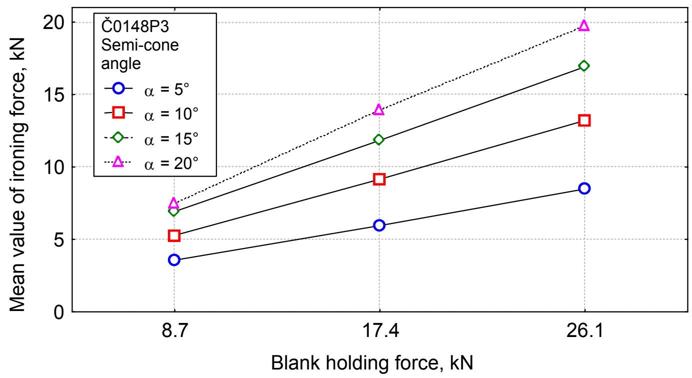


Figure 18 - Change of mean value of ironing force dependence on blank holding force for different semi-cone angles (Č0148P3)

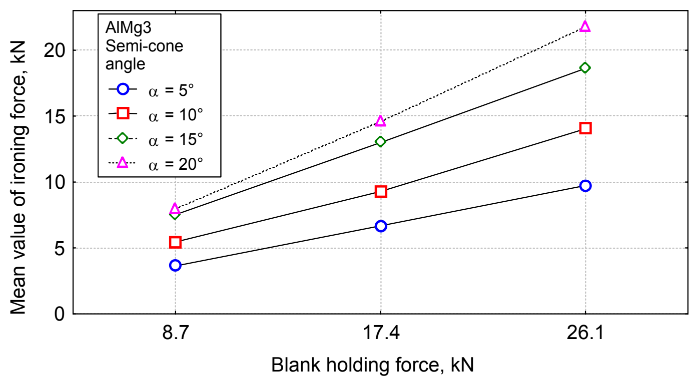


Figure 19 - Change of mean value of ironing force dependence on blank holding force for different semi-cone angles (AlMg3)

4. CONCLUSION

Ironing force represents a very important value in the ironing process, because the consumed power (energy) for process execution depends on it. On the other hand, ironing force represents output value of the process, together with piece quality. Ironing force will depend, more or less, on all relevant process parameters investigated in this paper (lubricant, tool material, punch roughness, die gradient angle and blank holding force), which can be seen on the basis of performed dispersion analysis. Prominent interaction of all considered factors has also been established.

For the ironing force it is characteristic that, on sliding path, it can be constant, increasing or decreasing, and in some cases it can have oscillatory (with some lubricants) and unstable character, which depends primarily on contact conditions.

Analysis of mean values of ironing force, carried out by using Duncan's test, shows the existence of necessary difference between the selected levels of particular factors and confirms the reliability of experimental approach, that is the selection of main factors and their levels.

5. LITERATURE

[1] Chertavskih A.K., Belosevich V.K.: *Friction and Lubricants in Metal Forming*, Metallurgy Moscow, (1968), (in Russian)

[2] Adamovic D.: *Behaviour of Materials in Contact in Cold Plastic Forming Processes with High Working Pressures*, Doctoral Thesis, the Faculty of mechanical Engineering in Kragujevac, Kragujevac, (2002), (in Serbian)

[3] Djukic H.: *Investigation of Method of Calculating the Optimal Technology for Elements Manufacture with Reduction of Casing Wall Thickness by Drawing*, Doctoral Thesis, the Faculty of Mechanical Engineering, Mostar, (1982), (in Serbian)

[4] Adamovic D., Stefanovic M., Plancak M., Aleksandrovic S.: *Analysis of Change of Total Drawing Force and Friction Force on Puncg at Ironing*, 3rd International Conference on Manufacturing Engineering, ICMEN, Kallitea of Chalkidiki, Greace, 1-3 October 2008. pp. 245-254.

[5] Adamovic D., Stefanovic M., Zivkovic M., Lazic V., Marjanovic N.: *Investigation of Influence of Tool Material and Lubricant on Ironing Force*, XXX SPM SCG, Vrnjacka Banja, (2005)., 303-308., (in Serbian)

[6] Adamovic D., Stefanovic M., Zivkovic M., Lazic V.: *Influence of Diferent parameters on Ironing Force During Ironing*, , XXXI SPM SCG, Kragujevac, (2006)., 171-180 (in Serbian)

[7] D. Adamovic, M., *Stefanovic*, V., Lazic*: Investigation of the Influence of Tool Material and Lubricant onto the Process Parameters and Quality of Work Piece Surface at Ironing,* Journal for Technology of Plasticity, Vol. 28 (2003), Number 1-2, 41-55.

ANALIZA UTICAJA RAZLIČITIH PARAMETARA NA SILU IZVLAČENJA I SILU TRENJA NA STRANI IZVLAKAČA PRI DUBOKOM IZVLAČENJU SA STANJENJEM DEBLJINE ZIDA

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REZIME

Procese hladnog plastičnog deformisanja karakteriše jedinstvo pozitivnog i negativnog uticaja sila spoljašnjeg trenja; na pojedinim površinama kontakta materijala i alata trenje treba intenzivirati, a u drugim zonama sile trenja se podmazivanjem moraju što više smanjiti. U procesu obrade dubokim izvlačenjem sa stanjenjem debljine zida značajnu ulogu imaju tribološki uslovi, odnosno ostvarene sile trenja.

Glavni faktori pri obradi dubokim izvlačenjem sa stanjenjem debljine zida su: brzina, stepen deformacije (zavistan od opterećenja i poluugla konusa matrice), stanje materijala u kontaktu (topografija površina, fizičke i hemijske karakteristike materijala), vrsta maziva i geometrija alata i radnog dela. Pravilnim izborom uticajnih parametara procesa moguće je dobiti deo zadovoljavajućeg kvaliteta uz minimalni utrošak energije.

U ovom radu, na odgovarajućem tribo-modelu klizanja epruvete od lima izmedju parova sa nagnutim kontaktnim površinama, biće data detaljna analiza uticaja navedenih parametara na ukupnu silu dubokog izvlačenja sa stanjenjem debljine zida kao i na silu trenja na izvlakaču.

Dobijeni rezultati ukazuju na složeno dejstvo izabranih analiziranih parametara procesa dubokog izvlačenja sa stanjenjem debljine zida (geometrija alata, hrapavost kontaktnih površina, materijal alata i obradjivanog dela, visoki kontaktni pritisci, mazivo na kontaktnim površinama, brzina deformisanja itd.) na silu izvlačenja.

Rezultati detaljnih istraživanja, pokazuju da sila izvlačenja i sila trenja na izvlakaču, na putu klizanja mogu da budu konstantne, da rastu, opadaju, ili pak mogu da imaju neki kombinovani karakter.

Ključne reči: *Duboko izvlačenje sa stanjenjem debljine zida, Sila izvlačenja, Sila trenja*