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THE POSSIBILITIES FOR APPLICATION OF NUMERICAL SIMULATION IN THE IRONING PROCESS OF THIN SHEETS

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Abstract: *In this research, results of experimental investigations and physical model were used as the input variables for numerical analysis of the ironing strip drawing process by application of lubricants. The numerical simulation was realized in the specialized applicative software Simufact.forming. By applying the software for the 3D modeling, a model of the tool element assembly was made, which served as the starting basis for numerical simulation by application of the Finite Element Method. Experimental values of the friction coefficient for each type of lubricants and the contact pressures were used for defining the contact conditions. Numerical simulation of the drawing process was done for each type of the contact conditions between the tool's elements and the thin sheet sample. After conducted tests comparison of experimental and numerical results of the drawing forces in different contact conditions was done. Comparison was done with taking into account appearance of galling due to difficult drawing process conditions. By comparation of numerical results to the experimental one it is possible to interpret what types of simplifications were adopted in creating the experimental physical-tribological model.*

Keywords: *strip drawing, ironing process, drawing force, numerical analysis.*

1. INTRODUCTION

Simulation of the production processes is applied in early design phases of both the new products and tools for their manufacturing [1]. Significant financial savings are realized and delays in products placing on the market are avoided by application of the physical and numerical modeling. Software, based on the Finite Element Method is used widely for optimization of the process parameters, eliminating the flaws during the material flowing, determination and minimizing the stresses in the tool, etc. Material's behavior during the forming process can be completely predicted by application of the corresponding software in the stress-strain analysis [2-4]. Analysis and simulation of the real processes can be done on cold and hot, by correction of tolerances between the die and the drawing tool, what directly influences the thin sheet thickness during the forming [5]. In that way, the higher degrees of drawing can be achieved without the appearance of destruction. Similarly, simulation results should lead to optimization of the process, so that fast and efficient reaction to market needs would be achieved [6]. Paper [7] also study the ironing of austenitic stainless steel cups by real experiment and FEM analysis. Aim of paper was to quantify the discrepancy (due to tool deformation) between nominal die–punch gap and real final wall thickness. As a result, the states of stress in the cup wall during and after drawing obtained by FEM are compared with results obtained by the analytical model. Since in processes of this kind the friction has the strong influence, in paper [8] is presented in details the procedure for determination of the friction coefficient between the tool and the thin sheet during the strip drawing process. Since the objective is to achieve resistance as least as possible, and by that the deformation forces in the ironing process, in paper [9] is presented an analysis of lubricants that are used in the multi-phase ironing process. It was concluded that the new group of ecological lubricants possesses somewhat better lubricating properties with respect to conventional lubricants (the zinc-phosphate layer, oil for deep drawing, etc.).

Within the experimental part of this work, the special attention was paid to lubricants that are used in the ironing process and to modern ecological lubricants [9]. The schematic is presented of the adopted physical model, as well as the used equipment, applied lubricants and the experimental results. They are used, together with the physical model, as the input variables for the numerical analysis of the strip deep drawing. The Finite Element Method simulation was done by the Simufact.forming software. Experimental values of the friction coefficient were used for definition of the contact conditions.

2. EXPERIMENTAL EQUIPMENT, PHYSICAL AND NUMERICAL MODEL

A special device that models the symmetrical contact between the thin sheet and the die in strip deep drawing was constructed for experimental investigations in this work, Figure 1, [10, 11].

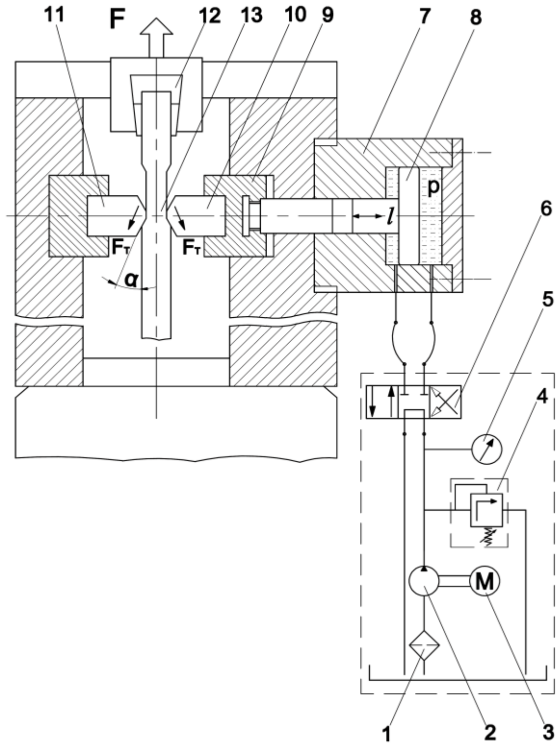


Figure 1. Block scheme of the experimental apparatus: 1-Filter, 2-Pump, 3-Driving motor, 4-Irreversible valve, 5-Manometer, 6-Two-position distributer, 7-Cylinder, 8-Piston of cylinder, 9-Holder with the T-groove, 10 and 11- Ironing die elements, 12-Jaws for sample camping, 13-Sample

The sheet strip is being placed into the clamping jaws 12 (Figure 1). The jaws with the sample are moving from the bottom upwards, by the holder of the mechanical part of the apparatus. The sample is being acted upon by the side elements 10 and 11, which simulate the die and perform the thinning. The moving sliding element 10 is placed into the holder with the T-groove 9, which is moving with the piston 8 of the hydro-cylinder 7. The sliding element 11 is fixed. Registering of the drawing force, during the drawing process, is done by the corresponding measurement chain at the total length of 40 mm.

2.1 Physical model

The physical model, used in this experiment, was realized based on previous research [10]. The applied model enables realization of high contact pressures.

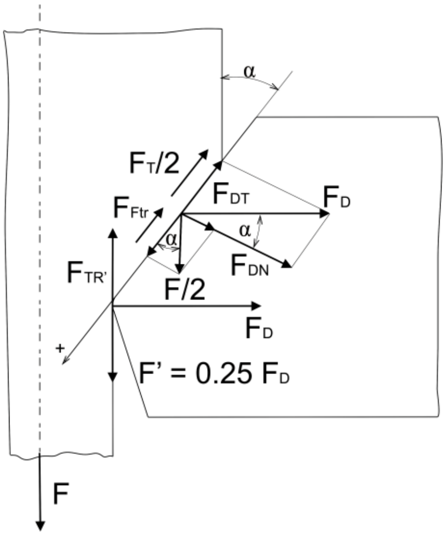


Figure 2. Tribological model-schematic of the forces' actions

The idea for realization of this experimental device was to determine the friction coefficient at the contact surface between the sliding elements and the sample (Fig. 2).

Calculation of the friction coefficient requires analysis of the forces that are acting at the inclined contact surface, as well as at the input portion of the sliding element (Fig. 2) [11]. The model is adjusted to the real process conditions by taking into account the friction forces (F_{TR}' and F'= 0.25·F_D, Fig. 2b). Based on the scheme of the forces action (Fig. 2), one can compose the equilibrium equation. By solving equilibrium equation for μ, one obtains the formula for the friction coefficient:

$$\mu = \frac{F + 2 \cdot F_D \cdot \left(0.25 - 2 \cdot tg\alpha\right)}{4 \cdot F_D + F \cdot tg\alpha}. \qquad (1)$$

The mean values for friction coefficient for each type of lubricants and the compressive force, obtained by application of formula (1).

2.2 Numerical model

To be able to perform the simulation of a certain process of plastic forming, it is necessary to enter some input variables into the software for numerical simulation. Primarily, it is necessary to create the 3D model in the corresponding CAD software and adjust its format to formats offered by the numerical simulation software. Besides that, one needs to define the contact conditions between the sliding elements and the thin sheet strip, what was realized by entering the experimental values of the friction coefficient for each type of lubricant and each value of the sliding elements compressive force from Table 1 into the numerical simulation program.

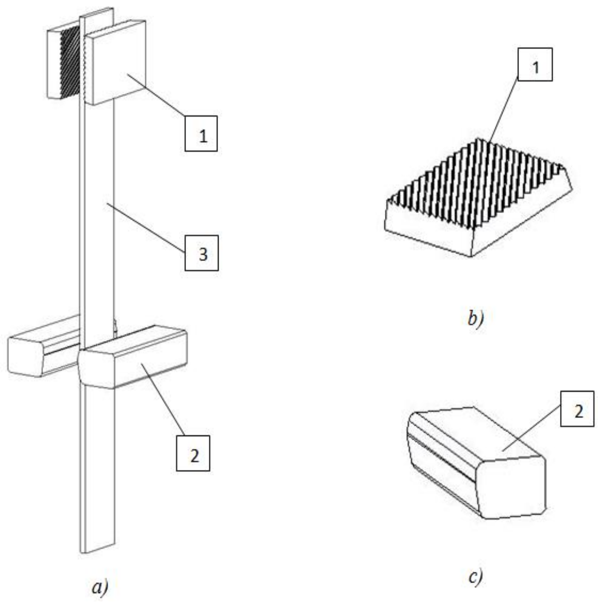


Figure 3. Numerical model after creating in the CAD program: 1-Clamping jaws, 2-ironing die elements, 3-thin sheet sample (DC04)

Table 1. Friction coefficient values for three values of compressive forces and four types lubricants

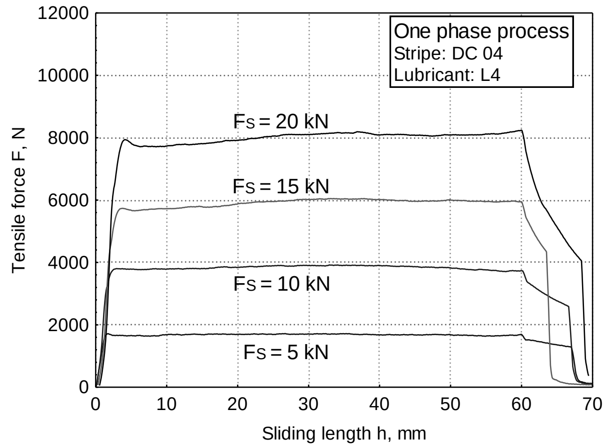
	Lubricant type	Compressive force, kN		
		10	**15**	**20**
Friction coefficient μ	L1 – The zinc-phosphate coating with oil	0.149	0.168	0.175
	L2 – Ecological single bath lubricant	0.132	0.144	0.154
	L3 – Grease based on MoS_2	0.153	0.160	0.164
	L4 – Oil for deep drawing	0.179	0.190	0.199

For this research case, the 3D CAD model was created in the 3D programming package CATIA V5 R18, while the numerical simulation was done in the specialized software for the plastic forming simulation Simufact.forming 2.1. The 3D model (Fig. 3) was created based on dimensions of real tools that are included in the process of strip drawing between the sliding elements according to the scheme shown in Fig. 2. The model was realized as the assembly consisting of the sliding elements, clamping platelets and the steel thin sheet strip DC04.

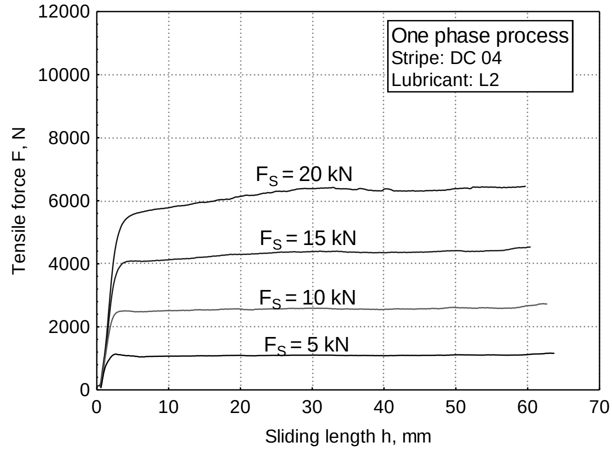
3. RESULTS

Within results of this physical-numerical experiment, the drawing forces, obtained in physical experiment were compared to forces obtained by numerical simulation. Diagrams of drawing forces obtained by physical experiment are presented first, Figs. 4 and 5. The obtained values of the drawing forces in the strip drawing process are different for all the types of lubricants and values of the compressive forces of the sliding elements. The largest values of the drawing forces were realized for the case of lubricant L4 (oil for deep drawing, Table 1) and L1 (phosphate layer with oil, Table 1) (Figs. 4a and 5a, respectively). Consequence of such large values is difficult contact conditions in applications of those lubricants, especially for drawing forces values of 15 kN and 20 kN (Fig. 4a). Besides that, the appearance of galling on the tool's sliders was noticed for those experimental conditions, what is a consequence of difficult sliding between the contact surfaces. That phenomenon directly causes increase of the drawing forces, especially for lubricant L4.

The lowest values of drawing forces were obtained in the case of single stage experiment of the new ecological lubricant L2, denoted as FL741 and lubricant L3 which represents oil based on MoS_2 (Figures 4b and 5b, respectively). Comparing to values of the drawing forces for other lubricants, one can conclude that the L2 lubricant exhibits the best lubricating properties, what is especially prominent in friction coefficient values (Table 1). Considering the drawing forces diagrams for various types of lubricants it could be assumed that the L2 lubricant has better properties than the conventional ones.



a)

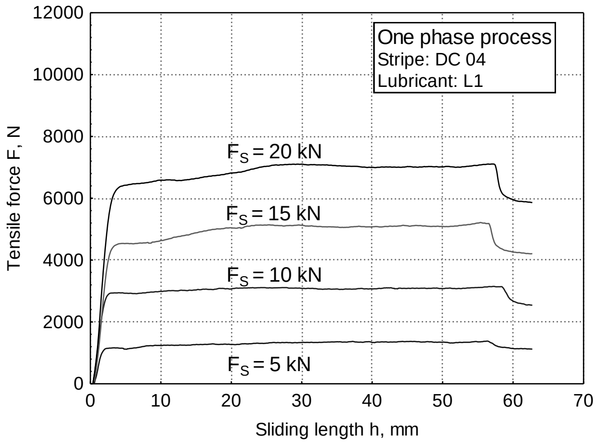


b)

Figure 4. Comparative presentation of drawing forces in experimental testing of lubricants: L4 (deep drawing oil); b) L2 (ecological lubricant)

Results of numerical analysis are in agreement with results of the physical experiment, to the great extent. This is the best illustrated for lubricant L4 where the highest values of the drawing forces were registered (Fig. 6a). Appearance of galling which was registered in physical experiment (lubricant L4) is manifested in numerical results by the high values of the drawing forces, especially at compressive forces of 15 kN and 20 kN. With increasing compressive force the appearance of galling is more prominent, since the squeezing of lubricant from the contact zone occurs.

The good correlation of experimental and numerical results was especially realized at higher values of the compressive forces of the sliding elements of 15 kN and 20 kN, for numerical experiments 15L1, 15L2, 15L3, 15L4, 20L2, 20L3.



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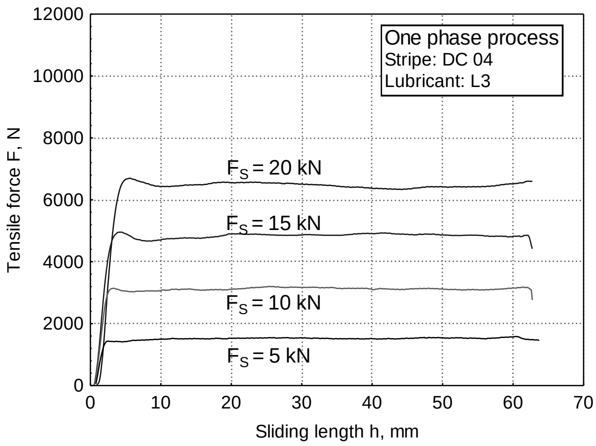

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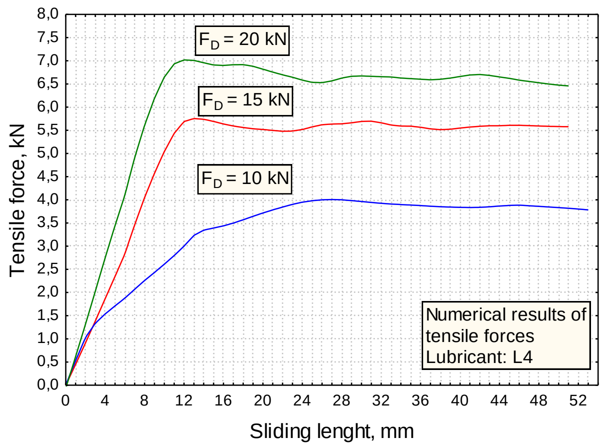
Figure 5. Comparative presentation of drawing forces in experimental testing of lubricants: a) L1 (phosphate layer with oil); b) L3 (grease based on MoS_2)

The average value of the drawing force obtained by numerical experiment 15L1 was approximately 5 kN (Fig. 7a), while the drawing force obtained experimentally had the average value of about 5.1 kN, what can be noticed on diagram in Fig. 5a. Matching of drawing forces values obtained numerically and experimentally, was realized for numerical experiment 15L3. There, the average value of the drawing force obtained by numerical simulation was 4.96 kN (Fig. 6a), while experimental drawing force has negligibly lower value of 4.9 k N (Fig. 5b).

For numerical experiment 15L4, drawing forces have somewhat lower value of 5.85 kN (Fig. 6a) with respect to experimentally obtained value of 6.0 kN (Fig. 4a). Somewhat larger discrepancies between numerical and experimental results was noticed in the case of 15L2, where numerical simulation gave the average value of the drawing force of approximately 4.7 kN, while experimentally the value of about 4.2 N was obtained (Fig. 4b). This discrepancy can be ascribed to the error in the measurement chain during the drawing force recording in the physical experiment. Results of average values of drawing forces, obtained for the compressive force of the slider of 20 kN, are presented in Table 2.

Table 2. Average value of drawing forces for the force of 20kN

Experiment	Num.value, kN	Fig	Exp.value, kN	Fig
20L1	6.7	7a	6.85	5a
20L2	6.1	6b	6.2	4b
20L3	6.4	7b	6.5	5b
20L4	6.85	6a	8.05	4a



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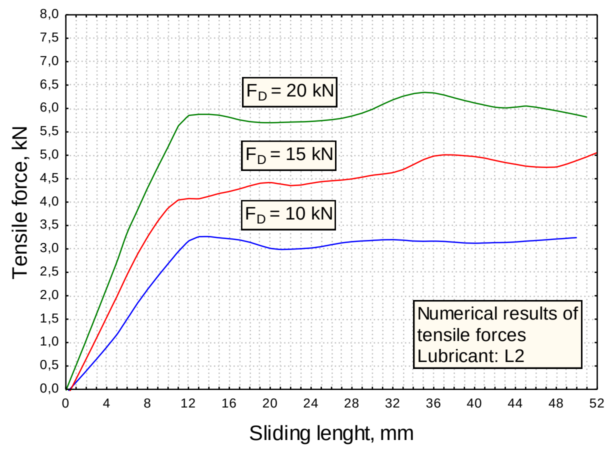

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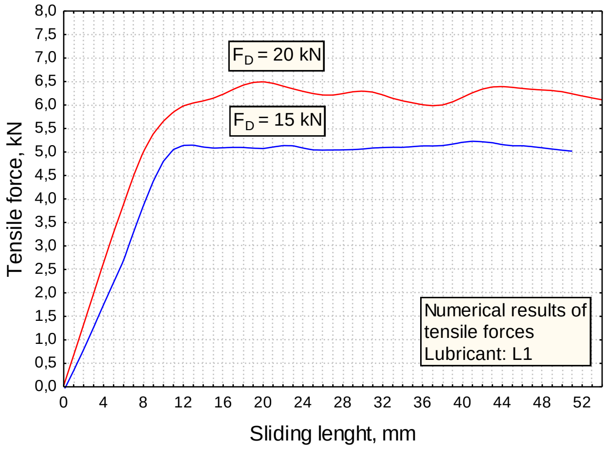
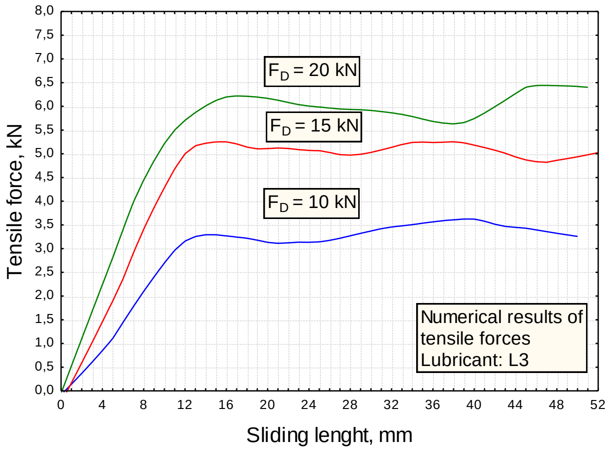
Figure 6. Comparative presentation of the drawing forces obtained by numerical simulation of lubricants' applications. a) L4 (oil for deep drawing); b) L2 (ecological lubricant)



a)

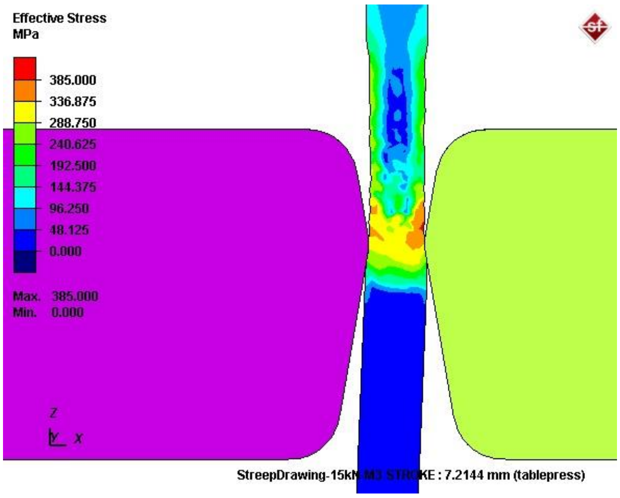


b)

Figure 7. Comparative presentation of the drawing forces obtained by numerical simulation of lubricants' applications. a) L1 (phosphate layer with oil); b) L3 (grease based on MoS_2)

Numerical and experimental results of average values of the drawing forces for experiments 20L1, 20L2 and 20L3 mainly have the similar values, so it could be concluded that there exist high correlation of the experimental and numerical results, what verifies that the numerical model was properly created. The only greater discrepancy between the experimentally and numerically obtained values of the drawing forces was for experiment 20L4. The high value of the drawing force of 8050 N (Fig. 4a) obtained in physical experiment is the consequence of difficult conditions for the sample sliding between the sliders, due to appearance of galling on sliders. That phenomenon results in very high friction coefficient due to worsen lubricating properties of lubricant L4. Subsequently, the drawing force must be greater to overcome the sliding resistance.

Influence of the contact conditions between the thin sheet strip and the sliding elements can be also monitored via the distribution of the effective stress (Figs. 8 and 9). Increasing of the compressive force of the sliding elements (10 and 20 kN) causes increase of stresses within the thin sheet strip, what is to be expected. Besides that, it is important to monitor the change of stresses for various lubricants for the same compressive force.



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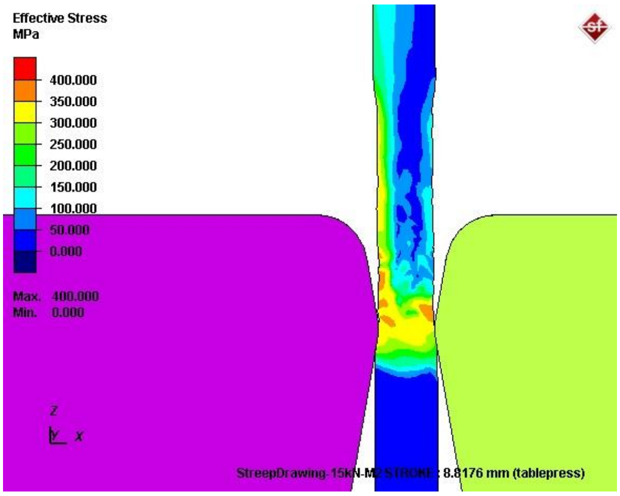
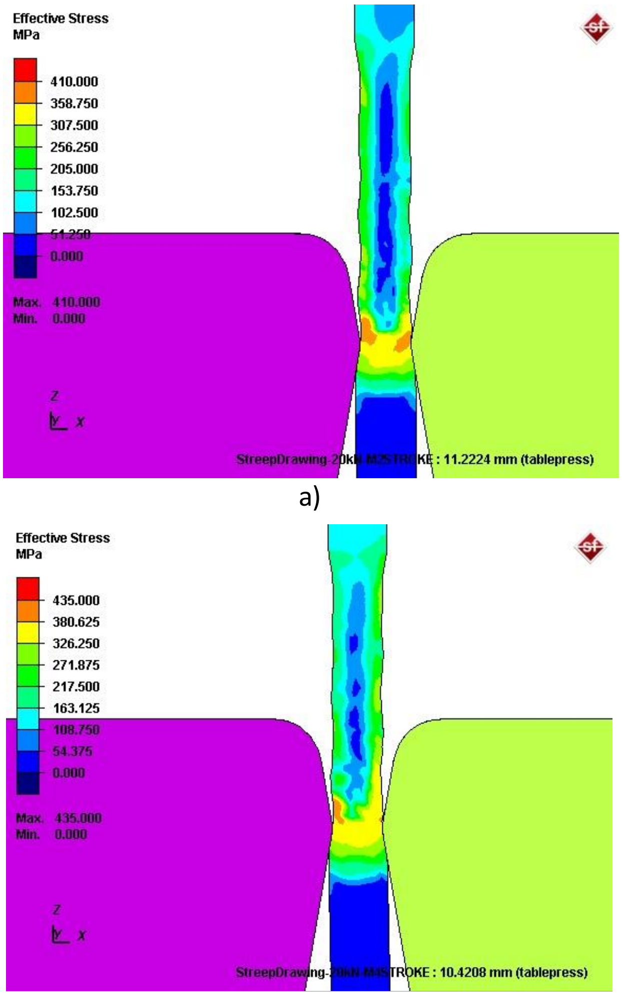


b)

Figure 8. Effective stress distribution in the thin sheet strip at compressive force of 15 kN for lubricants a) L2; b) L4

For the compressive force of 15 kN and lubricant L2 the maximum effective stress in the thin sheet strip amounts to 385 MPa (Figure 8a), while for the lubricant L4 it amounts to 400 MPa (Figure 8b). Increasing of the compressive force to 15 kN causes increase of the effective stresses. In this case, as well, the effective stresses values are lower for the lubricant L2

(410 MPa, Fig. 9a) with respect to lubricant L4 (435 MPa, Fig. 9b).



a)

b)

Figure 9. Effective stress distribution in the thin sheet strip at compressive force of 20 kN for lubricants a) L2; b) L4

Increase of stresses, for the same value of the compressive force, is explained by the contact conditions between the sliding elements and the strip during the drawing process. For the lubricant L4 case, sliding is difficult because of worse lubricating conditions, squeezing of lubricant out of the contact zone and appearance of micro galling. Worse lubricating conditions with lubricant are being manifested by increase of the drawing force due to more difficult sliding between the contact elements, as it was already emphasized earlier (Figures 4a and 6a). The properties of lubricant L2, could be considered as very good, what is especially reflected in low values of the friction coefficient, drawing force, stress distribution in the material and absence of appearance of galling on the contact surfaces of the sliding elements.

4. CONCLUSION

In this paper are united two research approaches, physical modeling, realized by the laboratory experiment, and numerical simulation of the ironing drawing process. By analyzing the obtained results, one can say that the technique of physical modeling with help of the laboratory equipment and numerical simulation by application of the FEM can be successfully used in studying the thin sheet ironing strip drawing process.

The conclusions of these investigations can be summarized in following:

a) Physical experiment is necessary to define the precise input data for numerical analysis. In that way, it is possible to create the numerical model based on experimentally obtained values of the friction coefficient, real tool and working piece geometry, values of the compressive force of the tool elements that provide for thinning.

b) As a result of numerical simulation, the distributions of the effective stresses in the strip material were obtained, as well as values of the drawing (deformation) forces.

c) It is significant to compare values of the deformation forces obtained by physical experiment to values obtained by the numerical simulation. In that way, it is possible to compare applied contact conditions (lubricants) and estimate coincidence of experimentally and numerically obtained values of the deformation forces.

d) Analysis of stresses in the working piece wall, during the thin sheet strip drawing, requires precise values of the friction coefficient.

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