Journal of the Balkan Tribological Association *Vol. 16, No 3, 329–339 (2010)*

Tribotechnics and tribomechanics

TRIBOLOGICAL MODEL OF THE IRONING PROCESS IN SHEET METAL FORMING FOR LUBRICANTS TESTING

D. ADAMOVIC[a], M. BABIC[a*], M. STEFANOVIC[a], S. ALEKSANDROVIC[a], Z. GOLUSIJA[b], S. MITOVIC[a]

[a] *Faculty of Mechanical Engineering Kragujevac, 6 Sestre Janjic Street, 34 000 Kragujevac, Serbia*
E-mail: babic@kg.ac.rs
[b] *Institute for Technology of Nuclear and Other Raw Materials* (*ITNMS*), *86 Franche d'Esperey Street, 11 000 Belgrade, Serbia*

ABSTRACT

In this paper is shown an original laboratory device for the tribological simulation of ironing process in sheet metal forming. The adopted model respects all the physical and geometrical conditions of the real process and enables determination of the friction coefficient, both between the thin sheet and the die and between the die and the punch in various contact conditions.

The presented and analysed results in this work show that the device is very convenient for fast comparative testing of tribological properties of various lubricants that are used in ironing.

Keywords: tribological model, ironing, lubricants tribological properties.

AIMS AND BACKGROUND

Characteristics of friction that appears on contact surfaces between the tool and the work piece in metal forming by ironing are significantly different from properties that are typical for sliding friction in various machine elements. Their studying and formulating of the corresponding parameters have exceptional importance, both from the aspect of determination of the necessary deformation forces, deformation energy, tool wear intensity and quality of the machined pieces, and from the aspect of metal plastic flow, distribution of the resulting deformations, material machinability, etc.[1] In ironing, the contact surface value changes during the process that means that the parts of material, which in the previous phase were not in contact, now enter into contact with the tool.

* For correspondence.

The necessity of lubricant selection depending on the kind of the deformed material (steel, coloured metals) mainly stems from the fact that some lubricants play well their role in steel machining, but can not be applied in forming the non-ferrous metals[2]. The second, very important factor is the working range of the tool speeds as well as the speed of the deformed material moving over the tool surface, and together with the change of speed the lubricant viscosity also changes due to the temperature change[3]. Thus, the same lubricant can be completely inadequate in drawing on the high speed press.

In some cases, the friction resistances can be useful (make easier the process realisation) and those zones of the tool do not need to be lubricated. Due to that the problem of lubricant selection for a given process can not be solved simply, but it requires a complex approach[4].

It is known that a lubricant testing is done in laboratory conditions by standard tests or on the corresponding process models, while verification of the obtained results is done in the real machining process.

For evaluation of lubricants that are used in cold three-dimensional forming several tests were developed like: ring test, the Nittel test, the Powel test, the Schlosser test, the Weygand test, the Kawai test, etc. All these tests are not equally convenient for all the types of metal forming, taking into account that they realise various ways of material flow as well as various contact pressures[5]. That is why for each individual type of metal forming specific tests are being developed where the tendency is to model the real metal forming conditions as realistically as possible. However, almost always there remains a certain number of factors that are not being taken into account, which can, in certain cases, have a very important role in the real process[6]. For lubricants testing as well as for investigation of tribological processes that are occurring in ironing, several authors developed a whole set of individual test models. The most important are: the Jonasson model, the Kawai model, the Deneuville–Lecot model, the Lihtman–Veiler model, the Doege model and the Gierzynska model[7].

For tribological investigation purposes of the ironing process, an original test model was developed at Laboratory at Mechanical Engineering Faculty of Kragujevac. That model is convenient for compare lubricants tests[7]. Experiments, conducted in this work, had as an objective to show the possibility of using the realised device for comparative evaluation of lubricants that are used in the ironing process.

EXPERIMENTAL

For experimental investigations in this paper an original model (Fig. 1) was realised, which two-sided symmetrically imitates the contact zone of the die with the punch[7]. This model enables realisation of high contact pressures and respects the physical and geometrical conditions of the real process (the die and the punch materials, the contact surfaces topography, the die cone half angle – α, etc.). The scheme of the mentioned tribo-model with presentation of the forces that act upon the work piece, namely the die and the punch, as well as the scheme of the measuring chain are given in Fig. 1.

The drawing device for ironing is installed on a special machine for testing the sheets ERICHSEN 141/12. The design solution is such that the device is fitted into the frame of the device for tension test, when the main machine drive is used for creating the punching force (force F). The second action, the pressure on the sample (force F_D) is being realised hydraulically, via a special pump of power 0.75 kW, nominal compression force of 50 kN, with its own force measuring.

The bent sheet stripe (sample, Fig. 1*c*) is being set onto the 'punch'. The die acts upon it with force F_D. The dies are set into the holders, where the left one is fixed, while the right one is moving together with the die. The punch consists of body 3 and front 4, which are connected to each other by the pickup with strain gauges 5. The sample is passing (sliding) between the dies due to the action of force F on the punch front, when the sample wall thickness is decreased. During

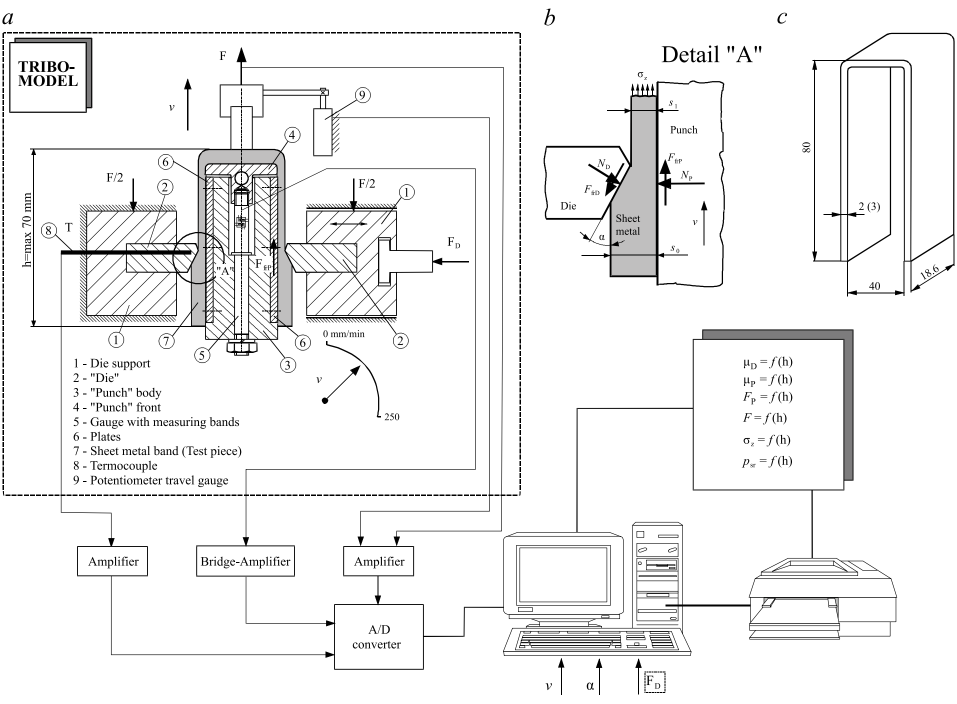

Fig. 1. Scheme of tribo-model with measuring chain for data acquisition (*a*), presentation of forces in strain zone (*b*) and test-piece form (*c*)

this sliding the external surface of the sample slides along the slope (at a die gradient angle α) of the die surface, while the internal surface of the sample slides over plates 6, which are fixed to the punch body.

Plates 6 and dies 2 can be made of various materials, with various roughnesses, and matrices slope α can have various values.

The basic idea in realisation of this device was to make possible determination of the friction coefficient, both on the die side and the punch side in various contact conditions.

The total punching force F presents the sum of the friction force between the punch and the work piece F_{frP} and the force that acts at the bottom of the work piece F_z, i.e.,

$$F = F_{\mathrm{frP}} + F_z.$$

The total punching force F is measured on the machine itself, while the friction force on the punch side F_{frP} is registered by the pickup with strain gauges 5.

Taking into account that there are a great number of influential factors, some of them being variable in the course of the process, and to a certain extent in interaction with each other that makes the whole problem extremely complex, it is not possible always to decisively grasp individual influence of all of them on the process output characteristics. In laboratory testing, especially in model investigations, it is not possible to take into account all the influential factors that requires adequate caution in making conclusions about effects of individual influential factors.

Based on the preliminary investigations and conducted dispersion analysis of individual factors influence and their mutual interactions, the most influential factors were determined in the ironing process. Based on the average values analysis by the Duncan test the levels of individual factors were selected[7].

For experimental investigations in this paper was chosen the sheet of the Al-alloy AlMg3 (43) (or according to DIN standards: AlMg3 F24) which is used for metal forming and belongs the group of alloys that are not prone to precipitation hardening. The presence of magnesium (2.6–3.5%) enables solidification and increases the corrosion resistance.

The appearance and dimensions of the sample on which the investigation was performed is shown in Fig. 1*c*. Mechanical properties and surface characteristics as well as all the other important data are given in Table 1.

In selection of the lubricant for experimental investigation it was important to keep in mind several factors like: various lubricants consistency – greases, pastes, oils as well as the origin of the lubricant – organic, synthetic, and mineral.

Based on previously stated facts the lubricants to be used in the experimental investigations were selected. Their review is given in Table 2.

Table 1. Properties of investigated material and experimental conditions

		Material	Mechanical properties	Surface characteristics
Tool	die	Č4750 (TS) (DIN17006: X165CrMoV12)	60÷63 HRC	R_a≈0.01 μm (N1)
	punch plate	Č4750 (TS) (DIN17006: X165CrMoV12)	60÷63 HRC	R_a≈ 0.01 μm (N1) and R_a≈ 0.4 μm (N5)
Test-piece		AlMg3 thickness: 3.0 mm width: 18.6 mm	R_p = 201 MPa R_m = 251 MPa A_{80} = 12%	R_a = 0.17 μm

Reduction degree: 1÷55%	angle of die gradient: α = 10°
Sliding path: max 70 mm	test temperature: room temperature
Ironing speed: 20 mm/min	blank holding force (F_D, kN): 8.7; 17.4; 26.1

Table 2. Review and main data on applied lubricants

Applied lubricants		
	On die side	L1, L2, L3, L4, L5 and L6
	On punch side	L1, L2, L3, L4, L5, L6 and D

– L1 – lithium grease with additive of molybdenum disulphide (Li + MoS_2) – grease
– L2 – mineral emulsifying water-soluble oil with EP, anti-wear and lubricating additives – oil
– L3 – mineral emulsifying agency – paste
– L4 – non-emulsifying mineral oil with mild EP qualities – oil (ν = 45 mm^2/s)
– L5 – paraffin-based oil with special additives – oil (ν = 80 mm^2/s)
– L6 – paraffin-based oil with special additives – oil (ν = 190 mm^2/s)
– D – no lubrication (dry)

RESULTS AND DISCUSSION

Within experimental investigations on the realised tribo-model were obtained results that are related to influence of the combination of various lubricants on the punch force, friction coefficients on the side of the die and punch, as well as the wall tensile stress[8,9].

In Fig. 2 is shown the variation of the ironing force with the blank holding force at various lubricants on the die side.

The smallest values of the ironing force were obtained by using lubricants L5 and L6 (lubricants aimed for metal forming of aluminum and its alloys). As the worst appeared lubricant L3 for which the highest values of the ironing force were obtained. Regardless of the fact that lubricant L3 contains EP additives, it is not capable of preventing cre-

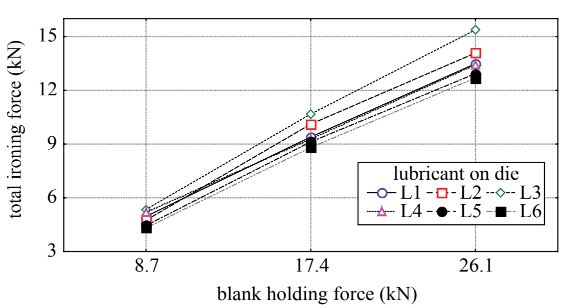

Fig. 2. Variation of the ironing force on the blank holding force at various lubricants on the die side

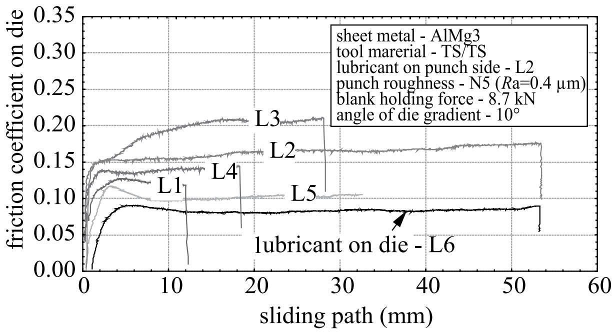

Fig. 3. Change of friction coefficient on die side in dependence on sliding path for various lubricants on die

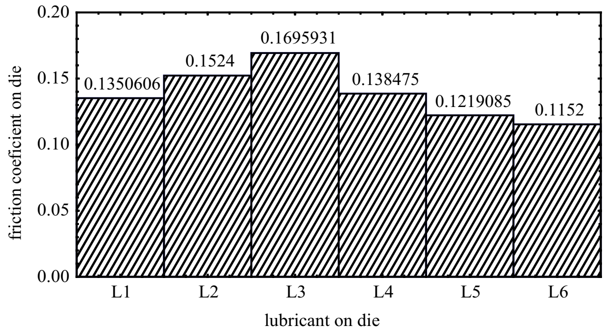

Fig. 4. Medium values of friction coefficient on die side for various lubricants on die

ation of aluminum adhesives on the tool that causes the phenomenon of galling and subsequently the damage of the sheet surface and increase of the ironing force[7].

The characteristic variations of the friction coefficient on the die side with the sliding path, for various lubricants, on the die side are shown in Fig. 3, whereas in Fig. 4 are shown the average values of the friction coefficient for all the analysed lubricants. In all the mentioned figures one can clearly notice that the lowest friction coefficient is obtained when lubricant L6 is applied. Somewhat higher values of the friction coefficient were obtained when lubricants L5 and L1 were used, while the highest values were for the lubricant on the die was L3.

Values of the friction coefficient on the die side and on the punch are shown in Fig. 5. The highest values of the friction coefficient μ_D are obtained with the

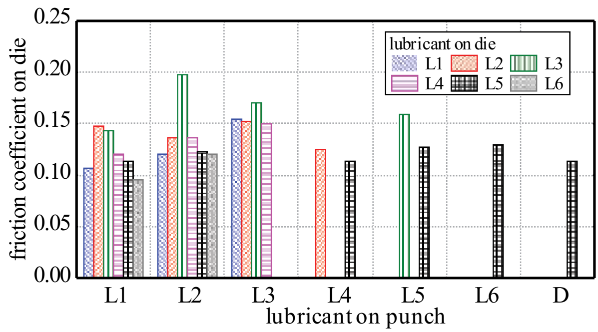

Fig. 5. Friction coefficient on the die for various combinations of lubricants on the die and the punch

L3 lubricant. This lubricant, regardless of the fact that it was giving satisfactory results for steel sheets[3], for sheets made of AlMg3 turned out to be very poor. During its application the intensive adhesion of aluminum to the tool occurred what is shown in Fig. 6. The created adhesives caused heavy damages of the tool surface (Fig. 6 – right). When lubricants L2 and L4 were applied, adhesives were also created, but significantly less than it was the case for the L3 lubricant. When lubricants L1, L5 and L6 were applied, adhesives did not appear.

The ironing process is characterised by unity of positive and negative effects of the external friction. The friction force between the punch and the work piece has a positive effect since it decreases the stress of the piece wall tension, thus the tension on that contact surface should be intensified. However, the friction on the punch side should not be too high since it could cause punch wear and make difficult to remove the work piece off the punch. On the other hand, the friction on the contact surface between the die and the work piece is harmful because it increases the total punch force and worsens the quality of the machined surface. On that contact surface the friction forces have to be decreased as much as possible, by use of new materials for tools with special coatings with high hardness and low tendency to forming adhesives and with application of efficient lubricants.

The variation of the friction coefficient on the punch side for various lubricants is shown in Fig. 7. In order to obtain the highest values of the friction coef-

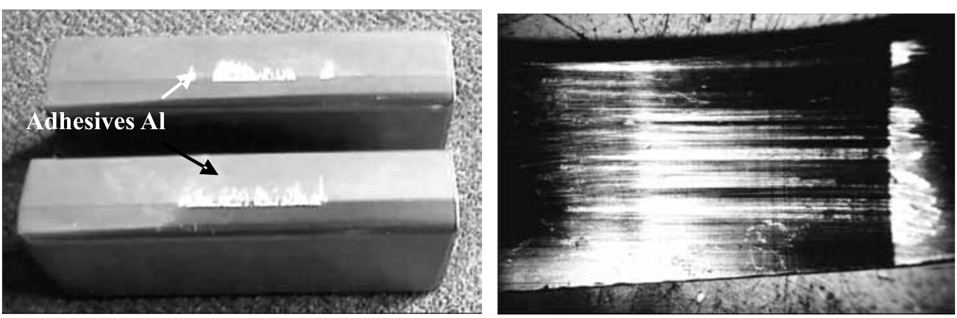

Fig. 6. Aluminum adhesives on the die created by application of lubricant M3 and rough damages on the test-piece surface (galling) made due to aluminum adhesives on the tool (right)

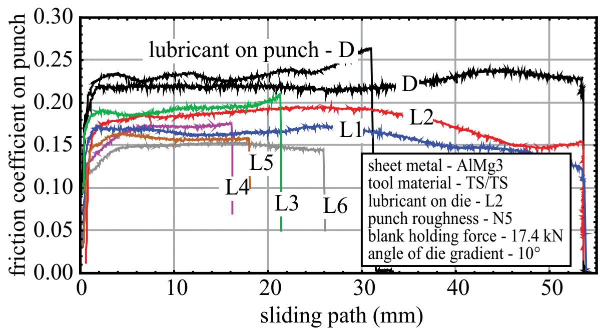

Fig. 7. Dependence of the friction coefficient on the punch side on sliding path for various lubricants on the punch

ficient on the punch, in one of the combinations of dry – degreased surface was applied (D). The logical expectations in experiment were met – the highest friction coefficient on the punch side was obtained without lubricant, but those values are not drastically higher than those obtained when lubricants were applied. It was noticed that on the punch side, when the same lubricants are applied, somewhat higher values of the friction coefficient are obtained with respect to the die. The explanation for this should be sought for, probably, in the different natures of material flow on the die side and on the punch side.

The significant influence on the friction coefficient on the punch side is exhibited by punch roughness and the blank holding force. The friction coefficient μ_p values for various lubricants are shown in Fig. 8. The friction coefficient on the punch at all lubricants (except for L2) and on both considered surfaces drops with increase of the blank holding force.

The average values of the friction coefficient on the punch side, obtained for all the blank holding forces, for all the tested lubricants, are shown in Fig. 9. In both tested materials the highest friction coefficient μ_p was obtained in the case when the sheet surface was not lubricated.

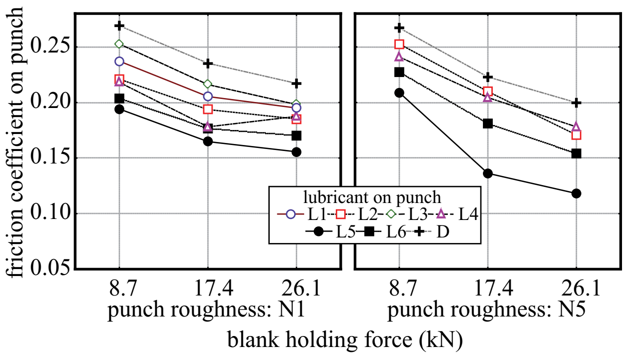

Fig. 8. Dependence of the friction coefficient on the punch side on blank holding force for various lubricants on the punch

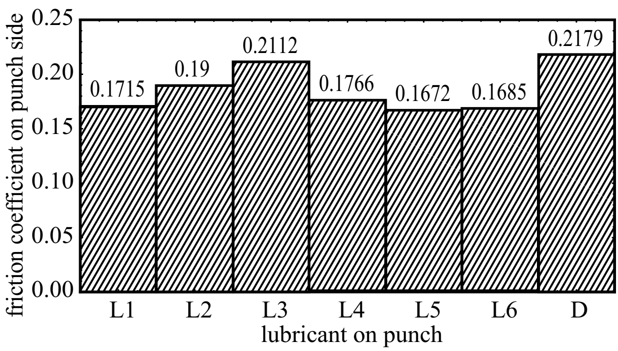

Fig. 9. Medium values of the friction coefficient on the punch side for various lubricants on the punch

In Fig. 10 are shown the average values of the friction coefficient on the punch side, obtained for various combinations of lubricants on the die and on the punch. It can be clearly noticed that the friction coefficient μ_p, with the same lubricant on the punch, depends on the lubricant on the die that confirms the previously stated.

By applying a punch of greater roughness (N5) in the case when ironing was done without lubrication, an intensive adhesion of aluminum onto the punch surface was noticed (Fig. 11 – right). Somewhat smaller adhesives were noticed with lubricant L3 (Fig. 11 – left). When other lubricants were applied adhesives were not noticed or they were negligibly small. It should be mentioned that the adhesives created on the punch were much easier to remove than those that were created on the die.

The tensile force on the work piece wall represents the difference between the punch force and the friction force on the punch. The worse the lubrication on the punch side the higher the friction force, and with that also lower the wall tensile force, i.e. the wall tensile stress. The wall tensile stress variation with the blank holding force at various lubricants is given in Fig. 12. The highest wall tensile stress is obtained on the walls with that lubricant which gives the highest friction coefficient on the punch.

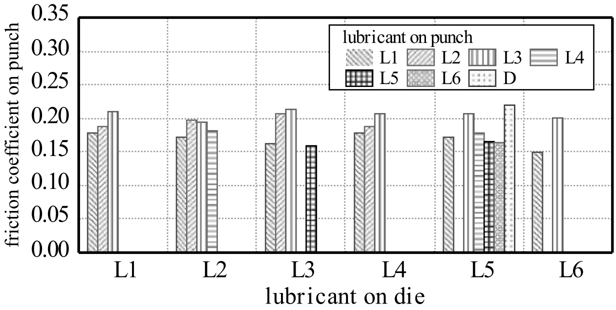

Fig. 10. Friction coefficient on the punch for various combinations of lubricants on the die and on the punch

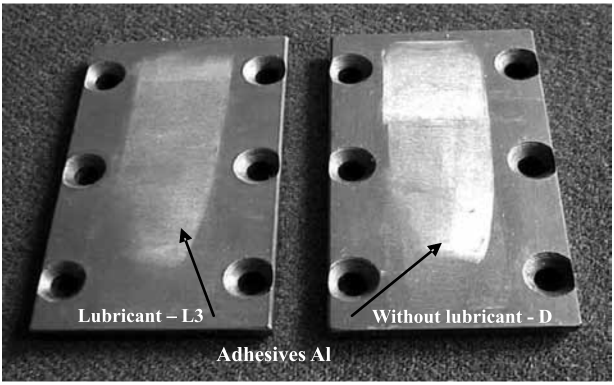

Fig. 11. Aluminum adhesives on punch surfaces

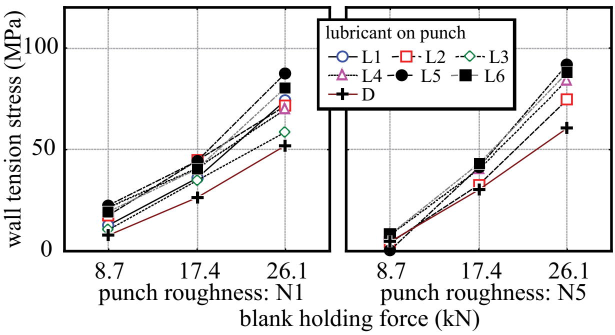

Fig. 12. Dependence of the wall tensile stress on the blank holding force for various punch roughnesses and lubricants on the punch

CONCLUSIONS

The proposed original tribo-model of ironing, two-sided symmetrically imitates the contact zone with the die and the punch. This model enables realisation of high contact pressures and respects the physical and geometrical conditions of the real process (the die and the punch materials, topography of the contact surfaces, the die cone half-angle α, etc.).

With the presented model, with all the mentioned limitations, the contact zone between the sheet and the die can be successfully simulated as well as the contact zone between the sheet and the punch, and the influence of individual tribological parameters (lubricant, materials in contact, the surface topography, specific pressure, etc.) can be studied in the ironing process. Separated studying of processes on the contact surfaces between the sheet and the punch, on the one side of the punch and the sheet, and on the other side of the die and the sheet, enables process control. By proper selection of lubricant on the contact surfaces it is possible to obtain a lower wall tensile stress of the drawn piece, and subsequently to increase the critical degree of the wall strain.

The obtained test results of the known lubricants in the metal cold forming processes exhibit sufficient sensitivity of the device to various types of lubricants.

The device also enables monitoring of the intense changes in the initial surface morphology and generating of new surfaces of the test piece under high pressures conditions.

REFERENCES

1. D. ADAMOVIC, M. STEFANOVIC, V. LAZIC: Investigation of the Influence of Tool Material and Lubricant onto the Process Parameters and Quality of the Work Piece Surface at Ironing, J. for Technology of Plasticity, Novi Sad, **28** (1–2), 41 (2003).
2. D. ADAMOVIC, M. STEFANOVIC, V. LAZIC, M. ZIVKOVIC: Estimation of Lubricants for Ironing of Aluminum Pieces. Tribologia – teoria i praktika, Warszawa, **XXXVI** (5), 9 (2005).
3. S. CHANDRASEKHARAN, H. PALANISWAMY, N. JAIN, G. NGAILE, T. ALTAN: Evalu-

ation of Stamping Lubricants at Various Temperature Levels Using the Ironing Test. Inter. J. of Machine Tools & Manufacture, **45**, 379 (2005).

4. D. ADAMOVIC, M. STEFANOVIC, M. ZIVKOVIC, F. ZIVIC: Investigation of Influence of Tribological Conditions on Friction Coefficient during Multiphase Ironing for Steel and Aluminum Sheet Metal. Tribology in Industry, **28** (3–4), 29 (2006).
5. K. LANGE, T. GRABENER: Tribologie in der Umformtechnik-Reibung, Schmierung, Schmierstoffprufung. In: 3rd Intern. Colloq., Esslingen, 1982, 15.1-15.14.
6. D. ADAMOVIC, M. STEFANOVIC, M. PLANCAK, S. ALEKSANDROVIC: Analysis of Change of Total Ironing Force and Friction Force on Punch at Ironing. J. for Technology of Plasticity, Novi Sad, **33** (1–2), 23 (2008).
7. D. ADAMOVIC: Behavior of Materials in Contact in Processes of Cold Plastic Forming with High Work Pressures. Ph. D. Thesis, Faculty of Mechanical Engineering, Kragujevac, 2002 (in Serbian).
8. D. ADAMOVIC, M. STEFANOVIC, V. LAZIC, M. ZIVKOVIC: Influence of Tribological Conditions on the Sheet Metal Surface Roughness at Multiphase Ironing. J. of Balkan Tribological Association, **11** (4), 499 (2005).
9. D. ADAMOVIC, M. STEFANOVIC, V. LAZIC, M. ZIVKOVIC: Estimation of Lubricants for Ironing of Steel Pieces. Tribology in Industry, **26** (1–2), 12 (2004).

Received 15 July 2009
Revised 29 July 2009