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INVESTIGATION OF THE INFLUENCE OF TOOL MATERIAL AND LUBRICANT ONTO THE PROCESS PARAMETERS AND QUALITY OF WORK PIECE SURFACE AT IRONING

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ABSTRACT

At cold plastic forming, the size of contact surface changes during the process, which means that parts of material which were not in contact in the previous phase now get in contact with the tool. This condition, as well as many others, create a series of specific problems, such as: change of friction coefficient in conditions of plastic forming, significance of tool roughness and its interaction with initial and then variable roughness of material being formed, and also prominently large differences in their mechanical properties, development of the wearing process and potential local welding (appearance of "galling"), possibility and quality of lubrication, etc.

If it is necessary to achieve the larger strain ratio during the ironing process, which would be possible without interoperation glowing, then the drawing is performed through many dies in succession. Thereat, due to the change of contact conditions (dislodging of lubricant, change of surface roughness, formation of diffusion and adhesion junctions), the friction condition change as well.

The aim of the experimental researches carried out in this paper was to indicate the changes which occur at multiphase drawing and to consider the influence of some factors (tool material, lubricant on die and punch) onto the process development.

1. INTRODUCTION

Ironing is applied in manufacture of cylindrical pieces in which the depth is larger then diameter, and bottom thickness is larger than wall thickness, such as bushes, thin-wall pipes, shock absorber casings, fire extinguishing devices, gas balloons, oil filters casings, screeds of piston engine cylinders and especially food and drink tin cans whose annual world production amounts to a billion of pieces. The aforementioned pieces are made of materials which have the sufficiently large plasticity in cold state, such as low carbon steels, austenite stainless steels, aluminium, brass and others. During the last few years, this method of forming found its application in electro-optical industry

as well, in production of optical and magnetic discs for obtaining the mirror surface, since this method is considerably cheaper then mechanical treatment.
The initial shape of the piece which is being ironed should have the cylindrical box shape which is obtained by deep drawing or opposite-direction pressing out. The piece obtained in such a way is being drawn further through one or more dies until it obtains the final shape.
In order to achieve the proper reduction of wall thickness, the drawing can be performed through many dies simultaneously (die block) or through one graded die. This is possible only in case when there is no need for inter-glowing. Multistage drawing is much more economical then single stage drawing.

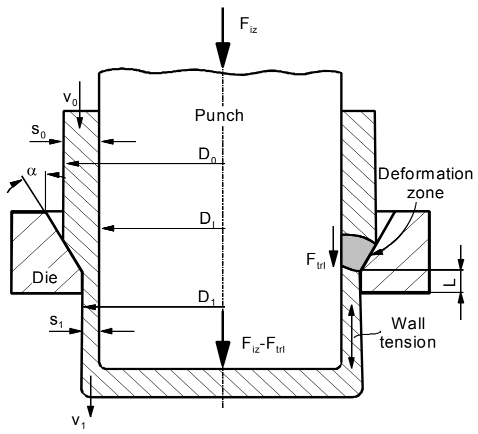


Figure 1 Scheme of ironing

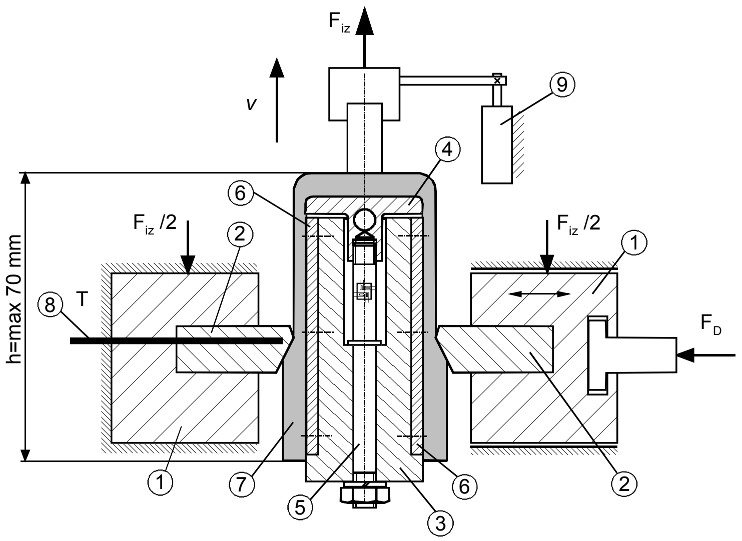
2. MODELLING OF IRONING

In the process of forming by ironing, the tribological conditions, i.e. realised friction forces, play the significant role. Stress-strain condition of plastically formed piece, the possibility for successful forming, as well as the force needed for performance of forming depend on the size and distribution of contact stresses. Since metal forming takes place in conditions of high contact pressures, the absence of lubricant in such conditions would lead to the direct contact of forming material and tool, i.e. it would lead to micro welding or adhesion of the softer material onto the harder tool, and thus to significant disturbance of forming conditions [7].

The process of ironing through single die is shown schematically in fig.1, with general outline of friction forces in contact of piece and die, i.e. punch. The effects of friction forces in forming zone are different: on the outer surface (between piece and die) these forces (F_{trM}) increase tension stresses, and on the inner side (between the piece and punch), forces (F_{trI}) disburden the critical section reducing the stresses in the wall of the piece being ironed. That is the main reason for achievement of high strain ratios and realisation of significant growth of relative depth at drawing.
Ironing is performed in conditions which are similar to plane forming state. The increase of friction on the side of the punch reduces the critical tension stress, but the total ironing force increases. Thereat, the force F_{trI} must not increase so much that it brings to the appearance of rough infringements and micro weldings of work piece metal particles onto the tool, which would cause the damage of work piece and tool and would make difficult the removal of work piece from the punch.
It is clear that the influence of tribological conditions at ironing is extremely important and it has been the subject of researches of many researchers during the past years, both in real processes and on tribo-models. The investigation of tribological conditions in real processes takes much more time and is considerably more expensive; therefore, investigations on tribo-models are more often practised.
Modelling of tribological conditions at ironing implies the satisfying of the minimum of necessary criteria, with regard to: similarity in stress-strain characteristics, in temperature-velocity conditions, in properties of tool and material surface and in state of their contact during forming.

In literature, it is possible to find the whole series of tribo-models which were mainly developed for particular purposes [1, 2, 3, 4, 5, 6]. The mutual property of all models is that they do not completely imitate the real process of ironing regarding tool geometry, stress-strain state or contact state during forming. For most of the illustrated models it is not possible to determine the friction force, i.e. coefficient of friction between work piece and punch, which has the extreme importance in the ironing process, as we have previously mentioned. Also, for most of the models, the angle of die cone is not taken into consideration etc. All this indicates that suggested models have limited application, which should be taken into consideration when using the data obtained by applying them [8].

Taking into account the advantages and disadvantages of the specified models and taking into consideration the objective possibilities, in this paper we have proposed one new tribo-model of ironing, which bilaterally symmetrically imitates the zone of contact with die and punch. This model allows the realisation of high contact pressures and takes into account physical and geometrical conditions of the real process (material of die and punch, topography of contact surfaces, angle of die cone – α etc) [9]. The scheme of mentioned tribo-model is given in figure 2.



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 2 Scheme of the model used in this paper.

Bent sheet metal band 7, in the U shape, (test piece), is assembled on the punch. It is affected upon by "dies" 2 with force F_D. The dies are assembled in supports, whereat the left support is immovable, and the right support is movable together with the die. The punch consists of the body 3 and front 4 which are interconnected with gauge with measuring bands 5. The test piece is moved (it slides) between dies, by action of force F_{iz}, onto the punch front, whereat the thinning of test piece wall thickness occurs. While the test piece is moved, its outer surface slides against die surface, slanted for angle α, and the inner test piece surface slides against plates 6 which are fixed onto the punch body.

The device is realised with compact construction of increased stiffness, with possibility for simple alteration of contact-compressive elements (die 2 and plate 6), with simple cleaning of contact zones and convenient assembling of test pieces.

Plates 6 and die 2 can be made of various materials and with various roughnesses, and dies can be made with various slope angle α as well.
When carrying out this device, the main idea was to make possible the determining of friction coefficient, both on the die side and on the punch side at various contact conditions.
The total ironing force F_{iz} represents the sum of the force of friction between punch and work piece, F_{trI} and force which acts upon the test piece bottom F_z, i.e.:

$$F_{iz} = F_{trI} + F_z \,. \tag{1}$$

Force F_{iz} is is measured on the device itself, and the friction force on the punch side F_{trI} is registered by means of gauge with measuring bands.
The friction coefficient on the punch side, taking into account that it changes according to *Coulomb*'s law, can be calculated on the basis of the following expression:

$$\mu_I = \frac{F_{trI}}{2 \cdot F_D}\,, \tag{2}$$

and friction coefficient on die side by the expression:

$$\mu_M = \frac{F_{iz} \cdot \cos\alpha - 2 \cdot F_D \cdot \sin\alpha}{F_{iz} \cdot \sin\alpha + F_D \cdot \cos\alpha}\,. \tag{3}$$

Knowing the dependency of forces F_{iz} and F_{trI} on sliding path h, it is possible to determine the friction coefficients (μ_M and μ_I) in function of sliding path on the basis of previous expressions.

3. EXPERIMENTAL RESEARCHES

The aim of experimental researches was to investigate the successive (through a larger number of dies simultaneously), i.e. multistage drawing (several times through one die). Multistage drawing implied the performance of investigation several times on one and the same test piece. The specified research is interesting from the aspect that the material always goes into the following drawing stage with changed topography, which influences the process itself (ironing force, friction coefficient etc).
This experiment does not completely imitate ironing through a larger number of dies simultaneously (distance between does is not taken into account, the total ironing force has somewhat different alteration process, since in one part of the process drawing is performed simultaneously through a larger number of dies), but at any rate, the proper conclusions can be made, especially regarding the topography of contact surfaces.
For experimental researches in this paper, two materials were chosen: classic low carbon steel sheet metal C0148P3 and Al-alloy sheet metal, marked with AlMg3 (43)[1]. (Old mark was: AlMg3-24; mark according to DIN: AlMg3 F24). In this way, two very different and very modern materials in contemporary industry were included. The mechanical properties of the investigated materials are given in table 1.

Table 1 Mechanical properties of investigated materials

Material	Angle, °	R_p, MPa	R_m, MPa	R_p/R_m, -	A, %	n, -	r, -	E, MPa

[1] In further text the short mark AlMg3 was used.

Č0148P3	0°	186.2	283.4	0.657	37.3	0.21860	1.31915	1.957×10^5
AlMg3	0°	201.1	251.0	0.801	12.0	0.13545	0.40510	$0,701\times10^5$

Contact pairs (“die” and “punch”) are made of alloyed tool steel (TS) with great toughness and hardness, marked with Č4750 (DIN 17006: X165CrMoV12). This steel is wear resistant and is foreseen for cold work. Before mechanical forming by abrading, calcinations in oil and loosening were performed.
With the aim of comparative researches, one set of tools was hard chrome plated (Cr). We should mention that the foundation (base) of the tool was thermally treated alloyed tool steel C4750.
One set of “dies” was made of hard metal (HM) marked with WG30 (DIN 4990:G30). Hard material (α-phase) was wolfram carbide (WC), and the connective material was cobalt (β-phase).
When selecting the lubricant for the experimental researches, it was necessary to pay attention to several factors, such as: kinds of material being investigated (steel, aluminium), different consistency of lubricants (grease, paste, lubricate coatings), various lubricant viscosity, lubricant origin (organic, synthetic, mineral), as well as height of contact pressures which dominate at ironing.
On the basis of aforementioned factors, the selection of lubricants which will be used in experimental researches was performed. Their review, including main properties, is given in table 2.

Table 2 Review and main data on applied lubricants

	Kind of lubricant					
Coded mark of lubricant	M1	M2	M3	M4	M5	M6
Consistency	Grease	Oil	Paste	Oil	Oil	Oil
Type of lubricant	Li + MoS_2	Mineral emulsifying water-dissolving oil with EP, anti-wear and lubricating additives	Non-emulsifying agency	Non-emulsifying mineral oil with mild EP qualities	Oil of paraffin basis with special additives	Oil of paraffin basis with special additives
Kinematic viscosity on 40˚C, mm^2/s	-	-	58	45	80	190

The experiment was performed under the following conditions:

- Angle of die slope: α = 10˚,
- Lubricant on die side:
  - for samples of C0148P3: M1, M2, M3, M4,
  - for samples of AlMg3: M1, M2, M3, M4, M5, M6,
- Lubricant on the punch side:
  - for samples of C0148P3: M2, M4, S (dry),
  - for samples of AlMg3: M6,
- Material of die/punch: AC/AC, TM/AC, Cr/Cr,
- Holding force: 8.7; 17.4 kN,
- Punch roughness: Ra = 0.01 μm (N1),

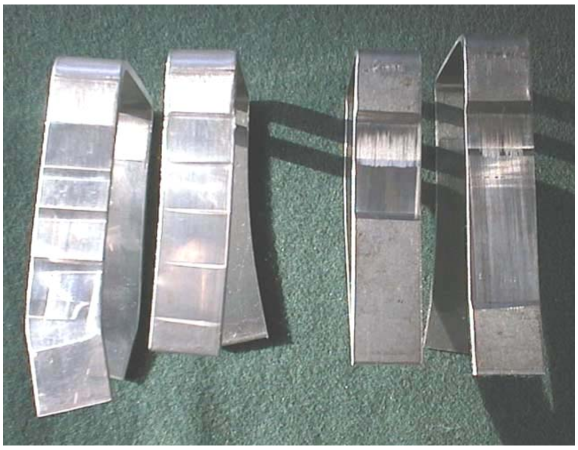


Figure 3 *The appearance of the test piece after multiple drawing*

The procedure of investigation performance consisted of the following: after one sliding, the one and the same test piece was put back in the same position, after which it was again slid, but the punch travel was always somewhat smaller than in the previous sliding in order to preserve a part of the test piece surface for further analysis (measuring of hardness, roughness etc). In some cases, the test piece surface on die side was lubricated only at the beginning of investigation, and in other cases it was lubricated before each sliding, which will be emphasised later in the result analysis. If the lubrication was performed before each sliding, then the tool surface was cleaned of oxides (samples of Č0148P3) and adhesives (samples of AlMg3), if any of them appeared. The test piece surface on punch side was always lubricated only before the beginning of first drawing. The number of slidings was 2-4. The appearance of the test piece after multiple drawing is shown in figure 3.

4. RESULTS OF EXPERIMENTAL RESEARCHES

At multiphase drawing, after each sliding completely new conditions are created on contact surfaces, which significantly influence the ironing force. Characteristic changes of ironing force from sliding path at different slidings, both for samples of Č0148P3 and for samples of AlMg3, are given in figures 4 and 5, respectively. At steel sheet metal samples, if the lubrication is performed only in the beginning and at larger holding forces, the significant disturbance of contact conditions occurs, which is why the ironing force is considerably increased at each following sliding (figure 4b). If lubrication is performed before each sliding, and die surface is being cleaned of resultant oxides, then after first sliding a small increase of ironing force will occur and after that, the ironing force becomes stable (figure 4a).

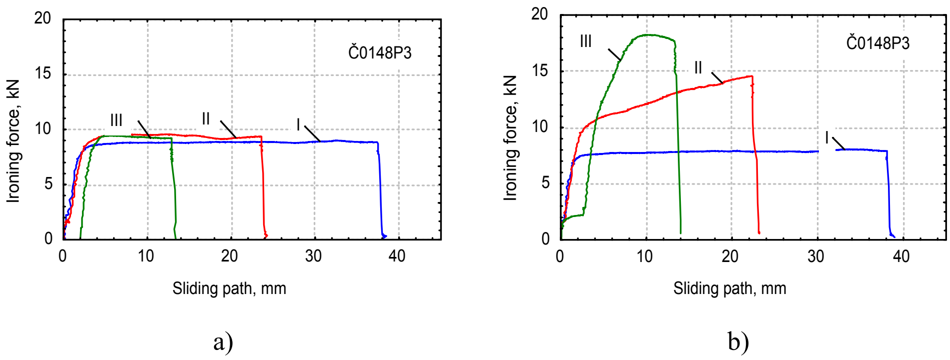


Figure 4 Change of ironing force at multiphase drawing of steel sheet metal samples

At samples of AlMg3 alloy, several characteristic cases of ironing force change in comparison to steel samples were noticed. The reason for that is a larger number of applied lubricants as well as the tendency of aluminium to create adhesives. The application of inadequate lubricants and effects of larger holding forces regularly lead to creation of adhesives and to significant disturbance of contact conditions, which causes the significant increase of ironing force at each following sliding (figure 5a). If the holding forces are small, and lubricants inadequate, then the ironing force can decrease in the second sliding, but already in the following slidings its intensive growth can be noticed (figure 5d). If the holding forces are small and the lubricant is adequate (good), then the ironing force decreases at each following sliding (figure 5b). At larger holding forces and adequate lubricants, the adhesives of aluminium on die were very small (the die was cleaned after each sliding) or there were none, which had such effects on the ironing force that in following slidings it either increased slightly or it decreased slightly in comparison to the first sliding (figure 5c and 5e). If the die would not be cleaned after each sliding, then due to the accumulation of adhesives the friction conditions could get worse after a few slidings, which would lead to the increase of ironing force which was stable in the previous phases (figure 5f).

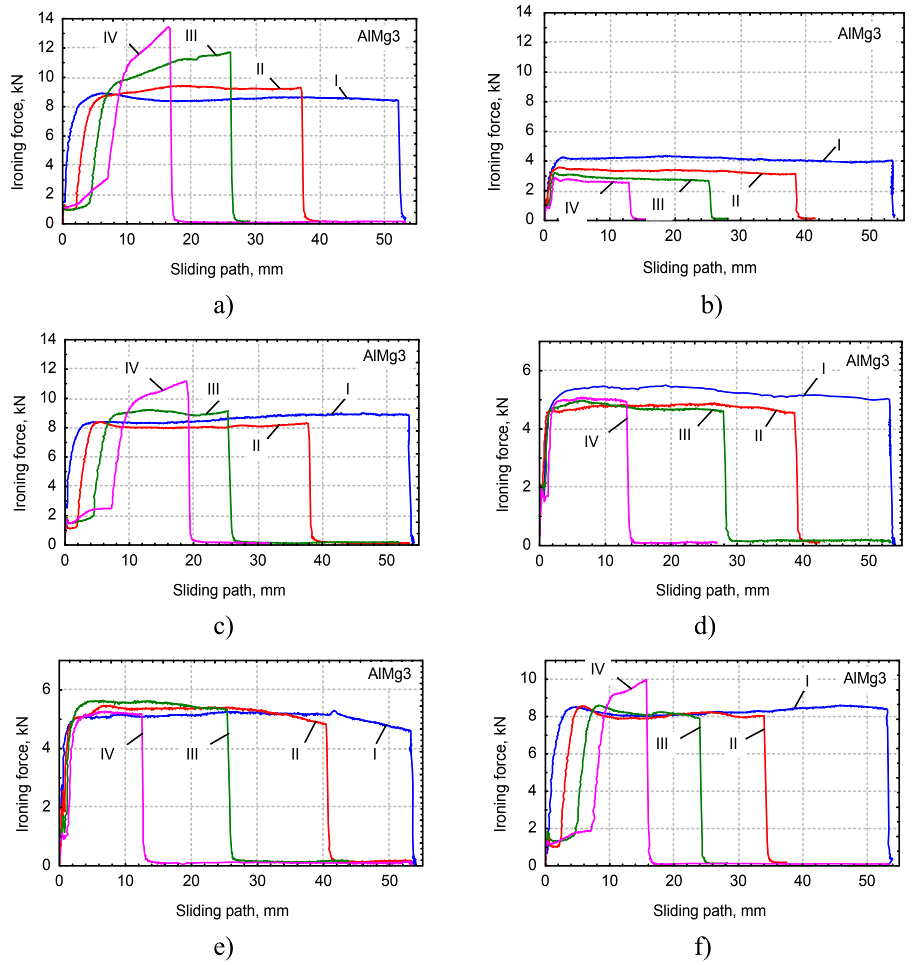
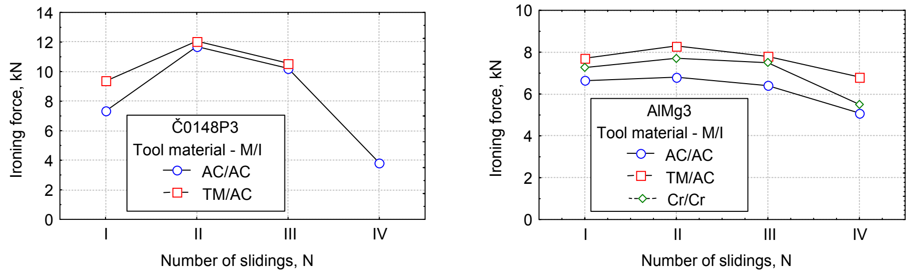


Figure 5 Change of ironing force at multiphase drawing of AlMg3 alloy samples

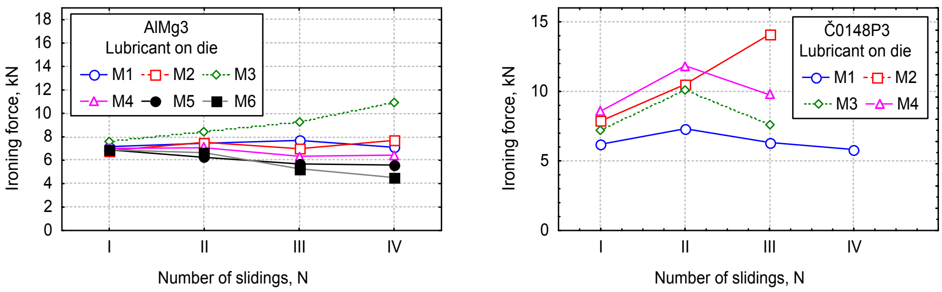
The influence of the tool material onto the ironing force per drawing phases is given in figure 6. At steel sheet metal, by application of alloyed steel tools, smaller ironing force is obtained then by application of hard metal tools (figure 6a). When drawing the sheet metal of aluminium alloy, the smallest ironing force is obtained with alloyed steel tool at all drawing phases (figure 6b). Somewhat higher values are obtained with hard chrome plated tool, and the highest values are obtained with hard metal tool.



a) b)

Figure 6 Influence of tool material onto the ironing force per drawing phases

The change of ironing force per drawing phases at various lubricants on die is given in figure 7. It should be mentioned that the shown results for lubricant M2 at steel sheet metal and for lubricant M3 at AlMg3 sheet metal correspond to the case when the test pieces were lubricated only before the first drawing. The shown ironing forces represent the average value obtained at all lubricants on punch and all holding forces. At steel sheet metal at all lubricants, except M2, with the increase of number of slidings the ironing force first increases and then it decreases (figure 7a). Only at lubricant M2, the ironing force constantly grows because of dislodging of lubricant and deterioration of contact conditions. For the same reasons, at lubricant M3, when drawing AlMg3 sheet metal, the ironing force also increases. Other lubricants lead to alternate or monotonous decrease or increase of ironing force (figure 7b).



a) b)

Figure 7 The influence of lubricant on die onto the ironing force per drawing phases

The influence of tool material onto the friction coefficient on die side per drawing phases is shown in figure 8. When drawing steel sheet metal, smaller values of friction coefficient μ_M are obtained with alloyed tool steel tool than with hard metal tool in all drawing phases (figure 8a). At alloy AlMg3 sheet metal, the smallest friction coefficient is also obtained with alloyed tool steel tool. Somewhat higher values are obtained with tool which is hard chrome plated. It has been observed that the friction coefficient decreases with increase of number of slidings, if the tool is made of alloyed tool steel. With the application of chrome plated tools and hard metal tools, with the increase of the number of slidings, the friction coefficient increases (figure 8b).

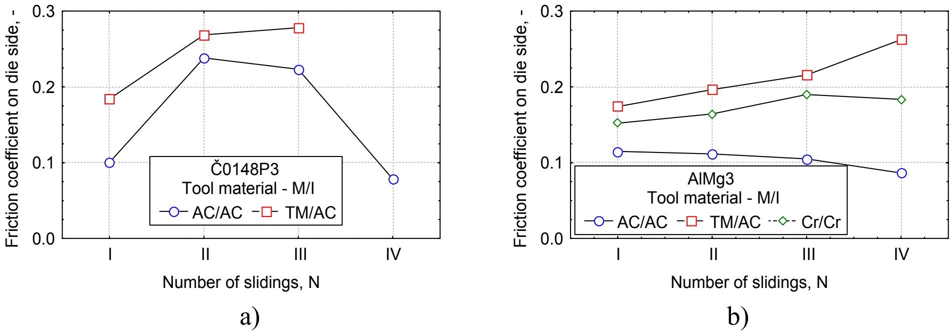


Figure 8 The influence of tool material onto the friction coefficient on die per drawing phases

Figure 9 shows the average values of friction coefficient on die side, per drawing phases, for different lubricants on die side, obtained for all tool materials, all holding forces and all lubricants on die. The trends of change of friction coefficient μ_M are practically the same as changes of ironing force, since coefficient μ_M directly depends on ironing force.

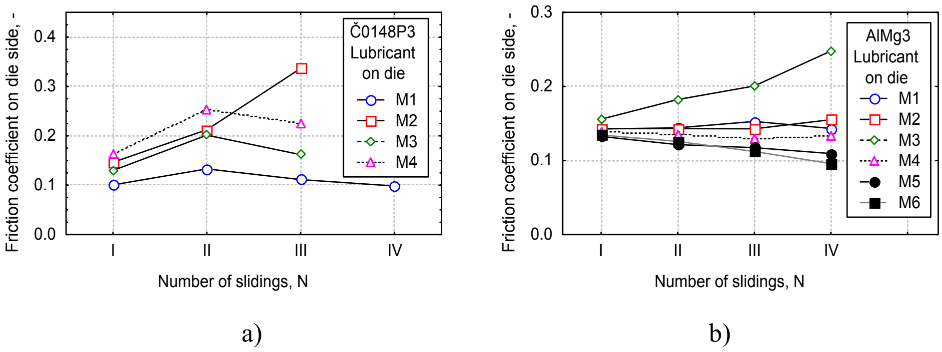


Figure 9 The influence of lubricant on die onto the friction coefficient on die per drawing phases

The friction coefficient on punch side in the second drawing phase drastically increases at all applied lubricants (figure 10). The reason for that is certainly the fact that the sheet metal was lubricated on punch side exclusively before the first drawing phase. During the first sliding, due to small punch roughness and existence of high contact pressures, most of the lubricant gets dislodged from the surface, so in the second drawing phase almost completely clean metal contact is made between sheet metal and tool, which has as the consequence a very high friction coefficient (above 0.3). Diagram in figure 10 is related to steel sheet metal. The analysis of the influence of lubricant on punch side onto the friction coefficient μ_I was not performed, because only one lubricant was used (lubricant M6).

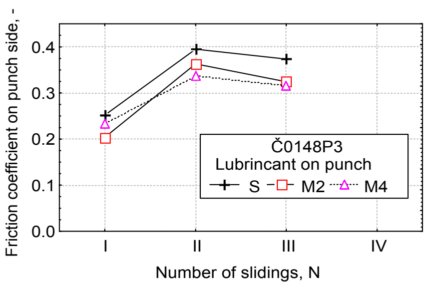


Figure 10 The influence of lubricant on punch per drawing phases onto the friction coefficient μ_I

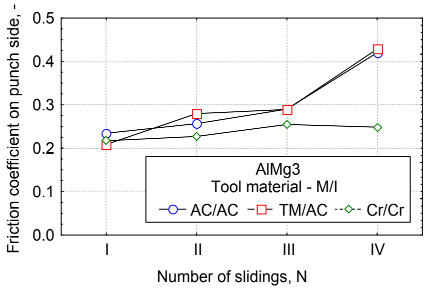


Figure 11 The influence of tool material on punch per drawing phases onto the friction coefficient μ_I

At alloy AlMg3 samples, the smallest friction coefficient on die side is obtained by using hard chrome plate tools in all drawing phases except the first one (figure 11). The increase of friction coefficient with increase of number of drawings was observed for all tool materials, but it was the smallest at chrome-plated tools, which indicates a small tendency to creation of diffusion connections between aluminium and chrome. The intensive growth of friction coefficient on die side, when the punch material was alloyed tool steel, is not observed before the fourth sliding. That can be explained by “complete” elimination of lubricant from contact surfaces due to which the intensive creation of adhesives occurs.

At multiphase drawing of steel sheet metals, after the very first sliding, a very significant reduction of roughness on die side occurs (figure 12a). With the increase of number of slidings, larger or smaller increase of roughness occurs in dependence on the applied lubricant. The largest increase of roughness occurs at lubricant M2 which was applied only before the beginning of drawing. It is assumed that, in the absence of lubricant, the resulting abrasive particles significantly influence the increase of roughness. It would be interesting to observe that after the second sliding, the friction coefficient μ_M decreases with simultaneous increase of sheet metal roughness. That can be explained by more favourable apportionment of lubricant in “pockets” of roughnesses. At AlMg3 sheet metal, at first sliding the roughness changes insignificantly, considering the small initial roughness of sheet metal (figure 12b). Only at lubricant M3 does the increased roughness appear already at first sliding, and during the further slidings the roughness gradually increases, and at fourth sliding, seizure occurs. Regardless of the fact that the lubricant M3 was applied only before the first sliding, the increase of sheet metal roughness already at first sliding indicates that this lubricant is very unfavourable at ironing of sheet metal of AlMg3 alloy.

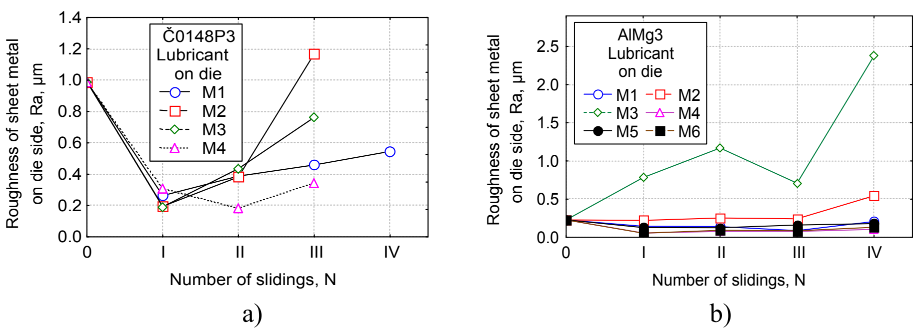
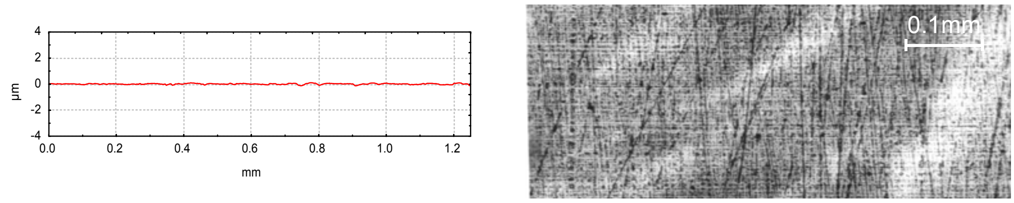
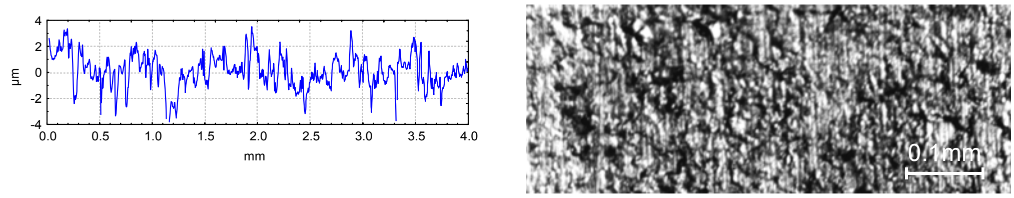


Figure 12 The influence of lubricant onto the die side per drawing phases

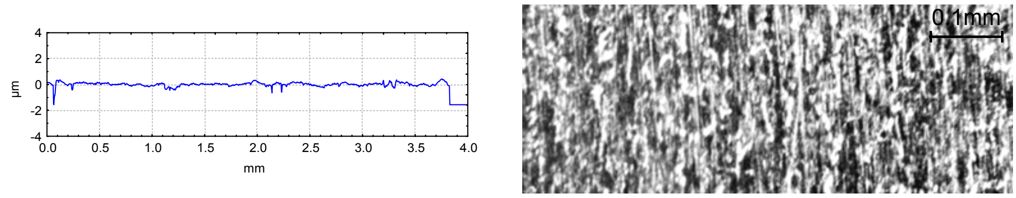
Figure 13 shows 2D roughness forms and microphotographs of steel sheet metal surfaces on die side, which were made in different drawing phases. If the lubricant M2 was applied on die side (lubrication only before the beginning of drawing), then already at first sliding the prominent levelling of roughnesses occurs. At next sliding (II), due to dislodging of lubricant, the roughness of surface increases, and in the following phase (III), rough notches appear and they are clearly visible on microphotographs (figure 13).



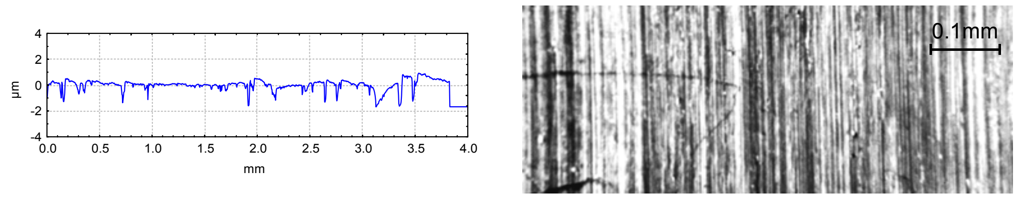
Die: AC, R_a = 0.01 µm (N1)



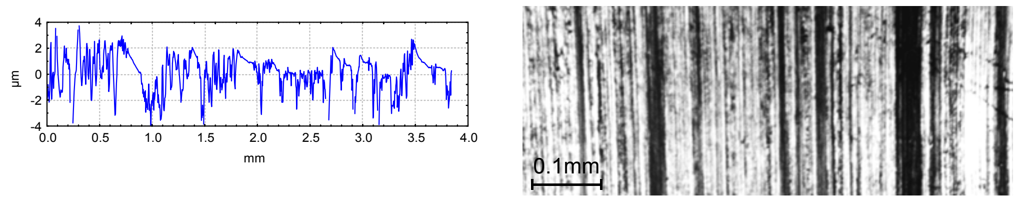
Sheet metal Č0148P3 – before ironing, R_a = 1.01 µm



I ironing, R_a = 0.20 µm



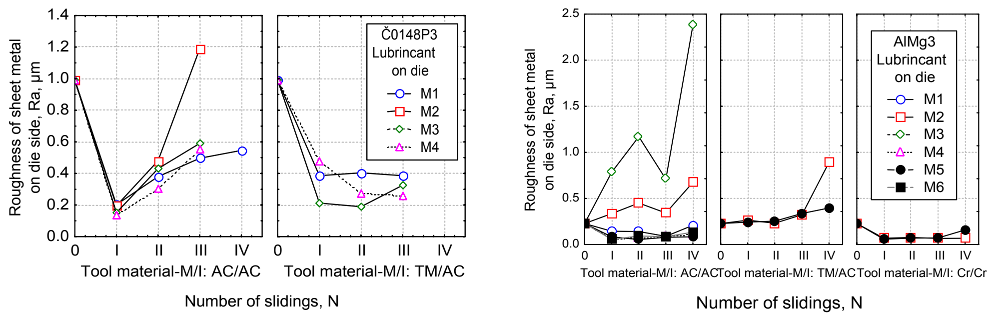
II ironing, R_a = 0.39 µm



III ironing, R_a = 1.18 µm

Figure 13 2D roughness form and microphotographs of steel sheet metal surfaces on die side, made at different drawing phases (lubricant on die/punch- M2/S)

The influence of interaction of lubricant and tool material onto the change of sheet metal roughness on the die side, per different drawing phases, is given in figure 14. At drawing of steel sheet metals with tool of alloyed tool steel (TS), after the first drawing, at all lubricants, the increase of sheet metal roughness occurs. If the material of tool (die) is hard metal (HM), then at first sliding somewhat larger roughness is obtained in comparison to tool steel, but at following slidings the roughness does not change significantly (figure 14a).



a) b)

Figure 14 The influence of lubricant onto the sheet metal roughness on die side at different tool materials per drawing phases

At drawing of AlMg3 sheet metal, the lubricant has a very significant function – to separate the sheet metal surface from tool and to prevent the creation of adhesives on tool, since the aluminium has a great tendency to adhere. In the performed experiment, only the lubricants M2 and M5 were used in all combinations with various tool materials. The difference in conduct of lubricant M2 at various tool materials is clearly visible (figure 14b). The lubricant M5 proved to be very stable in maintenance of a certain level of roughness in combination with all tool materials.
Figure 15 shows the change of sheet metal roughness on punch side, per drawing phases, at different lubricants on punch side and tool materials. It is clearly visible that at both investigated materials, the sheet metal roughness, at same lubricants, does not depend on the tool material. In all combinations of lubricant and tool material, the roughness realised after I sliding will be roughly maintained at all following slidings. At steel sheet metal, the smallest roughness is obtained if the drawing procedure is performed without lubrication. However, we should bear in mind the fact that in that case, higher values of friction coefficient μ_M are obtained, and therefore the larger punch wear should be expected.

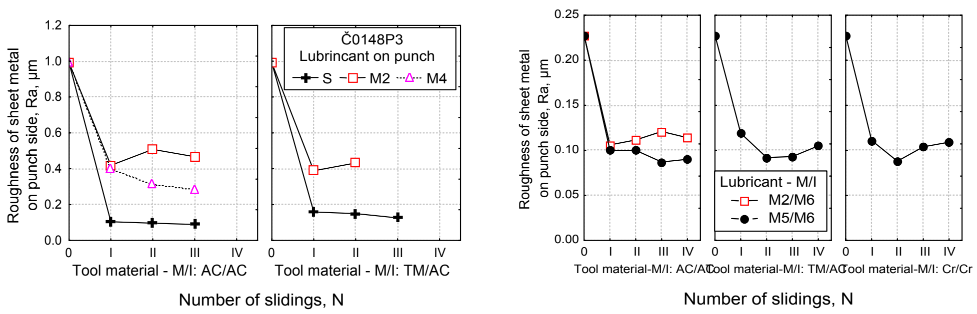


Figure 15 The influence of lubricant on punch onto the sheet metal roughness on punch side at different tool materials per drawing phases

The change of sheet metal roughness on punch side, per drawing phases, at various holding forces, is given in figure 16. The values R_a represent the average values obtained by application of all lubricants and tool materials. At both investigated materials, regardless of the value of holding force, the roughness achieved after first sliding is maintained at the other slidings as well. The increase of holding force leads to decrease of sheet metal roughness on punch side.

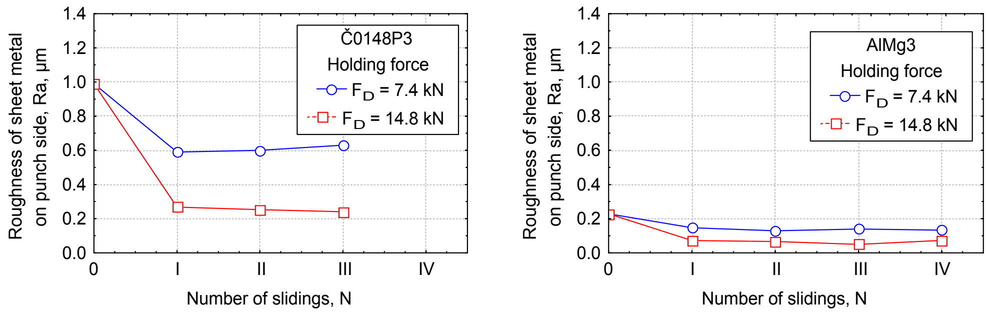


Figure 16 The influence of holding force per drawing phases onto the sheet metal roughness on punch side

5. CONCLUSION

In the process of ironing, if it is necessary to achieve a higher strain ratio which would be achievable without interoperation glowing, then the drawing is performed successively, through a larger number of dies. During that, due to the change of contact conditions (dislodging of lubricant, change of surface roughness, creation of friction connections etc), the friction conditions change as well. At multiphase drawing, after each sliding, completely new contact surface conditions appear, which will significantly influence both the ironing force and the quality of piece surface.
Detailed investigations performed in this paper clearly point out that lubricant and tool material have the crucial influence onto the increase or decrease of ironing force per drawing phases. Also, the holding force, i.e. strain ratio which will directly depend upon the holding force, has a very significant influence onto the trend of change of forming force per drawing phases.
At successive drawing, after I sliding, the roughness of sheet metal on die side rapidly decreases, and in the following phases, it can increase or remain approximately constant, which will primarily depend upon the applied lubricant. At drawing of AlMg3 sheet metal, the lubricant has a very important function – to separate the sheet metal surface from tool and to prevent the appearance of adhesives on tool, considering the great tendency of aluminium to adhere
In all combinations of lubricant and tool material, roughness of sheet metal on punch side, realised after I sliding, is roughly maintained at all following slidings as well. At steel sheet metal, the smallest roughness is obtained if the drawing procedure is performed without lubrication. However, one should bear in mind that in that case, the higher values of friction coefficient μ_I are obtained, and larger wear of punch should be expected as well.

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ISTRAŽIVANJE UTICAJA MATERIJALA ALATA I MAZIVA NA PROCESNE PARAMETRE DUBOKOG IZVLAČENJA SA STANJENJEM DEBLJINE ZIDA I KVALITET POVRŠINE RADNOG KOMADA

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REZIME

Pri hladnom plastičnom deformisanju veličina kontaktne površine se menja u toku procesa, što znači da u dodir sa alatom stupaju delovi materijala koji u prethodnoj fazi nisu bili u kontaktu. Ova i druge okolnosti otvaraju niz specifičnih problema kao što su: promena koeficijenta trenja u uslovima plastičnog oblikovanja, značaj hrapavosti alata i njene interakcije sa početnom i zatim promenjenom hrapavošću materijala koji se obradjuje, kao i upadljivo velike razlike u njihovim mehaničkim svojstvima, odvijanje procesa habanja i eventualnog lokalnog privarivanja (pojava "galling-a"), mogućnost i kvalitet podmazivanja, itd.

Ukoliko je u procesu dubokog izvlačenja sa stanjenjem debljine zida potrebno ostvariti veći stepen deformacije, a koji je moguć bez medjuoperacionog žarenja, onda se izvlačenje izvodi uzastopno kroz više matrica. Pri tome, zbog promene kontaktnih uslova (istiskivanje maziva, promena hrapavosti površine, stvaranje frikcionih spojeva itd), dolazi i do promene uslova trenja. Pri višefaznom izvlačenju, posle svakog prolaza, dolazi do stvaranja sasvim novih uslova na kontaktnim površinama koji će vrlo bitno da utiču, kako na silu izvlačenja, tako i na kvalitet površine dela.

Detaljna ispitivanja izvedena u ovom radu jasno ukazuju da mazivo i materijal alata imaju presudnu ulogu na povećanje ili pak smanjenje sile izvlačenja po fazama izvlačenja. Takodje, i sila držanja, odnosno stepen deformacije koji će direktno da zavisi od sile držanja, ima vrlo veliki uticaj na trend promene sile deformisanja po fazama izvlačenja.

Pri uzastopnom provlačenju posle I provlačenja hrapavost lima na strani matrice naglo opada, a u narednim fazama može da raste ili približno da ostane konstantna, što će da zavisi prvenstveno od korišćenog maziva. Pri izvlačenju lima od AlMg3 mazivo ima vrlo važnu ulogu; da razdvoji površinu lima od alata i da spreči stvaranje nalepina na alatu, s obzirom na veliku sklonost aluminijuma ka nalepljivanju

U svim kombinacijama maziva i materijala alata, hrapavost lima na strani izvlakača, ostvarena posle I provlačenja, približno se održava i pri svim narednim provlačenjima. Kod čeličnog lima najmanja hrapavost se dobija ukoliko se postupak izvlačenja izvodi bez podmazivanja. Medjutim treba imati na umu da se u tom slučaju dobijaju veće vrednosti koeficijenta trenja μ_I, a treba očekivati i veće habanje izvlakača.