Serbian Tribology Society

SERBIATRIB '17

15th International Conference on Tribology

Faculty of Engineering
University of Kragujevac

Kragujevac, Serbia, 17 – 19 May 2017

DAMAGE AND DESTRUCTION OF WORKPIECE AND TOOL SURFACES IN IRONING PROCESS

Dragan ADAMOVIC[1*], Miroslav ŽIVKOVIĆ[1], Tomislav VUJINOVIĆ[2], Slobodan MITROVIĆ[1], Jelena ŽIVKOVIĆ[1], Dragan DŽUNIĆ[1]

[1]Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia, adam@kg.ac.rs, zile@kg.ac.rs, boban@kg.ac.rs, jelena.zivkovic@kg.ac.rs, dzuna@kg.ac.rs

[2] APEIRON University, Banja Luka, Bosnia and Herzegovina; tomo.vujinovic@yahoo.com

*Corresponding author: adam@kg.ac.rs

Abstract: *All metal forming processes have some common features (one of the contact pairs is significantly plastically deformed, tool is always in contact with new surfaces, etc.), but still, certain processes differ from one another, both in terms of the contact geometry and of the values of process parameters (speed range, specific pressures, operating temperatures, etc.). Change of friction parameters is reflected in different intensity of the tool wear and damage of the workpiece surface.*

Experimental studies presented in this paper were performed on the original tribo-model of ironing process and aimed to point out the changes that occur during the ironing process, as well as to consider the influence of certain factors (tool material, lubricant on die and punch) on the damage of sheet metal and tool surfaces.

Key words: *ironing, galling, steel, aluminum, roughness, die, punch*

1. INTRODUCTION

Basic factors that have influence on tribological phenomena in metal forming can be divided into five groups:

1. *Geometric factors* (macro- and micro-geometry of the contact, deformation of macro- and micro- zones of contact, surface of actual contact),
2. *Kinematic factors* (type and character of movement, speed, duration of contact),
3. *Dynamic factors* (distribution and value of normal pressures, character and change of the load),
4. *Physic-chemical factors* (type of contact pair material, chemical affinity of contact pair material, crystalline structure, type of oxide, type of lubrication) and
5. *Energy factors* (temperature of micro-zones of contact, energy balance in macro- and micro-zones of contact, results of the energy processes).

Factors 1 and 4 characterize the basic properties of contact pairs (internal factors), while others define the basic parameters of the friction process (input factors).

Assessment of the influence of various factors on the friction force value and the friction itself is required primarily for practical reasons. Depending on the change of friction characteristics the process characteristics are changing, and that is necessary to know for more accurate selection of equipment and technological process.

In practice, a number of factors simultaneously change, so despite the fact that each of them has an influence on the process, it affects the change of some other factors' influence as well. For example, speed change affects the temperature change of contact pairs, change of specific pressure is closely related to the degree of deformation, and so on.

In other words, besides the individual influence of each factor there is also an interaction between some factors. Therefore, the value of friction coefficient is determined according to collective influence of all interconnected factors.

2. DAMAGE AND DESTRUCTION OF METAL SURFACE IN METAL FORMING

The question of optimal contact pairs according to their type of material was and still is the subject of many detailed tests, that have been carried out mostly on mechanical elements so far. The selection of optimal contact pairs also has the great influence in metal forming process. However, in the case of pairs of mechanisms contact elements can be chosen quite freely, while in the case of metal forming, the free choice is almost impossible since one of the contact pair materials, the one that is plastically deformed, has already been determined and represents an independent factor. Only material of the tool can be changed, and the choice of materials that could be used for creating the tool is quite limited (carbon or alloyed steel).

In the case of conventional plastic forming of steel the unfavorable contact pair is steel against steel, while in case of forming of non-ferrous metals, unfavorable contact pairs are: tool steel – nonferrous metal (for example Fe-Al, Fe-Zn, Fe-Cu, etc.). Intensive wear of the tool used for metal forming indicates that reduction of roughness and increase in tool hardness do not always give satisfactory results. In order to manage selection of contact materials and thus the process of tool wear one should know physical and chemical processes that occur in friction zones.

2.1 Micro-fractographic analysis of surface topography in the friction process

Specific (closed) system of the contact kinematic pair prevents direct observation of the contact zone and thus monitoring the phenomena that occurs there. Therefore, indirect tests of change of force or moments of friction are performed, and the effects of friction manifested as wear or damage of the contact surfaces are monitored. Based on the intensity and character of these changes, the type of friction is selected.

Analysis of the change of surface topography due to the effects of friction performed at the moment of big increase can provide a very detailed detection of phenomena that occur in the contact zone, as well as the evaluation of friction mechanism [1].

This analysis aims to show the mechanism of deformation in micro-zones of contact and transfer of material, as well as the way of its removal from the contact surfaces, i.e. introduction of the specific mechanisms of friction for higher values of pressure as well as developing a physical model of the friction process. Since the crystal structure is considered to be one of the main factors that affects the tribological properties of the metal and the friction mechanism, it is necessary to analyze the change of surface topography after friction in case of metals that are crystallized in various crystallographic systems.

2.2 Damage and destruction of metal surface in case of same material pairs

In order to examine the effect of the crystalline structure to the mechanism of metal transfer in micro-zones of contact and to present the friction mechanism between same metals it is interesting to consider a contact pair Fe-Fe.

Contact pair Fe-Fe. Examples of damage of mild steel specimens in friction process show visible plastically deformed adhesion compounds wherein the smaller elongation of micro-zone of the contact is observed (compared to Al and Cu), indicating a greater reinforcement of the metal. This also leads to the notching (galling) and breaking the oxide. Micro cracks at the edges of the notches indicate the local metal reinforcement in the zones of contact with friction.

2.3 Damage and destruction of metal surface in case of different material pairs

Analysis of the change of surface topography in the friction process due to contact between two different metals is carried out considering the influence of the crystal structure and the chemical affinity of the micro kinematics of material transfer in the contact zone. Analyzed pairs are: Cu-Ni, metals that crystalize in the same crystallographic system (grid A_1[1]), then metals that crystallize in different crystallographic systems, for example Fe-Al, Fe-Cu (grid A_1-A_2) as well as the pairs where one of the metal has a hexagonal structure, for example Cu-Zn (grid A_2-A_3) and Fe-Zn (grid A_1-A_3).

Contact pair Fe-Al. In case of this contact pair the adhesion of aluminum on the steel surface can be observed. Adhesives of aluminum have the form of a very elongated strips, which indicates the great plasticity of the metal.

In case of these pairs destruction of adhesion compounds occurs in outer layer of aluminum, not on the initial contact surfaces. This shows that the resulting compound is characterized by higher strength regardless the low chemical affinity of these two metals. Mechanism of destruction of the adhesion compounds is analogous as in the case of regular metal grid A_1, A_2, which means that micro-zones of contact are strongly plastically deformed and then are separated without clearly visible slip planes. As a result of significant plastic deformation of adhesion compounds a relatively slight increase of the surface roughness occurs. Metals of this contact pair are significantly apart in the periodic table, have different values of atomic radius and are not soluble in the solid state. These characteristics suggest that the intensity of formation of friction compounds is small. However, in the case of this contact pair extreme adhesion of aluminum on the steel workpiece surface is observed.

X-ray examinations [1] indicate that these are no fusion joints. Formation of no fusion compounds instead of diffusion ones is a result of a high tendency of aluminum to oxidation. The obtained aluminum oxides are very hard (approximately 1800 HV) and thus very brittle, so the destruction occurs even in the case of shear stress of 2MPa, which causes direct metal contact.

Contact pair Fe-Zn. Adhesives of the contact pair Fe-Zn have a layered character. Regardless of the relatively low chemical affinity of the metal of this contact pair, the destruction of adhesion compound does not take place on the surface of the initial contact, but in the outer layer of weaker Zn, where the layered character of the material transfer in micro-zones of contact is visible.

In the case of these metals, traces of pulling have not been observed but only the shear of adhesion compounds associated with a small strength to shear of Zn, which is a property of the metal with a hexagonal shape of crystal grid.

Given the small strength to shear of Zn, the frictional resistance is small, though transfer of the metal is significant, which cause a significant increase in surface roughness.

Summarizing the test results of contact pairs of the same and different metals it can be concluded that the crystal structure shows a substantial influence to frictional resistance and mechanism of deformation, as well as to destruction (shear) of adhesion compounds, mostly in the case of similar metals. In the case of a pair of dissimilar metals, the influence of the crystal structure and mutual chemical affinity of contact pair metals should be considered. The greater tendency to the formation of adhesion compounds occurs in the case of dissimilar metals. This is the result of a significant approaching of surfaces under

[1] In crystallography, A_1 denotes face-centered cubic grid, A_2 – body-centered cubic grid, A_3 compact hexagonal grid.

the influence of higher normal pressures and a significant increase in real contact zone. The result of such interaction is significant adhesion of one metal to another, whereby, as a rule, metal with lower melting point is pasted on the metal with higher melting point which can be explained by higher chemical activity of the first one.

Great adhesion leads to the fact that the resistance of adhesion compounds is higher than the resistance of at least one metal of contact pair regardless of the chemical affinity of these metals. Destruction of the compound occurs mainly in the outer layers of metal with lower strength and not on the initial contact surface. In contrast, the mechanism of micro deformation of adhesion compounds, and the way of their destruction (shear), are greatly dependent on the crystal structure, although there is some influence of the chemical affinity of contact pair metals.

In the case of metals with face or body centered grid (A_1 and A_2) which have a higher plasticity, the resulting adhesion compounds reach a significant plastic deformation during the friction as evidenced by the elongation of micro-zone of the contact. In contrast, quite different character of movement in micro zones of the contact occurs in the case when one of the metals of contact pair has a hexagonal grid. Then deforming of the metal in micro-zones of contact has a layered character. In the case of these contact pairs destruction of compounds is carried out always in the outer layers of the metal's hexagonal grid, regardless of the chemical affinity of metals of contact pair, which results from the low strength to shear of metal with A_3 grid, and great number of smooth zones is observed on a surface.

Effect of the chemical affinity to mechanism of surface damage can be observed in the case of contact of metals with cubic grid, body or face centered. If the metals of the contact pair have higher chemical affinity then the resistance of resulting compounds is greater than both of the metals of contact pair (those are always diffusion compounds), so in addition to plastic deformation, deep pulling can be observed, followed by the increase of surface roughness. In the case of small chemical affinity of metals of contact pair classical deformation dominated in micro-zones of contact, and there is no pulling during the shear of adhesion compounds. The increase of surface roughness in that case is insignificant. [1].

From abovementioned considerations, it follows that, the crystal structure, as well as the chemical affinity of the contact pair metals belong to the factors that have a very large impact on:

- Friction resistance,
- Mechanism of destruction of adhesion compounds and consequently the way of moving the material,
- Type of damage of contact surfaces and in particular the increase of roughness,
- Intensity of wear.

3. EXPERIMENTAL RESEARCH

Experimental studies presented in this paper were performed on the original tribo-model of ironing process, which bilaterally symmetrically imitates the contact zone of die and punch. This model enables the realization of high contact pressures and respects the physical and geometrical conditions of the real process (material of die and punch, topography of contact surfaces, angle of die cone - α, etc.) [2].

The bent sheet metal band, U-shaped test piece, is assembled on the ''punch''. Holding force F_D acts on test piece by dies. Dies are assembled in supports, where the left support is motionless and the right support is movable together with the die. The test piece slides between the dies under the force that is applied at the punch head, whereby the thinning of the test piece wall thickness occurs. During ironing process, the outer surface of the test piece slides against die surface inclined by an angle α, and the inner surface of the test piece slides against plates attached to the punch body.

The device was realized with the compact construction of high rigidity, with the possibility of easy changes of contact-pressing elements (die and plate), with simple cleaning of contact zones and suitable assembling of test pieces.

Plates and die can be made of various materials and with various roughnesses, and dies can also have a various inclination angle α.

For experimental tests in this paper material is selected from Al-alloys, in the form of sheet, mark AlMg3(.43)[2] (old mark: AlMg3-24; mark according to DIN: AlMg3 F24, mark according to EN AW-5754: AlMg3). This material is very important in modern industry. Mechanical properties of the tested material, determined for samples cut in the rolling direction of the sheet are: R_p=201.1 *MPa*, R_m=251 *MPa*, A=12 %, n=0.13545, r=0.40510, E=0,701×105 *MPa*.

Contact pairs ("die" and "punch") are made of alloy tool steel (TS) with high toughness and hardness, with mark Č4750 (DIN17006: X165CrMoV12). This steel is resistant to wear and is intended for operation in the cold conditions. Oil quenching and tempering is carried out before the mechanical treatment by grinding.

Hard coating of TiN is applied to one set of tools made from heat treated alloy steel Č4750.

4. RESULTS OF EXPERIMENTAL RESEARCHES

In case of deep drawing with thinning of the wall thickness, depending on the type of the contact pair (tool-die, the punch/sheet metals) and used lubricant, creating the adhesives on the tool can occur. Every adhesion on the tool deteriorates the surface quality (adhesion on punch, dies, etc. is reflected in the drawn parts) and is one of the main problems in technology of deep drawing with thinning of the wall thickness, both regarding the product quality as well as the wear of the tool. This phenomenon is often referred to as "*galling*" in literature and represents the subject of detailed study of many authors [3, 4, 5, 6].

Appearance of smooth and notched surfaces made by scratching due to aluminum adhesives is shown in Figure 1.

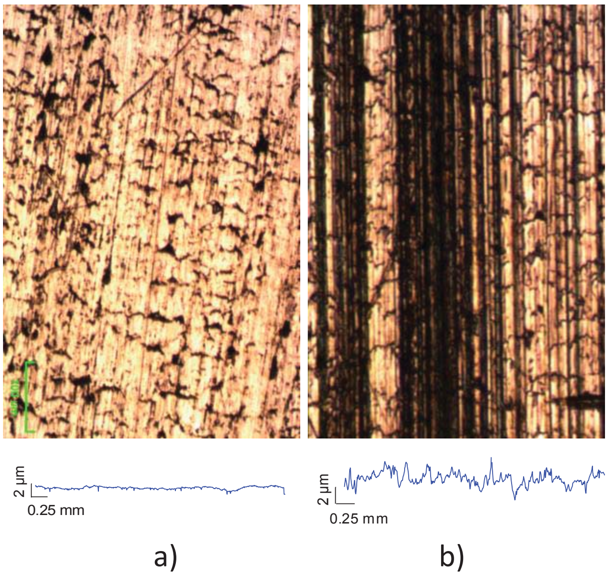

Figure 1. Smooth and notched surface Al samples and their roughness

As previously stated, adhesives especially occur in case of drawing of aluminum alloys, both on the punch and on the side of the die, Figure 2.

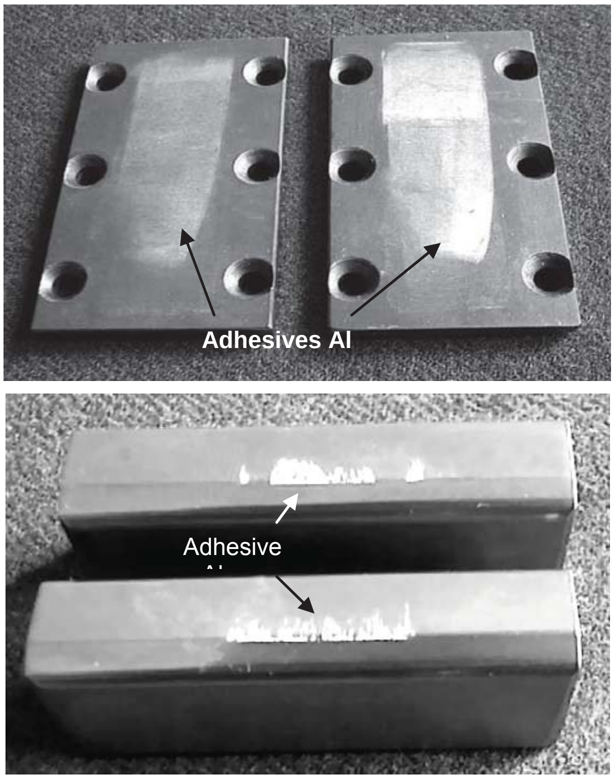

Figure 2. Aluminum adhesives on the punch and die surfaces

EDS analysis of the surface of the punch and the die with a TiN coating confirmed the presence of aluminum adhesives, Figure 3.

[2] - Mark AlMg3 will be used further in text

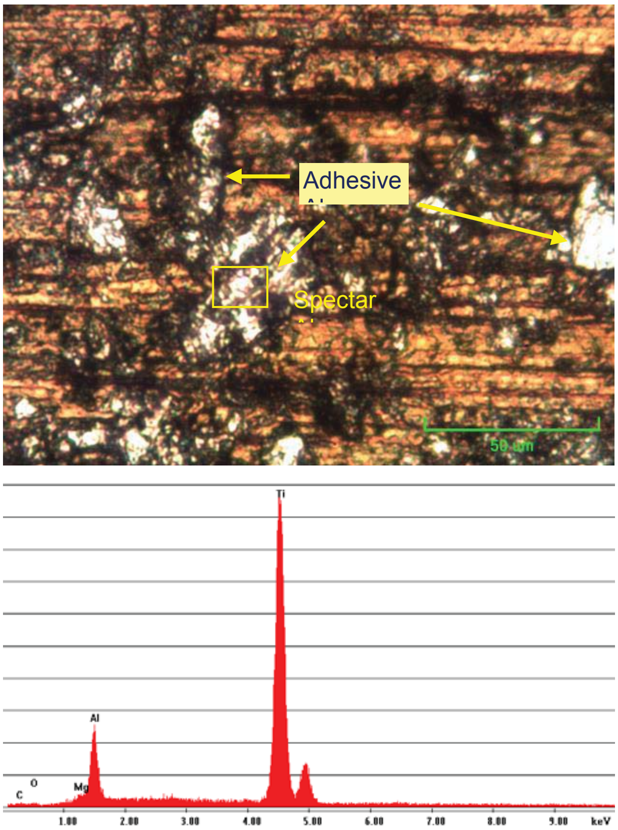

Figure 3. EDS analysis of aluminum adhesives on punch made from tool steel with TiN coating

Using inadequate lubricants, followed with the effect of greater holding force, in the process of deep drawing, regularly leads to the formation of adhesives and significant disruption of contact conditions, and therefore at each subsequent phase ironing force increases significantly (Figure 4).

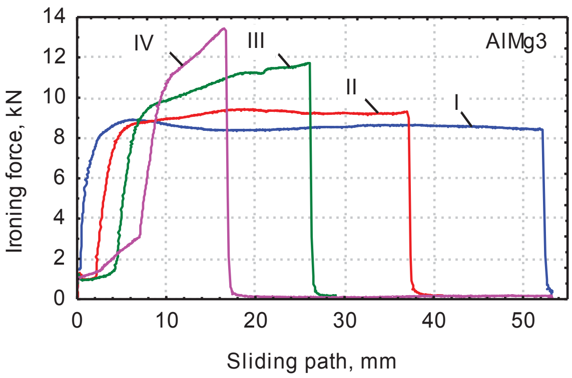

Figure 4. Change of ironing force at multiphase drawing of steel sheet metal and AlMg3 alloy samples

5. CONCLUSION

In the case of deep drawing process with thinning of wall thickness it is characteristic that if the coupled contact pair (tool-Fe, Ti/sheet metals-Al) is made from different metals (tool - Fe, Ti / sheet - Al), there is an intensive formation of aluminum adhesives on the surface of the tool.

As a result of preponderance of the adhesion forces to the resistance to plastic flow of adhesion layer, plastic deformation of formed adhesions occurs, i.e., their pulling and smudging. In the case of a sufficiently large thickness of adhesion layers, as a result of many times repeated process of their plastic deformation, the process of separating formed adhesives from the base metal (tool) begins, by means of flaking (shear) or pulling, whereby there is a considerable damage to the tool surface, and therefore an increase of the surface roughness of the workpiece. Such processes are especially typical in deep drawing with thinning of the wall thickness of sheets if adequate lubricant is not used.

ACKNOWLEDGMENT

The part of this research is supported by Ministry of Education and Science, Republic of Serbia, Grant TR32036, TR33015 and TR35021

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