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INFLUENCE OF LUBRICANT TYPE ON THE SURFACE QUALITY OF ALUMINIUM PARTS OBTAINED BY IRONING

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Abstract: *If it is needed to achieve a higher strain rate during the ironing process, which is possible without inter-stage annealing, the ironing is performed in succession through multiple dies. During that process, changes of friction conditions occurs due to the change of contact conditions (dislodging of lubricants, changes of surface roughness, formation of friction junctions, etc.). In the multistage ironing, after each stage, the completely new conditions on the contact surfaces occur, which will significantly affect the quality of the workpiece surface. Lubricant has a very important role in ironing process of Al-alloy sheet metal: to separate the sheet metal surface from the tool and to prevent creation of adhesions on the tool, considering the high adhesive tendency of aluminum. The influence of tribological conditions in ironing process is extremely important and it was a subject of study among researches in recent years, both in the real processes and on the tribo-models. Investigation of tribological conditions in the real processes is much longer and more expensive, so testing on the tribo-models is more frequent. Experimental research on the original tribo-model presented in this paper was aimed to indicate the changes that occur during multistage ironing, as well as to consider the impact of some factors (tool material, lubricant on die and punch) on increase or decrease of the sheet metal surface roughness in ironing stages.*

Key words: *multistage ironing, lubricant, roughness, die, punch.*

1. INTRODUCTION

The main objective of metal forming is to obtain the object of a certain shape that depends on the geometry and shape of the tool.

The contact surface in the deformation process depends on the geometry of the contact, which significantly affects friction and wear parameters, as well as the nominal and real unit pressures. The shape of the contact surface (dimensions, curvature radius, change of cross section) affects the type of contact and the stress state in the contact zone, both in the surface layer and in the overall volume of deformed material, as well as on the value of the force needed for the realization of the process. It should be kept in mind that the full contact, i.e. nominal fitting of the workpiece along the full working surface of the tool, comes progressively – from very fragmentary contact in the initial state to the full contact in the final state.

The surface microgeometry is defined by: roughness (Ra, Rz, R_{max}, etc.), waviness, profile irregularity coefficient, line and surface bearing capacity. In the description of the friction, significant importance has an indicator rapprochement of surfaces a, which depends on the load, the nominal contact surface, the surface roughness and the mechanical properties of material [1].

Although the research of surface micro geometric parameters is performed for years and there is a great progress in the field of surface roughness measurements, the appropriate mathematical method for description of the surface micro geometry has not been developed yet. The above listed roughness indicators are not suitable enough to describe the changes of surface topography under friction. So far conducted tests in this area allow the assertion that:

- the geometric structure of the outer layers requires statistical description;
- for approximated mathematical description of the topography it should be aimed at getting the spatial distribution of surface microgeometry parameters, which can be achieved by replacing the 2D measurement method with 3D;
- existing methods of microsurface geometry measuring and also indicators and description methods used so far, do not enable the monitoring of the contact dynamic in the friction processes.

In papers of Ahmatov [2], Bovden and Tabor [3] and Krageljski [4] it was shown that the surface roughness significantly affects the coefficient of friction. However, regardless of the multiple theoretical tests and numerous empirical data, a direct correlation between roughness parameters and coefficient of friction has not been established, and this factor has not been introduced in the equation of friction.

Wiegand and Kloos [5] performed certain studies that explain the change of surface microgeometry due to friction in the cold metal forming processes, which claim that increase or decrease of the roughness depends on the adhesive tendency of the contact pairs metal. In the case of metals with a low adhesive tendency (e.g. the contact pair steel-brass) changes of surface microroughness are relatively small. In case of coupling the same metals, adhesion forces are larger and friction processes are accompanied by a significant increase in surface roughness which causes the “cold welding” and leveling of uneven areas on contact surfaces.

According to studies of Gierzynska [6], the mechanism of contact of two rough surfaces can be partially reduced to the elastic-plastic problems. As follows from the presented results, the microgeometry of the contact surface may have a significant impact on the type and character of the contact phenomena, especially in the initial stage of plastic deformation (the emergence of local stress concentration areas causes the occurrence of “cold welding”). In the later stages of plastic deformation, so significant increase of actual contact surface of plastically deformed metal occurs, that original state of contact microgeometry becomes completely disrupted.

New “parties” of materials, that previously lay within the deformed part are coming out on the surface and as a result of this process, the final state of micro roughness is obtained, which has a random character and it is difficult to predict.

An important issue is also a change of tool surface micro roughness caused by friction. The initial state of tool surface micro roughness depends on the performed machining (milling, grinding, polishing) at which in most cases the surface roughness of the tool is Ra = 0.5 to 0.8 µm.

Surface micro-roughness of the tool and micro-notches, residual from machining, can act as stress concentrators which creates conditions for the formation of microcracks and accelerates abrasive as well as other kinds of wear. To prevent this unfavorable effect of roughness it is necessary to polish the working surface of the tool.

The increase of the tool surface roughness causes increasing of coefficient of friction. That change can be linear or nonlinear depending on the type of material, the type of lubricant and the strain rate [7].

If the “cold welding” occurs, then a higher coefficient of friction is obtained than in case of the high tool surface roughness.

Coefficient of friction also depends on the surface roughness of deformed material. This is related to the fact that the micro-relief of metal surface plays a crucial role in the formation and effect of the separating lubricating film. With increasing of surface roughness of deformed material the conditions of lubricant feeding into the zone of deformation are improved, but along with it the number of micro overlaps on contact surface is increasing which is a cause of the increase of the friction coefficient. In the ironing process, due to the high normal load and simultaneous relative displacement of the sheet metal in relation to the tool, there is an intensive shearing of roughness and increasing of the real contact surface. High local temperatures lead to the micro-welding of roughness peaks, which significantly increases the required deformation force.

2. EXPERIMENTAL RESEARCH

The experimental research was aimed to investigate successive (through multiple dies at a time), or multistage ironing (through the same die repeatedly). The multistage ironing meant that the test is performed multiple times on the same test piece. The aforementioned research is interesting because material always come with altered topography in the next ironing stage, which affects the process itself (ironing force, coefficient of friction, etc.).

This experiment does not completely imitate ironing through multiple dies at once (does not take into account the distance between dies, total ironing force has a different course of change considering that in one part of the process ironing is performed at the same time through multiple dies), but in any case the appropriate conclusions can be drawn, especially related to the topography of the contact surfaces.

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.) [8].

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.

The material made of an Al-alloy in shape of sheet metal, marked with AlMg3(.43)[1] (Old mark: AlMg3-24; mark according to DIN: AlMg3 F24, mark according to EN AW-5754: AlMg3). This material is often used in modern industry. Mechanical properties of the test material determined for samples that are cut in the rolling of the sheet metal direction are: R_p = 201.1 MPa, R_m = 251 MPa, A = 12 %, n = 0.13545, r = 0.40510, $E = 0{,}701 \times 10^5$ 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.

One set of tools is hard chrome plated (Cr) for the purpose of comparative testing. It should be noted that the tool base was made of heat-treated alloy tool steel Č4750.

One set of dies is made of hard metal (HM) marked with WG30 (DIN 4990: G30). Hard material (α-phase) is Tungsten carbide (WC), and bounding material is Cobalt (β-phase).

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[1]Designation AlMg3 will be used further in the text

In selection of lubricant for experimental testing it is necessary to take into account the several factors, such as: different consistency of lubricants (grease, paste, oil, lubricant coatings), various viscosity of lubricant, lubricants origin (organic, synthetic, mineral), as well as the level of contact pressures during ironing process.

Based on the abovementioned factors, the selection of lubricant which will be used in experimental testing was done. Their review, with the key features, is:

- M1 – grease (Li + MoS_2)
- M2 – oil (Mineral emulsifying water-dissolving oil with EP, anti-wear and lubricating additives),
- M3 – paste (Non-emulsifying agency, η^2 = 58 mm^2/s),
- M4 – oil (Non-emulsifying mineral oil with mild EP qualities, η = 45 mm^2/s),
- M5 – oil (Oil of paraffin basis with special additives, η = 80 mm^2/s),
- M6 – oil (Oil of paraffin basis with special additives, η = 190 mm^2/s),

The experiment was performed under the following conditions:

- Die inclination angle: α = 10°,
- Lubricant on die side: M1, M2, M3, M4, M5, M6,
- Lubricant on punch side: 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),

Performed tests consisted of returning of the same specimen to its original position after one slide, after which it is was again slid, but the punch stroke was always slightly 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 is lubricated only at the beginning of testing, and in other before each sliding, which will be highlighted later in the analysis of the obtained results. If the lubrication is performed before each sliding then the tool surface is also cleaned from adhesions, if they have occurred. The test piece surface on the punch side was always lubricated only before the start of the first sliding. The number of slidings was from 2 to 4. Figure 1 shows the appearance of the test specimens after multistage ironing.

Figure 1. The appearance of the test piece after multistage ironing

3. RESEARCH RESULTS

In multistage ironing of AlMg3 sheet metal, during the first sliding, roughness is slightly changed, considering the low initial roughness of the sheet metal (Fig. 2). Only when the M3 lubricant was used, even during the first sliding there is an increase in roughness that increases even more in further slidings, and in the fourth sliding it comes to galling.

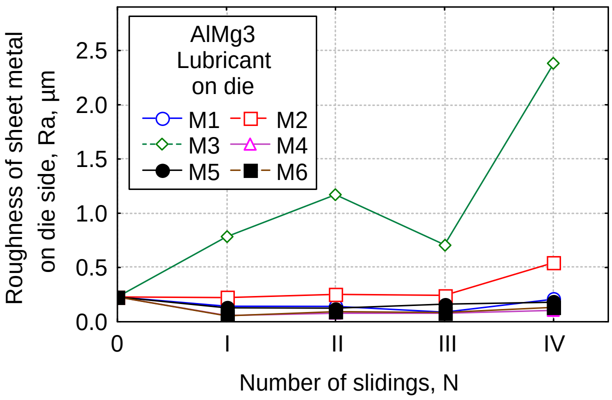


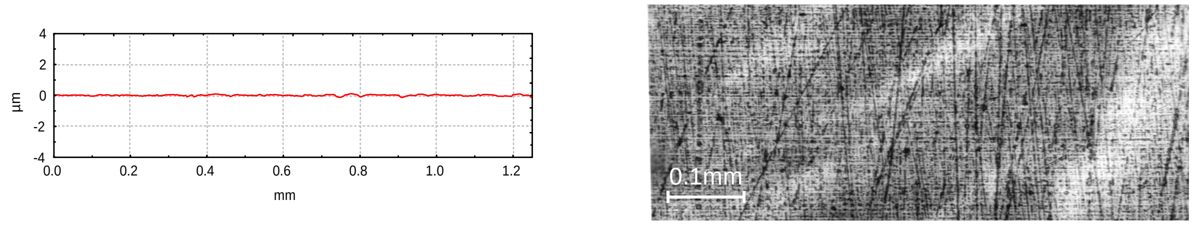
Figure 2. The influence of lubricant onto the die side per ironing stages

No matter that M3 lubricant was applied only before the first sliding, an increase of sheet metal roughness at the first sliding indicates that it is very inconvenient for ironing of sheet metal made of AlMg3 alloy [9].

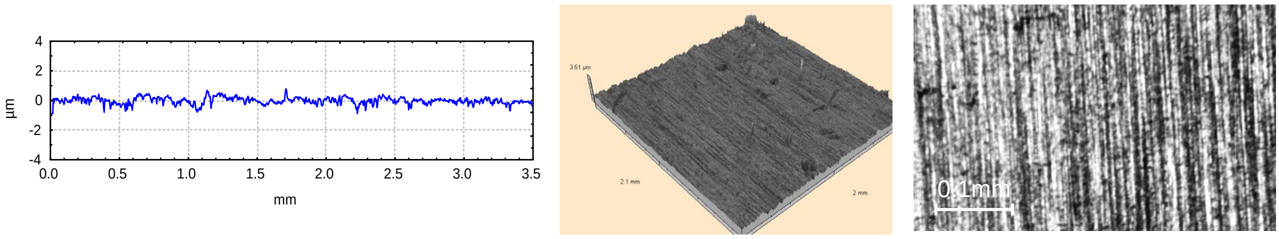
[2]Kinematic viscosity on 40°C, mm^2/s

Figure 3 shows 2D and 3D roughness forms as well as photomicrographs of the sheet metal surfaces on the die side formed at different ironing stages. If the lubricant M3 is applied on the die side (lubrication only before the beginning of the ironing), then already at the first slide increasing of roughness occurs.

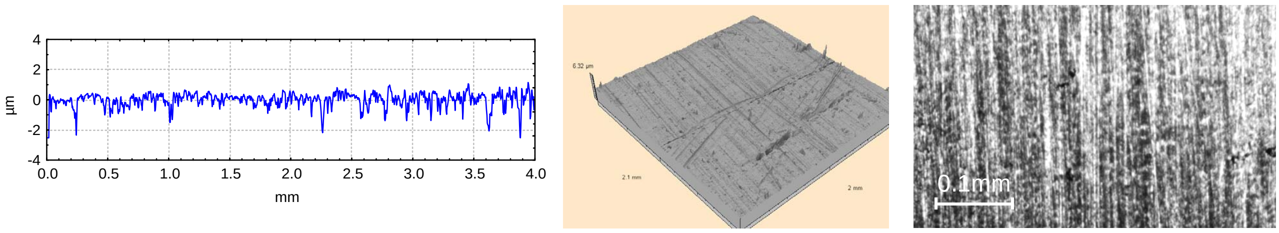
At the next sliding (II) surface roughness increases due to the dislodging of lubricant, and in the next stage (III) a rough notches are formed that are even more increasing in phase IV, which is clearly shown on a photomicrographs (Fig. 3).



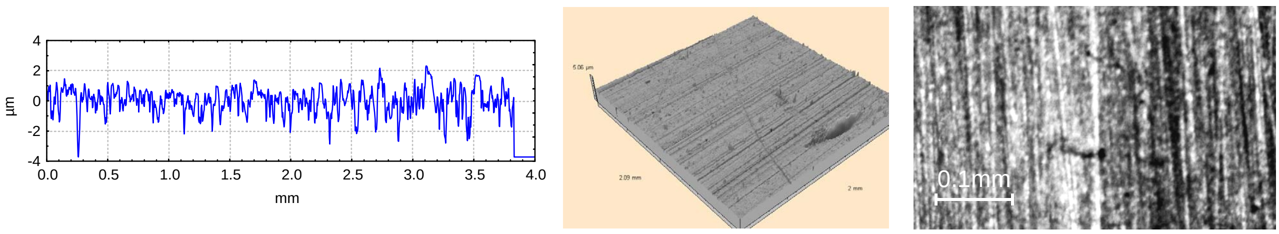
Die: AC, *Ra* = 0.01 µm (N1)



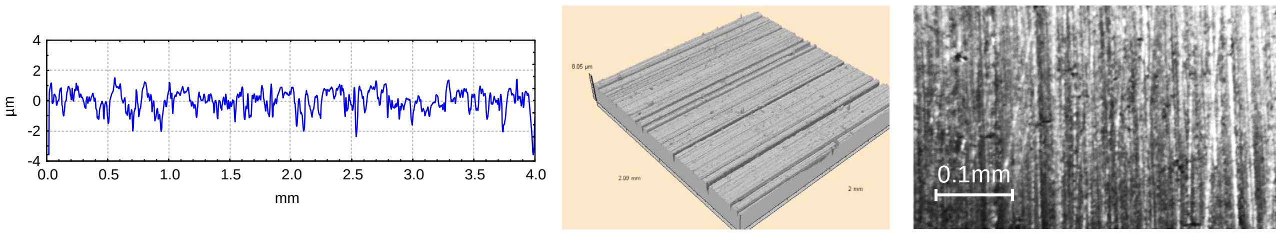
Lim AlMg3 – before ironing, *Ra* = 0.2 µm



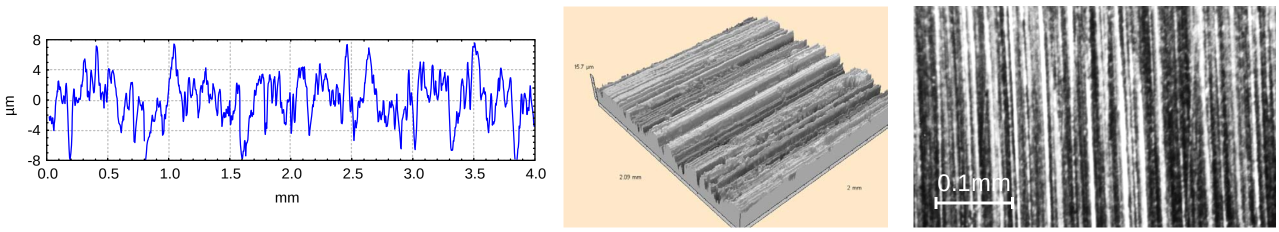
I ironing, *Ra* = 0.78 µm



II ironing, *Ra* = 1.17 µm



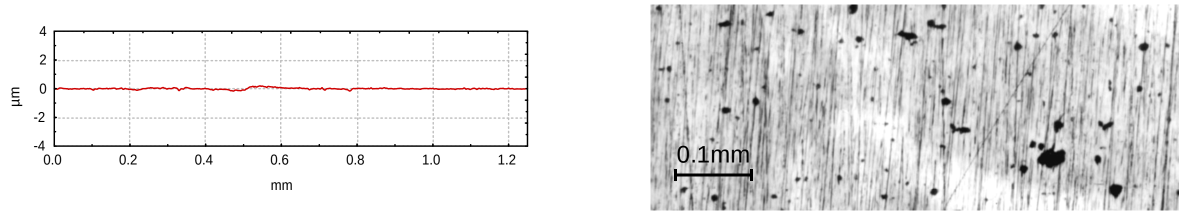
III ironing, *Ra* = 0.71 µm



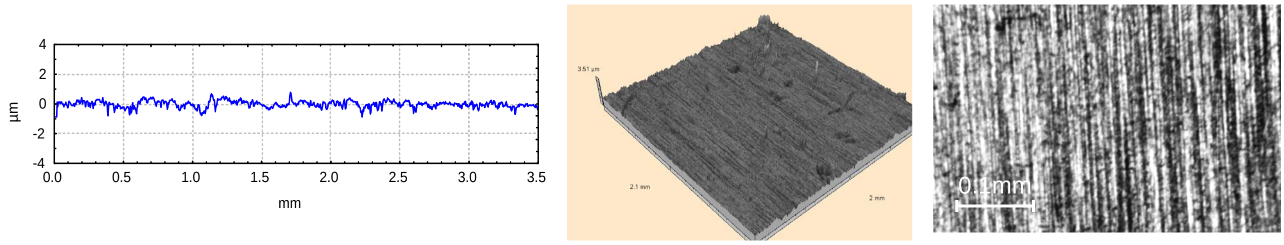
IV ironing, *Ra* = 2.38 µm

Figure 3. 2D and 3D roughness form and photomicrographs of AlMg3 sheet metal surfaces on die side formed at different stages of ironing (lubricant on die/punch – M3/M6)

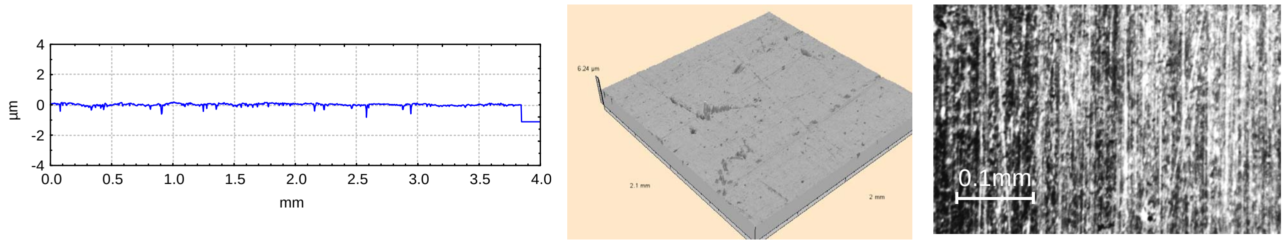
At the first slide a reduction of sheet metal surface roughness occurs by using the M5 lubricant on the die side. During the II and III slide that roughness will be retained, and its slight increase will occur during the IV slide (Fig. 4). This indicates that the lubricant M5 is good because it enables maintaining a high surface quality in all stages of ironing (low roughness).



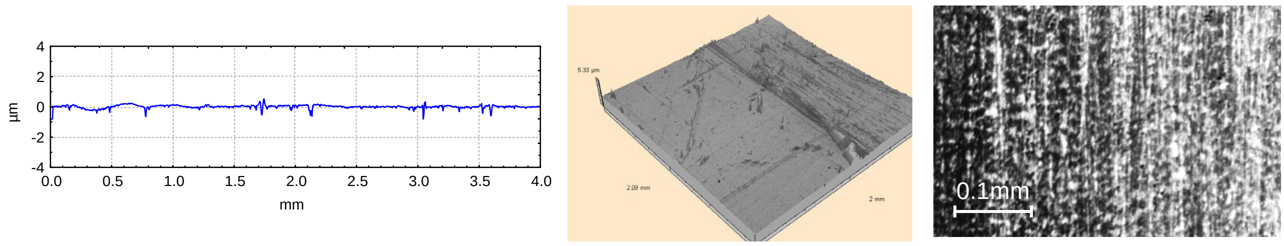
Die: Cr, *Ra* = 0.01 µm (N1)



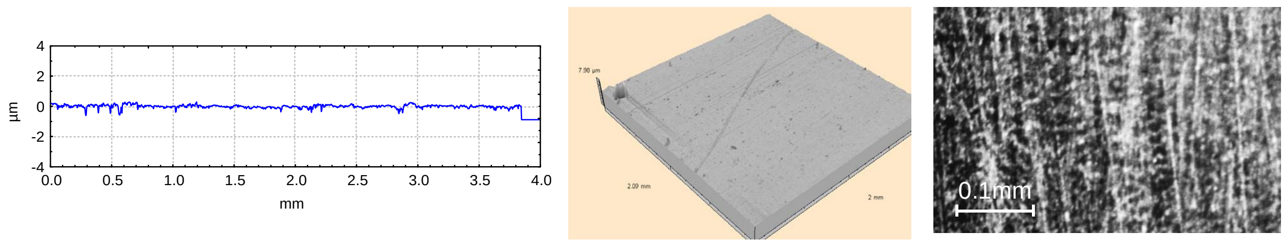
Lim AlMg3 – before ironing, *Ra* = 0.23 µm



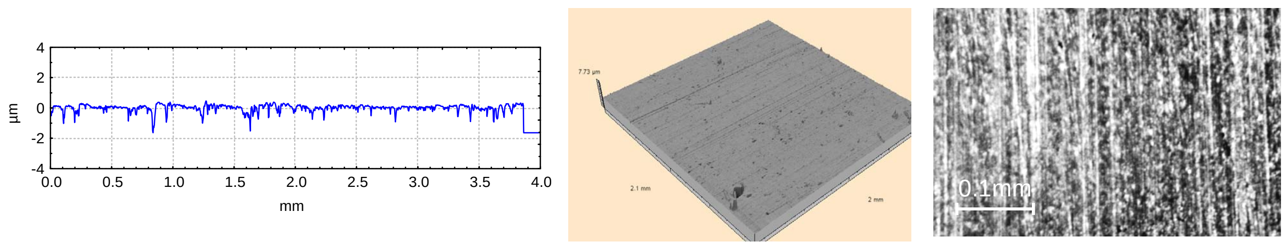
I ironing, *Ra* = 0.13 µm



II ironing, *Ra* = 0.13 µm



III ironing, *Ra* = 0.16 µm



IV ironing, *Ra* = 0.18 µm

Figure 4. 2D and 3D roughness form and photomicrographs of AlMg3 sheet metal surfaces on die side formed at different stages of ironing (lubricant on die/punch – M5/M6)

Figure 5 shows the comparative review of AlMg3 sheet metal roughness per ironing stages on die side, obtained using the M5 lubricant on die side and different tools materials. It is obvious that the highest roughness is obtained if the tool is made of hard metal. Thereby a certain waviness of the surface occurs which is particularly present in the first two slidings. Also, in case of using the M2 lubricant in conjunction with HM tool the creation of surface waviness is noticed, but the logical explanation was not found.

The influence of interaction between the lubricant and tool material on change of the sheet metal roughness on die side, per different ironing stages, is shown in Figure 6.

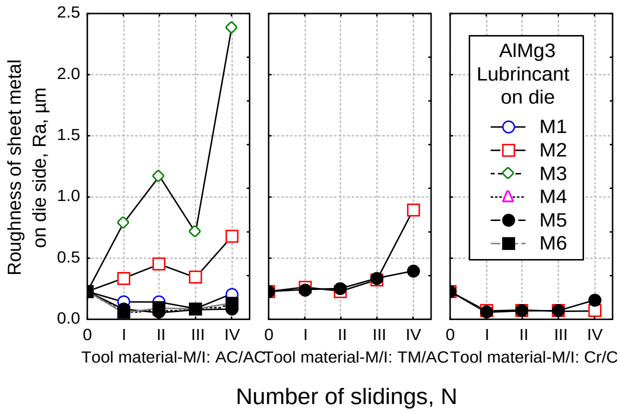


Figure 6. The influence of lubricant onto the sheet metal roughness on die side at different tool materials per ironing stages

At ironing of AlMg3 sheet metal, the lubricant has a very important function to separate the sheet metal surface from the tool

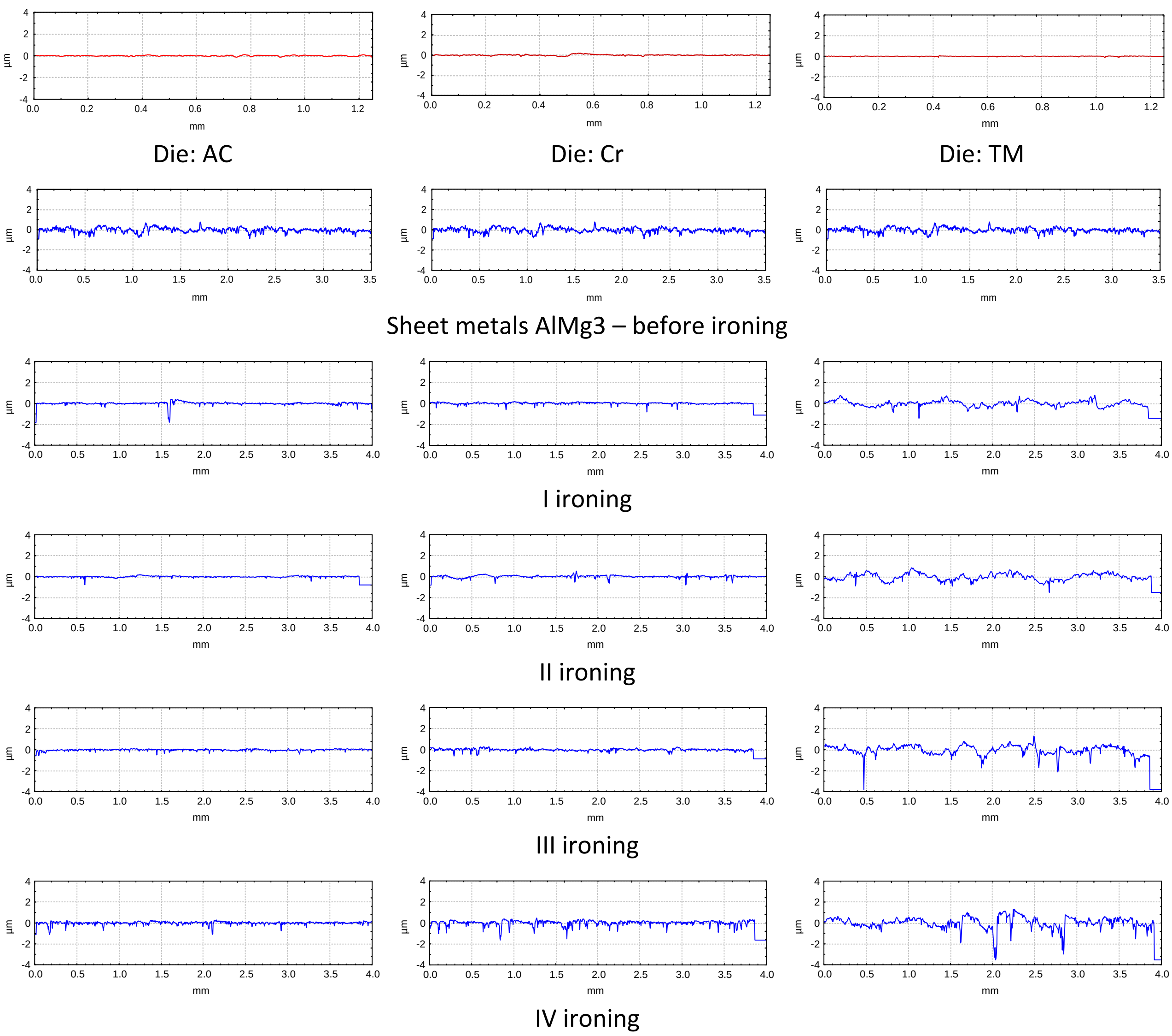


Figure 5. 2D roughness form of AlMg3 sheet metal surfaces on die side formed for different die materials (lubricant on die/punch – M5/M6; holding force F_D = 17.4 kN)

and to prevent the creation of adhesions on the tool, given the high adhesion tendency of aluminum. In performed experiment, only the lubricants M2 and M5 were used in all combinations with different tool materials. There is a clear difference in behavior of the M2 lubricant with different tool materials (Fig. 6). Lubricant M5 has proved to be very stable in maintaining a certain level of roughness in combination with all tool materials.

Change of the sheet metal roughness on punch side per ironing stages, with different lubricants on the punch side and tool materials, is shown in Figure 7. It can be seen that the sheet metal roughness does not depend on tool material when the same lubricant is used. In all combinations of lubricants and tool material, roughness obtained after I sliding will approximately be held in all subsequent slidings.

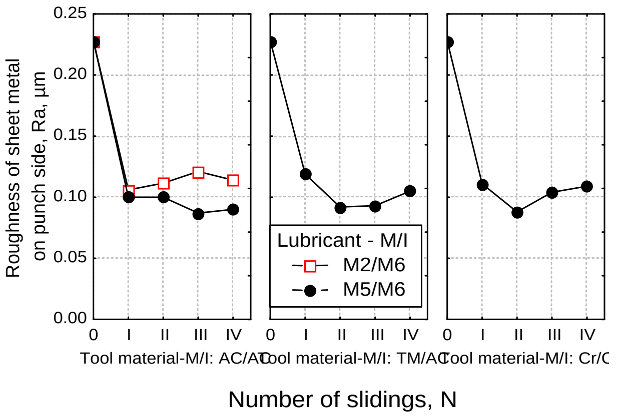


Figure 7. The influence of lubricant on punch onto the sheet metal roughness on punch side at different tool materials per ironing stages

The change of sheet metal roughness on punch side, per ironing stages, for different holding forces is shown in Figure 8. Values *Ra* represent mean values obtained using all lubricants and tool materials. Regardless of the value of holding force, the surface roughness achieved after first sliding is maintained at the other slidings as well. With the increase of the holding force there is a decrease of sheet metal roughness on punch side.

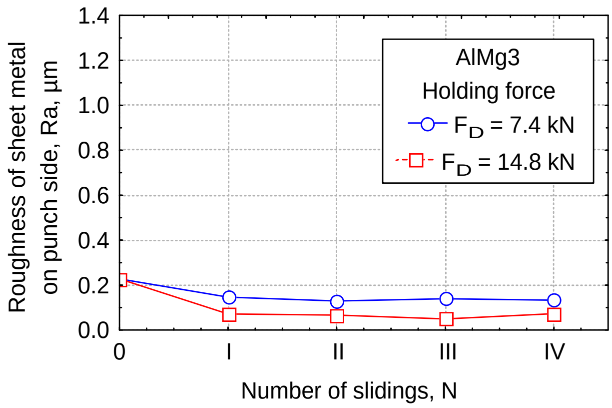
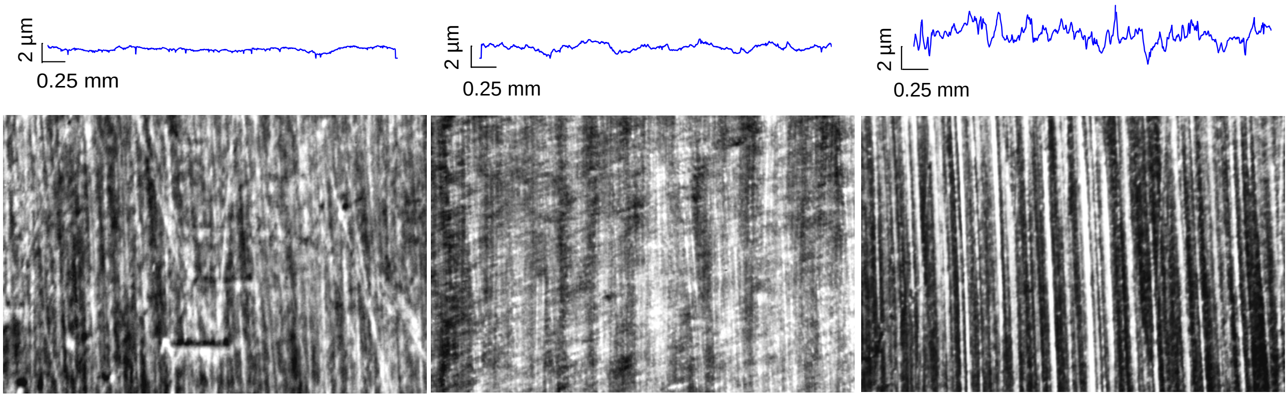


Figure 8. The influence of holding force per ironing stages onto the sheet metal roughness on punch side

Sheet metal surfaces formed after ironing, based on their roughnesses, can be classified into three characteristic groups (Fig. 9):

- smooth (Fig. 9a),
- scratched (Fig. 9b) and
- gouged (Fig. 9c).

Smooth surface occurs mainly at small degrees of deformation and thereby it comes almost to complete leveling of uneven areas (*Ra* < 0.3 µm).



AlMg3, ε = 2.5 %, M5
(a)

AlMg3, ε = 18.5 %, M5
(b)

AlMg3, ε = 40.5 %, M5
(c)

Figure 9. Characteristic surface looks formed after AlMg3 sheet metal ironing: (a) smooth surface, (b) scratched surface, and (c) striated surface

The obtained surface has a mirror appearance when observed with the naked eye. These surfaces generally have the low value of the coefficient of friction. The processed material particles crumble due to increase of degree of deformation, and sporadically make scratches on the sheet metal surface, among which the smooth surface will be kept. Slightly higher coefficients of friction correspond to scratched surfaces in comparison with smooth surfaces. A further increase of the degree of deformation leads to even more intensive crumbling of particles that will roughly encroach a softer sheet metal surface and significantly increase roughness, causing a further increase in the coefficient of friction [10].

These changes will occur in case of the low deformation speed. At higher deformation speed, and depending on the lubricant properties (viscosity, coexistence, types of additives), change of the friction type may occur, and therefore different changes of roughness as well [11-14].

4. CONCLUSIONS

The ironing process leads to very significant changes on the sheet metal surfaces that had been in contact with the tool. Because the sheet metal is in contact with conical die at one side, and on the other side with punch, different changes on the sheet metal surface occur due to the different material yielding compared to the tool. The obtained sheet metal roughness depends on: the initial sheet metal roughness, the tool surface condition, the degree of deformation, the type of lubricants, etc.

In successive sliding, after the first sliding the roughness of sheet metal on the die side rapidly decreases, and in the subsequent stages can grow or remain approximately constant, which will primarily depend on the used lubricant.

In all combinations of lubricants and tool material, roughness of the sheet metal on the punch side obtained after first sliding is approximately maintained at all subsequent slidings.

In case of ironing of AlMg3 sheet metal the lubricant has a very important role; to separate the sheet metal surface from the tool and to prevent adhesions on the tool, given the high adhesion tendency of aluminum.

Three characteristic types of surfaces that are noticed appeared in both materials: smooth, scratched and striated, although at a more detailed analysis it was possible to perceive the other subtypes of mentioned surfaces.

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