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ANALYSIS OF TRIBOLOGICAL PROCESS DURING IRONING OF SHEET METAL MADE OF AlMg3

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Abstract: *The paper gives detailed analysis of tribological processes which occur in ironing, their influence on tool and formed material by means of specially developed physical model of drawing process. The typical property of such cold forming procedures is multiple repetitions of operations, i.e. several thinnings in one operation, which leads to gradual increase of thickness of glued material layer on contact surfaces of the tool. At sufficiently large thickness of glued layers, plastic forming of created glued particles occurs, i.e. their tear-off, disruption of forming process stability and increase of surface roughness of work piece. The obtained results indicate the basic influence of tribo-conditions on ironing process, tool durability and quality of obtained parts.*

Key words: *Ironing, tribo-modeling, tribological processes*

1. INTRODUCTION

Friction accompanies all physical processes that involve movement. It is also very important in metal forming, during which only external friction is considered. External friction occurs between material which is being plastically deformed and material of tool.

External friction shows significant influence on the course of plastic deformation, and thus the useful properties of the final product as well as the tool lifetime. The friction force, i.e. its contact components, show a significant influence on the stress field in a deformed metal, especially in its outer layers that came in contact with work surface of tool. Stress field has influence on the course of metal forming, and thus the movement of deformed metal surface on the acting surface of tool, and this movement have influence on the friction force. During this process, certain types of reverse elastic releases occur as well.

This type of resulted external friction between the plastically deformed metals and tool (technically dry friction with distinct adhesion effect between contact surfaces, coupled with boundary friction), significantly influences the quality of the product. If the adhesions (compounds formed by friction due to the "cold welding") are formed on surface of the tool they can be causes of scratch and allowances on the surface of the product that deteriorates its quality.

As a result of the friction notable changes in characteristic of outer layers occur, with different character of the changes that happens on the products surface layers in comparison to changes on tool surface.

The most of the work piece surface is in contact with the working surface of the tool and will have share in the friction process only once, while tool surface takes part in this process multiple times.

The characteristics of tool deformation and the work piece deformation are also different. The outer layer of the work piece (as well as the entire volume), has lower yield stress than tool, resulting in plastic deformations, while, at the same time, tool generally remains in the zone of elastic deformation. Given the fact that surface layer has the highest stress gradient, properties of outer layers, for both product and tools, will be different from properties of other parts of product and tools. As a result of the friction, tool wear occurs. Mechanism and the intensity of tool wear are functions of friction force magnitude and type of the friction [1].

Model of the phenomena that occurs in micro-zones of contact during friction is shown in Figure 1 [2]. One can distinguish three main stages of interaction between contact surfaces during friction

Stage I. At this stage contact occurs as well as mechanical action between contact surfaces which are initially covered with oxide layers, whereby the amount of oxide depends largely on the type of processes (metal forming of hot or cold), and susceptibility to oxidation of the metals that form contact pairs. The dominant phenomenon at this stage of contact is the plastic deformation, not only of the surface roughness but also, and in the considerable volume of the material.

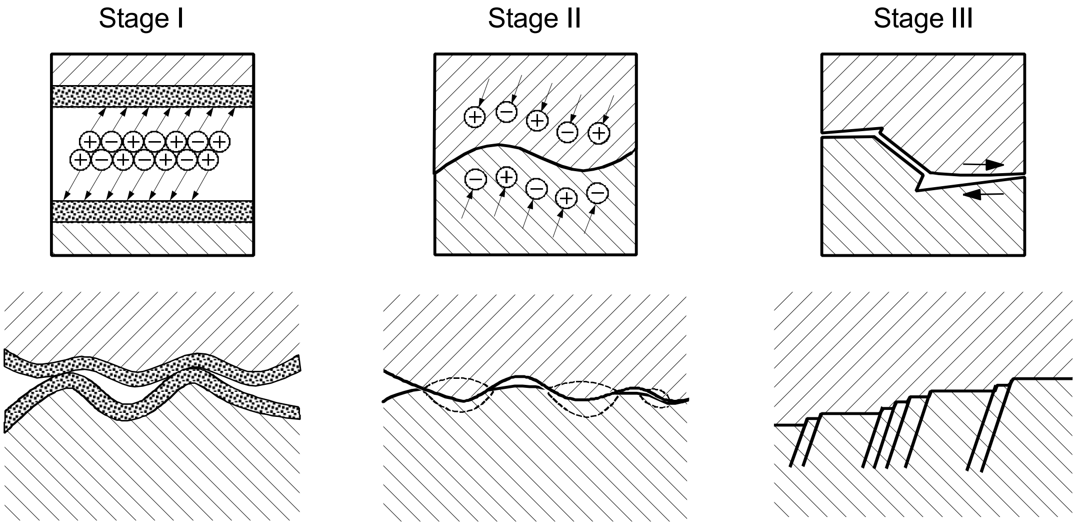

Figure 1. Model of the phenomena that occur in the micro-areas of contact during friction [1]

Stage II. As a result of molecular interaction, adhesive joints (compounds) are formed. The quantity of joints depends largely on the geometry of the contact and the specific pressure.

Stage III. This stage of the contact surface interaction includes the destruction of adhesion joints which were formed during the relative displacement of contact pair metals. Failure mechanism of contact joints can be very complex. In the first stage of joint destruction micro-slip will surely occur, and therefore the complex phenomena of movements and mutually dependent movement of dislocations. As a result of these phenomena surface defects such as micro-cracks and micro-notches can be created.

As a result of repeated displacement of deformed metals in regards to the surface of the tool, the effect of friction and the associated forming and destruction of adhesive joints, tool wear occurs.

In the case of metal forming, process is characterized by the fact that multiple repeated operations (forging or ironing) causes a gradual increase in thickness of glued layer, which means that the sum of the individual joints goes into a continuous layer.

As a result of predominance of adhesive force over resistance to plastic flow in the glued layer, in further stage glued particles suffer from plastic deformation until they are torn off and smeared.

When a sufficiently large thickness of glued layers is formed as a result of repeated process of plastic deformation (in a series of passages which leads to increasing and decreasing of mutual interaction), process begins which leads to the separation of adhesive joint from tool surface by peeling (shear) or tearing. This leads to the significant damage of the tool surface layers, and therefore to the increase in surface roughness. The occurrence of peeling or tearing depends on the type of formed joint.

In case of contact pairs with higher chemical affinity, the strength of diffusion produced joints (solid solutions) may be greater than strength of material of contact pairs, causing the destruction of joint to occur in depth of less strong and no fortified material, which means it occurs at such a depths at which there is no more squeezing.

In the case of diffusion-less joints, as well as for the occurrence of brittle inter-metallic phases, the destruction of joint will be based mainly on layered peeling of metal with less strength. Tearing off of glued particles also occurs. Further relative displacement of contact elements (the work piece is plastically deformed in relation to the tool), makes these glued particles to reappear on the surface of the friction. Afterwards they are compressed on the tool surface, which results in creation of grooving in "partner" made of material with less hardness (usually plastically deformed work piece). The type and intensity of this secondary effect depends on the hardness of the plastically deformed and strengthened adhesive joints.

In addition, as a result of cyclic loading of the tool, on its surface there might be occurrence of such defects such as intrusion and extrusion, as well as micro-cracks, which are characteristic of the metal fatigue process.

2. EXPERIMENTAL TESTS

Tests were conducted on the original tribo-model of ironing, which simulate the two-sided symmetrical zone of contact with the die and the punch [3]. This model enables the realization of high contact pressures with the respect of physical and geometric conditions of the real process (the material of the die and material of the punch, the topography of the contact surface, the angle of the die cone - α, etc.). Diagram and image of the aforementioned tribo-model is shown in Figure 2.

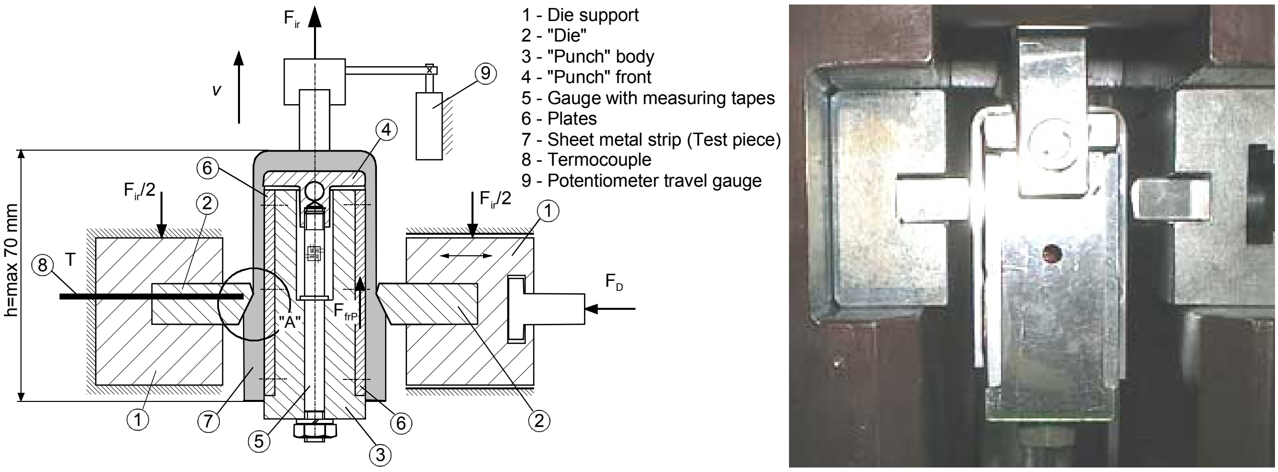

Figure 2. Diagram and image of the tribo-model used in this research

Device for testing of ironing was installed on a special machine designed for sheet metal testing ERICHSEN 142/12.

For the experiments presented in this paper, we used sheet made of aluminum alloy, AlMg3(.43) (according to EN: AlMg3 F24, and in text below only AlMg3). Mechanical properties of tested material are given in Table 1.

Table 1. Mechanical properties of tested material

Materijal	Rp, MPa	Rm, MPa	A, %	n, -	r, -
AlMg3	201.1	251.0	12.0	0.135	0.405

Contact pairs ("die" and "punch") are made of alloyed tool steel with high toughness and strength, designated as Č4750 (EN: X160CrMoV121).

3. EXPERIMENTAL RESULTS

During ironing friction coefficients of die and punch can have a wave-like (unstable) form (Fig. 3). Friction coefficients alternately rise and fall with irregular and approximately the same amplitude and frequency. At a particular time, friction coefficients can have slightly increasing, constant or slightly decreasing flow.

Very interesting explanation of this type of friction is given in the papers [4, 5]. It is considered that the wavy type friction coefficients occur when there is a micro-welding of roughness peaks in the "form of the islands".

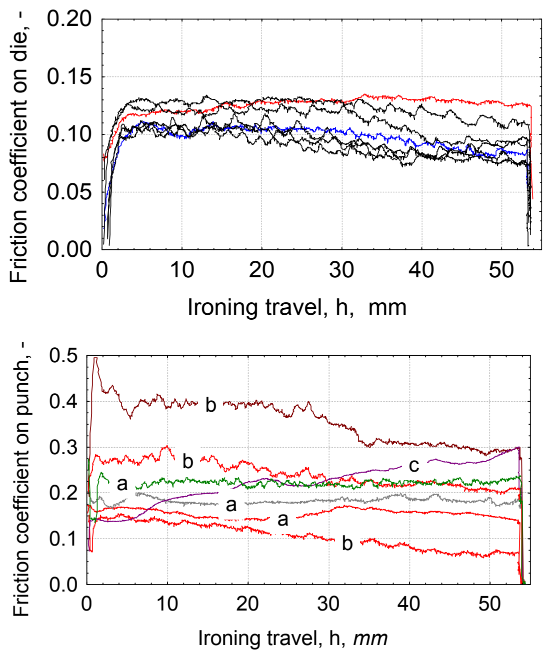

Figure 3. Examples of unstable friction coefficients on the side of the die and punch: a-constant, b-decreasing, c-growing

Subsurface layer of the contact surface on the exit part of the die, which surface is about 80% of the total contact area between the tool and the material, suffers considerable distortion due to shear stress which is result of friction forces. This stress is approximately equal to the shear stress in the weld zone. This zone is therefore called the "zone of quasi-welding". At the entrance part of the die, where there is a layer of the lubricant which is not yet squeezed out, there is a formation of so-called "nipple slip". During this process quasi-weld zone is steadily increased and thus coefficient of friction is increased as well. When the surface of quasi-weld zone become equal to the entire friction surface, friction coefficient reaches its maximum value. In addition, due to strong friction connections, micro cracks in the subsurface layer are formed. Due to the continuous material inflow in the zone of deformation noticeable nipple is formed, which at some point, because of cracks caused by the weakening of the frictional connection, detach itself from the base material. In this way the quasi-welded zone is reduced and lubricant starts to penetrate places of broken connections, which reduces the friction coefficient. Chipped of metal fragments are trapped between the die and the surface of sheet metal and are being continuously moved towards the exit part of the die. When they came out of the zone of deformation coefficient of friction will have a minimum value. Then, the aforementioned process continuously repeats itself.

Figure 4. Aluminum glued particles on die and puncher surfaces

Some lubricants, no matter the fact that they produce satisfactory results in steel plates, in case of plates made of AlMg3 have very poor results. Their usage leads to intense gluing of aluminum onto tool, which is shown in Figure 4. Glued particles that are formed on the die during the ironing can cause severe damage to the sheet metal surface (galling) (Figure 5).

If the inadequate lubricant is used coupled with greater gripping forces, stickers are formed and contact conditions are greatly deteriorated which lead to the significant increase of drawing force for each subsequent passage (Fig. 6).

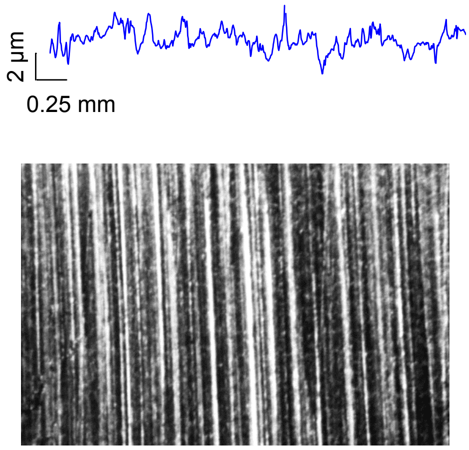

Figure 5. Grooved surface

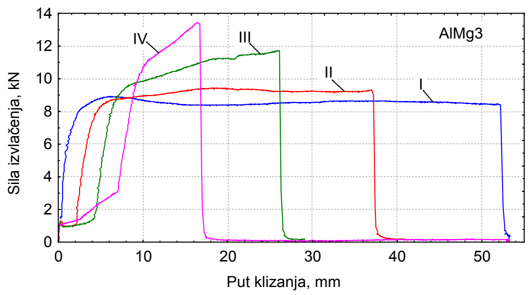

Figure 6. Change of drawing force

4. CONCLUSION

In the case of ironing one of the main characteristic of this processes is the fact that multiple repeated operations lead to a gradual increase in thickness of glued layer, which means that the sum of the individual resulting layers crosses over into the continuous layer.

As a result of predominance of the adhesion forces over resistance to plastic flow within glued layer plastic deformation of glued particles occurs followed by their tearing off and smearing.

When a sufficiently large thickness of the glued layers is achieved, as a result of the multiple repeated process of plastic deformation, process of separating glued particle from tool material begins. This separation is done by pealing (shear) or tearing off, and creates significant damage to the surface layers of tool, and therefore increases the surface roughness of the work piece. Such processes are characteristic of ironing sheet metal made of aluminum alloys, where no adequate lubricant is applied.

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REFERENCES

[1] Леванов А.Н, Колмогоров В.Л. и др.: *Контактное трение в процессах обработки металлов давлением*, Металлургия, 1976.

[2] Gierzynska M.: *Tarcie zużycie i smarowanie w obrobce plastycznej metali*, WNT, Warszawa, 1983.

[3] Adamović D.: *Ponašanje materijala u kontaktu pri procesima hladnog plastičnog oblikovanja sa visokim radnim pritiscima*, Doktorska disertacija, Mašinski fakultet u Kragujevcu, Kragujevac, 2002.

[4] Kawai N., Nakamura T., Seko S.: *The welding mechanism in drawing of aluminum sheet*, Journal of Engineering for Industry, Vol. 102, No. 8, pp. 229-238, 1980.

[5] Kawai N.: *Laboratory simulation for galling in metal forming, metal transfer and galling in metallic systems,* Proc. Conf. Orlando, Florida, Metal. Soc. AIME, pp.63-86, 1987.