INFLUENCE OF TRIBOLOGICAL CONDITIONS AND CONTINUOUSLY VARIABLE CONTACT PRESSURE ON THE PROCESS OF THE THIN SHEET SLIDING DURING THE FLAT-DIE TEST

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ABSTRACT

Influence of the contact pressure in the deep drawing processes is a very actual research topic in the thin sheets forming technology. In this research a tribological model was developed, based on the process of a strip sliding between the flat contact surfaces during the continuous setting of the variable contact pressure and an original experimental computerized device was created. During the process, a complex multi-factor experiment was conducted, by application of single-sided zinc coated low carbon steel sheet and the variable contact pressure. The oil for deep drawing was applied as a lubricant.

Experimentally obtained variations of the drawing force and the friction coefficient along the sliding path are presented in this paper, as well as the description of the experimental device. Dependencies of the drawing force were obtained for each of the experimental conditions, based on the predefined functional variations of the contact pressure. By calculating the friction coefficient, based on the obtained drawing forces, it is possible to monitor the influence of tribological factors on the process of the strip drawing in the variable pressure conditions. In this way, it is possible to perform the analysis of comparative influence of the contact elements' surfaces conditions and the pressure functions.

KEYWORDS: Deep drawing, Flat-die tribological test, Variable contact pressure, Friction coefficient

1. INTRODUCTION

Possibilities to influence the deep drawing process during its course are limited. They are reduced to influences on the thin sheet flange, mainly through the contact pressure (holding force) and by action of the draw-bead at the holder. In the majority of research thus far, the constant values of the holding force or the pressure of the holder on the deep drawing die were set. The continuous setting of the variable pressure, via the predefined functions, during the sliding process and development of the corresponding physical model, represents the subject of this research, with aim to cover influence of the variable contact pressure, besides the other influences - of the tool, contact conditions, material, etc. Influence of the variable contact pressure in the deep drawing process represents a very actual research topic with objective of discovering the new possibilities for controlling this process. Different physical-tribological models were developed for that purpose, out of which the most present is the model of the strip sliding over the flat surfaces, what is proven by numerous papers on this subject /1-5/. The problem of physical modeling of the deep drawing process, at the thin sheet flange, between the flat surfaces of the holder and the die was considered in those papers. The tribological models were formed in the completely real environment: material, tool, machine, contact conditions, etc. In the majority of investigations, one was monitoring the variation of the friction coefficient and the deformation (drawing) force by varying those real conditions of the process' course. The tool elements of various roughnesses were applied, as well as modifications of surfaces with different hard coatings. The various contact conditions were realized, besides by the tools' contact surfaces, by application of different types of lubricants for deep drawing and thin sheets with various coatings (Al and steel thin sheets). Besides that, the speed of the strip sliding was varied /6-7/. The objective of majority of investigations was to control the output parameters of the deep drawing process, with tendency to obtain the friction coefficients and the deformation forces values, as low as possible, at one hand and the desired geometry, without defects on the flange, at the other /8-11/.

2. EXPERIMENTAL DEVICE

Experimental device, developed for the purpose of this research, represents a simulator for realization and studying of the physical model of an important segment of the deep drawing process in the completely real conditions. This refers to the model of sliding betwen the flat surfaces. The structure of the device basically consists of laboratory tripple-action press *ERICHSEN 142/12*, basic hydraulic-mechanical module, separate hydraulic module and electro-electronic module. The block-scheme of the experimental aparatus is shown in Figure 1. The separate hydraulic module consists of hydraulic aggregate (pump, reservoir, filter, regulatory valve and three-position distributer with manual control), which provides the necessary pressure. The electro-electronic module provides the reliable power control of all the components and program control (PLC) of the hydraulic system for the purpose of realizing the functional pressure variations. The mechanical-hydraulic module (Figure 2) is a part of the device, which is realizing the drawing of the thin sheet sample between the two contact elements. It is mounted on the hydraulic press, which provides the pulling action, while the pressure of the changeable sliding elements (Figure 3) is realized by the hydraulic components of this module /12/.

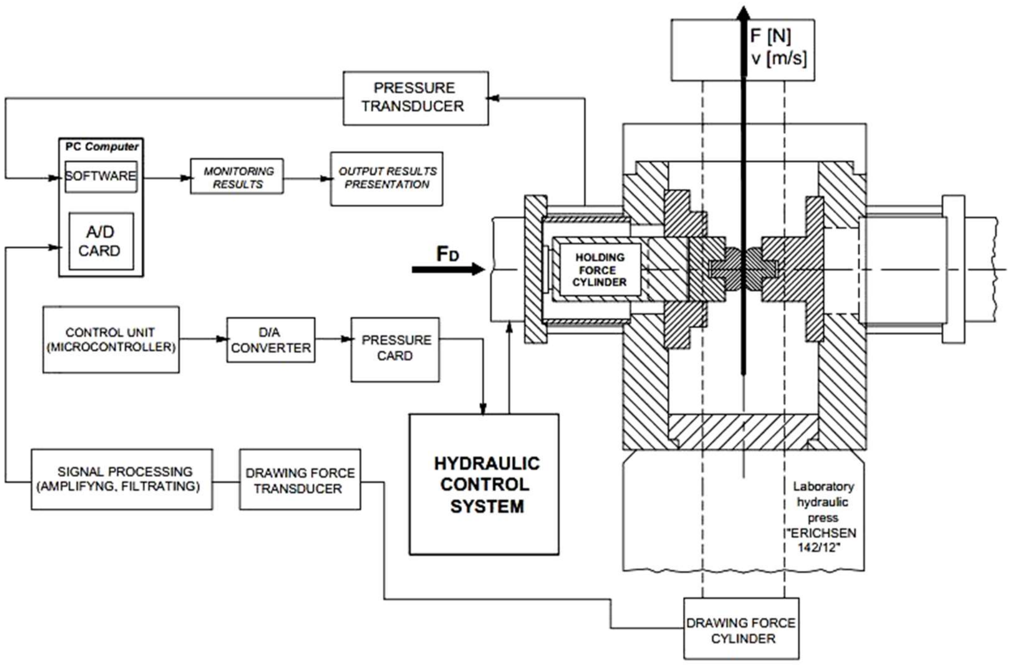


Figure 1: Scheme of the device for drawing the thin sheet strip between the flat contact surfaces

The thin sheet strip is placed between the pair of contact elements with the flat surfaces and radius of 5 mm, which are changeable and made with surfaces prepared in different ways (ground, nitrided, polished and with the TiN coating, Figure 3b). The laboratory hydraulic press *ERICHSEN* with its main action was used for realizing the strip drawing force. The machine main action possesses the sensor which gives the analogue (voltage) signal. The voltage signal at the exit has relatively low intensity, which is amplified, filtered and adjusted to the type of the A/D converter. The A/D converter is built directly onto the connectors of the main board of the PC. The control unit (the microcontroller) is the most important segment of the electro-electronic module, since it provides the support to the control system by the built-in software. It generates the control signals to executive elements of the hydraulic system, via the pressure control card /12/. The program for the four variables of the nonlinear dependencies, two linear and the four constant values of pressure are entered into the microcontroller's memory (Figure 1).

The key element in the hydraulic module is the voltage controllable proportional valve. For the certain value of the voltage signal from the control card, one obtains the certain value of the flow, namely the certain pressure in the cylinder, which provides the holding force. That force is transferred to the changeable contact elements in the hydraulic-mechanical part of the device, which provides the holding of the sample-thin sheet strip. The strip is clamped in the jaws at the upper side of the holder (Figure 2).

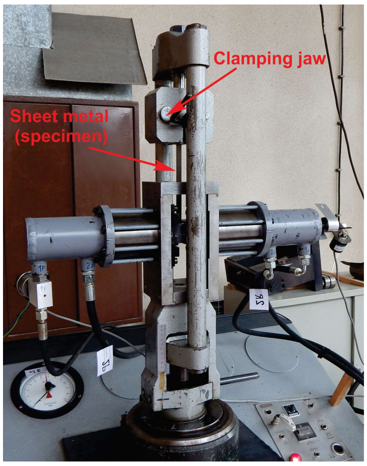
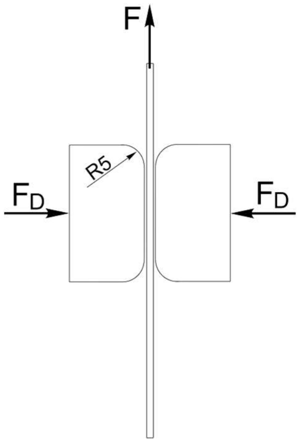


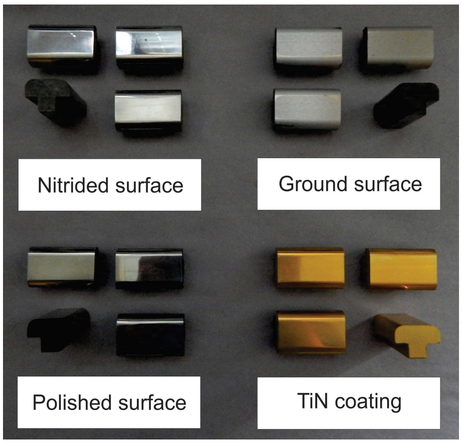
Figure 2. Appearance of the experimental setup

The important element of the electro-electronic module is the device for measurement of the pressure and the drawing force. The pressure sensor is placed at the hydraulic line, which supplies the device for measuring the pressure and the drawing force. The sensor records the pressure released from all the previous losses, incurred from the control valve to the cylinder (Figure 1).

The scheme of the tool contact elements is shown in Figure 3a. The friction coefficient was calculated based on the normal compressive components F_D and the drawing (forming) force F.



(a)

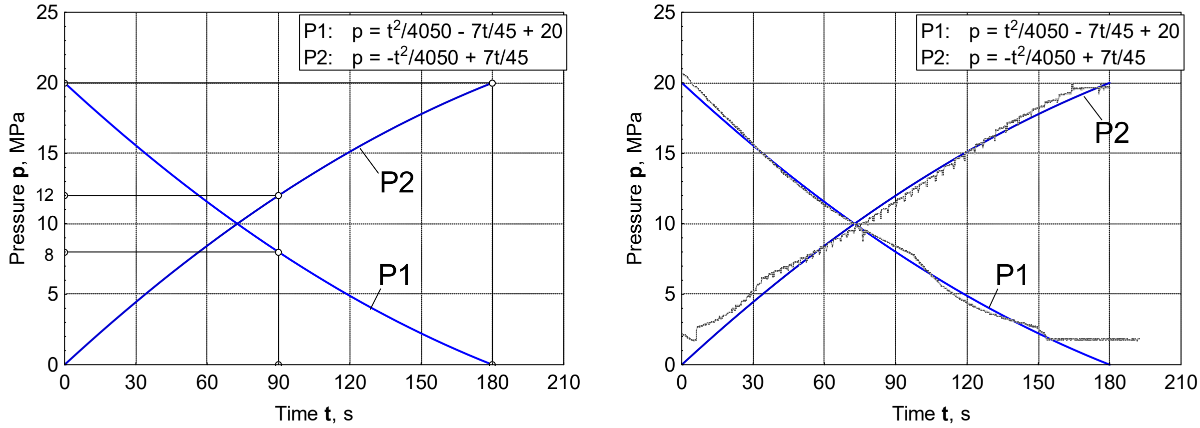


(b)

Figure 3. Scheme of the sliding elements' forces action on the thin sheet strip (a) and appearance of the sliding elements (b)

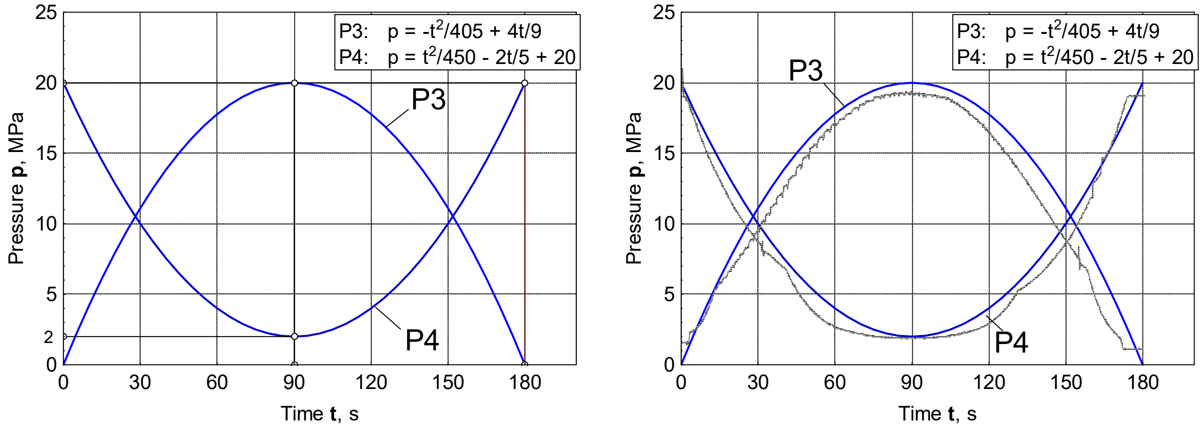
3. PREVIOSLY DEFINED AND ACTUALLY REALIZED PRESSURE DEPENDENCIES

Six variable dependencies of the contact pressure were defined for the needs of the planned experiments. The nonlinear, parabolic dependencies are given by curves presented in Figures 4 and 5 and denoted as P1 to P4. The other two dependencies were linear. Those functions are defined, based on empirical recommended values, in the range 0 to 20 MPa /13-14/. The sliding path of the strip is 60 mm, corresponding to properties of the laboratory press /15/. The drawing speed was selected as 20 mm/min, what enabled solving the control of the process parameters. In that way, the maximum process duration of 180 s was obtained. The parabolic quadratic functions were defined through the three points in empirically defined frame of maximum pressure of 20 MPa and time of 180 s (Figures 4 and 5). The pressure functions ranges were defined with various characters: monotonouslly decreasing (P1), monotonouslly increasing (P2), combined increasing-decreasing (P3) and combined decreasing-increasing (P4). In that way, the possibility was created for investigating the influence of the variable contact pressure on the drawing force, friction coefficient and the roughness variation of the thin sheet and the tool, simultaneously with other influential factors. Other factors, that should be mentioned, are the type of material of the thin sheets, type of coating on the die and influence of different types of lubricants in contact. In this research only one type of lubricant and one type of strip material were used.



(a) (b)

Figure 4. (a) Analytically defined pressure functions P1 and P2; (b) comparative presentation of analytical and experimental dependencies.



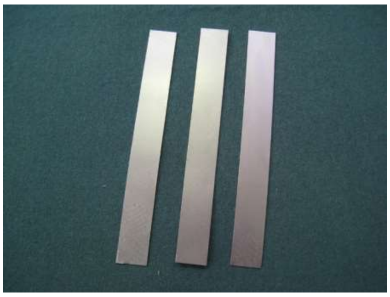
(a) (b)

Figure 5. (a) Analytically defined pressure functions P3 and P4; (b) comparative presentation of analytical and experimental dependencies.

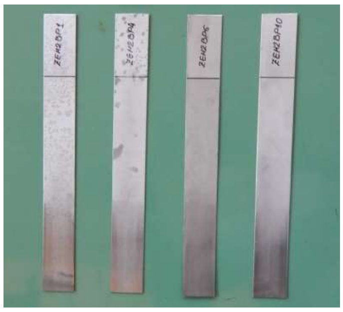
4. RESULTS OF THE REALIZED EXPERIMENT

The complex multi-factor experiment was conducted with the presented device and numerous combinations of tribological conditions in contact. That implies different contact surfaces of the sliding elements, different types of thin sheets and lubricants /16-18/ with simultaneous setting of the previously defined pressure functions P1-P4 (Figures 4 and 5). The linear pressure dependencies were also applied, as well as the constant pressure values. In this paper is presented only a portion of obtained experimental results. The dependencies of the drawing force and the friction coefficient on the sliding path are also given.

The material samples were prepared as strips, 250 mm long, 30 mm wide and 0.8 mm thick (Figure 6). The strips are cut from the low-carbon steel thin sheet DC04+ZE, which was galvanic zinc coated on a single side /15/. The contact surfaces were richly lubricated (by sponge) with mineral oil for deep drawing of the following properties at 40°C: kinematic viscosity $45\cdot10^{-6}$ m^2/s, dynamic viscosity $42\cdot10^{-3}$ Pas and density 0.93 kg/dm^3.



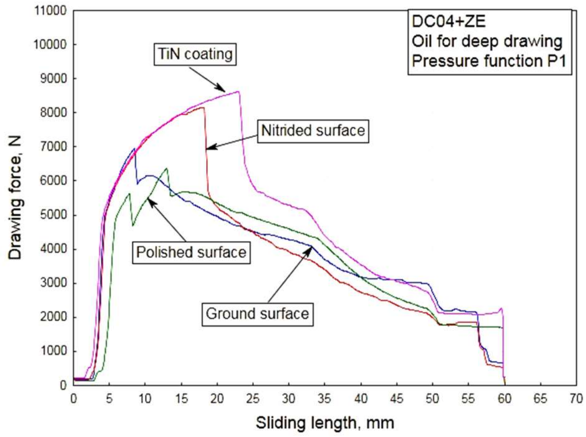
(a)



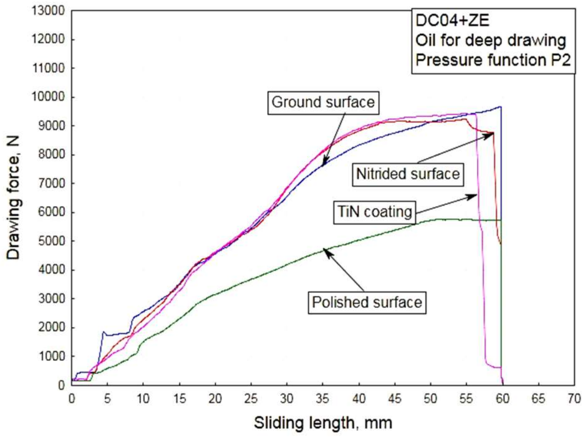
(b)

Figure 6. Photographs of the thin sheet strips made of DC04+ZE: (a) before the drawing process; (b) after the drawing process.

For each of the analytically set pressure functions (P1, P2, P3 and P4) the real variations of pressure, drawing forces (Figures 7 and 8) and the friction coefficient (Figures 9 and 10) were measured. The friction coefficient was calculated by the point-to-point principle for the whole sliding path. The number series, with about 1000 values for the drawing force and pressure, were obtained.



(a)



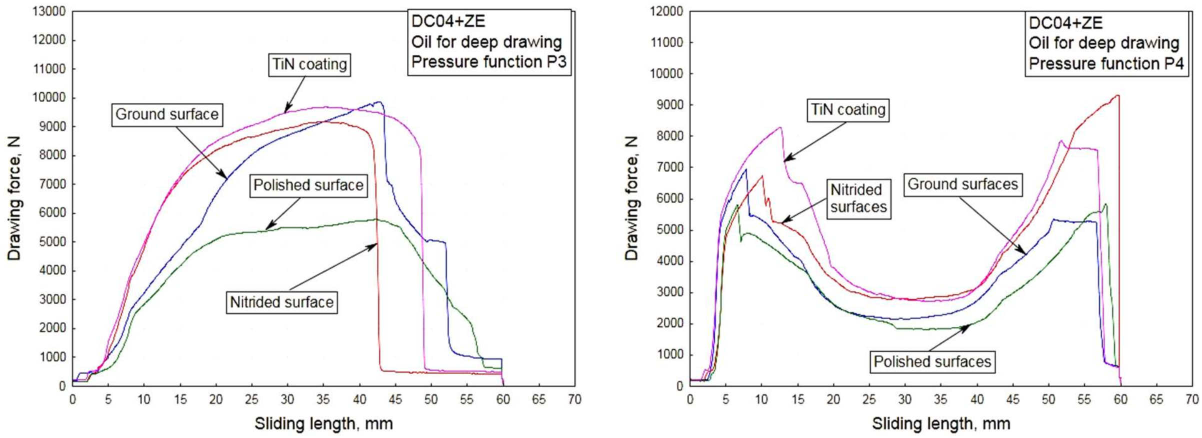
(b)

Figure 7. Dependencies of the drawing forces on the sliding path for pressure functions: (a) P1; (b) P2.

The four types of sliding elements were applied (ground, nitrided, polished and TiN coated surfaces). The basic die material is steel X210Cr12 (EN 10027). In the first case, hardness after the heat treatment was 58 HRC, active surfaces of die elements were ground with average absolute roughness height $R_a \approx 0.3$ μm. In the second case, surfaces of the die elements were ground and nitrided. The nitrided layer thickness was 0.4 mm, $R_a \approx 0.3$ μm and hardness 62 HRC. In the third case, after the fine grinding, the surfaces were polished to $R_a \approx 0.06$ μm. The fourth version was application of the titanium nitride coating of thickness of about 0.1 mm and with roughness $R_a \approx 0.25$ μm.

The influence of the sliding elements on the drawing force can be seen in Figures 7 and 8. The lowest intensity of the drawing forces was recorded for the polished surfaces and the highest for the TiN coating. The polished surface has the lowest roughness and the TiN coating retains the lubricant the worst. For the sliding elements with nitrided surfaces and the TiN coating, the plastic deformation was noticeable, the strips elongation for the case of the P1 pressure function application

(Figure 7a). The deformation occurred in the first part of the sliding path, as a result of the high initial pressure P1. The elongation was present, to a certain extent, in the case of the pressure function P4 action, as well, also in the first part of the sliding path, for the contact surfaces with the TiN coating (Figure 8b) due to the higher pressure values. As it was expected, the character of the drawing force variation is to a great extent caused by the contact pressure function, while its intensity depends on the surface roughness and the lubricant type. Influence of the surface modification is not so pronounced, probably due to the single-phase sliding with cleaning of the die surfaces. The effects of the thin sheet material gluing on the tool surfaces and the tool wear were not considered in this research.



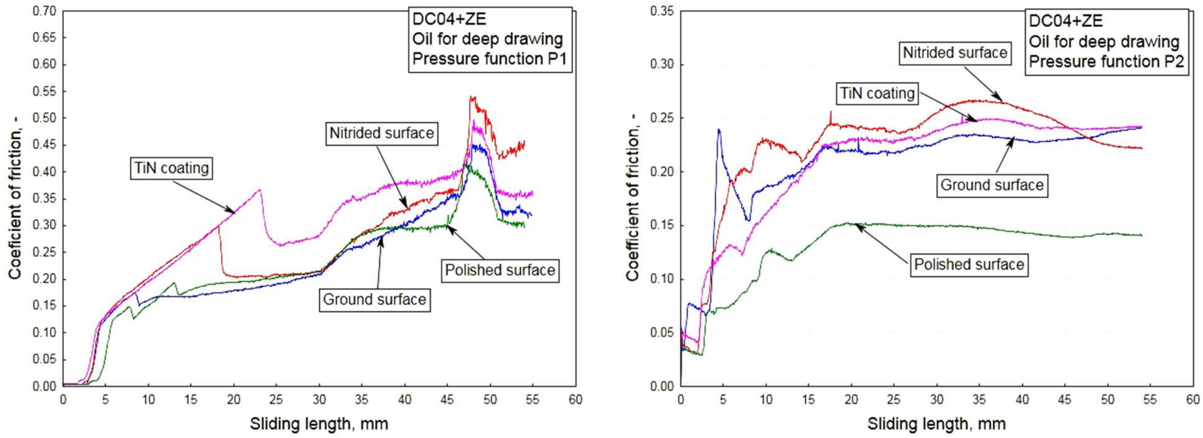
(a) (b)

Figure 8. Dependencies of the drawing forces on the sliding path for pressure functions: (a) P3; (b) P4.

The important property of this physical model is the possibility of calculating the friction coefficient (*μ*) and monitoring its variation during the sliding process. The friction coefficient was calculated according to expression

$$\mu = \frac{F}{2F_D} = \frac{F}{2 \cdot p \cdot A}, \quad (1)$$

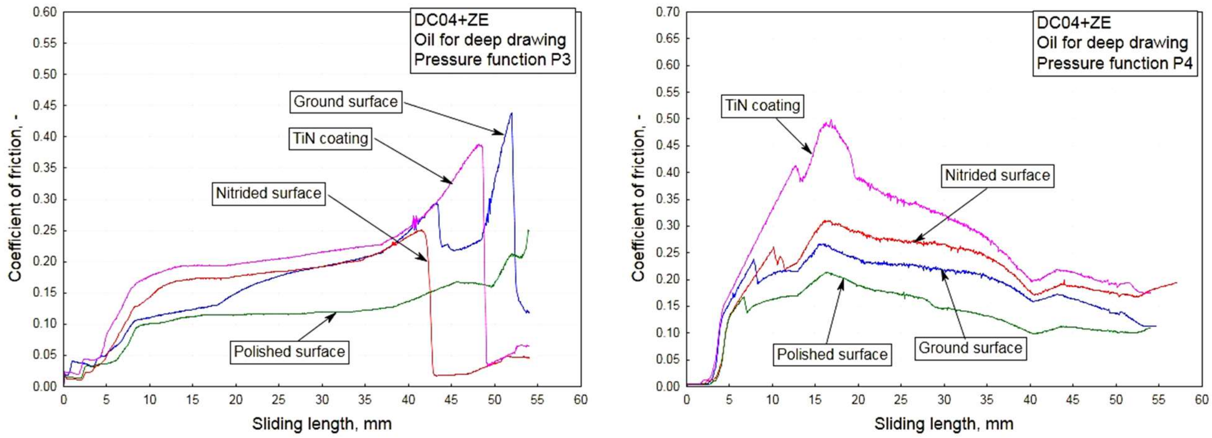
based on the value of the drawing force *F* and the set real function of pressure *p*, for each point in the whole measurement range. It can be noticed that the friction coefficient variations, in all the presented examples, are very sensitive to any change of pressure, i.e. the drawing force. In addition, the character of the friction coefficient variation is related to the character of the contact pressure function. That fact indicates that by variation of the contact pressure one can control directly the drawing force, but also that the influence on the friction coefficient is of a more complex nature. In the zones of the sliding path with the very low values of pressure and the corresponding drawing force intensities, the friction coefficient reaches high values. That is especially prominent for the pressure variations P1 and P3 (Figures 9a and 10a, respectively) close to the end of the sliding path (approximately after 50 mm), when the obtained values of the friction coefficient can become unrealistic. Similar behavior can be observed for the pressure function P4, where the minimum of the curve is at the middle of the path. In that case, the maximum of the *μ* value is moved to the left into the zone of intensive decrease of pressure, with relatively high intensity of the drawing force still present.



(a) (b)

Figure 9. Dependencies of the friction coefficient on the sliding path for pressure functions: (a) P1; (b) P2.

When one considers the possible influence of the character of the pressure function on intensity of the friction coefficient, the positive effect of the increasing function P2 could be noticed, where the maximum value is μ = 0.25. In all the other cases, the values were in the range 0.4 to 0.5. Similar observation is valid for the P3 function, as well, but only for the first 2/3 of the path. After that, the decrease of the contact pressure causes the abrupt increase of the friction coefficient. The differences in the friction coefficients curves positions indicate the influence of roughness, primarily, and then of the ability to retain the lubricant. It is easily ejected from the contact surfaces in the path zones with the high contact pressure, especially when the TiN coating and nitriding were used for the surface modification.



(a) (b)

Figure 10. Dependencies of the friction coefficient on the path for functions: (a) P3; (b) P4.

The good illustration of the previous statement can be observed in Figure 10b. In the first part of the path, the pressure is intensive; the lubricant is being ejected from the contact zone, what results in a relatively insufficient decrease of the drawing force intensity. Finally, in the middle zone of the path, the high values of the friction coefficient are obtained with clearly separated curves according to type of the surface.

5. CONCLUSION

The original experimental device, developed for realization of the physical model of the contact between the flat surfaces is described in this paper. This model is very important for studying the behavior of the thin sheets at the flange during the deep drawing process. Presented results indicate that by the adequate selection of the functional dependence of the contact pressure on the tribological conditions one can influence the thin sheet sliding at the flange. In such a way, this investigation contributes to better understanding of the material behavior and to minimizing the possible problems that are accompanying this process in the real manufacturing conditions.

The conclusions, following from the presented research can be summarized in the following way:

a) The apparatus is completely functional and can successfully realize the set mathematical nonlinear pressure functions what is shown by diagrams of the dependencies of the drawing forces and the friction coefficient (Figure 7 to 10),
b) The character of the pressure function variation directly causes the change of the drawing force, while the influence on the friction coefficient is of the more complex nature,
c) Through the adequate selection of the pressure curve and combination of the type of the surface modification on the tools with the corresponding lubricant, it is possible to significantly influence the sliding process with control of the deformation force and the friction force in the contact,
d) The lowest values of the friction coefficient and the drawing forces were obtained by application of the increasing tendency of the pressure function P2 (Figure 9b) and combined increasing-decreasing tendency of the P3 function in the first 2/3 of the sliding path (Figure 10a),
e) It is possible to avoid the unfavorable situation of permanent local deformation of sheet metal by gradual increase of the pressure from the lowest to the highest value,
f) The titanium-nitride coating did not produce significantly lower values of the friction coefficient due to the surface roughness and worse lubricant retaining in the contact zone. The favorable properties of this coating are manifested in the multiple slips with detachment of particles from the thin sheet material and their tendency towards gluing to the surfaces without coating,
g) It is planned, for the future research, to investigate the influence of different materials on the sliding process (thin sheets made of aluminum alloys, sheets of high strength steels, stainless steel sheets, etc.), as well as influence of various types of lubricants aimed for deep drawing. In addition, the attention should also be paid to experimental investigations of the multi-phase sliding processes, with monitoring the tool wear.

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6. REFERENCES

1. Fratini L., Casto S.L., Valvo E.L., A technical note on an experimental device to measure friction coefficient in sheet metal forming, Journal of Materials processing technology, 172-26 (2006) 16-21.

2. Szakaly E.D., Lenard J.G., The effect of process and material parameters on the coefficient of friction in the flat-die test, Journal of Materials Processing Technology, 210-30 (2010) 868-876.
3. Figueiredo L., Ramalho A., Oliveira M.C., Menezes L.F., Experimental study of friction in sheet metal forming, Wear, 271 (2011) 1651-1657.
4. Coello J., Miguel V., Martinez A., Avellaneda F.J., Calatayud A., Friction behavior evaluation of an EBT zinc-coated trip 700 steel sheet through flat friction tests, Wear, 305 (2013) 129-139.
5. Yanagida A., Azushima A., Evaluation of coefficients of friction in hot stamping by hot flat drawing test, CIRP Annals-Manufacturing Technology, 58 (2009) 247-250.
6. Manoylov A.V., Bryant M.J., Evans H.P., Dry elasto-plastic contact of nominally flat surfaces, Tribology International, 65-21 (2013) 248-258.
7. Kondratiuk J., Kuhn P., Tribological investigation on friction and wear behaviour of coatings for hot sheet metal forming, Wear, 270 (2011) 839-849.
8. Ghiotti A., Bruschi S., Tribological behaviour of DLC coatings for sheet metal forming tools, Wear, 271 (2010) 2454-2458.
9. Lee B.H., Keum Y.T., Wagoner R.H., Modeling of the friction caused by lubrication and surface roughness in sheet metal forming, Journal of Materials Processing Technology, 130/131 (2002) 60-63.
10. Kirkhorn L., Bushlya V., Andersson M., Stahl J.E., The influence of tool steel microstructure on friction in sheet metal forming, Wear, 302 (2013) 1268-1278.
11. Aleksandrovic S., Stefanovic M., Adamovic D., Lazic V., Babic M., Nikolic R., Vujinovic T., Variable tribological conditions on the flange and nonmonotonous forming in deep drawing of coated sheets, Journal of the Balkan Tribological Association, 17-2 (2011) 165-178.
12. Vujinovic T., Deep drawing of thin sheets with control of the sliding at the flange, PhD thesis, Faculty of Engineering, Kragujevac. (2011) (In Serbian).
13. Stefanovic M., Tribology of deep drawing, monograph, Yugoslav Society for Tribology and Faculty of Mechanical Engineering, Kragujevac. (1994) (In Serbian).
14. Emmens W., Tribology of Flat Contacts and its Applications in Deep Drawing, PhD thesis, University Twente, The Netherlands. (1997) (In English).
15. Aleksandrovic S., Babic M., Nedeljkovic B., Vujinovic T., Taranovic D., Lazic V., Milosavljevic D., Variable drawbead height and variable contact pressure as tribological influences in sheet metal stripe sliding test, Journal of the Balkan Tribological Association, 18-2 (2012) 184-194.
16. Djordjevic M., Aleksandrovic S., Lazic V., Arsic D., Nikolic R.R., Hadzima B., The variable contact pressure influence on the tensile force in the process of strip sliding in the flat die in ironing, Materials Engineering - Materialove inzinierstvo, 23-2 (2016) 74-83.
17. Peña-Parás L., Maldonado-Cortés D., Taha-Tijerina J., García-Pineda P., Tadeo Garza G., Irigoyen M., Gutiérrez J., Sánchez D., Extreme pressure properties of nanolubricants for metal-forming applications, Industrial Lubrication and Tribology, 68-1 (2016) 30-34.
18. Mucha J., Jaworski J., The tool surface wear during the silicon steel sheets blanking process, Eksploatacja i Niezawodnosc – Maintenance and Reliability, 18-3 (2016) 332-342.