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TRIBOLOGICAL PROPERTIES OF THIXOTROPIC LUBRICANTS

WŁAŚCIWOŚCI TRIBOLOGICZNE SMARU TIKSOTROPOWEGO

Key words:

tribology, friction coefficient, deep drawing, thixotropic lubricant

Słowa kluczowe:

tribologia, współczynnik tarcia, głębokie ciągnienie, smar tiksotropowy

Summary

Research in the branch of tribological effects is strongly focused on the automotive industry because of the use of coated sheets for corrosion protection. The "galling effect" takes place on these sheets, so producers of lubricants and sheets are trying to find products that are able to eliminate

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or at least minimise this negative effect. The aim of this paper is to compare tribological properties of the common lubricants used at car-body stampings with the possibility of the application of "hotmelts" (thixotropic ones) in the branch of stamping technology or more precisely car-body stamping. The experiment was carried out under the conditions similar to real stamping by means of a device SOKOL 400 and methodology developed at the Department of Engineering Technology, Technical University of Liberec.

INTRODUCTION

The great development of the automotive industry during last year revealed the necessity of using many new materials. This includes sheets for car-body production and lubricants as particular parts of the whole tribological system during the design process.

Metal forming by deep-drawing of the non-regular shaped parts ("car-body stampings") is one of the most difficult processes and non-regular shaped stampings have much higher requirements concerning drawing conditions and non-uniform drawing depth. Because this forming process includes the use of lubricants, the tribological system conditions that greatly influence the final stamping quality are very important to design process. During design, there are many lubricants to be considered, and the best of them one has to take into account the changes in the forming conditions. If the lubricants are to fulfil their functions, it is necessary to make the proper selection when choosing the material for the forming tools.

Lubricants and their function

Some years ago lubricants were looked upon as only supporting agents. Now experts know that the importance of lubricants equals the importance of the other tribological system parts. During lubricant selection, the user has to realise that there are no absolutely good or bad lubricants, but there is one lubricant more or less suitable for a particular operation under given conditions. There exist quite a lot of specific requirements lubricants. Generally there is the required ability to but simply remove lubricant films; however, it must also provide the optimal friction coefficient to relieve the separation of the friction couples, to minimise wear, to prevent corrosion and to protect the surface **[L. 1]** without colour changes. However the most important lubricant property represents lubricity and the ability to dissipate the introduced heat. It is known that drawing without lubrication or low-efficient lubricity can results in a increase of drawing forces about by 40 to 45 per cent which is truly uneconomical. With the decreasing volume of lubricant, there is a gradual change in the friction type between the tool and the formed part from being most suitable (fluid friction) to the worst case – (dry friction). These changes can cause galling of the stamping in the forming tool and "micro-welds" (welding between tool and forming metal) which damage the quality of the formed parts **[L. 2]**.

Lubricants used during drawing

In modern press-shop operation it is necessary to keep in mind the functionality of the tribological system and to select the amount and type of lubricant properly **[L. 3]**.

However, the presence of lubricant on the stamping surface complicates subsequent operations, such as welding, bonding, painting and so on. That is why (beside the lubricant consumption) there is the clear tendency to use the minimum quantity. The lubricant application and quantity, on the stamping semi-product and tool is very different for particular forming methods. Thus, there is the tendency to minimise the amount of applied lubricant, in the case of wash-oils, to within 1.0 to 2.0 $g \cdot m^{-2}$. For prelubes and drawing oils, the quantity is 2.0 to 3.0 $g \cdot m^{-2}$, and emulsions 4.0 to 5.0 $g \cdot m^{-2}$. However, it is important to take into account that the presence of lubricant itself and its amount influence and change drawing conditions, or more precisely, changes friction during the operation, which can cause galling under certain conditions **[L. 4]**.

Nevertheless, to provide the optimal amount of lubricant amount which is dependent on particular lubricant type on the whole stamping area, is very difficult, mainly during real conditions of mass production **[L. 5]**.

During mass production, the selection of types and amounts of lubricants is particularly difficult of liquid oils or emulsions. Such problems can be found at stocking final parts where slumping of lubricant can take place. Moreover transportation and manipulation of liquid lubricant can reveal different complications. That is why lubricants producers are trying to find possibilities for applying new lubricant types, e.g., "Hotmelts". Hotmelt lubricant reveals a behaviour defined as "shear thinning" or pseudo-plastic liquids, which means that their viscosity decreases during shear loading. When applying sufficient shear force, the viscosity decreases so much that it achieves the level of a lubricant like mineral oil. Such a rapid decrease in viscosity during changes in shear force represents the thixotropic property which is used by lubricant producers to change solid lubricant into liquid and vice versa.

Car-body stampings (panels) are known for their demanding production requirements because of the variation on shape. Thus, sheets for these stampings have to fulfil requirements for good pressability **[L. 6, 7]**. Tribology is one of the evaluating criterions having an influence on sheet pressability and its surface features.

Lubricant tribological properties evaluation

During last few years attention has been paid to tribological problems and the optimisation sheet stamping. It is the research of processes that markedly influences the sheet drawing process design and final stamping quality. The tribological system (*tool* - nodular cast iron GGG70L- (1) – *material* –sheet metal (2) – *lubricant* -oil (3)) is connected with tribological conditions as shown in the **Fig. 1**.

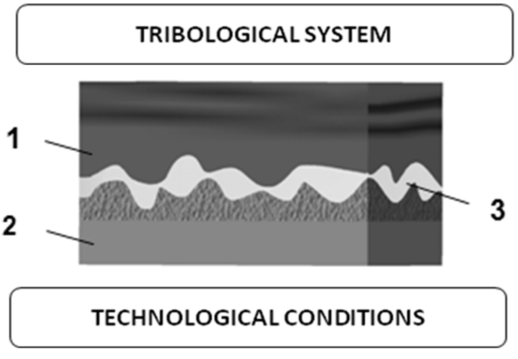

Fig. 1. Tribological system: tool (1) – material (2) – lubricant (3)
Rys. 1. Tribologiczny system: narzędzie (1) – materiał (2) – smar (3)

Nowadays, the description of the tribological conditions in the machine-tool-material-lubricant system is an essential part of the whole drawing process. Research in this branch commonly uses numerical simulations of the drawing process for stamping design. Generally, the more difficult the tribological system is the more expensive is its testing. High result correlation of laboratory testing and real tribological systems can be expected only when testing conditions correspond to real ones on production lines **[L. 8]**.

For the evaluation of sheet tribological properties, coatings, lubricants or tool materials, the Department of Engineering Technology (Technical University of Liberec) in cooperation with the ŠKODA AUTO a.s. Mladá Boleslav developed a testing device SOKOL 400, to which was given utility design CZ 21386: *Zkušební přípravek pro tribologické zkoušky zaměřené na technologii hlubokého tažení plechů.*

The detailed principle of this device and the description of the methodology can be found in **[L. 9]**, which have been published in many technical papers dealing with the tribological problems solving at TU of Liberec **[L. 10–13].**

Functional parts of this device are two grips made from the material (*Nodular Cast Iron GGG70L*), which is used for tool production designed for car-body stamping. One grip is fixed and the second one is controlled by means of a hydraulic system. Between the grips of testing jig is drawn a 45 mm sheet strip of with an applied lubricant type and amount. It is possible to change the displacement rate within the interval from 1 to 400 mms^{-1}. The jig design enables the researcher to simulate drawing conditions in the area of die drawing edge (variant 1A) and in the area of blank-holder (variant 1B). The device for tribological tests and the test are presented in **Fig. 2.**

Fig. 2. Equipment „SOKOL 400" for tribological testing and principle of test
Rys. 2. Urządzenie do testu „SOKOL 400" i zasady badania tribologicznego

EXPERIMENTAL MEASUREMENT [L. 14]

For experimental measuring of tribological conditions variant 1B was used spheroidal graphite cast-iron GGG70L, which was case hardened because of increasing tool service life, was used as the material for the grips **[L. 15]**. Tool temperature was chosen as 60±2°C according to real drawing conditions. **H**ot **D**ip **G**alvanised zinc coated sheet (HDG), thickness 0.79±0.2mm with morphology produced by method EDT (***E**lectric **D**ischarge **T**exturing*), was used as the test material **(Fig. 3)**.

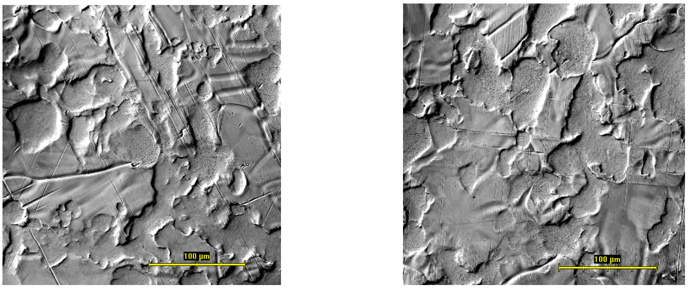

Fig. 3. Surface morphology with texture EDT, Sheet side 1 and 2
Rys. 3. Morfologia tekstury powierzchni i charakter EDT, strona arkusza 1 i 2

Micro-geometrical properties (Ra – Arithmetical mean surface roughness, Rz-Maximum height of the assessed profile, RPc – Number of peaks) of tested substrate, both edges respectively, were changed in the rolling direction (direction 0°) and normal to rolling direction (direction 90°). Computed results as average values from three measurements are summarised in the **Table 1.**

Table 1. HDG sheet surface micro-geometry values
Tabela 1. Wartości mikrogeometrii arkusza powierzchni HDG

HDG	**Sheet side 1**			**Sheet side 2**		
EDT	Ra [µm]	Rz [µm]	RPc [cm^{-1}]	Ra [µm]	Rz [µm]	RPc [cm^{-1}]
direction 0°	1.253	5.783	54	1.234	6.157	61
direction 90°	1.196	5.953	55	1.228	5.890	58

There were tested 3 types of lubricants. Tests were carried out to compare them to lubricants presently used in the press-shop during mass production. One of the common lubricant liquid type is "*wash-oil*" (AC PL 3802-39LV). This oil is applied by a washing process before drawing where sheet semi-products put into washing machines and by means of washing oils where all impurities are removed including preservative oil, which is already applied in smelting works. After washing, the obtained sheets are treated by a washing oil layer, which is important during the deep drawing process.

The second tested lubricant used was "*technological lubricant – drawing oil*" (Multidraw KTL N20), which is applied on the semi-product just before deep drawing and only on the areas where there is a need to prevent friction.

The third lubricant type was "*Hotme*lt", which is a – lubricant with thixotropic properties that can be modified (two types- Multidraw E1 and modification Multidraw E1 SE) **[L. 16]**.

Lubricants were applied in compliance with their types and use during mass production (oil -1.5 g · m^{-2}, drawing oil -2.0 g · m^{-2}, and Hotmelts -1.3 g · m^{-2}.

The amount of lubricant applied on the testing strip during the experiment was checked by means of special measuring apparatus from FUCHS EUROPE SCHIERSTOFFE (see **Fig. 4**). Device design allows the IR beam to scan the surface of sheet sizes 10x10 mm and record the amount of lubricant deposited on a controlled area. The values are displayed on the LCD. The device allowes to measure the lubricant layers in the range of values from 0.2 to 6.0 gm^{-2}.This apparatus is unique for its compact design and easy handling and usability in industrial conditions and was lent from company ŠKODA AUTO a.s. Mladá Boleslav for the experiments **[L. 17].**

Experiment conditions

- sliding velocity: $v = 1\ mms^{-1}$
- contact pressure: p = 8; 23; 38; 53; 68; 83 MPa
- temperature tool: T = 60±2°C
- contact area tool: $S = 400\ mm^2$
- material tool: GGG70L (hardened)
- material: steel sheet (HDG -EDT)
- variant: 1 B

Fig. 4. Measuring apparatus to check lubricant quantity
Rys. 4. Aparatury pomiarowe do kontroli ilości smarowania

Experiment results

Measurement results in the form of a graph of dependence force – verses displacements can serve as basis for the evaluation of the tribological properties of system lubricant – (tested sheet – tool). With regard to the fact that zinc coated sheets are sensitive to the galling effect (stick – slip effect), the friction coefficient computation also took into account the oscillation of the drawing force Ft. With regard to friction coefficient computation, only variant 1B was chosen for measurements. Then the actual friction coefficient μ was calculated from the following simple equation (1):

$$\mu = \frac{Ft}{2 \cdot p \cdot S} \qquad [-] \tag{1}$$

Where: *Ft* – drawing force [N], *p* – actual contact pressure [MPa] and
S – contact area [mm^2]

Results and discussion – coefficient of friction of lubricants

From results presented in **Fig. 5**, it is obvious that tribological conditions are for every lubricants changed in a dependence on contact pressure when there is increasing contact pressure and a decrease in the friction coefficient. Shape and friction coefficient curves characteristics are the same for every used lubricant. From the measured relationships, it is obvious that, both Hotmelts reveal an increase in the friction coefficient in the area of higher pressures compared to commonly used drawing and wash-oils. The lowest friction coefficient was found in the case of drawing oil (0.156, 0.127, 0.104). From the results, it is possible to presume that different friction coefficient values are given by different chemical composition and technological determination of individual lubricant types. Drawing oils (Multidraw KTL N20) have the highest viscosity (200 mm^2s^{-1} for temperature 40°C) compared to wash-oils (AC PL

3802-39LV, viscosity 15 mm^2s^{-1} for temperature 40°C) and are designed for drawing under the most demanding conditions. There are thixotropic additives in lubricants marked as Hotmelts (Multidraw E1 and Multidraw E1 SE) that reveal a semi-solid state without sagging from the stamping surface. With increasing temperature and pressure there is clear step change within the interval approx. 40–50°C, and this is probably the reason for the poor results of Hotmelts under higher pressures. Hotmelts, by their chemical composition, are not designed for demanding stampings. In the area of lower pressures (8,23,38 MPa), when there is not violation of semi-solid lubricant (Hotmelt) film, Multidraw E1 SE has the lowest friction coefficient (0.195, 0.199, 0.190) of all tested lubricants, followed by drawing oil Multidraw KTL N20 (0.216, 0.220, 0.195) and by wash-oil AC PL 3802-39LV (0,226, 0.228, 0.208). Modified Multidraw E1 revealed the worse results of all (0.266, 0.263, 0.256).

On the basis of the statistical computations for particular measurements where standard deviations did not exceed 2% from measured results for every force measurement of strip drawing test, it is possible to state that Hotmelt Multidraw E1 SE has favourable conditions for lower pressures (i.e. lower friction coefficient). According to the producer the Multidraw E1 SE is improved version of modified Multidraw E1 which has been proved by results presented above **(Fig. 5)**.

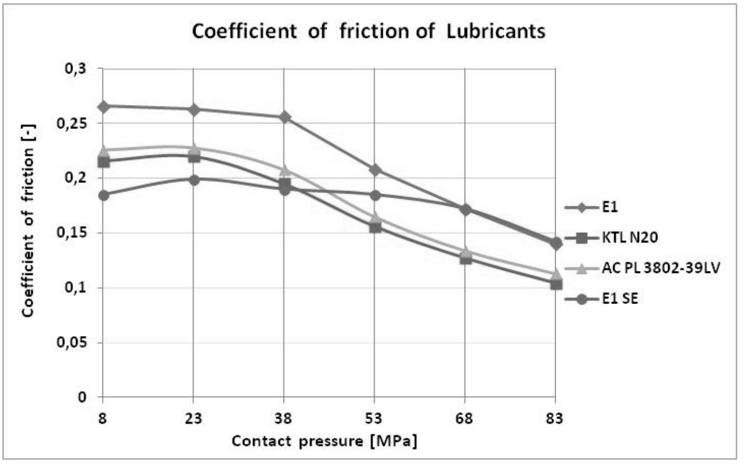

Fig. 5. Final graphs of friction coefficients of tested lubricants
Rys. 5. Powstałe wykresy współczynników tarcia badanego smaru

CONCLUSIONS

The tribological tests were focused on the determination friction coefficients in relation to contact pressure for a new generation of semi-solid lubricants

(Hotmelts). To determinate the relationship zinc coated hot dip galvanized sheet (HDG) with surface morphology EDT was used, which is processed in the automotive industry. Tribological tests were carried out at a loading rate of 1 mm/sec when the galling effect (stick-slip-effect) reached its maximum and surface quality between individual lubricants revealed its maximal influence.

For illustration there are trial reports and the course of draught forces charts demonstrated on **Figures 6, 7, 8** where *x*-axis represents measured track (mm), *y*-axis represents intensity of a drawing force F (N).

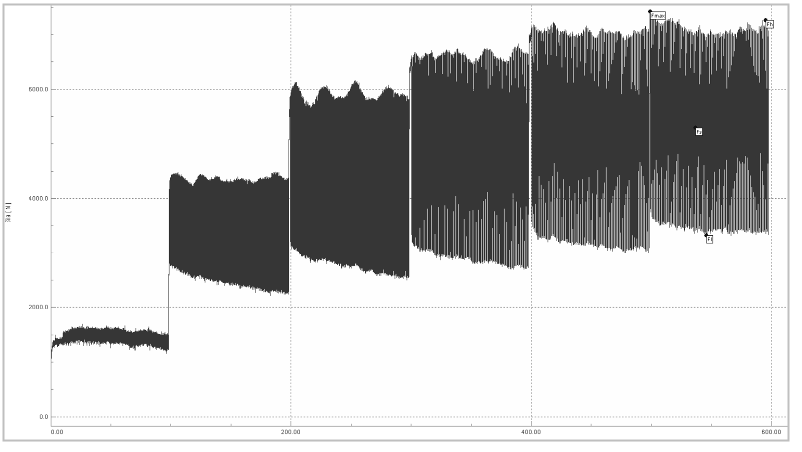

Fig. 6. Graphs of measurement evolution for coating HDG-EDT, Lubricant – Drawing oil (6 pressures, p = 8 – 83 MPa, v = 1 mm · s-^{1})

Rys. 6. Wykres pomiarów do powlekania HDG EDT, smar – olej tłoczenia (6 ciśnień, p = 8–83 MPa, v = 1 mm· s^{-1})

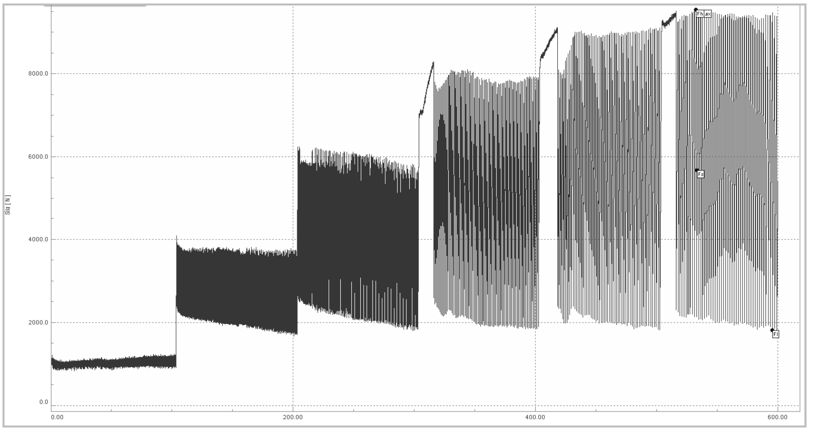

Fig. 7. Graphs of measurement evolution for coating HDG-EDT, Lubricant – Hotmelt 2 (6 pressures, p = 8 – 83 MPa, v = 1 mm · s$^{-1)}$

Rys. 7. Wykres krzywych sił do powlekania HDG EDT, smar – „Hotmelt 2" (6 ciśnień, p = 8–83 MPa, v = 1 mm · s^{-1})

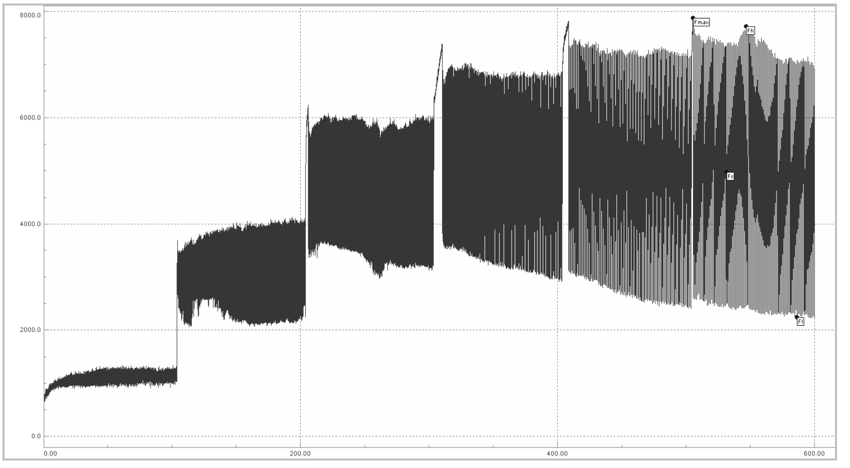

Fig. 8. Graphs of measurement evolution for coating HDG-EDT, Lubricant – Wash-oil (6 pressures, p = 8 – 83 MPa, v = 1 mm · s^{-1})

Rys. 8. Wykres krzywych do powlekania HDG EDT, smar – olej czyszczący (6 ciśnień, p = 8–83 MPa, v = 1 mm · s^{-1})

Knowledge obtained from these experiments represents only a partial evaluation of the tribological system (tool – material – lubricant) – technological conditions, because the friction coefficient is not only one final ratio about lubricant usability but was set as a criterion for lubricant tribological property evaluations. The experiments are the first verification of the tribological properties of thixotropic lubricants in the Department of Engineering Technology of the Technical University of Liberec.

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REFERENCES

1. Štěpina V.,Veselý V.: Maziva v tribologii. VEDA Bratislava 1985.
2. Suchánek, J.: Opotřebení materiálu. In: Tribotechnika 4/2009, s. 58–59.
3. Laber S., Jenek M.: Investigation of the influence of operating preparations on the change of the lubricating properties of oils and the tribological properties of cast iron. In: Tribologia, vol. 41, No 6, 2010.
4. Kochanek H., Sadowski J.: The issue of the influence of wear on the temperature field of a friction couple. In: Tribologia, vol. 43, No 1, 2012.
5. Maldonado Cortés D., Trejo Montemayor L.A., Treviño Castán J.A., Molina Vargas D., Berlanga Zamarrón R.: Methodology for lubricant selection in deep drawing steel process for the automotive industry, a new development and validation. In: Tribologia, vol. 42, No 4, 2011.

6. Sobotová L., Dulebová L.: Technologická spracovatělnosť plechov. In: Strojárstvo č. 9 /2011, s. 114–115.
7. Sobotová L., Dulebová L.: Príspevok k poznatkom vybraných vlastností plechov vhodných k hlbokému ťahaniu. In: Kovárenství. No. 38, 2010, p. 23–27.
8. Gawędzki W., Lepiarczyk D., Tarnowski J.: Laboratory identification of the friction process in the frictional pair cast iron-cast iron. In: Tribologia, vol. 42, No 1, 2011.
9. Kolnerová, M.: Vliv technologických podmínek na vznik zadírání pozinkovaných plechů při tažení, Disertační práce, TU v Liberci 2005.
10. Kolnerová M., Sobotka J., Němečková K.: Influence of pressure regulation onto friction coefficient at deep drawing. In: Kovárenství, číslo 33 – Mezinárodní sympozium FORM 2008, Brno 17–18.9.2008, s. 51–54.
11. Kolnerová M., Solfronk P., Sobotka J., Doubek P.: Vliv technologických parametrů na koeficient tření při tažení. In.: Mezinárodní konference „Technológia 2005“, Bratislava, SR, 2005.
12. Kolnerová M.: Innovation of SOKOL 400 Testing Device for Evaluation Tribological Properties of Sheets Metal. In: mezinárodní konfernce ERIN 2008, 23–24.4.2008, Bratislava, STU v Bratislavě, 2008, s. II–18.
13. Kolnerová M., Solfronk P., Sobotka J., Doubek P.: Tribologické vlastnosti tenkých plechů s hliníkovým povlakem ALUMINIERT. In: Strojírenská technologie, ročník XVI, č. 4, s. 20–25, 2011.
14. Research reports of lubricants TU of Liberec for company ŠKODA AUTO a.s., Mladá Boleslav 2012.
15. Zdravecká E., Leško R., Fescu Š., Ondáč M., Tkáčová J.: Possibilities of lifetime increasing for cold metal forming dies. In: Tribotechnika 2/2010, s. 72–74.
16. Product information Multidraw E1, Zeller+Gmelin GmbH &Co. KG.
17. Technical materials of company Fuchs-Europe Schmierstoffe GmbH.

Streszczenie

Badania zjawisk tribologicznych realizowane są dla branży przemysłu motoryzacyjnego, m.in. przy zastosowaniu pokryć antykoryzyjnych do blach. Producenci środków smarnych zajmują się dopracowaniem produktów, które pozwolą na zminimalizowanie negatywnego efektu powstawania deformacji blachy spowodowanego tarciem. Celem niniejszej pracy jest porównanie właściwości tribologicznych smarów stosowanych przy formowaniu karoserii samochodowych z wykorzystaniem aplikacji zwanej „hot-melts” w technologii kształtowania karoserii. Eksperyment zostanie przeprowadzony za pomocą urządzenia SOKÓŁ 400 w warunkach zbliżonych do panujących w środowisku produkcyjnym i metodologii opracowanej na Wydziale Inżynierii Technicznej Uniwersytetu Technicznego w Libercu.