ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20161215205553
Original scientific paper

# Simulation of Flat Die Deep Drawing Process by Variable Contact Pressure Sliding Model

Milan DJORDJEVIĆ, Srbislav ALEKSANDROVIĆ, Slaviša DJAČIĆ, Aleksandar SEDMAK, Vukić LAZIĆ, Dušan ARSIĆ,
Milan MUTAVDŽIĆ

**Abstract:** Influence of the contact pressure in the deep drawing processes is a very actual research topic in the metal forming technology. Within this research the tribological model of the strip sliding in the flat die was developed. The original experimental computerized apparatus for testing of the strip sliding in the variable contact pressure conditions was developed, as well. The complex, multi-factor experiment was performed by application of the Al thin sheet, with the contact elements of various roughnesses, with different lubricants application and with the variable contact pressure. Besides the description of the developed apparatus, the theoretical way for determination of the pressure dependences was also presented. Based on the theoretical changes of pressure, set in advance, the real influence of the contact pressure was obtained, for each of the given conditions. That makes possible to determine the influence of the tribological factors on the actual pressure. The obtained real contact pressure has verified the reliability of the experimental apparatus, namely the degree of the theoretical pressure dependences deviation from the real ones.

**Keywords:** computerized experimental apparatus; contact pressure; deep drawing; flat-die test; friction coefficient; tribological model

## 1 INTRODUCTION

There are just a few options to influence the deep drawing process, mainly by the contact pressure effect on the thin sheet flange and by the draw beads action at the holder. In majority of researches in this field, presented until now, the pressure within a die was set as constant. This research is focused on the variable pressure, i.e. on its continuous setting during the sliding process via functions established in advance, as well as on development of the matching real model. Influence of the variable contact pressure is the actual subject of research, in order to discover the new possibilities for controlling this forming process. Analysis shown in paper did not take into consideration the other influential factors (the die, the contact conditions, material etc.).

For that purpose, various physical-tribological models were developed, of which the most present is the flat die sliding model [1]-[5]. The problem treated in those papers, was the modeling of the deep drawing process at the thin sheet flange, at the flat contact surfaces between the holder and the die. The tribological models were created taking into account all relevant factors like material, die, machine, and contact conditions enabling monitoring of variation of friction coefficient and drawing force.The tools of various surface roughness were applied. The contact conditions were realized, besides by the contact surfaces conditions, as well as by application of many types of the deep drawing lubricants and by thin sheets with different coatings. Besides that, variation of the sliding speed of the thin sheet was enabled, [6]-[8]. The objective was typically how to control the output parameters of the process in order to reduce deep friction coefficient and drawing forces as much as possible, on one side, and to get desired geometry without the wrinkles at the flange on the other side, [9]-[11].

An experimental evaluation of the friction coefficient during the thin sheet strip sliding is presented in [1]. The simple measurement system records the force variation on the strip (specimen), including cylindrical dies and strips made of different sheets, with or without certain coatings. Contact conditions can be set depending on applied lubricant, die and material coatings, roughness, etc. The reliable results were obtained, which could be used in the forming processes of the thin sheets with the similar sliding schematics. In investigation, reported in [2], another device was used, which was of more massive build. The realized contact pressure was from 1 to 15 MPa. Only one (mixed) friction regime was used. Experiment assumed variation of the die surface roughness. Obtained results confirmed the current findings. For the higher sliding speed and the higher contact pressures the friction coefficient values were decreasing. However, the higher roughness of the die did not always imply the higher values of the friction coefficient. Authors of paper [3] presented a research of the friction coefficient of thin sheets effects on two models. The results have shown that by the cross-sliding test one can obtain reduced friction probably because of slightly increased contact pressure. It was also noticed that the friction coefficient decreases with the number of realized slidings due to the surfaces running-in effect. Extensive investigation of the thin sheet sliding between the flat surfaces was reported in [4]. The zinc coated thin sheet was made of high strength steel and roughness in the form of asperities was determined. One would expect that such roughness would cause creation and retaining of the micro-pockets of lubricant and more favorable friction conditions, with respect to classical thin sheets. The researchers concluded that friction coefficient was decreasing with increase of the sliding speed and the contact pressure. Increase of thickness of lubricant layer does not affect the obtained results. In paper [5] the influence of lubricant, tempearture and contact pressure on the friction coefficient was monitored. Besides the usually expected results, it was especially emphasized that the influence of lubricant was mainly weaker for the sheet made of aluminum.

## 2 EXPERIMENTAL INVESTIGATIONS

### 2.1 Tribological Aspect of the Flat Die Sliding

The deep drawing complex parts are accompanied by numerous influental parameters, making it one of the most complex and demanding forming processes. Therefore, the principle of physical modeling of this complex part characteristics is applied, which is used as a basis for complete tribological modeling of the process, [12], Fig. 1a. The thin sheet sliding (strip pulling) between the flat surfaces of the holder and the die (model "A", Fig. 1a) corresponds to zones of the working piece that are not subjected to lateral compression but only to stretching in the radial direction. The drawing force, as a consequence of the pulling action, is transferred via the die's edges rounding to the zones below the holder, Fig. 1b.

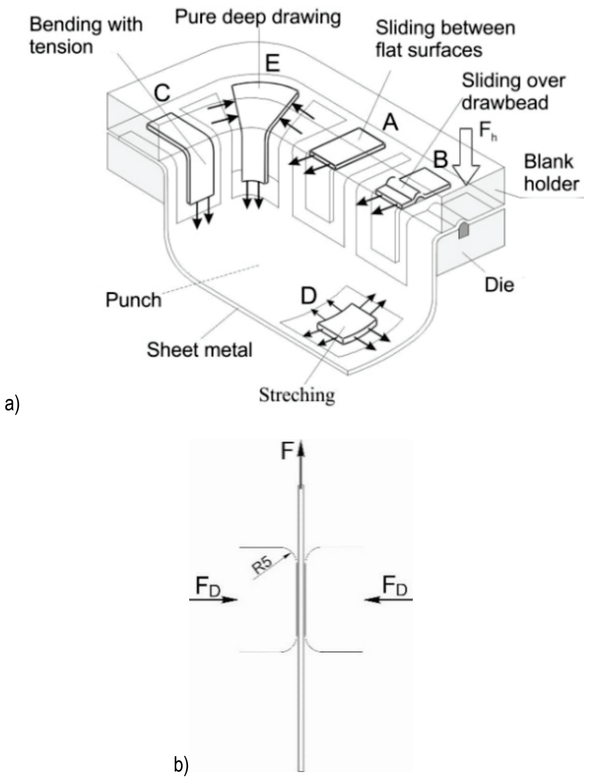


**Figure 1 a)** Scheme of the physical modeling of the parts with the complex geometry; **b)** Scheme of the flat dies test.

The surface pressure during the sliding is lower than the yield strength, so deformation remains elastic. Changes on the contact surfaces (wear, glued particles) can disturb the stable course of the sliding process. Otherwise, the failure of the drawed part can occur [13], [14].

## 2.2 Experimental Apparatus

The experimental apparatus, developed especially for this investigation, is shown in Fig. 2 and explained in more details in [15].

The control unit (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. The control signals to the executive elements of the hydraulic system are generated via the pressure control card [15].

The key element in the separate hydraulic module is the voltage proportional valve. For a certain value of the voltage signal from the control card one obtains a certain flow, namely a certain pressure in the cylinder which ensures the blank holding force. That force is transferred to the exchangeable contact elements in the hydraulic-mechanical part of the apparatus, which provides the holding of the sample – the thin sheet strip. The strip is clamped in the jaws at the top side of the holder, Fig. 2. Fig. 3 shows the exchangabe sliding elements.

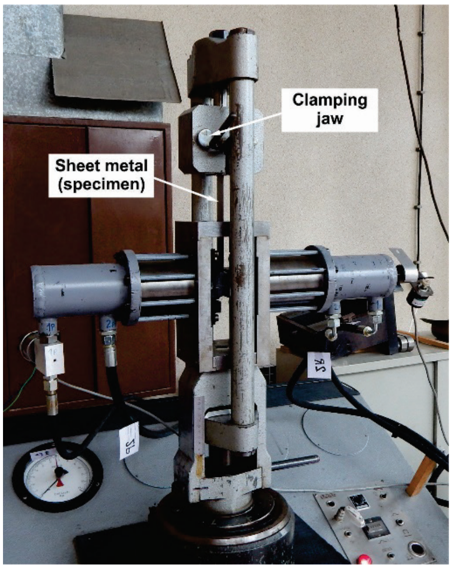


**Figure 2** Mechanical part of the apparatus during the pulling

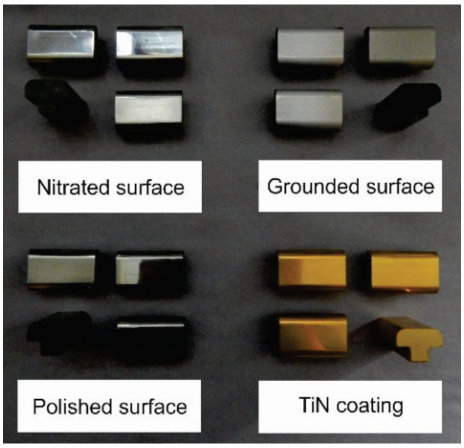


**Figure 3** Exchangeable sliding elements

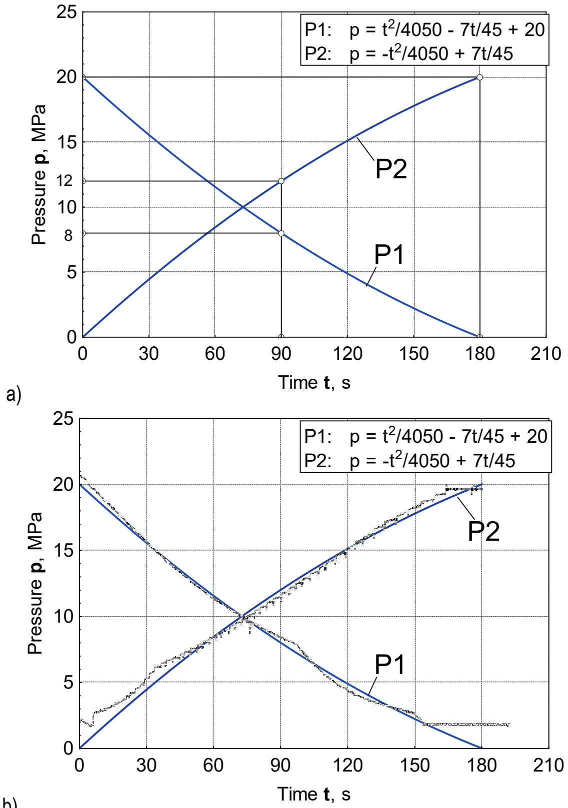
## 3 PREVIOUSLY DEFINED AND REALIZED PRESSURE DEPENDENCIES

Six variable dependencies of the contact pressure in terms of time were predefined for the needs of the planned experiment. Those dependencies are presented in Figs. 4 to 6; curves are marked as P1 to P6. Dependencies P5 and P6 are linear, while P1 to P4 are non-linear. Functions are defined based on empirical values of the minimum and maximum pressure (0 to 20 MPa) [16], [17]. The pressure step is 60 mm, corresponding to the properties of the laboratory press [18], [19]. The pulling speed of 20 mm/min was chosen, what enabled solving the process parameters control. In that way, the maximum duration of the process of 180 s was obtained. The parabolic square functions were defined through the three points in the empirically defined frame 20 MPa – 180 s, Figs. 4 and 5. The wide range of the pressure functions of various characters was formed – the monotonically decreasing (P1), monotonically increasing (P2), combined increasing-decreasing (P3), combined decreasing-increasing (P4), linear – increasing (P5) and linear-decreasing (P6). In such a way a possibility was created for investigation of the influence of the variable contact pressure on the drawing force, the friction coefficient and variation of the thin sheet surface roughness, simultaneously with other influential factors. Of those factors one should mention the type of the thin sheet material, type of the coating on the die and influence of the various types of lubricants in the contact.

The objective was to obtain the answers to the following questions:

a) Is it possible to directly change the drawing force and the friction coefficient by changing the character of the contact pressure function?

b) How much could other influences (materials, coatings, lubricants) disturb the pressure action and transfer of the pressure function character onto the drawing force?



a)

b)

**Figure 4 a)** Analytically pre-defined pressure functions; **b)** Comparative presentation of the analytical and the experimental pressure dependencies.

The general form of the quadratic function is given by expression

$$p = a \cdot t^2 + b \cdot t + c\,, \tag{1}$$

where $a$, $b$ and $c$ are the unknown constants. For the pressure curve P1 (Fig. 4a) the constants were determined from the following conditions:

At $p$ =20 MPa and at $t$ = 0 Eq. (1) gives

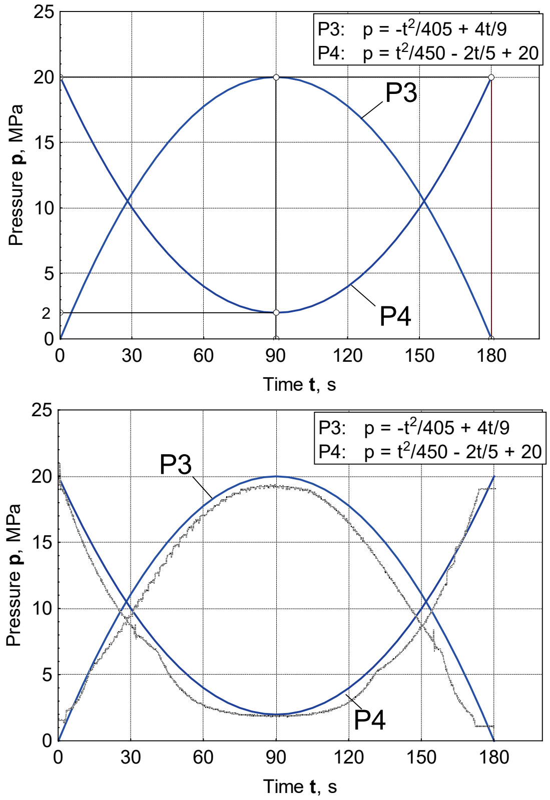
$$c = 20. \tag{2}$$

At $p$ =0 MPa and at $t$ = 180 Eq. (1) gives

$$0 = 32400 \cdot a + 180 \cdot b + 20. \tag{3}$$

At $p$ =8 MPa and at $t$ = 90 Eq. (1) gives

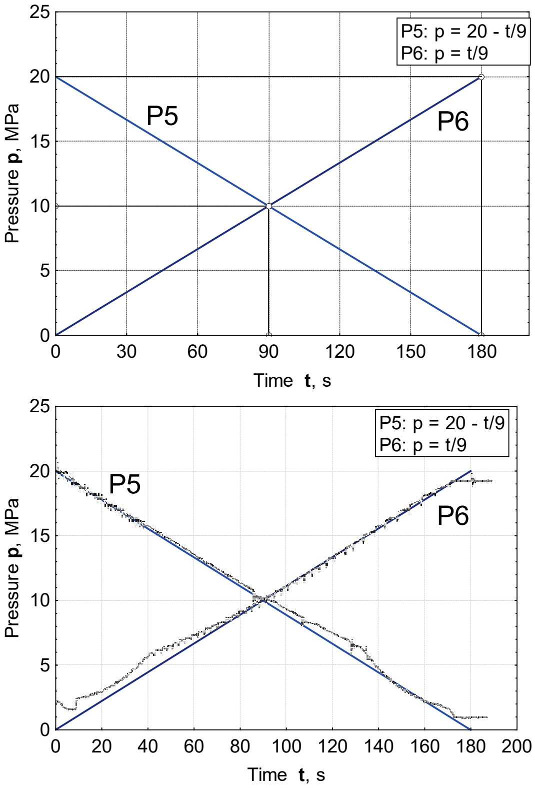
$$8 = 8100 \cdot a + 90 \cdot b + 20. \tag{4}$$



a)

b)

**Figure 5 a)** Analytically pre-defined pressure functions; **b)** Comparative presentation of the analytical and the experimental pressure dependencies



a)

b)

**Figure 6 a)** Analytically pre-defined pressure functions; **b)** Comparative presentation of the analytical and the experimental pressure dependencies.

Based on Eqs. (3) and (4) one solves for the other two unknown constants:

$$a = \frac{1}{4050};\; b = -\frac{7}{45} \tag{5}$$

and obtains the expression for the pressure variation function P1 as

$$p = \frac{1}{4050}t^2 - \frac{7}{45}t + 20. \tag{6}$$

By analogous procedure one can obtain expressions for the pressure functions P2 to P4, Figs. 4a and 5a. Defining the linear functions P5 and P6 is similar and simple, Fig. 6. The real pressure dependencies, shown in Figs. 4b, 5b and 6b were realized for the sake of comparison, without activating the drawing force.

## 4 EXPERIMENTAL RESULTS AND DISCUSSION

The complex, multi factor experiment was realized with the presented apparatus, with numerous combinations of the tribological conditions at the contact. That implies various roughnesses of the contact surfaces of the sliding elements, various types of thin sheets and lubricants [19]-[22], with simultaneous setting of previously defined pressure dependencies P1 to P4 (Figs. 4 and 5). Numerous results were obtained caused by different combinations of the aforementioned conditions. This paper presents only a portion of results, which is related to analysis of the realized pressure dependencies in terms of the drawing step, on aluminum thin sheet AlMg4.5Mn0.7 (0.9 mm), for two types of lubricants (oil for deep drawing and the lubricating $MoS_2$ based grease) for the set pressure functions P1 to P4.

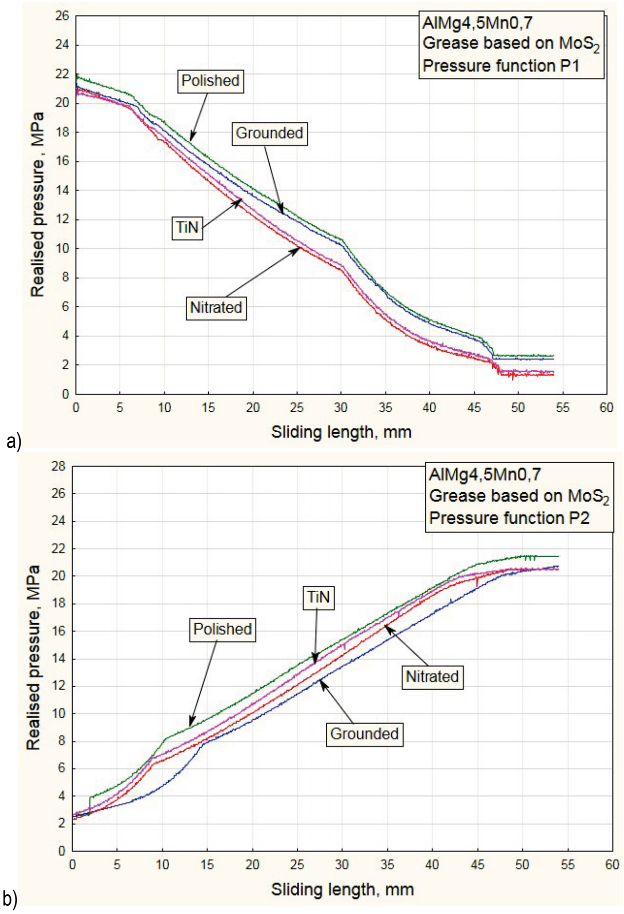


**Figure 7** Obtained pressure dependencies with application of the $MoS_2$ based lubricating grease: **a)** P1; **b)** P2.

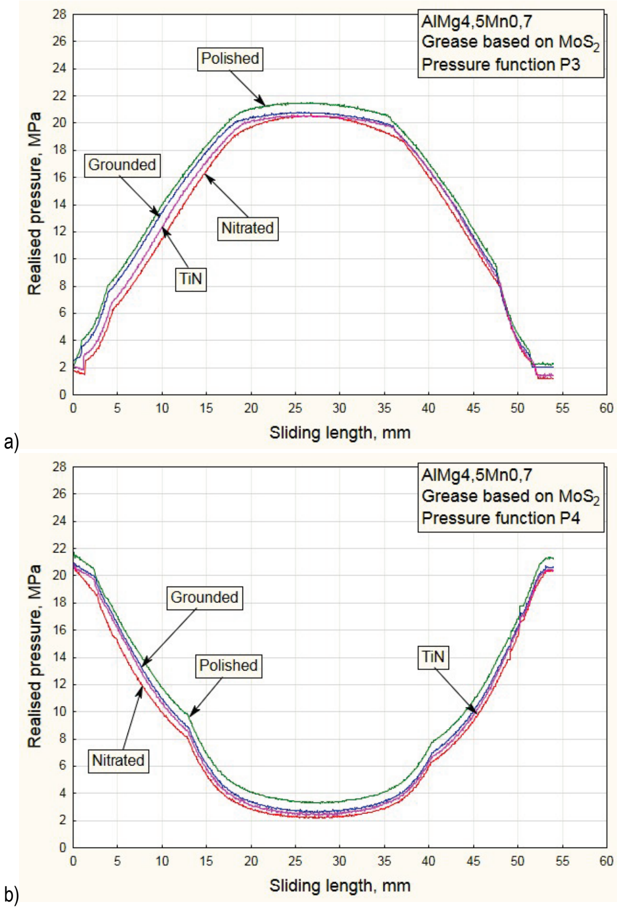


**Figure 8** Obtained pressure dependencies with application of the $MOS_2$ based lubricating grease: **a)** P3; **b)** P4.

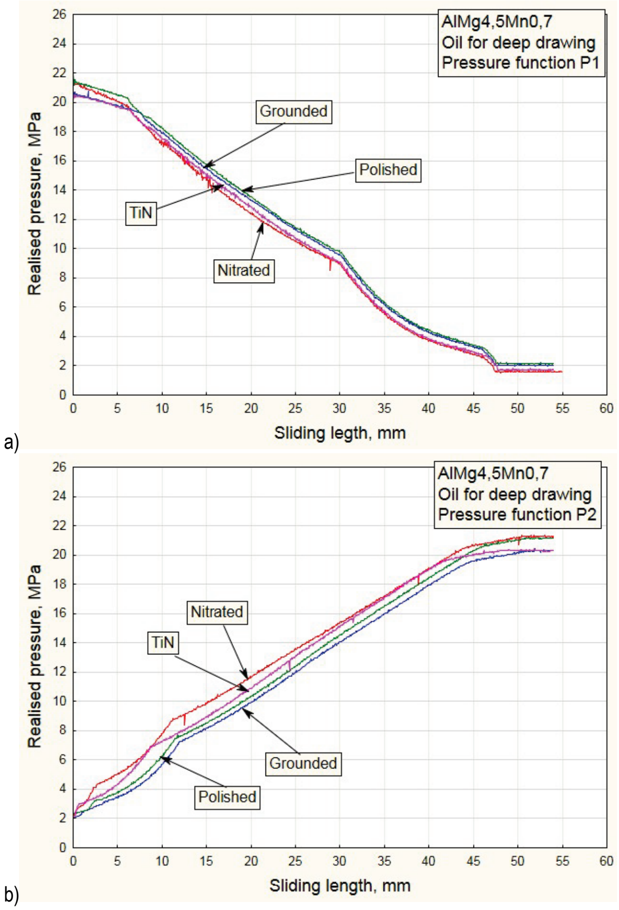


**Figure 9** Obtained pressure dependencies with application of oil for deep drawing: **a)** P1; **b)** P2.

The emphasis was to compare the real pressure dependencies with every analytical function (P1 to P4). Four different types of the contact surfaces of the punches were applied (ground, nitrided, polished and TiN coated), Figs. 7 to 10. In this way it was possible to deduce conclusions on operation of the designed apparatus, i.e. to what extent are present certain deviations of the realized pressure curves from the theoretically obtained curves, under the mentioned conditions. Besides that, it was also possible to determine how strong the influence of the tribological conditions on the really attained pressure is.

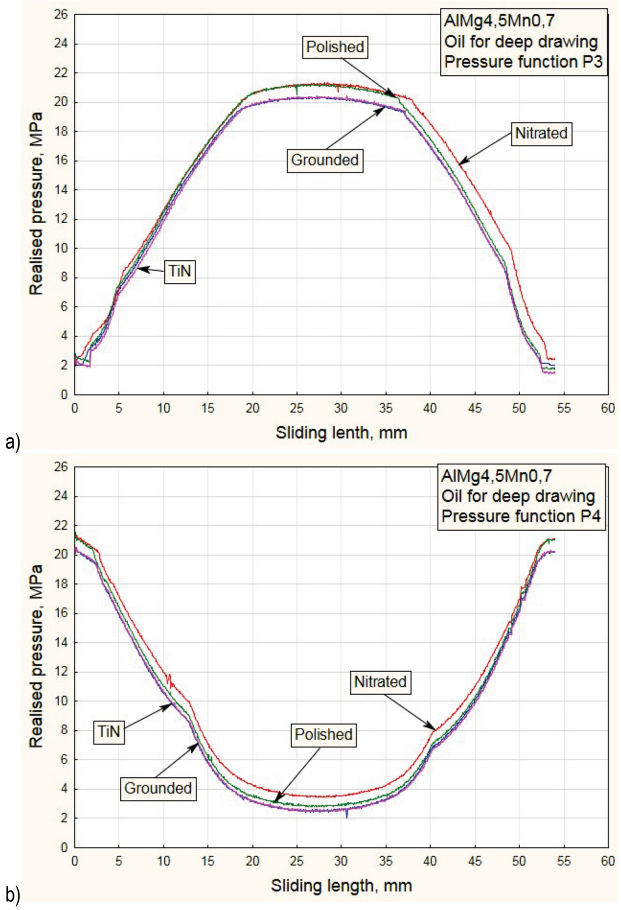


**Figure 10** Obtained pressure dependencies with application of oil for deep drawing: **a)** P3; **b)** P4.

The curves of really obtained pressure are following the set of analytical curves with minor deviations, for both the case of intensive friction (lubricating with oil) and the case of the lower friction (application of the lubricating $MoS_2$ based grease). Influence of the contact surfaces type on the real pressure is minimal. Coalescence of curves is especially prominent for the case of the pressure function P4 for lubricating with the $MoS_2$ based grease (Fig. 8b) and also for the function P1 for lubricating with oil, Fig. 9a. Some deviation was noticed for diagrams in Figs. 9b and 10a, what could be ascribed to somewhat larger roughness of the nitrided surface and appearance of sticking of material particles to the die, what is a consequence of long duration of the test. All the deviations were relatively small and within the acceptable limits.

## 5 CONCLUSION

Based on obtained experimental results, one can draw the following conclusions:

a) The apparatus is fully functional and it is capable of successfully realizing the set mathematical functions of pressure variations, what is shown in diagrams of the really obtained pressure dependencies (Figs. 7-10). Repeatability of results is very good and only minimal deviations from the theoretical pressure functions were present (Figs. 4-6).

b) Influences of lubricant type and surfaces conditions on the measured pressure were negligible. Varying the mentioned tribological conditions would lead to different dependencies of drawing force and friction coefficient, what gives scope for the future research and application of the developed apparatus.

c) Introduction of experimental apparatus (together with obtained results) has large significance in a modern technology of thin sheets forming. With appropriate modification of the mechanical and control system, it would be possible to explore other influences as well, including drawing beads at the flange.

d) For the future research the plan is to use different materials for the thin sheets such as TWB, TRIP and TWIP sheets, the high strength steels, stainless steels and others.

### Acknowledgements

Research presented in this paper was financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia through Grants TR 34002, TR 35021 and TR35024.

## 6 REFERENCES

[1] Fratini, L., Casto, S. L., & Valvo, E. L. (2006). A technical note on an experimental device to measure friction coefficient in sheet metal forming. *Journal of Materials Processing Technology, 172*(26), 16-21. https://doi.org/10.1016/j.jmatprotec.2005.08.008

[2] Szakaly, E. D. & Lenard, J. G. (2010). The effect of process and material parameters on the coefficient of friction in the flat-die test. *Journal of Materials Processing Technology, 210*(30), 868-876. https://doi.org/10.1016/j.jmatprotec.2010.01.019

[3] Figueiredo, L., Ramalho, A., Oliveira, M. C., & Menezes, L. F. (2011). Experimental study of friction in sheet metal forming. *Wear*, 271, 1651-1657. https://doi.org/10.1016/j.wear.2011.02.020

[4] Coello, J., Miguel, V., Martinez, A., Avellaneda, F. J., & Calatayud, A. (2013). Friction behavior evaluation of an EBT zinc-coated trip 700 steel sheet through flat friction tests. *Wear*, 305, 129-139. https://doi.org/10.1016/j.wear.2013.06.002

[5] Yanagida, A. & Azushima, A. (2009). Evaluation of coefficients of friction in hot stamping by hot flat drawing test. *CIRP Annals-Manufacturing Technology*, 58, 247-250. https://doi.org/10.1016/j.cirp.2009.03.091

[6] Manoylov, A. V., Bryant, M. J., & Evans, H. P. (2013). Dry elasto-plastic contact of nominally flat surfaces. *Tribology International, 65*(21), 248-258. https://doi.org/10.1016/j.triboint.2013.02.029

[7] Kondratiuk, J. & Kuhn, P. (2011). Tribological investigation on friction and wear behavior of coatings for hot sheet metal forming. *Wear*. 270, 839-849. https://doi.org/10.1016/j.wear.2011.02.011

[8] Ghiotti, A. & Bruschi, S. (2010). Tribological behavior of DLC coatings for sheet metal forming tools. *Wear*, 271, 2454-2458. https://doi.org/10.1016/j.wear.2010.12.043

[9] Lee, B. H., Keum, Y. T., & Wagoner, R. H. (2002). Modeling of the friction caused by lubrication and surface roughness in sheet metal forming. *Journal of Materials Processing Technology*, 130-131, 60-63. https://doi.org/10.1016/S0924-0136(02)00784-7

[10] Kirkhorn, L., Bushlya, V., Andersson, M., & Stahl, J. E. (2013). The influence of tool steel microstructure on friction in sheet metal forming. *Wear*, 302, 1268-1278. https://doi.org/10.1016/j.wear.2013.01.050

[11] Aleksandrović, S., Stefanović, M., Adamović, D., Lazić, V., Babić, M., Nikolic, R., & Vujinovic, T. (2011). Variable tribological conditions on the flange and nonmonotonous forming in deep drawing of coated sheets. *Journal of the Balkan Tribological Association, 17*(2), 165-178.

[12] Vujinović, T. (2011). Duboko izvlačenje tankih limova pri upravljanju klizanjem na obodu. *PhD thesis*. Fakultet inženjerskih nauka Kragujevac.

[13] Djordjević, M., Mandić V., Aleksandrović S., Lazić V., Arsić D., Nikolić R., & Gulišija Z. (2017). Experimental-numerical analysis of contact conditions influence on the ironing strip drawing process. *Industrial Lubrication and Tribology, 69*(4), 464-470. https://doi.org/10.1108/ILT-05-2016-0113

[14] Torkar, M., Tehovnik, F., & Podgornik, B. (2014). Failure analysis at deep drawing of low carbon steels. *Engineering Failure Analysis*, 40, 1-7. https://doi.org/10.1016/j.engfailanal.2014.02.003

[15] Djordjevic, M., Aleksandrovic, S, Sedmak, A., Nikolic, R., Lazic, V., & Arsic, D. (2016). Flat Die Sliding Model with Variable. Contact Pressure in Deep Drawing Process. *Proceedings of TEAM Conference*, Trnava, Slovakia, 255-258.

[16] Emmens, W. (1996). Tribology of flat die contact. *PhD thesis*, Netherlands.

[17] Aleksandrović, S., Babić, M., Nedeljković, B., Vujinović, T., Taranović, D., Lazić, V., & Milosavljević, D. (2012). Variable draw bead height and variable contact pressure as tribological influences in sheet metal stripe sliding test. *Journal of the Balkan Tribological Association, 18*(2), 184-194.

[18] Djordjević, M., Aleksandrović, S., Lazić, V., Arsić, D., Nikolić, R. R., & Hadzima, B. (2016). 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), 74-83.

[19] Đorđević, M., Arsić, D., Aleksandrović, S., Lazić, V., Milosavljević, D., Nikolić, R., & Mladenovic, V. (2016). Comparative study of an environmentally friendly single-bath lubricant and conventional lubricants in a strip ironing test. *Journal of the Balkan Tribological Association, 22*(1), A-II, 947-958.

[20] Peña-Parás, L., Maldonado-Cortés, D., Taha-Tijerina, J., García-Pineda, P., Tadeo Garza, G., Irigoyen, M., Gutiérrez, J., & Sánchez, D. (2016). Extreme pressure properties of nanolubricants for metal-forming applications. *Industrial Lubrication and Tribology, 68*(1), 30-34. https://doi.org/10.1108/ILT-05-2015-0069

[21] Mucha, J. & Jaworski, J. (2016). The tool surface wear during the silicon steel sheets blanking process. *Eksploatacja i Niezawodnosc – Maintenance and Reliability, 18*(3), 332-342. https://doi.org/10.17531/ein.2016.3.3

[22] Sanjay, S. M. & Ankush, A. (2017). Friction and wear behaviour of Fe-Cu-C based self lubricating material with CaF2 as solid lubricant. *Industrial Lubrication and Tribology, 69*(5), 715-722. https://doi.org/10.1108/ILT-04-2016-0085

**Contact information:**

**Milan DJORDJEVIĆ,** Assistant professor
Faculty of Technical Sciences, University of Priština,
Filipa Višnjiča bb, 38220 Kosovska Mitrovica, Serbia
E-mail: milan.t.djordjevic@pr.ac.rs

**Srbislav ALEKSANDROVIĆ,** Full professor
Faculty of Engineering, University of Kragujevac,
Sestre Janjić 6, 34000 Kragujevac, Serbia
E-mail: omdlab@kg.ac.rs

**Slaviša DJAČIĆ,** MSc mech. eng. and PhD student
1) Coal Mine, Pljevlja, Montenegro
2) Faculty of Engineering, University of Kragujevac,
Sestre Janjić 6, 34000 Kragujevac, Serbia
E-mail: djale@t-com.me

**Aleksandar SEDMAK,** Full professor
Faculty of Mechanical Engineering, University of Belgrade,
Kraljice Marije 16, 11120 Belgrade 35, Serbia
E-mail: asedmak@mas.bg.ac.rs

**Vukić LAZIĆ,** Full professor
Faculty of Engineering, University of Kragujevac,
Sestre Janjić 6, 34000 Kragujevac, Serbia
E-mail: vlazic@kg.ac.rs

**Dušan ARSIĆ,** Research and teaching assistant
Faculty of Engineering, University of Kragujevac,
Sestre Janjić 6, 34000 Kragujevac, Serbia
E-mail: dusan.arsic@fink.rs

**Milan MUTAVDŽIĆ,** Professor
High Technical School,
24. novembra nn, 38218 Leposavić, Serbia
E-mail: mutavdzicmilan57@gmail.com