THE VARIABLE CONTACT PRESSURE INFLUENCE ON THE TENSILE FORCE IN THE PROCESS OF STRIP SLIDING IN THE FLAT DIE IN IRONING

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Resume

Possibilities to influence the deep drawing process during its duration are limited and generally consist of influences at the flange of the thin sheet, mainly by the contact pressure (the blank holding force). The common characteristics of previous investigations were setting of the fixed values of the blank holding force or the holder's pressure within the ironing tool. The objective of this investigation was the continuous setting of the variable pressure during the sliding process, via the preset functions, in order to analyze the variable pressure influence on the ironing process.

This is why an experimental computerized device was designed and constructed for analyzing the influence of the variable contact pressure on the sliding process of the model strip during the flat-die test. The multi-parameter experiment was conducted; various materials of the tested pieces were applied (primarily thin sheet made of Al alloys and low-carbon steels sheet, with and without coating); different versions of the tool's contact elements were used, with various friction regimes and influential parameters (variable contact pressure during the sliding process, etc.). This experimental device practically represents a simulator for realization and studying of the physical model of an important segment of the ironing process in the completely realistic conditions (materials, tools, etc.).

The aim was to find the optimal combination of the variable contact pressure and the tribological parameters, so that the punch force, as one of the process output parameters, would have the minimal value, as well as to avoid the undesired effects during the forming (difficult sliding of the flange, appearance of thin sheet's wrinkling, structural destruction, etc.).

Understanding the mutual dependence of the holder's variable pressure and other influences should enable improvement of the ironing process control and should contribute to better understanding of the phenomena occurring at the thin sheet's flange.

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1. Introduction

Possibilities to influence the deep drawing process during its time of conducting are limited. They are reduced to influence on the thin sheet flange, mainly through the contact pressure (the blank holding force) and by action of the draw beads on the holder. The characteristics common to all the previous investigations in this field were setting of the fixed values of the blank holding force or the holder's pressure within the ironing tool. The objective of this investigation was continuous setting of the variable pressure during the sliding process, via the preset functions, in order to analyze the variable pressure influence on the ironing process, as well as other influences (die, contact conditions, material, etc.).

Influence of the variable contact pressure in the ironing process represents a very interesting current topic of research with the aim of discovering the new possibilities for control of this process. This is why the physical-tribological models are being developed. The most present is the model of the strip sliding between the flat surfaces, investigated in numerous papers in this area [1 - 5]. The problems of the ironing process modeling at the flange between the flat contact surfaces of the holder were considered in those papers. The tribological models were formed in the completely real environment: material, tool and machine, contact conditions, etc. In the majority of investigations, researchers were monitoring the variation of the friction coefficient and the punch (deformation) force, by varying the mentioned real conditions in which the process is conducted. They were using the dies with surfaces of different roughness. Different contact conditions were realized, not only by varying the states of the dies contact surfaces, but also by application of several types of lubricants for ironing and thin sheets with various coatings (Al and steel sheets), as well. In addition, it is possible to vary the sliding speed of the strip [6, 7]. The objective of the majority of investigations was to control the output parameters of the ironing process. The tendency is to obtain the least values of the friction coefficient and the deformation forces, on one hand, while on the other to obtain the parts of the desired geometry, without defects on the flange (wrinkles) [8 - 10].

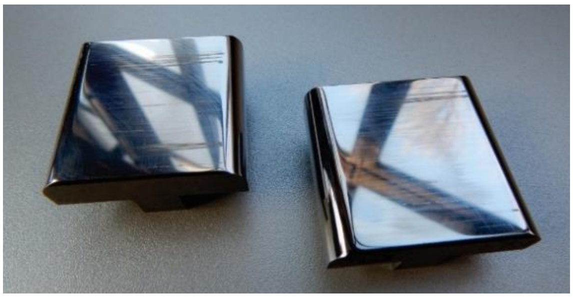
Fratini et al. in [1] presented experimental investigations of the friction coefficient during the sliding of the thin sheet strips. The measurement system for the data acquisition was relatively simple and it monitored the variation of the force at the strip during the sliding process. The device enabled application of strips made of different thin sheets, as well as the cylindrical tool made of various materials. It was possible to set different contact conditions depending on the applied lubricant, coating on the material and the tool, roughness, etc. The obtained results were reliable, applicable in the thin sheets ironing processes, with the similar schematics of sliding. Szakaly and Lenard [2] were using a massive constructed device with the large contact surface. The contact pressure had constant values within range 1 to 15 MPa. Only one regime of the mixed friction was realized while the tool roughness was varied. Results obtained for the friction coefficient dependences mainly confirmed the known influences. The friction coefficient decreases for the higher speeds and contact pressures. However, the higher roughness did not always result in increase of the friction coefficient values. Figueiredo et al. in [3] presented experimental investigation of the friction coefficient in thin sheets on the two models. Results show that the test by the crossed sliding produced the lower values of the friction coefficient and that the reason for that probably was somewhat higher value of the contact pressure. In addition, they noticed that the friction coefficient decreased with realized number of passes due to the running-in process of surfaces. Coello et al. [4] presented voluminous investigation of the effects of the strip sliding between the flat surfaces. The thin sheet was made of the high strength steel with zinc coating and roughness in the form of bumps. Due to such roughness, it was expected that micro-pockets of lubricant would be formed and maintained what would cause the more favorable lubricating conditions. Authors have determined dependences of the friction coefficient on the sliding speed and the contact pressure for various lubricating conditions. The friction coefficient was decreasing with increase of the sliding speed and pressure, but not with increase of the lubricant layer's thickness. Kalbarczyk et al. [5] were monitoring the variation of the friction coefficient in terms of the contact pressure, temperature and applied lubricants. Besides the expected influences, authors especially emphasized that the effect of lubricants was significantly lower in thin sheets with the aluminum coating. Manoylov et al. [6] were considering the possibility of solving the dry contact problems that arise when the lubricant film is not thick enough to prevent the contact between the working surfaces. For that purpose, they were using the simple elastic-plastic model whose results were compared to results obtained by the FEM modeling of the rough surfaces contacts. Kondratiuk and Kuhn [7] were considering the friction and wear behavior of coatings during the hot sheet strip drawing. They were comparing the friction coefficient and worn mass loss in coated strip drawing of two coating alloys – Al-Si and the Zn-Ni. The electro-plated Zn-Si after the heat treatment had higher mass loss, but the lower friction coefficient, while the Al-Si coated blanks had more aggressive wear behavior, i.e. the adhesive wear to the die. Ghiotti and Bruschi [8] were studying the tribological behavior of the DLC (diamond-like-carbon) coatings as solution to appearance of the dry contact between the blank and the tool surfaces. They concluded that in the lubricated conditions the type of coating does not significantly influence the friction coefficient. However, in the dry coating conditions only the DLC coating has the friction coefficient value lower than in the lubricated conditions. Lee, Keum and Wagoner [9] were modeling the friction caused by different lubricants and surface roughness by designing the sheet metal friction tester. They verified the validity and accuracy of their model by comparing the tribological parameters results, obtained by the model, to experimental measurements' results. Kirkhorn et al. [10] were studying the influence of the tool steel microstructure on the friction in sheet metal forming. They concluded that the direct correlation between the amount of carbides in different steels and the friction coefficient during the sheet forming could not be reliably established. Bachchhav et al. [11] were studying the influence of various types of lubricants on tribological phenomena during the ironing process and they have ranked the tribological parameters according to their influence of the metal forming. Kalbarczyk et al. [12] considered the influence of three different oils of the scuffing of the concentrated friction joints with the low-friction coated elements, by the four-balls scuffing test. They were studying the PVD (plasma-vapor-deposited) coatings and concluded that the coatings take the role of additives to the lubricants used in the process. Djordjević et al. [13, 14] were studying the influence of different lubricants types on the multi-phase ironing process, while Pena-Paras et al. [15] considered the properties of the nano-lubricants and their properties under the extreme pressure during the ironing process. Addition of copper or titanium nano-particle additives to various lubricants results in increase of the load-carrying capacity of those lubricants and of the seizure loads, as well.

2. Experimental equipment and conditions

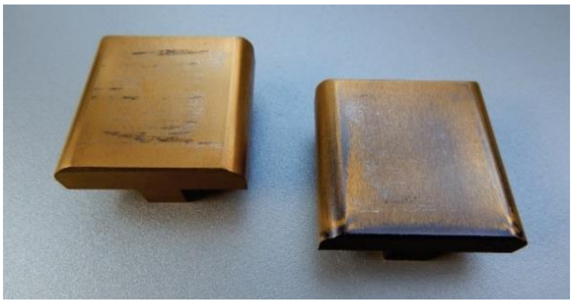
The experimental device, which was developed for this research, represents a simulator for realization and studying of the physical model of an important segment in the deep drawing process in the completely real conditions. The structure of the device consists of the hydraulic, electrical and mechanical modules. The hydraulic module consists of hydraulic aggregate (the pump, reservoir, filter, regulatory valve and the three-position distributer with manual control) and it provides the necessary pressure. The electric module provides reliable power to all the components and programmed control of the hydraulic system, to realize the functional pressure variations. The mechanical module (Fig. 1a) is the part of the device, which realizes the pulling of the sample between the two contact elements. It is mounted on the hydraulic press, which provides the pulling action, while the pressure of the sliding elements is realized by the hydraulic module.

The two materials of the working pieces were applied in the form of thin strips made of the Al alloy and the low-carbon steel thin sheets. The contact elements were prepared in two versions (Fig. 1b, c); the two friction regimes were applied (lubricating grease based on MoS_2 and oil for deep drawing) and four functions of the contact pressure variation, which is being set simultaneously during the process.

a) mechanical part of the device



b) contact elements with polished surface



c) contact elements with the TiN coating.

Fig. 1. Mechanical part of the device with sliding elements.

(full colour version available online)

The pressure functions are predefined in advance and they are set by the electro-module (micro controller), which controls the hydraulic system (Fig. 2). The pressure is being set simultaneously during the drawing process and it is coupled with the pulling action provided by the hydraulic press. The setting time of functions is 180 s, what corresponds to the drawing step of 60 mm (Figs. 3 and 4).

3. Results and discussion

In Figs. 3 and 4 are presented graphs of the punch forces for samples made of the aluminum alloy and the low carbon steel thin sheets, for the four pressure functions shown in Fig. 2. The following conditions were applied for both materials' thin sheets: polished flat surfaces, the grease based on MoS_2 (Fig. 3), the TiN coating on the flat surfaces of the contact elements and deep drawing oil (Fig. 4). Besides the same conditions for both materials, there is a slight difference in the punch force values, though the trends on the curves are similar. There are somewhat higher values for all the contact pressure functions for the steel sheets. This could be explained by the better retaining of the lubricant on the aluminum sheets than on the steel one. In addition, the aluminum sheet is more deformable and it possesses better machinability than the steel sheets, thus the smaller punch forces are needed for its forming.

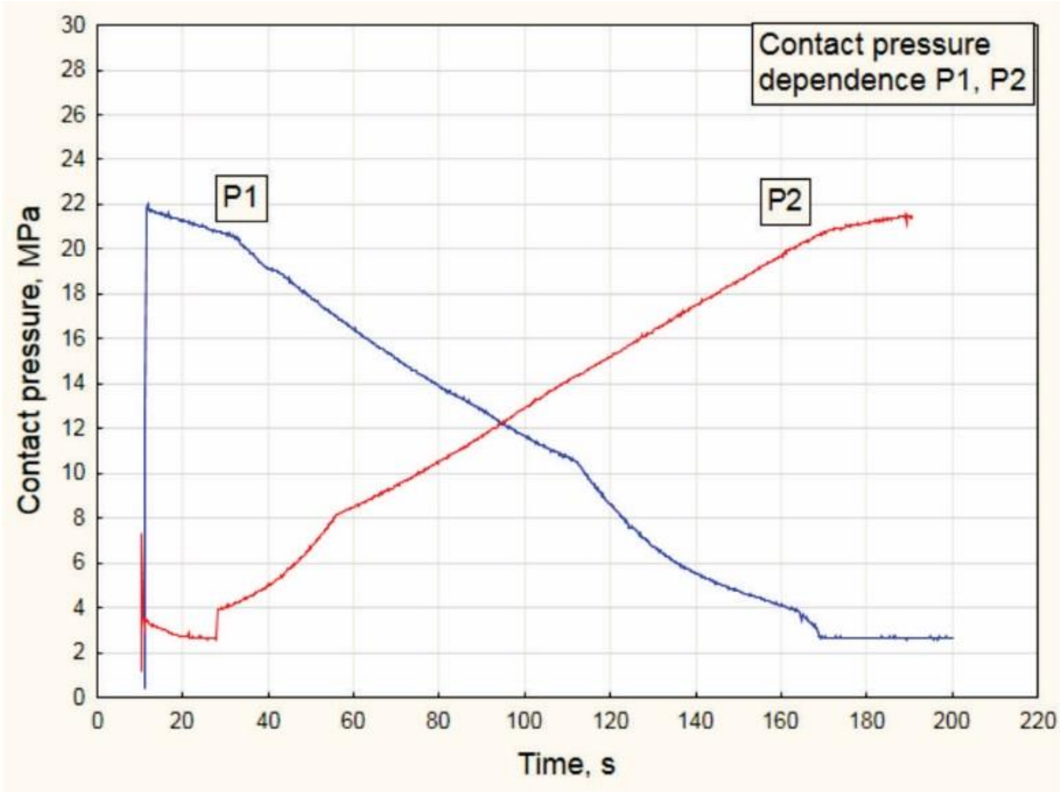
From both graphs in Fig. 3 one can notice that the highest values of the punch force were obtained by application of the pressure functions P2 and P3 (Fig. 2). The P2 function is of the increasing character and so is the P3 function up to the half of the step.

Increasing of the punch force worsens the sliding conditions, especially for the P2 functions, since the pressure gradually increases and it could squeeze out a large portion of the lubricant. For the P3 function, one could notice the prominent increase of the punch force in the first half of the step; with the pressure decrease in the second half the sliding conditions are improving and accordingly the punch force curve decreases. For the P1 and P4 functions, one could notice lower values of the punch force (Fig. 3a, b), what is a consequence of the decreasing character of pressure. The punch forces values thus show that it is better to start the process with the maximal pressure and then decrease it gradually during the drawing step (P1 and P4), than to start with the lowest pressure (P2 and P3) and then increase it gradually. One of the reasons for such behavior is the better retaining of the lubricant during the decreasing pressure phase, what was confirmed by experiments. The pressure curve P4 decreases more intensively in the first part of the step than the P1 curve during the whole step, thus the values of the punch force are lower for the P4 pressure curve.

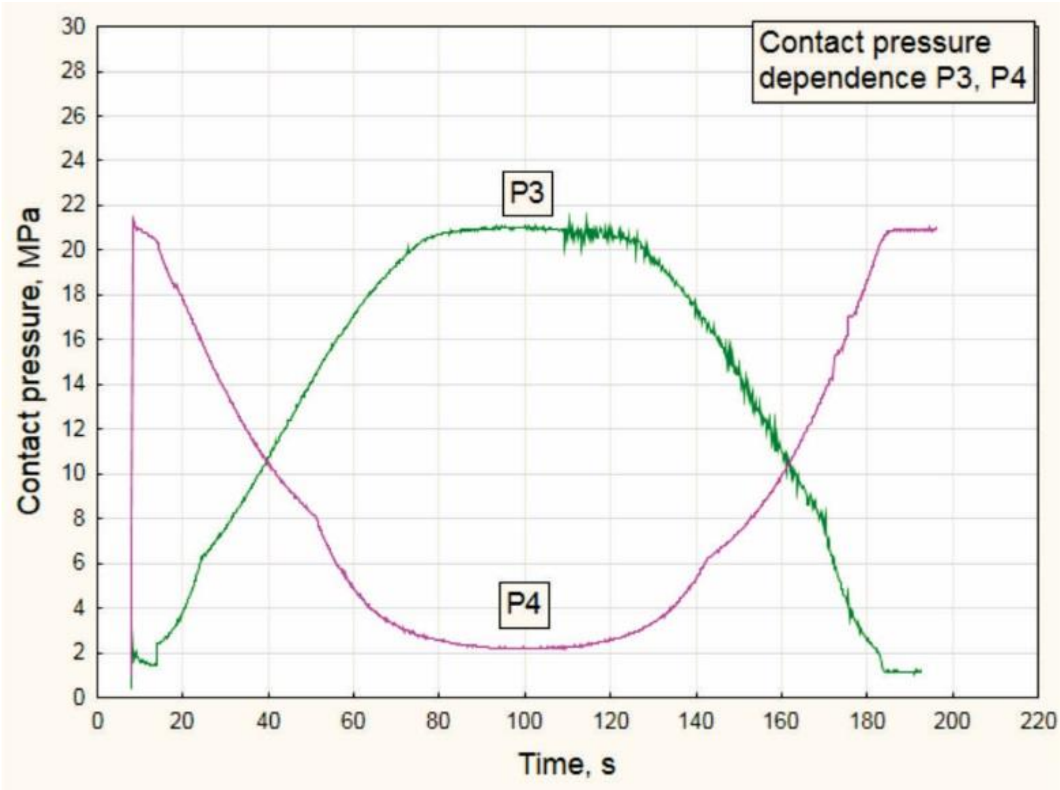
In the second case are presented graphs of the punch force realized in somewhat different tribological conditions, (Fig. 4). The flat contact surfaces are coated by the titanium nitride (TiN) and as a lubricant the oil for deep drawing was applied. This oil, as it is known, has worse lubricating properties than the MoS_2 based grease. Those are the reasons that the significantly higher values of the punch forces were obtained for both strips, since sliding is more difficult. The high values of the contact pressure only augment the effect of the worsen lubricating by the oil. It possesses lower viscosity and density than the MoS_2 based grease, thus it can easier be squeezed out of the contact zone.

The highest values of the punch forces were obtained for application of the decreasing pressure function P1. It has the highest values of the contact pressure at the beginning of the step and at that moment the oil is squeezed out, what, as a consequence, has difficult strip sliding, even stopping (seizure). The P1 curve has the slow decreasing trend so the "braking" effect is being extended up to the half of the step, all the way to the point when the pressure reaches the value when the sliding becomes possible. The complete seizure results in thin sheet elongation, what could be concluded based on the punch force graph trend, which resembles the uniaxial tension diagram (P1, Fig. 4a, b). On the P2 and P4 punch force graphs one could notice the constant tendency at the beginning of the step, which could be explained by the strip skidding within the punch jaws, as a results of the difficult sliding. The punch force starts to increase from the moment when the blank holding force within the jaws supersedes the value that causes the constant pressure.

For the case of the P4 curve, the highest values of pressure at the beginning of the step are quickly superseded due to the more intensive decreasing trend (Fig. 2b) with respect to the P1 curve (Fig. 2a), thus as a results the difficult sliding does not occur and values of the punch force are very low during the large portion of the step (Fig. 4a, b). The punch force graph is completely in accordance with the pressure curve P4, i.e. the force has the lowest values at the portion of the step where the pressure is the least and the highest values at the beginning and at the end of the step. The P4 curve could be considered as the optimal pressure variation since the values of the punch force are the lowest of all the applied pressure functions, regardless of the fact that the lubricating is done by oil or the MoS_2 based grease. For the force graphs obtained by application of the P2 and P3 pressure functions the similar conclusions could be drawn for this case as for the case when lubrication was done with the MoS_2 based grease.



a) increasing (P1), decreasing (P2)



b) increasing-decreasing (P3) and decreasing-increasing (P4)

Fig. 2. Predefined functions of the contact pressure.

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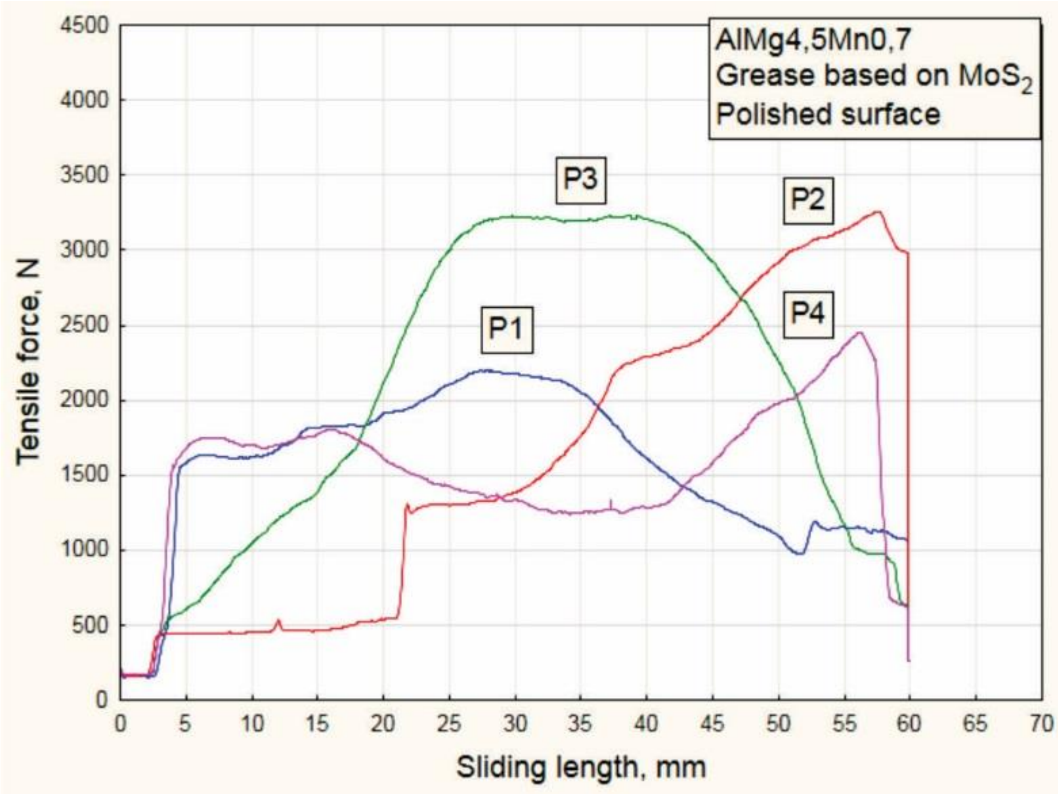
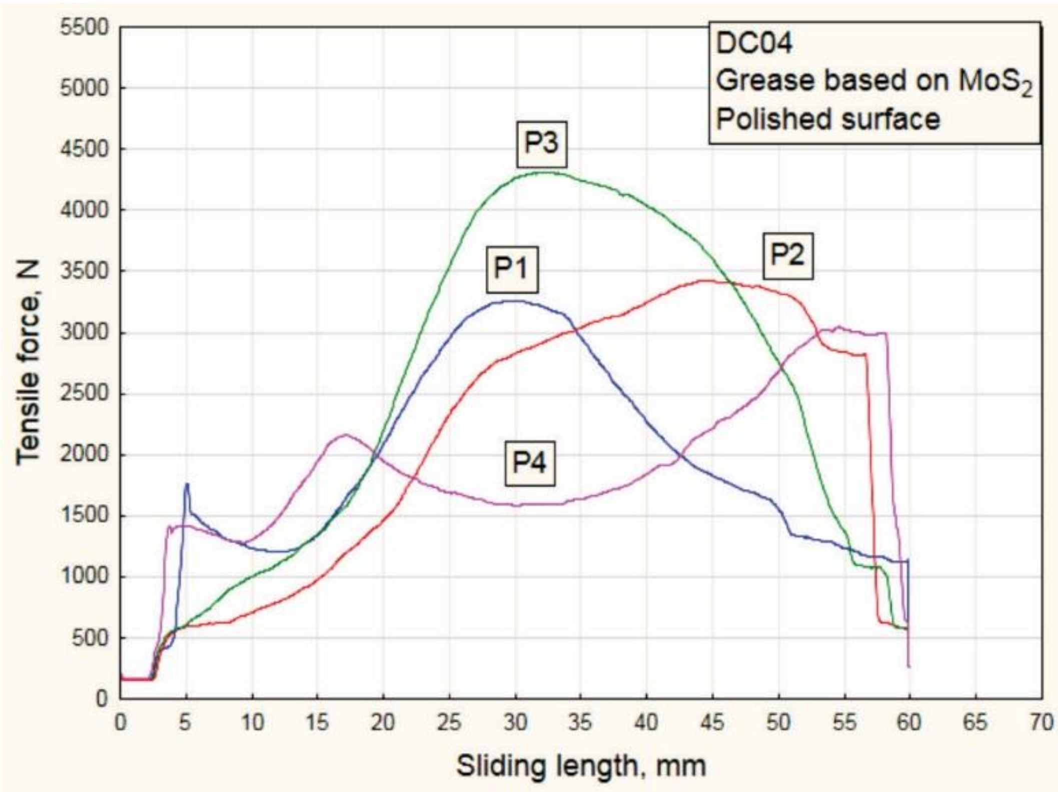


a) Al-alloy strip



b) low-carbon steel strip

Fig. 3. The punch forces graphs for the strip sliding between the polished contact surfaces and the MoS2 based lubricating grease.

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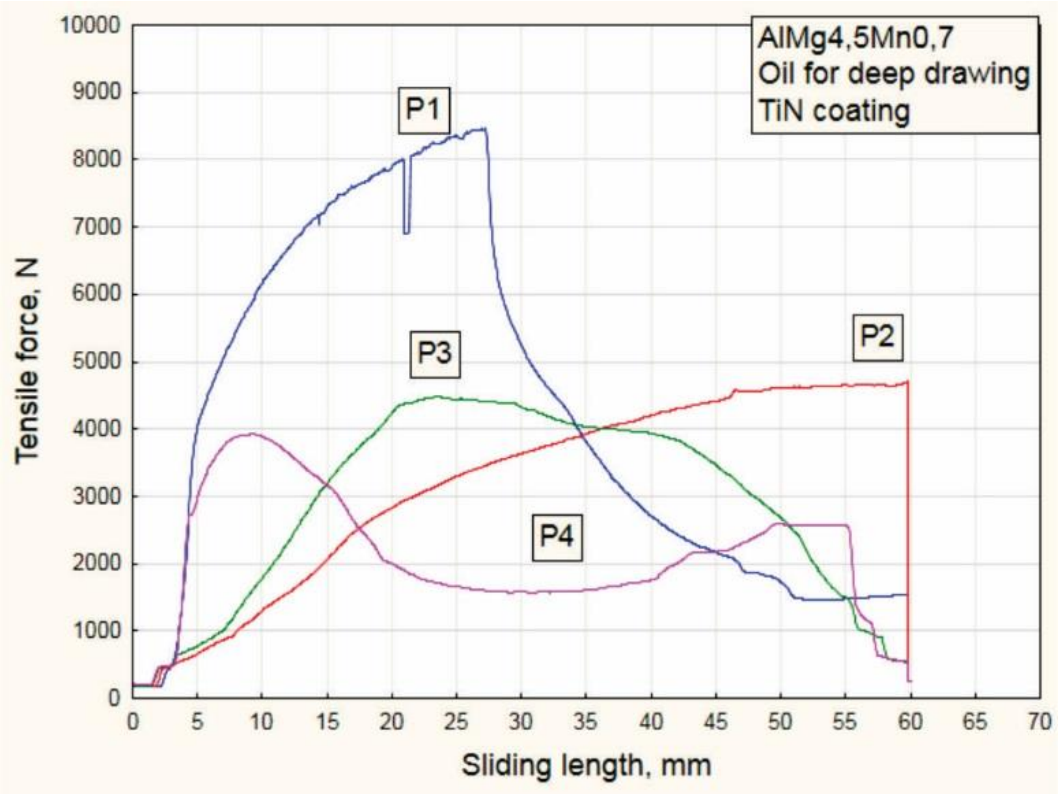
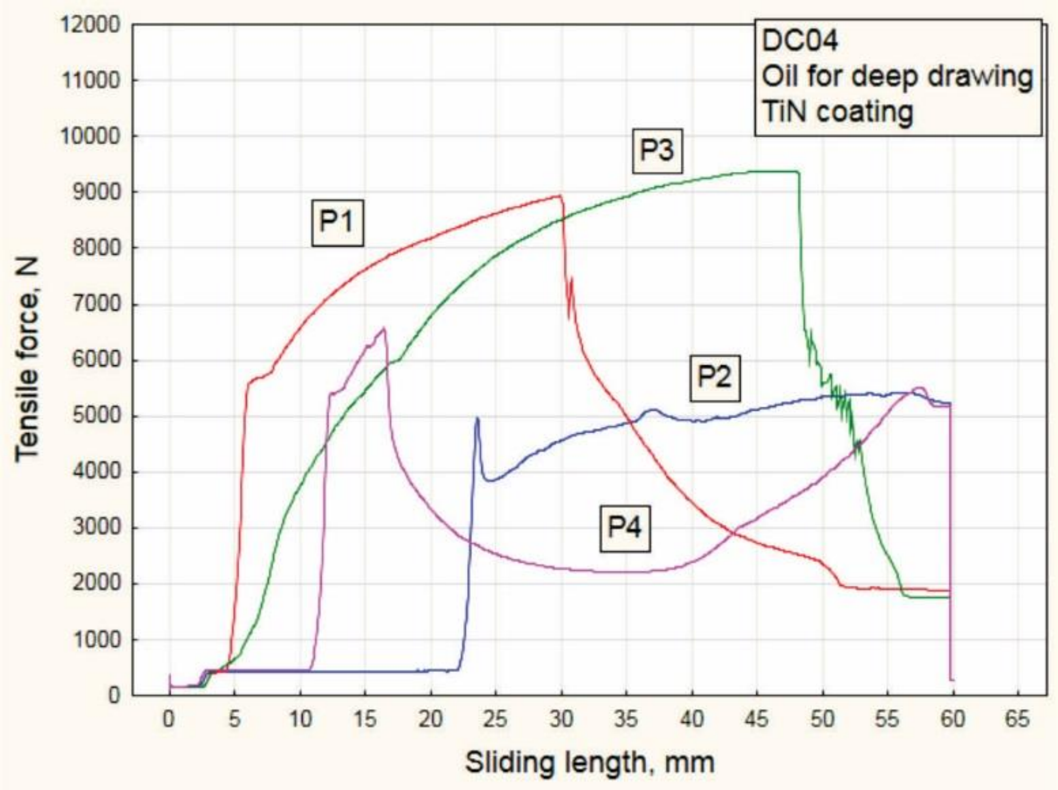


a) Al-alloy strip



b) low-carbon steel strip

Fig. 4. The punch forces graphs for the strip sliding between the contact surfaces with the TiN coating and the deep drawing oil.

(full colour version available online)

4. Conclusion

Based on the conducted research, the following conclusions can be drawn:

a) Realization of this experimental apparatus and obtained results has the broader significance as the alternative approach in an area of the high technology. With the adequate changes in the mechanical part of the device, as well as in the control system, it is possible to investigate the influence of the drawing bead at the thin sheet flange, by setting the variable pressure;

b) The character of the punch force response shows that by the adequate combination of the simultaneous action of the contact pressure and the friction conditions one can influence the thin sheet forming process in a substantial and controlled manner;

c) The optimal combination of the tribological conditions and the variable pressure implies producing the tool's contact surfaces with the least roughness, application of the lubricant with good lubricating properties and the pressure variation with the more intensive decreasing trend in the first half of the step (P4). It is recommended to avoid the increasing pressure variation functions (P2 and P3), especially when the lubricant with worse properties is applied;

d) Application of the new materials, like the thin sheets made of the high strength steels, thin sheets with anti-corrosive coatings, stainless steel thin sheets, laminate and TWB thin sheets, etc. represents additional possibilities for using this apparatus in further investigations.

The presented results show that by the adequate selection of functional relation between the contact pressure and the tribological conditions one can successfully control the thin sheet sliding at the flange in the ironing process. In that way, it is contributed to better understanding of the material behavior at the flange and to minimizing the numerous problems that are accompanying this process in the real manufacturing conditions.

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Note

The shorter version of this research was presented at the SEMDOK 2016 International Seminar, 27. – 29. January, 2016, Terchová, Slovak Republic, reference [16].

References

[1] L. Fratini, S. L. Casto, E. L. Valvo: J. Mats. Process. Technol. 172(26) (2006)16-21.

[2] E.D. Szakaly, J.G. Lenard: J. Mats. Process. Techno. 210(30) (2010) 868-876.

[3] L. Figueiredo, A. Ramalho, M. C. Oliveira, L.F. Menezes: Wear 271 (2011) 1651-1657.

[4] J. Coello, V. Miguel, A. Martinez, F.J. Avellaneda, A. Calatayud: Wear 305 (2013) 129-139.

[5] A. Yanagida, A. Azushima: CIRP Annals-Manufac. Technol. 58 (2009) 247-250.

[6] A.V. Manoylov, M.J. Bryant, H.P. Evans: Tribology International 65(21) (2013) 248-258.

[7] J. Kondratiuk, P. Kuhn: Wear 272 (2011) 839-849.

[8] A. Ghiotti, S. Bruschi: Wear 271 (2010) 2454-2458.

[9] B.H. Lee, Y.T. Keum, R.H. Wagoner: J. Mats. Process. Technol. 130-131 (2002) 60–63.

[10] L. Kirkhorn, V. Bushlya, M. Andersson, J.E. Stahl: Wear 302 (2013) 1268-1278.

[11] B.D. Bachchhav, G.S. Lathkar, H. Bagchi: Indus. Lubrication and Tribology 66(6) (2014) 640-644.

[12] M. Kalbarczyk, R. Michalczewski, W. Piekoszewski, M. Szczerek: Eksploatacja

i Niezawodnosc – Maintenance and Reliability 15(4) (2013) 319-324.

[13] M. Djordjević, S. Aleksandrović, V. Lazić, M. Stefanović, R. Nikolić, D. Arsić: Mater. Eng.–Mater. Inž. 20(3) (2013) 147-152.

[14] M. Djordjević, D. Arsić, S. Aleksandrović, V. Lazić, D. Milosavljević, R. Nikolić: J. Balkan Trib. Assoc. 22 (2016) (in press).

[15] L. Peña-Parás, D. Maldonado-Cortés, J. Taha-Tijerina, P. García-Pineda, G. Tadeo, G. M. Irigoyen, J. Gutiérrez, D. Sánchez: Ind. Lubr. and Trib. 68(1) (2016) 30-34.

[16] M. Djordjević, S. Aleksandrović, R. R. Nikolić, V. Lazić, D. Arsić: In Proc. of Abstracts of "SEMDOK 2016" – 21st International Seminar, Terchova, Slovakia 2016, p. 10.