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Investigation of the lubricants influence on the ironing process

Milan Djordjević[a], Srbislav Aleksandrović[a], Vukić Lazić[a], Dušan Arsić[a], Ružica Nikolić[a,b], Branislav Hadzima[b], Peter Koteš[c]*

[a]*Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, Kragujevac 34000, Serbia*
[b]*Research Centre, University of Žilina, Univerzitna 8215/1, Žilina 010 26, Slovak Republic*
[c]*Faculty of Civil Engineering, Univerzitna 8215/1, Žilina 010 26, Slovak Republic*

Abstract

Results of experimental and numerical investigations of the three types of lubricants influence on the ironing process are presented in this paper. The tribological model was based on the strip sliding between the two lateral contact elements. The strip was made of the low carbon steel. Variations of the friction coefficient and the contact pressure in the single-stage ironing were recorded at the constant sliding speed for each of the tested lubricants. The effective normal stress distribution within the material was simulated by the finite element method (FEM). The objective was to compare the applied lubricants from the aspect of their applicability in the ironing process.

Keywords: Ironing; Tribological model; Coefficient of friction; Contact preasure; Finite element analysis.

1. Introduction

The ironing process in cold conditions is frequently characterized by the high contact pressures and local load of the tool, especially in the case of the multi-phase process. In such conditions, the lubricant has the decisive influence on plastic forming. Absence of lubricant would cause the direct contact of the machined piece with the tool, what would significantly disrupt the stability of the forming process. Lubrication, as a measure of reducing the damaging influence of friction, enables increase of the deformation and the degree of deep drawing [1]. Application of

* Corresponding author. Tel.: +421-41-513-5663; fax: +421-41-513-5690.
E-mail address: kotes@fstav.uniza.sk

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lubricants eliminates or decreases the harmful phenomenon of galling, wear of the tool's working surfaces and improves the quality of the machined piece surfaces, [2].

Based on the adopted tribological model, [3, 4], the original device was developed, based on sliding of the thin sheet samples between the side elements (die) in a single phase. The contact surfaces between the sample and the die were separated by the layer of lubricant, [5, 6, 7]. The three types of lubricants were applied: a) lubricant in the form of the zinc phosphate coating with oil, b) lubricating grease based on molibdenum-disuplhate and c) oil for deep drawing. For each type of lubricants and the blank holding force, the measurements of the coefficient of friction and the drawing force were performed. Numerical simulation was conducted in order to monitor the stress distribution within the material. Experimentally obtained values of the friction coefficient were used as the input variables for the simulation, [8, 9].

Nomenclature
F – Tensile (drawing) force
F_S – Lateral (side) force
F_{SFR} – Friction force caused by the action of the normal component ($a \cdot Fs$) of the lateral force F_S
F_{FFR} – Friction force caused by the action of the normal component of the tensile force F
F'_{FR} – Friction force caused by the action of the component $(1\text{-}a) \cdot F_S$ of the lateral force F_S
a – Parameter of the lateral force F_S
t_0 – Sheet thickness before the ironing process
t_1 – Sheet thickness after the ironing process
α – Angle of the sliding element slope
L1 – Lubricant in the form of the zinc-phosphate coating with oil
L2 – MoS_2 based grease
L3 – Oil for deep drawing

2. Experimental device and the tribological model

For experimental investigations a device was constructed, which models the symmetrical contact of the thin sheet with the die during the ironing process, [10, 11], Fig. 1. The metal strip is being placed into the holding jaw 12. The jaw with the sample is moving from the bottom towards the top, by the mechanical part of the device. The sample is being acted upon by the side elements 10 and 11, which simulate the die and perform the ironing. The moving sliding element 10 is placed into the holder with a T-groove 9, which is moving with piston 8 and hydro-cylinder 7. The sliding element 11 is fixed. During the ironing process, the recording of the tensile force is being done over the total length of the punch travel of approximately 60 *mm*, by the corresponding measurement's chain.

The tribological model, used in this experiment, was developed based on an idea presented in [3]. In the large number of cases, the tribological models cannot completely simulate real processes, [4]. Due to that, the more detailed analysis of the process being modelled was necessary. The applied model enables realization of the high contact pressures, Fig. 2a.

The basic idea in realization of this device was to provide for determination of the friction coefficient at the contact surface between the siding element and the sample, based on what the estimate of the lubricant became possible, Fig. 2b. Calculation of the friction coefficient requires analysis of forces that act on the contact surface at certain angle, as well as on the input portion of the side element, Fig. 2b, [10].

3. Experimental results

Samples made of steel thin sheet DC 04 (EN 10027.1), with thickness of 2.5 *mm* and width of 20 *mm*, were used in the experiment. The following three lubricants were applied: zinc phosphate coating with ~ 10 μm thickness with oil for deep drawing (L1), lubricating grease based on MoS_2 (L2) and oil for deep drawing (L3) (kinematic viscosity 100 mm^2/s at 40 °C and density 0.93 g/cm^3 at 20 °C). The sliding speed was 100 *mm/s*.

Estimates of the lubricant's quality could be monitored via the variations of the tensile force and the friction coefficient in terms of the sliding length. In Fig. 3 are presented variations of the tensile force in terms of the sliding length for all the three types of lubricants. The obtained values of tensile forces are different for all the types of lubricants and blank holding forces (15 *kN* and 20 *kN*). The highest values of the tensile forces were obtained for the case of the L3 lubricant (the deep-drawing oil, Fig. 3c). The consequence of such high values was the harsher contact conditions, especially for the ca se of the blank holding force of 20 *kN* (Fig. 3c).

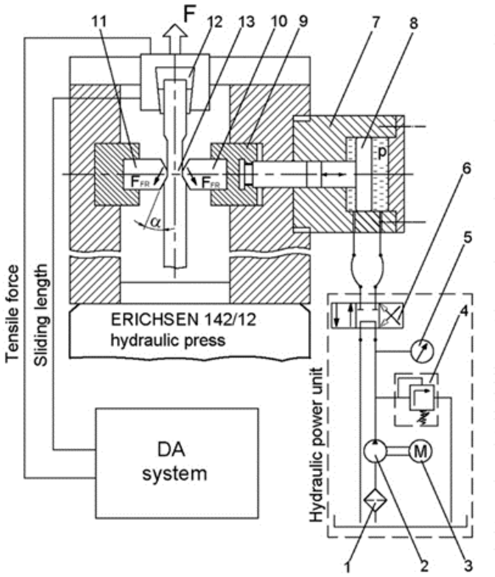

Fig. 1. Block scheme of the experimental device: 1 – Filter; 2 – Pump; 3 – Actuator; 4 – Irreversible valve; 5 – Manometer; 6 – Two position distributer; 7 – Cylinder; 8 – Piston of cylinder 7; 9 – Holder with the T-groove; 10 and 11 – Sliding elements; 12 – Jaw for sample holding; 13 – Sample.

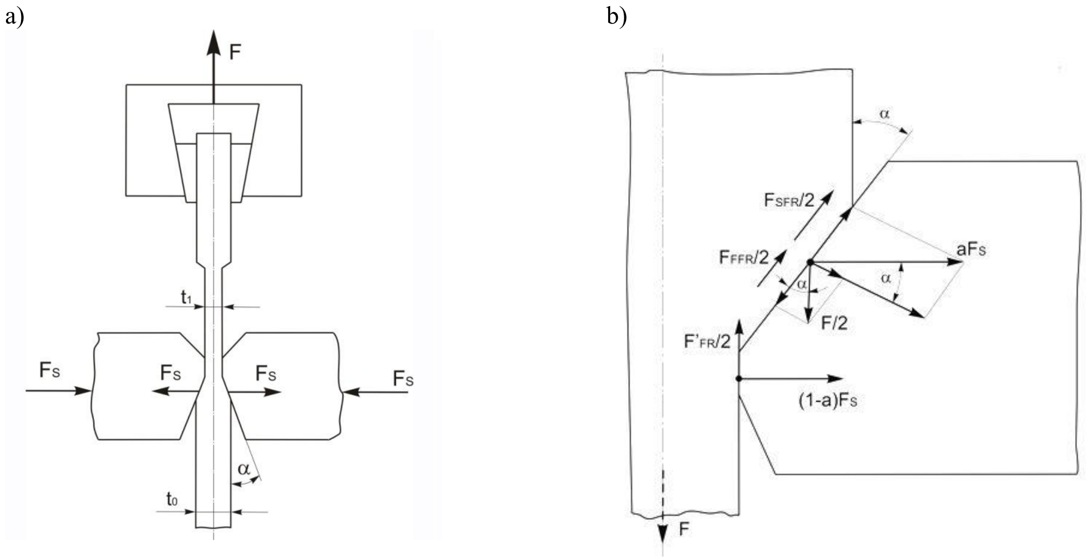

Fig. 2. The tribological model: a) scheme of the contact between the sliding element and samples; b) Scheme of the forces' action.

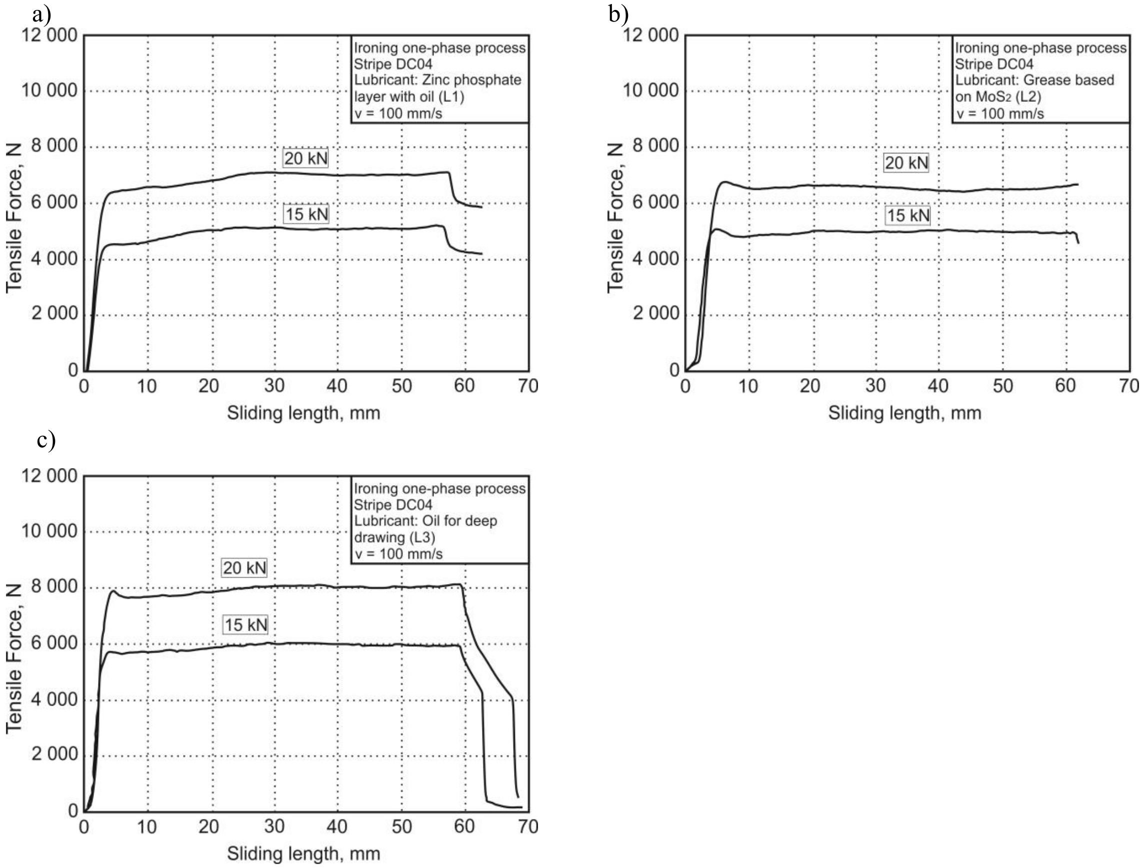

Fig. 3. Diagrams of tensile forces: a) phosphate coating; b) grease based on MoS_2; c) oil.

The appearance of galling was noticed on the sliding elements, especially for the mentioned testing versions, what is the results of more difficult sliding between the contact surfaces. This phenomenon directly influences the increase of the tensile force, especially for the case of lubricant L3. The lowest values of the tensile forces were realized by application of the lubricant based on MoS_2, with absence of galling (Fig. 3b). Values of tensile forces for lubricant in the form of the phosphate coating with oil (L1, Fig. 3a) are somewhat higher than for lubricant L2.

The friction coefficient variation was calculated for each tensile force dependence on the sliding length. The obtained curves of the friction coefficient variation in terms of the sliding length are presented in Fig. 4.

It is clear that the friction coefficient was much higher when the mineral oil (L3) was applied, with a range of approximately 0.18 to 0.2. This confirms that this lubricant's lubricating properties are worse than those of the other two.

The friction coefficient variation for the grease based on MoS_2 (L2) is presented in Fig. 4b. The values are the lowest, ranging from 0.15 to approximately 0.165. The increase in the lateral force from 15 to 20 *kN* does not significantly influence the increase in the friction coefficient.

When the phosphate layer with mineral oil was applied (L1, Fig. 4a), the values are similar to those for lubricant L2, ranging from approximately 0.16 to 0.175. The influence of the lateral force variation is somewhat greater than that for L2. The most probable cause is the worse lubricating properties of the mineral oil.

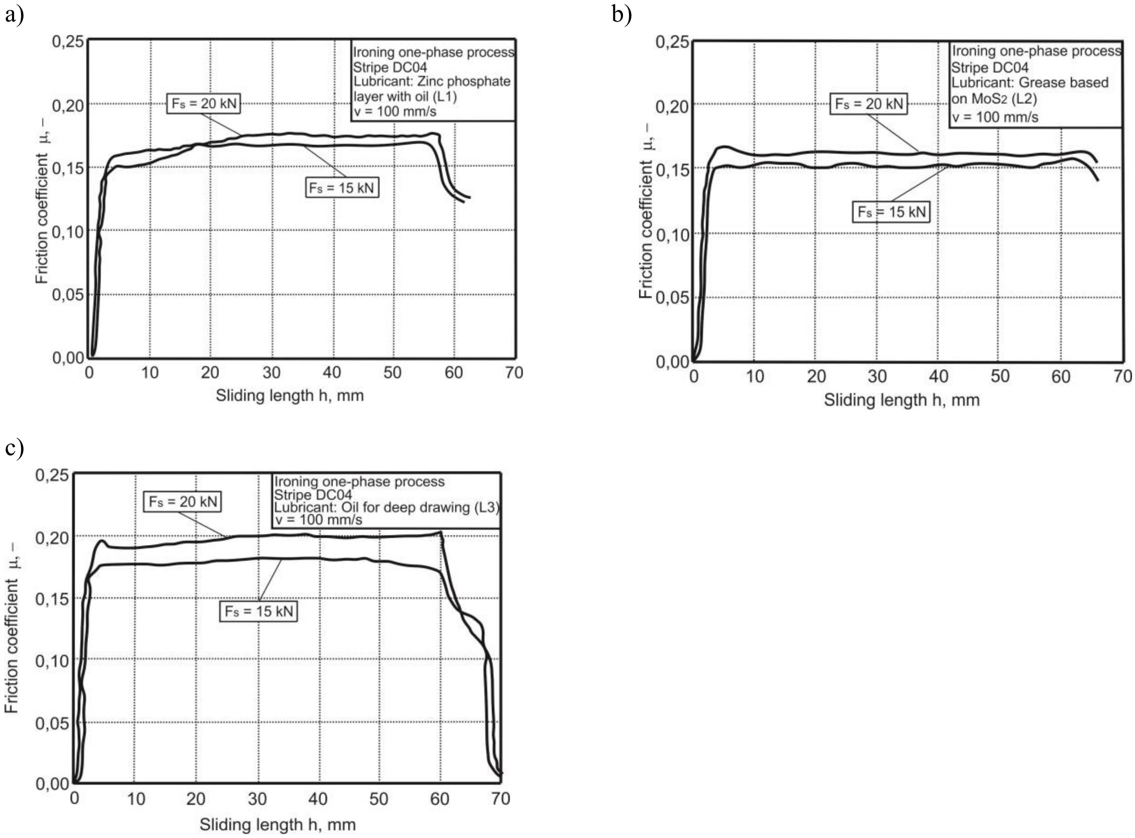

Fig. 4. Diagrams of the friction coefficient for different lubricants: a) phosphate coating; b) grease based on MoS_2; c) oil.

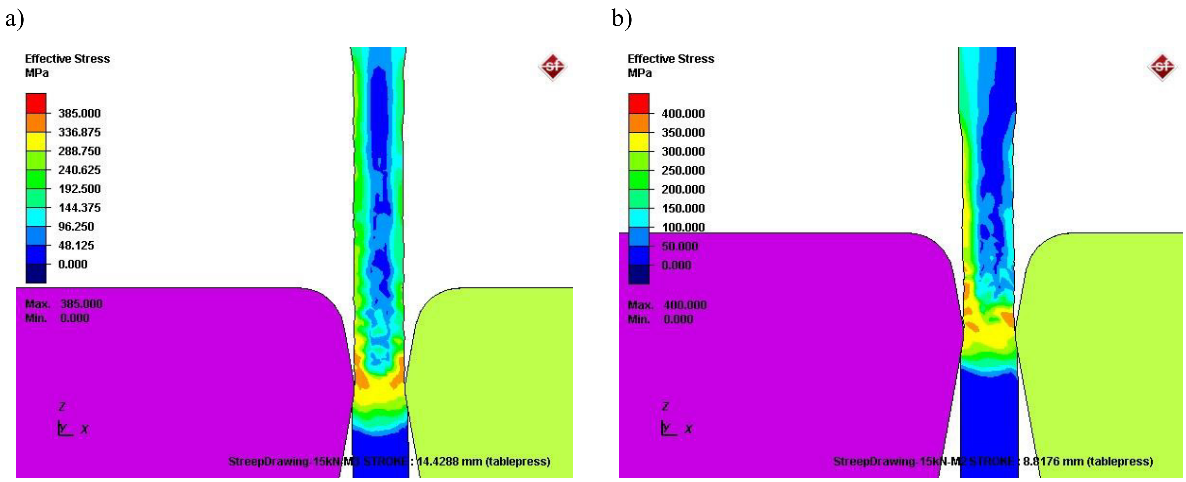

Fig. 5. Effective stress distribution in the thin sheet strip at compressive force of 15 kN for lubricants a) grease based on MoS_2; b) oil for deep drawing.

At the end, the numerical simulation, which is shown by the effective stress distribution in the thin sheet strip, confirmed the poor characteristics of the deep-drawing oil. In Fig. 5 are presented the stress distributions in material obtained for application of the grease based on MoS_2 (Fig. 5a) and of deep-drawing oil (Fig. 5b), for the same value of the blank holding force of 15 *kN*. Values of the effective stress in the thin sheet strip are noticeably higher for the second lubricant, what is the consequence of the harder sliding of the strip between the contact elements and appearance of micro galling.

4. Conclusion

Based on the presented results of the tensile forces, friction coefficient and stress distribution within the material, one can conclude that the deep-drawing oil is not convenient for applications in the ironing process and when the values of blank holding forces are high, since it possesses the prominent proneness to appearance of galling and easy extrusion of lubricant from the contact zone. The coating made of the phosphate layer with oil possesses the more favorable properties than the deep-drawing oil, what could be concluded based on lower values of the tensile forces and absence of galling. If the higher contact pressures were applied, extrusion of oil from the phosphate coating may occur and consequently the increase of the friction coefficient. Thus, from that aspect, the application of this lubricant is limited.

The lubricant based on MoS_2 possesses the optimal characteristics and good sustainability of the lubricating layer, without appearance of galling, thus it could be applied even at somewhat higher blank holding forces. Besides that, the ecological aspect is present in application of the MOS_2 based lubricant and the phosphate coating. The disposal of lubricants after application and the phosphatizing process could be toxic for human and for the environment. This is actually the reason that caused development of the new environment-friendly lubricants.

Acknowledgements

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