Vol. 37, No. 2 (2015) 215-224

Tribology in Industry

www.tribology.fink.rs

RESEARCH

Influence of the Lubricant Type on the Surface Quality of Steel Parts Obtained by Ironing

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Keywords:

Multistage ironing
Lubricant
Roughness
Die
Punch

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A B S T R A C T

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 occur 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 during the steel sheet metal ironing process; to separate the sheet metal surface from the tool and to reduce the friction between the contact surfaces.
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.

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

Although the research of surface microgeometric 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 microgeometry 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 geometrical 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 metal contact pairs. In the case of metals with a low adhesive tendency (eg. 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 the increase of actual contact surface of plastically deformed metal is so significant that the 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 R_a=0.5 to 0.8 μm.

Surface micro-roughness of the tool and micro-notches, residual from machining, can act as stress concentrators which create conditions for the formation of microcracks and accelerate 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 increase 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 means 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 FD 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 punch), with simple cleaning of contact zones and suitable assembling of test pieces. Punch and die can be made of various materials and with various roughness, and dies can also have a various inclination angle α.

Sheet metal shape steel with mark Č0148P3 (according to EN: DC04) was used for experimental testing presented in this paper. This material is up-to-date material in modern industry. Mechanical properties of the test material determined for work pieces obtained by cutting in the rolling direction of the sheet metal are: R_p=186.2 MPa, R_m=283.4 MPa, A=37.3 %, n=0.2186, r=1.31915, E=1.957×10^5 MPa.

Contact pairs ("die" and "punch") are made of alloy tool steel (AC) 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 dies is made of hard metal (TM) marked with WG30 (DIN 4990: G30). Hard material (α-phase) is Tungsten carbide (WC), and bounding material is Cobalt (β-phase).

In selection of lubricant for experimental testing it is necessary to take into account 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 the 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^1=58 mm^2/s),
- M4 – oil (Non-emulsifying mineral oil with mild EP qualities, η=45 mm^2/s).

The experiment was performed under the following conditions:

- Die inclination angle: α = 10°,
- Lubricant on die side: M1, M2, M3, M4,
- Lubricant on punch side: M2, M4, S (dry)
- Material of die/punch: AC/AC, TM/AC,
- Holding force: 8.7; 17.4 kN,
- Punch roughness: R_a = 0.01 μm (N1).

Performed tests consisted of returning of the same specimen to its original position after one slide, after which it was slid again, 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 lubrication is performed before each sliding then the tool surface is cleaned of oxides, if they existed. 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 the multistage ironing.

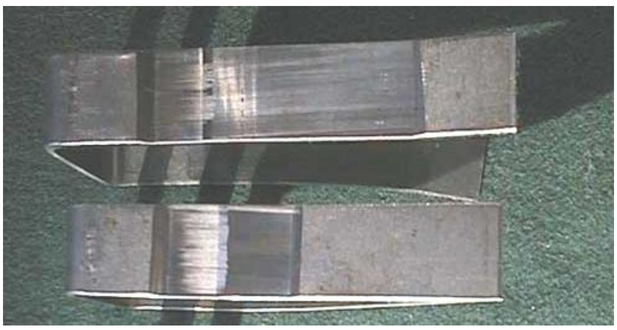


Fig. 1. The appearance of the test piece after multiple ironing.

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

3. RESEARCH RESULTS

At multiphase drawing of steel sheet metals, after the very first sliding, a very significant reduction of roughness on die side occurs (Fig. 2). 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 [9]. That can be explained by more favourable apportionment of lubricant in "pockets" of roughnesses.

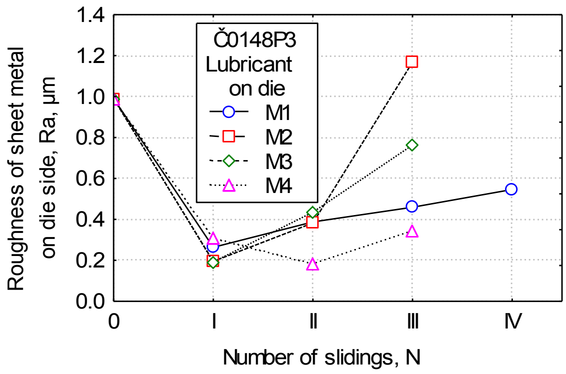
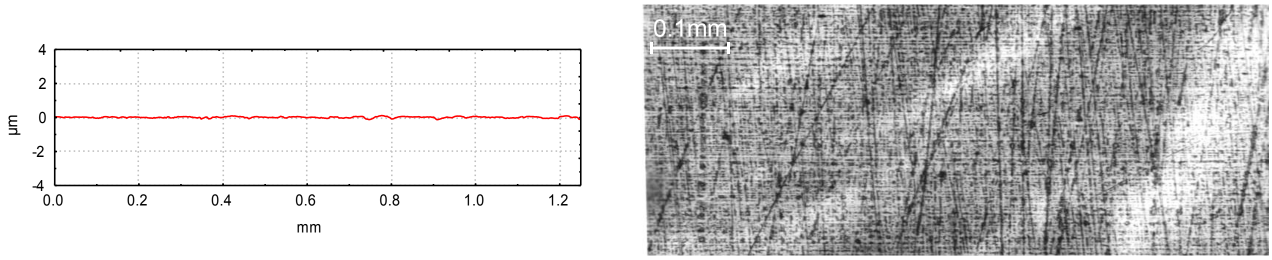
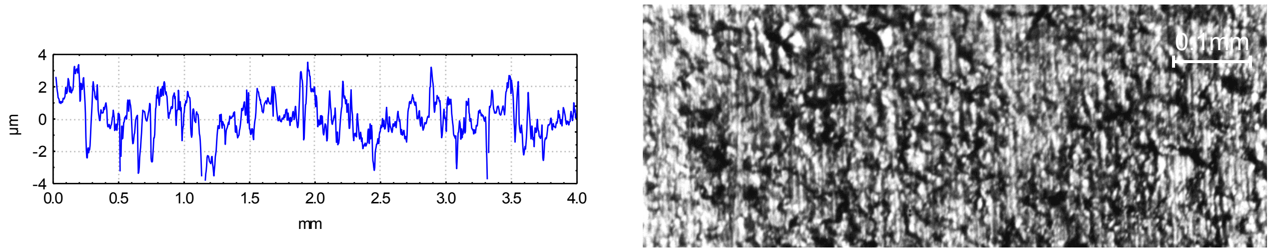


Fig. 2. The influence of lubricant onto the die side per ironing phases.

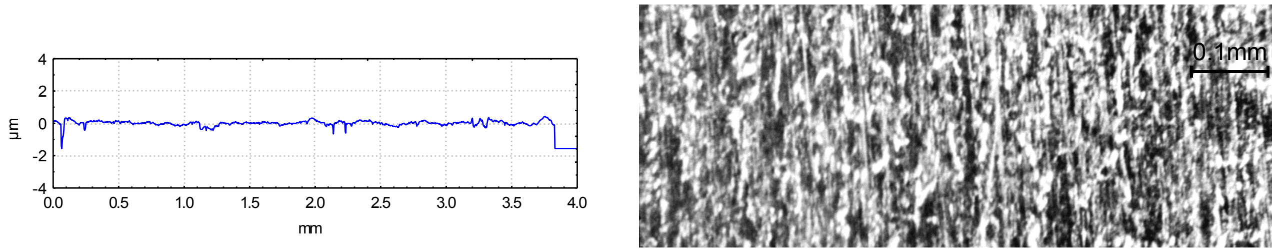
Figures 3 and 4 shows 2D roughness forms and microphotographs of steel sheet metal surfaces on die side, which were made in different drawing phases. If the lubricant M2 was applied on die side (lubrication only before the beginning of drawing), then already at first sliding the prominent levelling of roughness 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 (Fig. 3). In case of phosphated steel sheet metal and lubricant M1 (MoS_2) as well, a large reduction of roughness is noticed during the first sliding, which in subsequent sliding slightly increases, but without formation of distinct burrs on the surface (Fig. 4).



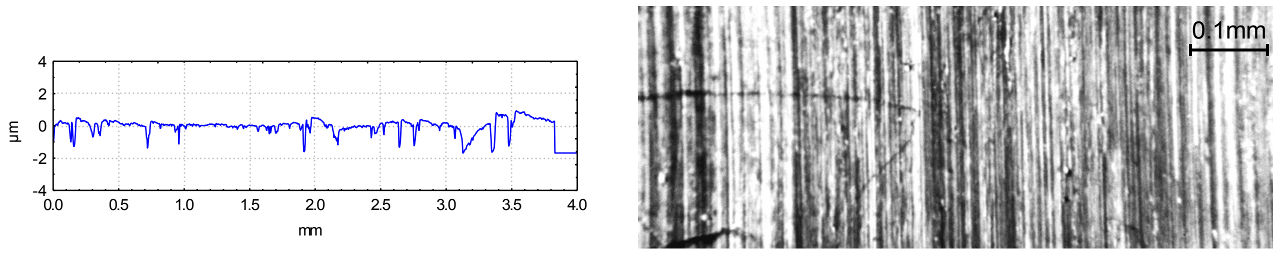
Die: AC, R_a = 0.01 µm (N1)



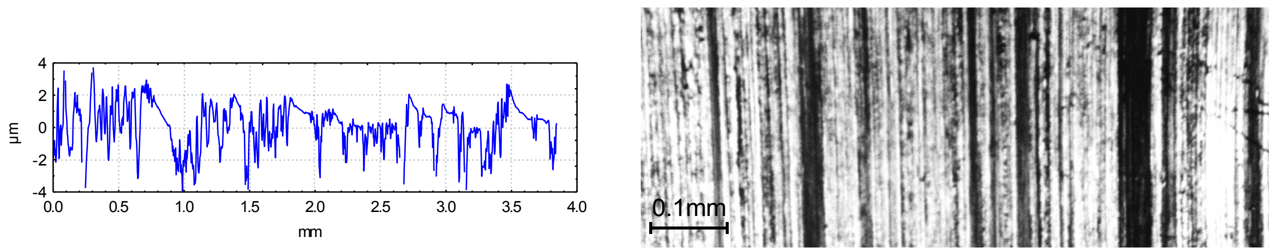
Sheet metal Č0148P3 – before ironing, R_a = 1.01 µm



I ironing, R_a = 0.20 µm

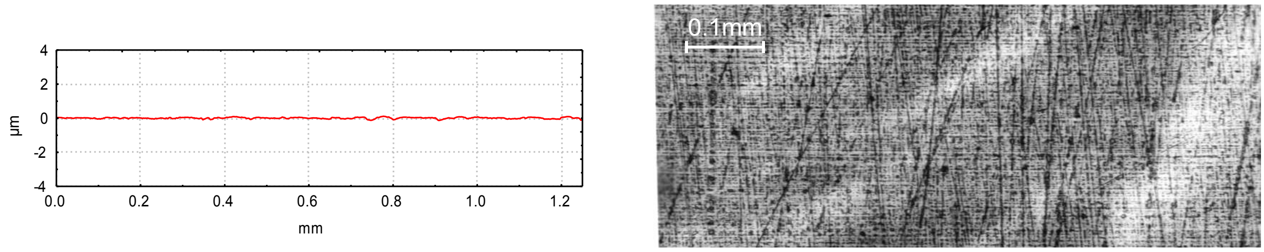


II ironing, R_a = 0.39 µm

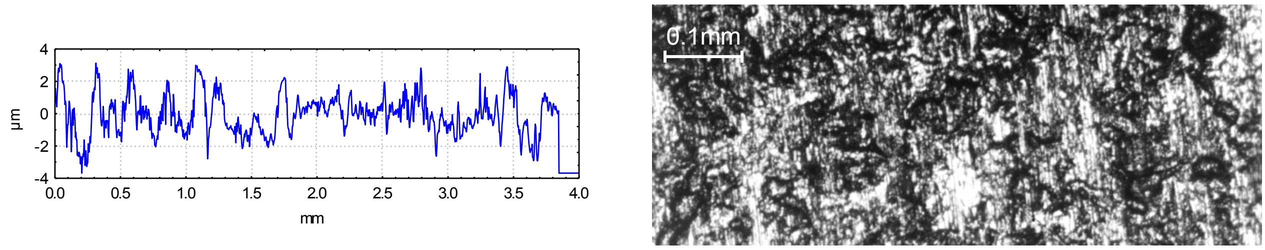


III ironing, R_a = 1.18 µm

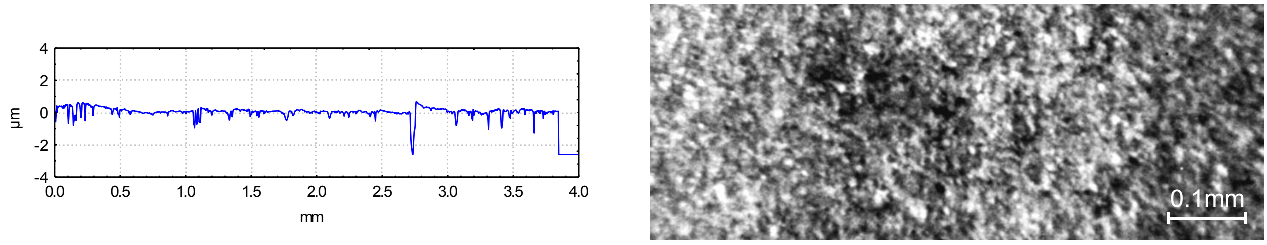
Fig. 3. 2D roughness form and photomicrographs of steel sheet metal surfaces on die side formed at different stages of ironing (lubricant on die/punch – M2/S).



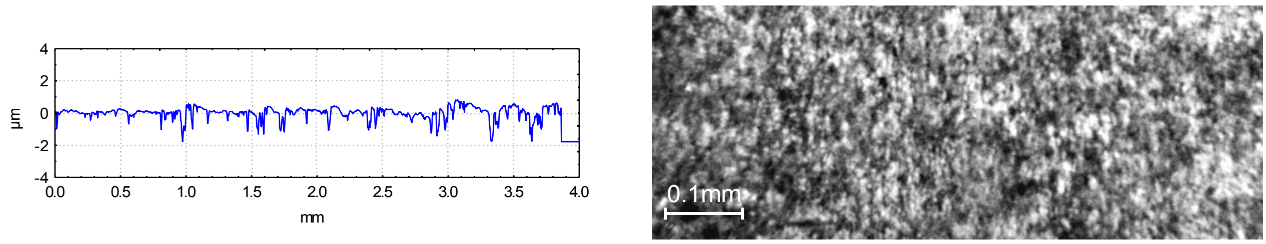
Die: AC, R_a = 0.01 μm (N1)



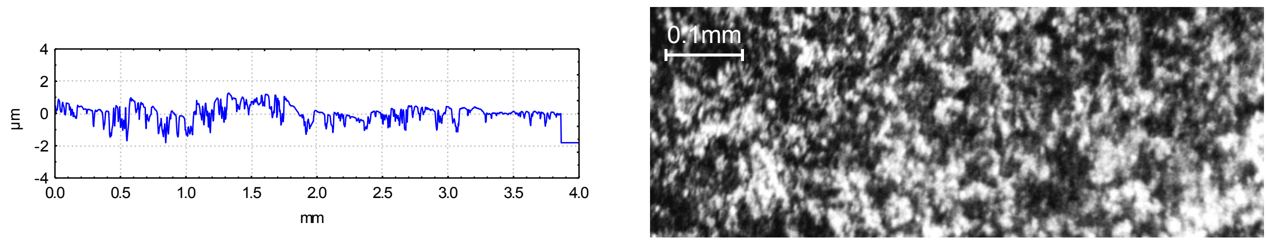
Sheet metal Č0148P3 phosphated – before ironing, R_a = 1.01 μm



I ironing, R_a = 0.152 μm



II ironing, R_a = 0.260 μm



III ironing, R_a = 0.395 μm

Fig. 4. 2D roughness form and photomicrographs of phosphated steel sheet metal on die side formed at different stages of ironing (lubricant on die/punch – M1/M2)

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 Fig. 5. At drawing of steel sheet metals with tool of alloyed tool steel (AC), after the first drawing, the increase of sheet metal roughness occurs with all of the lubricant types. If the material of tool (die) is hard metal

(TM), then at first sliding somewhat larger roughness is obtained in comparison to tool steel, but at following slidings the roughness does not change significantly (Fig. 5).

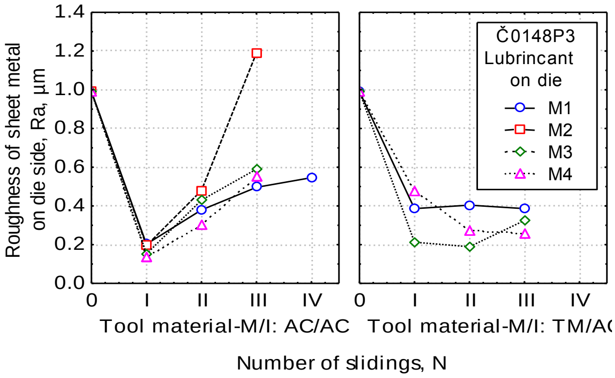


Fig. 5. The influence of lubricant onto the sheet metal roughness on die side at different tool materials per ironing phases.

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 Fig. 6. 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 sidings. 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_I are obtained, and therefore the larger punch wear should be expected [9].

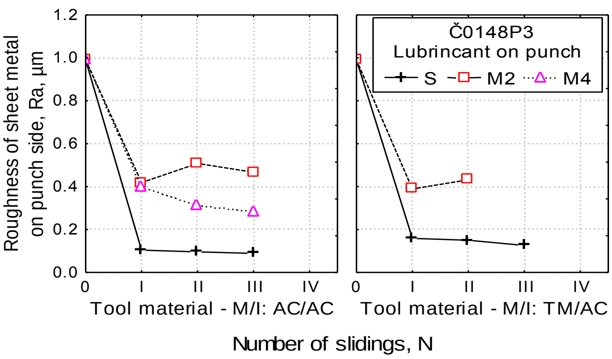


Fig. 6. The influence of lubricant on punch onto the sheet metal roughness on punch side at different tool materials per drawing phases.

The change of sheet metal roughness on punch side, per drawing phases, at various holding forces, is given in Fig. 7. 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 the first sliding is maintained at the other slidings as well. The increase of holding force leads to decrease of the sheet metal roughness on punch side.

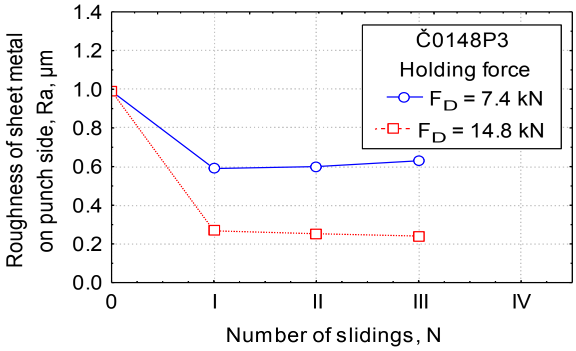


Fig. 7. The influence of holding force per drawing phases onto the sheet metal roughness on punch side.

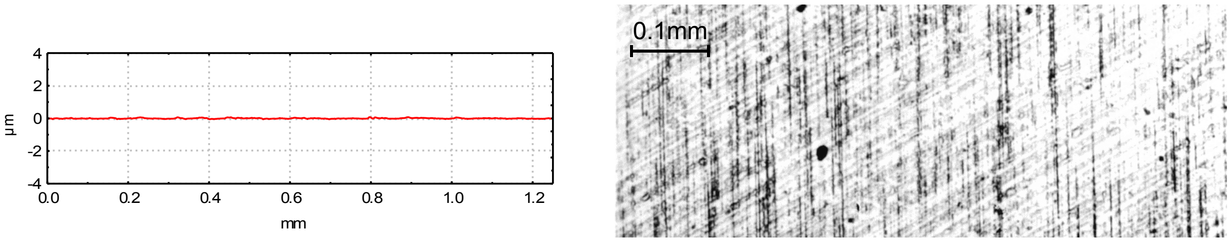
2D roughness forms and photomicrographs of phosphated steel sheet metal and lubricant M2 on punch, as well as ordinary steel sheet metal without lubricant on punch side (S), at various ironing phases are shown in figures 8 and 9 respectively. Those figures confirm previously mentioned statements.

Sheet metal surfaces formed after ironing, based on their roughnesses, can be classified into three characteristic groups (Fig. 10):

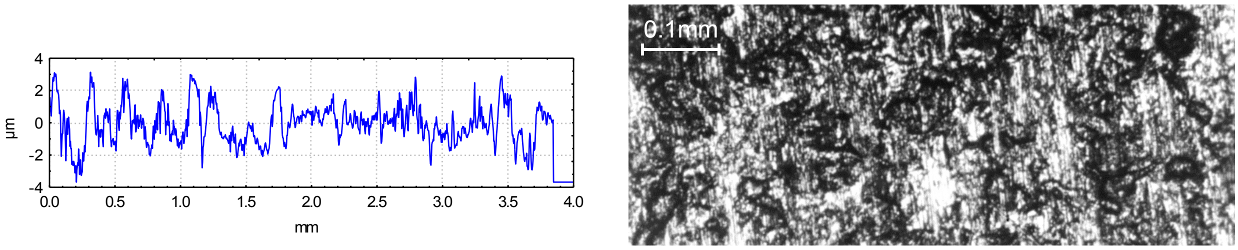
- smooth (Fig. 10a),
- scratched (Fig. 10b) and
- gouged (Fig. 10c).

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

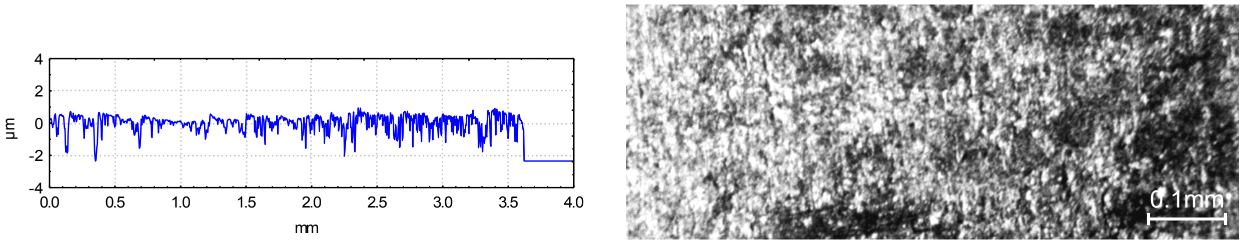
The obtained surface has a mirrory appearance when observed with the naked eye. These surfaces generally have the low value of the coefficient of friction. The processed material particles crumble due to increase of degree of deformation, and sporadically make scratches on the sheet metal surface, among 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].



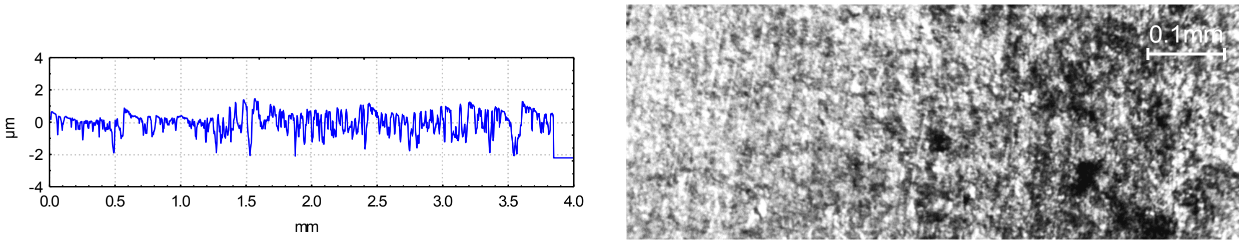
Punch: AC (R_a = 0.01 µm – N1)



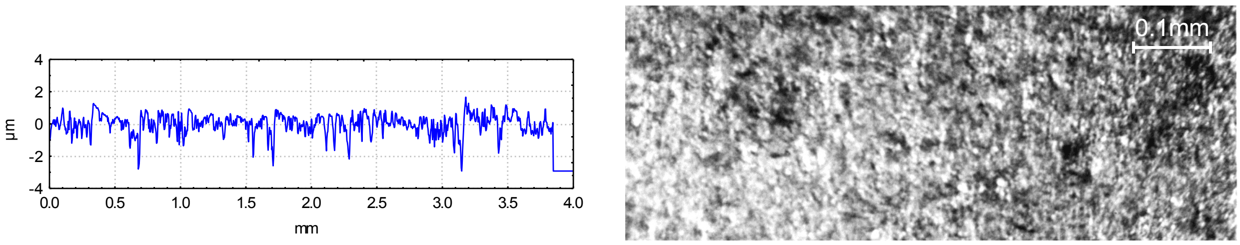
Sheet metal Č0148P3 phosphated – before ironing, R_a = 1.01 µm



I ironing, R_a = 0.419 µm

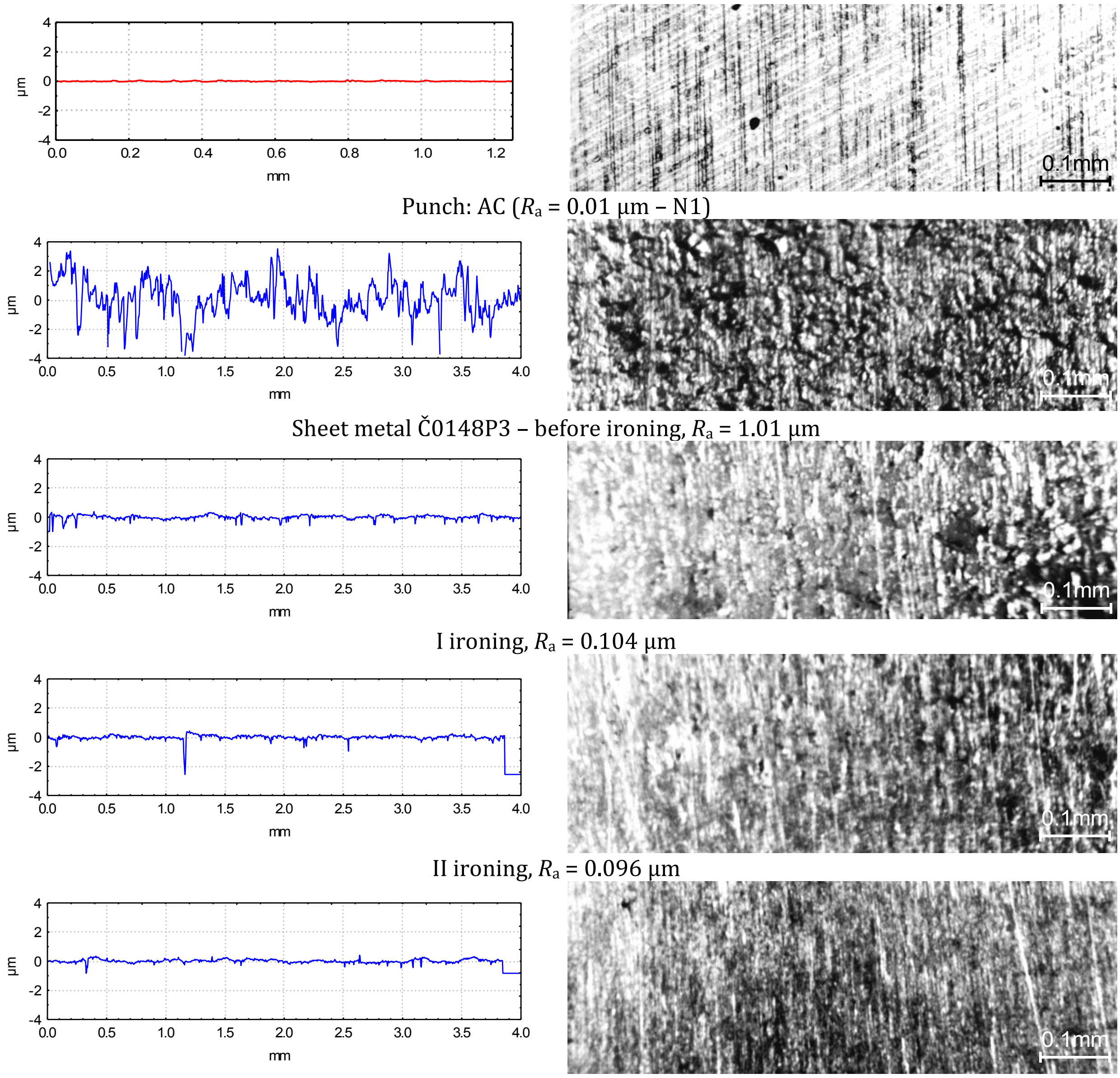


II ironing, R_a = 0.508 µm



III ironing, R_a = 0.467 µm

Fig. 8. 2D roughness form and photomicrographs of phosphated steel sheet metal on punch side at different stages of ironing (lubricant on die/punch – M1/M2).



Punch: AC (R_a = 0.01 μm – N1)

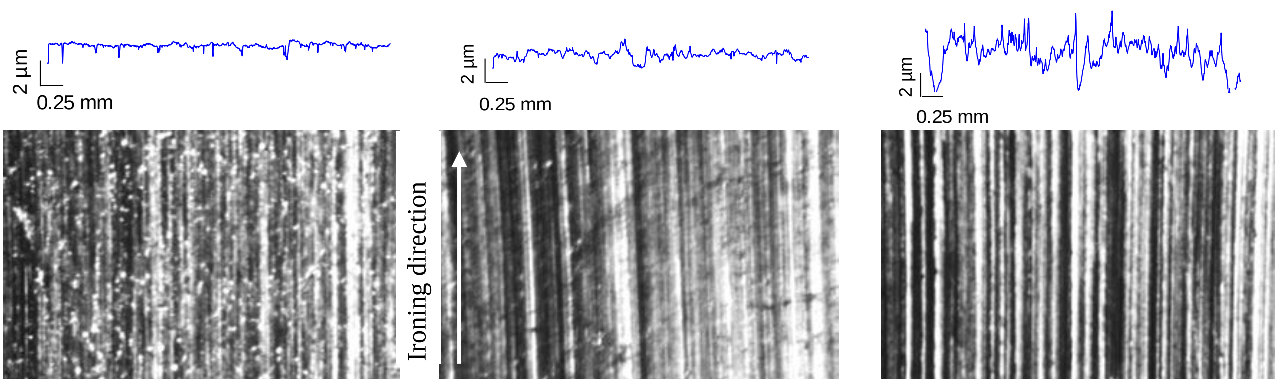
Sheet metal Č0148P3 – before ironing, R_a = 1.01 μm

I ironing, R_a = 0.104 μm

II ironing, R_a = 0.096 μm

III ironing, R_a = 0.089 μm

Fig. 9. 2D roughness form and photomicrographs of steel sheet metal on punch side at different stages of ironing (lubricant on die/punch – M2/S).



Č0148P3, ε =3.5 %, M2 | Č0148P3, ε = 20.5 %, M2 | Č0148P3, ε = 45.5 %, M2

a) b) c)

Fig. 10. Characteristic surface looks formed after sheet metal ironing: a) smooth surface, b) scratched surface, c) gouged surface.

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 [11-15].

4. CONCLUSION

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.

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.

Acknowledgment

The part of this research is supported by Ministry of Education and Science, Republic of Serbia, Grant TR32036 and TR34002

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