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RESEARCH

Investigation of Influence of Tribological Conditions on Friction Coefficient During Multiphase Ironing for Steel and Aluminium Sheet Metal

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 friction coefficients which occur at multiphase ironing and to consider the influence of some factors (tool material, lubricant on die and punch) onto the process development.

Keywords: Multiphase ironing, friction coefficient, sheet metal

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, aluminum, 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.

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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.

In the process of forming by ironing, the tribological conditions, i.e. realized 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].

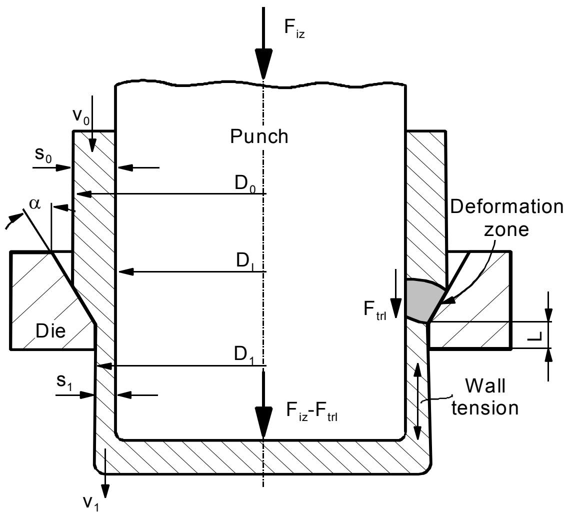


Figure 1: Scheme of ironing

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 realization 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 welding 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 practiced.

Modeling 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 and 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].

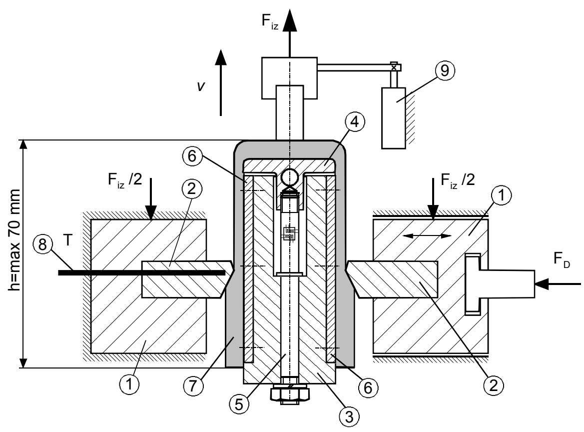


Figure 2: Scheme of the model used in this paper

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

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 realization 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 etc.) [9]. The scheme of mentioned tribo-model is given in Figure 2.

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, it's outer surface slides against die surface, and the inner test piece surface slides against plates 6 which are fixed onto the punch body.

The device is realized 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 angles as well.

2. 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). (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
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, aluminum), 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	L1	L2	L3	L4	L5	L6
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-emulsifyin g agency	Non-emulsifying mineral oil with mild EP qualities	Oil of paraffin basis with special additives	Oil of paraffin basis with special additives
Cinematic viscosity on 40˚C, mm^2/s	-	-	58	45	80	190

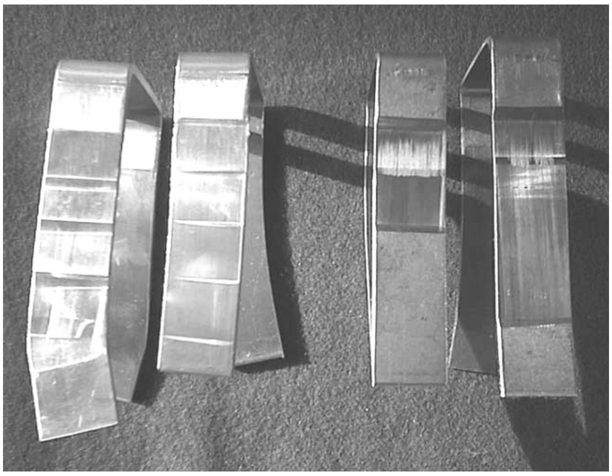


Figure 3: The appearance of the test piece after multiple drawing

The experiment was performed under the following conditions:

- Angle of die slope: $\alpha = 10˚$,
- Lubricant on die side:
  - For samples of C0148P3: L1, L2, L3, L4,
  - For samples of AlMg3: L1, L2, L3, L4, L5, L6,
- Lubricant on the punch side:
  - For samples of C0148P3: L2, L4, D (dry),
  - For samples of AlMg3: L6,
- Material of Die/Punch: TS/TS, HM/TS, Cr/Cr,
- Holding force: 8.7 and 17.4 kN,

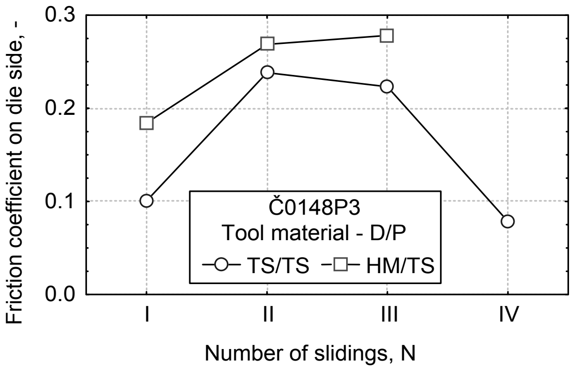
Punch roughness: Ra = 0.01 μm (N1).

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 emphasized 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 sidings was 2-4. The appearance of the test piece after multiple drawing is shown in Figure 3.

3. RESULTS OF EXPERIMENTAL RESEARCHES

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 4a). 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 sliding, 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 sliding, the friction coefficient increases (Figure 4b).

Figure 5 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.



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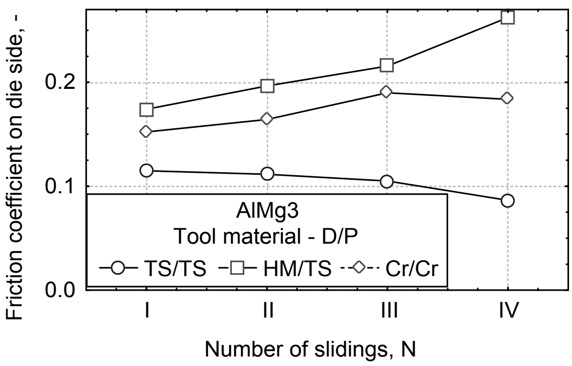
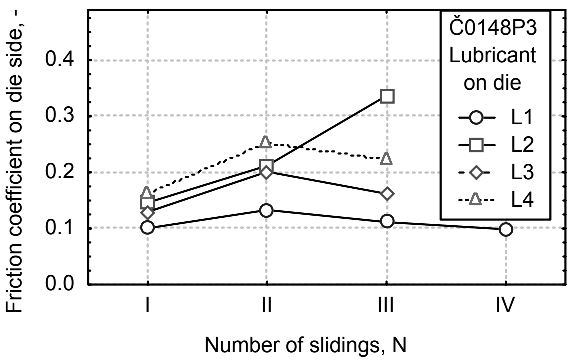


b)

Figure 4: The influence of tool material onto the friction coefficient on die per drawing phases

Figure 5 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.



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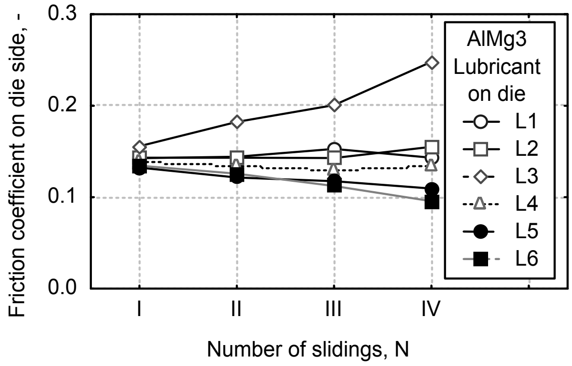

b)

Figure 5: 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 6). 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).

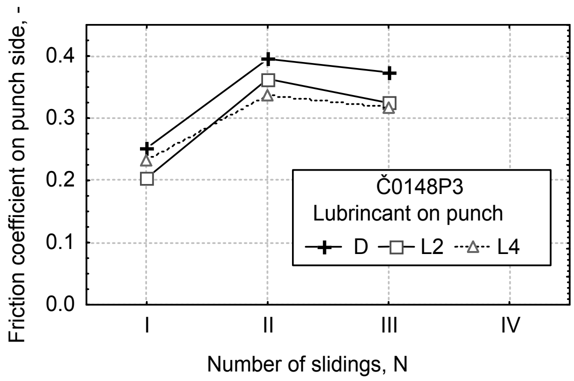

Figure 6: The influence of lubricant on punch per drawing phases onto the friction coefficient μ_I

Diagram in Figure 6 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).

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 7).

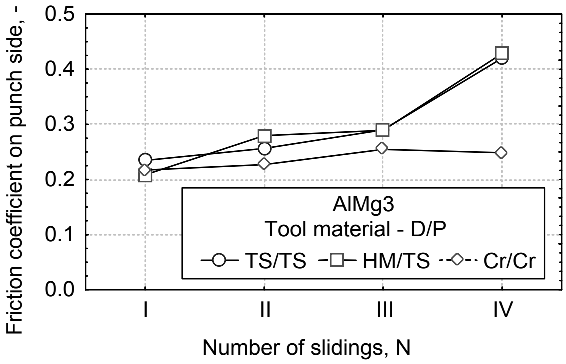

Figure 7: The influence of tool material on punch per drawing phases onto the friction coefficient μ_I

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 aluminum 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.

4. 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 friction coefficient 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.

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