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University of Kragujevac
Faculty of Engineering

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INFLUENCE OF CONTINUOUSLY VARIABLE LATERAL FORCE ON THICKNESS OF THE MATERIAL DURING STRIP THINNING

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Abstract: *In this research a tribological model of the sliding of sheet metal between the two contact elements that perform thinning was investigated. Unlike usual thinning procedures, here are applied previously set variable functional dependences of the lateral force on the stroke, which are given simultaneously during the thinning procedure. In this way authors tried to better manage the process of deep drawing with thinning as well as to manage the change in thickness by application of variable lateral force. The investigation was done using one functional dependency of variable lateral force, one type of lubricant and one material. Besides, an original computerized testing device was developed. Based on the obtained diagrams it was possible to calculate the coefficient of friction and evaluate the obtained results, especially possibility to achieve certain thickness of the sample across the cross section after the thinning.*

Keywords: *strip ironing test, friction coefficient, contact pressure, continuously variable lateral force*

1. INTRODUCTION

This research is based on experimental investigation of deep drawing with thinning, which involves the use of thick sheets (3 mm). The experiment involves controlling the movement of tool components during thinning to achieve varying sheet thickness along the contour of the parts. In terms of its characteristics, the process falls under bulk forming and differs from the deep drawing of thin sheets (where the thickness is generally less than 1 mm), where changes in thickness are mostly neglected.

The mechanical model chosen in this case is the drawing of a thicker metal strip with bilateral thinning. This is a reliable and well-tested model that has been applied in numerous studies, both by other authors [1-5] and in our own research [6-8].

The idea to research this area arose because the problem of drawing with thinning is highly prevalent in real-world industrial practice. A prime example is the production of sheet metal parts such as food and beverage cans, kitchenware, and similar items. Controlling the thickness of a part during its drawing can be unpredictable, and the goal is to achieve the most accurate dimensions of the finished part. Additionally, since the process involves thinning relatively thick sheets, the use of lubricants is almost mandatory due to the significant forces that arise during the process. Therefore, the aim of this work is to assess the extent to which it is possible to achieve the planned (designed) continuous variation in strip thickness based on variable lateral force, along with other influencing factors. If proven feasible, the process could be applied to obtain different profiles of working parts using a single tool and one lubricant, which would significantly speed up the process and enhance its reliability.

2. MECHANICAL MODEL

For the purposes of this research, a mechanical-mathematical model has been developed to determine the parameters thinning process, based on the model of drawing a thicker metal strip with bilateral thinning. The model was verified through its publication in a study [9] and has demonstrated significantly more realistic values for the coefficient of friction and contact pressure compared to previously used models. The main input variables for the model's formulas are: the dependencies of the drawing force on stroke or time (obtained from the experiment), predefined dependencies of lateral force [10], and geometric data about the tool or contact pairs. The output variables are the coefficient of friction, actual contact pressure, and precisely measured changes in the thickness of the deformed strips under all conditions.

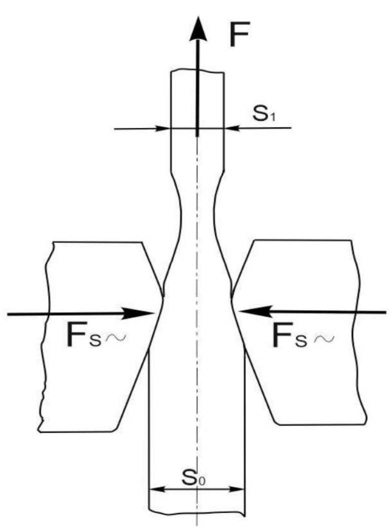


Figure 1. Contact zones during ironing with variable lateral force

The model investigated in this study is the one with variable lateral forces (Fig. 1), and it should be distinguished from the previously used model with continuous forces [10].

The coefficient of friction, as an important output parameter, was determined based on a previously adopted model [9], according to expression (1). Similarly, the actual contact pressure was calculated using expression (2). In the given expressions:

- μ is the coefficient of friction,
- F is the drawing force,
- Fs is the lateral force,
- b is the width of the metal sample,
- s_0 and s_1 are the initial and final thicknesses of the metal sample.

$$\mu = \frac{F}{0.17101F + 1.357785F_S + 0.6F_S} \tag{1}$$

$$p = \frac{0.03015F + 0.34202F_S}{b\left(s_0 - s_1 + 0.0302302\right)} \tag{2}$$

3. EXPERIMENTAL INVESTIGATION

The process of deep drawing with thinning involves intense friction accompanied by tool wear and potential negative impacts on the surface quality of the workpiece and the dimensional accuracy of the finished part. Therefore, it is crucial to understand the influence of the initial surface conditions in contact, the type of tool material, the type of workpiece material, the applied lubricant, and the contact pressure on the coefficient of friction as the most critical parameter in the contact zone. The investigation of thinning conditions was conducted using samples (sheets) made of DC04 steel [11], with a surface roughness of Ra = 1.018 µm. The metal strips were cut longitudinally relative to the rolling direction. The approximate dimensions of the strips for both materials were: length 300 mm, width 20 mm, and thickness 3 mm. The chemical composition of the material used is provided in the study [11].

Additionally, as previously mentioned, the use of lubricants is unavoidable in such processing operations due to the high contact pressures. For this research, a deep drawing oil was selected, the characteristics of which are provided in the study (kinematic viscosity 170 mm^2/s at 40 °C, density 0.950 g/cm3 at 20 °C) [11].

The thinning tool was made of high alloyed tool steel X37CrMoV5-1, ground with roughness Ra= 0.107 µm and hardness 60 HRC (Fig.2). Sliding speed was 20 mm/min in all cases. The samples were 200 mm long.

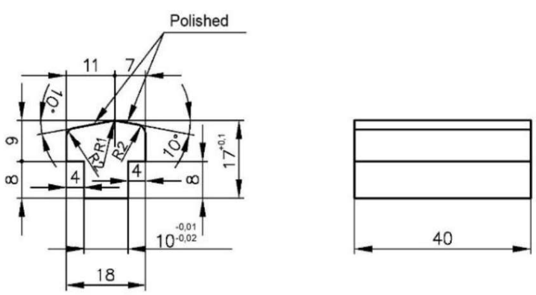
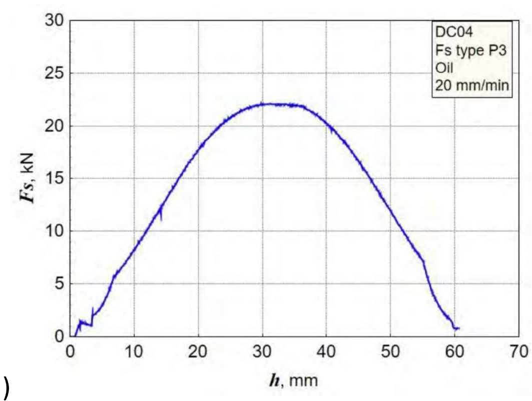
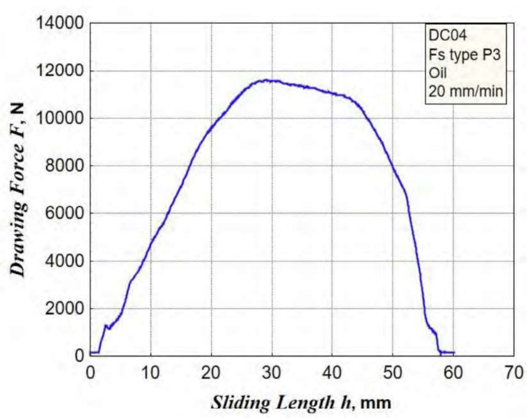


Figure 2. Drawing of contact element



a)



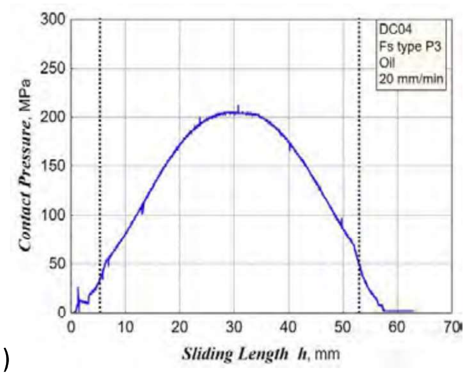
b)

Figure 3. Dependence of the lateral force on stroke (a) and i dependence of drawing force on stroke (b) for combination steel sheet-oil

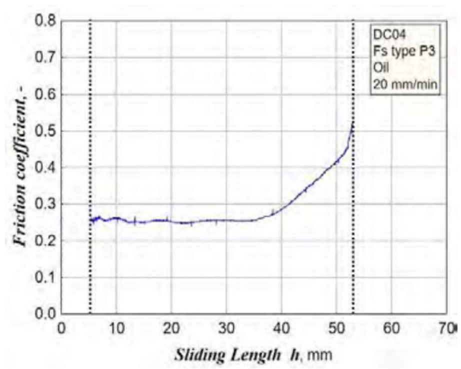
3.1 Results of lateral force dependence

The previously defined dependencies of the lateral force Fs on the stroke are of parabolic type with an increasing-decreasing trend (P3) used in some previous researches [10].

In Figures 3 and 4, the functional dependencies of lateral force, drawing force, contact pressure, and friction coefficient on the sliding stroke of the sample (≈60 mm) are presented. Samples made of DC04 steel sheet in combination with deep-drawing oil were used. The actual variation of the lateral force (Fig. 3) fully follows the theoretically defined nonlinear continuous function of an increasing-decreasing character, here denoted as P3. The contact pressure and friction coefficient were determined according to expressions (1) and (2). The curves of contact pressure variation (Fig. 4 a and b) follow the trend of the curves from Fig. 5.



a)



b)

Figure 4. Dependence of the contact pressure on stroke (a) and dependence of friction coeffcient on stroke (b)

The friction coefficient curves in the initial and final phases of the stroke (Fig. 4b, left and right of the dashed vertical line) yield unrealistic values that are not shown. The probable reason is a certain instability of the thinning process at the beginning and end, as well as the property of expression (1) to result in a sharp increase in the friction coefficient with a sudden drop in the intensity of the lateral force, which begins after a stroke of 43 mm. In the stationary part of the stroke, the values are entirely correct.

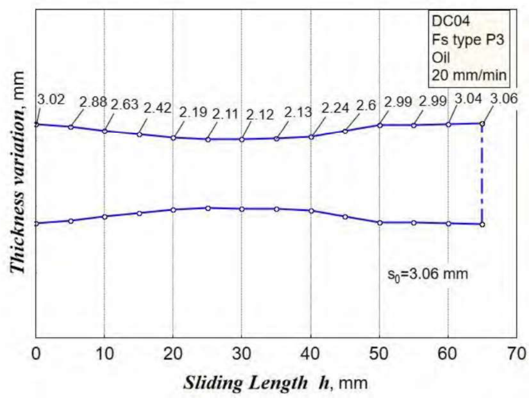


Figure 5. The change in sample thickness along the stroke

4. CONCLUSION

Based on results obtained from conducted experiment, the several conclusions can be drawn:

- For the purposes of experimental research, an original tribological model of the deep drawing process with thinning was developed, implemented through appropriate control equipment. The device allows for continuous, simultaneous application of variable lateral force (Fs) and measurement of deformation force (drawing force F), actual contact pressure, and achieved-real values of lateral force.
- Based on the obtained diagrams of actual contact pressure (Figs. 3 and 4), it can be concluded that the equipment very well realizes the specified change/function P3, as the trend of the curve is almost identical to the mathematical formulation.
- The values of the friction coefficient are significantly influenced by the nature of the specified functional changes (P3) of the lateral force Fs (Fig. 3), as well as the tribological conditions in the contact. It has been shown that the combination of the P3 change and steel sheet under lubrication with oil (Fig. 3a) provides favorable drawing conditions compared to some earlier combinations of conditions [10].
- In the case of the P3 lateral force change, there is a limitation when calculating the friction coefficient for the case where the lateral force has the lowest values in P3 (Fig. 3, the first 6 mm of the stroke and from 53 mm of the stroke), resulting in unrealistic values of the friction coefficient for this process.

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REFERENCES

[1] D. Schlosser, ”Influence of friction during the strip drawing of austenitic sheet metal: different lubricants and tools made of sintered hard materials”, no. 7/8, pp. 302–306, 1975. (In German).

[2] H.C.E. Van der Aa, M.A.H. Van der Aa, P.J.G. Schreurs, F.P.T. Baaijens and W.J. Van Veenen, ”An experimental and numerical study of the wall ironing process of polymer coated sheet metal”, *Mechanics of Materials,* vol. 32, no. 7, pp. 423–443, 2000, https://doi.org/10.1016/S0167-6636(00)00013-2

[3] T. Trzepiecinski, M. Szewczyk and K. Szwajka, ”The use of non-edible green oils to lubricate DC04 steel sheets in sheet metal forming process”, *Lubricants,* vol. 10, 210, 2022, https://doi.org/10.3390/lubricants10090210

[4] Y. Sagisaka, I. Ishibashi, T. Nakamura, M. Sekizawa, Y. Sumioka and M. Kawano, “Evaluation of environmentally friendly lubricants for cold forging“, *Journal of Materials Processing Technology, vol. 212, no. 9,* pp. 1869–1874, 2012, https://doi.org/10.1016/j.jmatprotec.2012.04.011

[5] P. Havaej, J. Degroote and D. Fauconnier, “Sensitivity of TEHL Simulations to the use of different models for the constitutive behaviour of lubricants“, *Lubricants*, vol. 11, 151, 2023, https://doi.org/10.3390/lubricants11030151

[6] S. Aleksandrović, M. Đorđević, M. Stefanović, V. Lazić, D. Adamović and D. Arsić, “Different ways of friction coefficient determination in strip ironing test“, *Tribology in industry*, vol. 36, no. 3, pp. 293–299, 2014,

[7] M. Djordjević, V. Mandić, S. Aleksandrović, D. Arsić and V. Lazic, “Experimental-numerical analysis of contact conditions influence on the ironing strip drawing process“, *Industrial Lubrication and Tribology,* vol. 69, no. 4, pp. 464–470, 2017, doi 10.1108/ILT-05-2016-0113

[8] M. Đorđević, D. Arsić, S. Aleksandrović, V. Lazić, D. Milosavljević and R. Nikolić, “Comparative study of an environmentally friendly single-bath lubricant and conventional lubricants in a strip ironing test“, *Journal of Balkan Tribological Association*, vol. 22, no. 1A-II, pp. 947–958, 2016.

[9] S. Aleksandrović, S. Đačić, M. Đorđević, N. Ratković, D. Arsić and V. Lazić, “New method of defining of process parameters in double side thinning strip ironing test“, *Tribology in industry*, vol. 42, no. 1, pp. 59–69, 2020. https:// doi.org/10.24874/ti.2020.42.01.06.

[10] M. Djordjević, S. Aleksandrović, D. Arsić, R. Nikolić, J. Szmidla, A. Todić, D. Čukanović and R. Ulewicz, “Influence of TiN coating on the drawing force and friction coefficient in the deep drawing process of AlMg4.5Mn0.7 thin sheets“, *Materials*, vol 16, no. 11, 3968, 2023, https://doi.org/10.3390/ma16113968

[11] S. Djačić, M. Djordjević, D. Arsić, S. Aleksandrović, M. Delić, Dj. Ivković and V. Lazić, “Possibilities of ironing process control in conditions of continuously variable lateral force“, *Transactions of FAMENA*, vol. 49, no. 2, in press, 2025.