Vol. 36, No. 3 (2014) 293-299

Tribology in Industry

www.tribology.fink.rs

RESEARCH

Different Ways of Friction Coefficient Determination in Stripe Ironing Test

S. Aleksandrović[a], M. Đorđević[a], M. Stefanović[a], V. Lazić[a], D. Adamović[a], D. Arsić[a]

[a]*Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, 34000 Kragujevac, Serbia.*

Keywords:

Thick sheet metal
Stripe ironing test
Friction coefficient
Lubricant test

Corresponding author:

Srbislav Aleksandrović
University of Kragujevac,
Faculty of Engineering,
Sestre Janjić 6,
34000 Kragujevac, Serbia
E-mail: srba@kg.ac.rs

ABSTRACT

The sheet metal stripe ironing laboratory test has been developed to study tribological appearances and performance of lubricants in ironing process. Most common way for friction coefficient determination in the test is use of different equations which gives relation between active forces and reactive friction forces. In application of such equations some difficulties occurs because of improper friction coefficient values, especially at small intensities of tensile or drawing forces. In this paper for literature an approach were analyzed and after that defining of new equation was proposed. New equation was tested numerically and experimentally. Obtained results indicated that the suggested improvement gives much more acceptable values of friction coefficient. That fact is particularly significant in lubricant evaluation process.

1. INTRODUCTION

Ironing is technological process which combines characteristics of sheet metal forming and bulk forming. Thinning strains reach over 25 %, and contact pressure over 1000 MPa [1]. Most often applies in manufacture of cylindrical geometry pieces whose depth is much bigger than diameter, and bottom thickness is bigger than wall thickness.

Ironing is normally applied following deep drawing (or extrusion) when forming high, thin walled cans. Such cans are used for beverages, cartridge cases, high pressure cylinders, housings for pumps and shock absorbers etc. World annual production (especially for beverage cans) is more than billion pieces [2].

Of the sheet metal forming processes, ironing is one of the tribologically most severe, owing to the high surface expansion and normal pressure at the tool-workpiece interface. This is particularly significant in the case of forming of pour formability materials such as stainless steel, high strength steel, etc. [3]. Because of that, use of proper performance lubricants is very significant [4-5]. In order to quantify the performance of the individual lubricants, a different simulative test method has been developed. All the tests are modeling the process conditions in ironing. It is a very convenient to use coefficient of friction at contact surfaces change as a criterion for lubricants evaluation.

For this study one of classic stripe ironing tests was chosen [6]. By analysis of acting of drawing force, side forces and friction forces well known equation was determined. This particular equation established the connection between tool geometry, forces and coefficient of friction. The equation was used in different researches, [6-10] in genuine or modified form.

However, by more accurate measurements of the drawing force was shown that equation gives negative friction coefficient values in range of force smaller intensities. That fact was indicated yet in article [7]. That was motive for making analysis of several approaches with goal to obtain more convenient equation appropriate for above mentioned strip reduction test.

2. DEFINING OF FRICTION COEFFICIENT

Figure 1 shows scheme of the stripe ironing test tooling which models the symmetrical contact of the sheet with the die during the ironing process. The metal strip is being placed into the holding jaw. The jaw with the sample is moving from the bottom towards the top, by the mechanical part of the device. The sample is being acted upon by the side elements with force F_D, which simulate the industrial tool die and perform the ironing. During the ironing process the recording of the drawing force is being done at over the total length of the punch travel, by the corresponding measuring system.

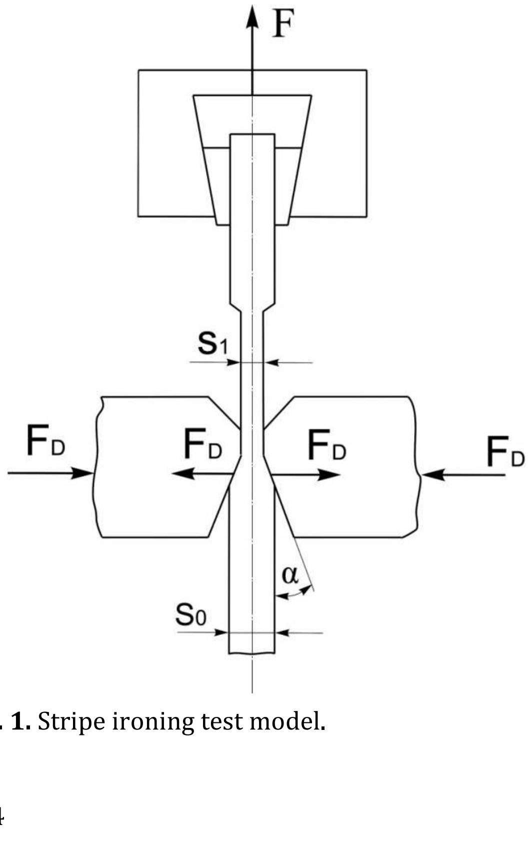

Fig. 1. Stripe ironing test model.

Term (1) gives friction coefficient μ dependence on drawing force (F), side force (F_D) and inclination angle α and that is well-known classic equation [6].

$$\mu = \frac{\frac{F}{2F_D} - tg\alpha}{1 + \frac{Ftg\alpha}{2F_D}} = \frac{F - 2F_D tg\alpha}{2F_D + Ftg\alpha} = \frac{F\cos\alpha - 2F_D\sin\alpha}{2F_D\cos\alpha + F\sin\alpha} \quad (1)$$

Similar term (2) was proposed in article [8]. If instead of force F is inserted F/2 term (1) was given.

$$\mu = \frac{F\cos\alpha - F_D\sin\alpha}{F_D\cos\alpha + F\sin\alpha} \quad (2)$$

Term (3) is using in article [2].

$$\mu = \frac{F\cos\alpha - 2F_D\sin\alpha}{F_D\cos\alpha + F\sin\alpha} \quad (3)$$

Previous three equations give negative friction coefficient values for smaller intensities of drawing force in the sliding process starting phase. This notice was given yet in article [7] where was assumed that cause of such a disadvantage is negligence of the forces in narrow vertical zone between side element inclined surfaces. Scheme of forces at Fig. 2 was formed according to propositions from that study [11]. After force analysis friction coefficient is given by:

$$\mu = \frac{F + 2F_D(0.25 - 2tg\alpha)}{Ftg\alpha + 4F_D} \quad (4)$$

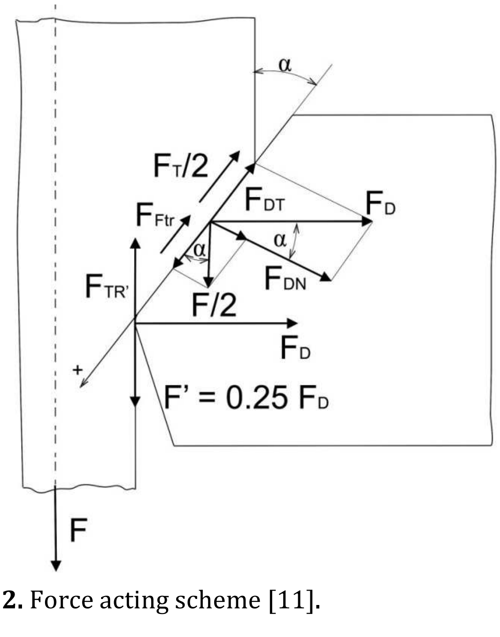

Fig. 2. Force acting scheme [11].

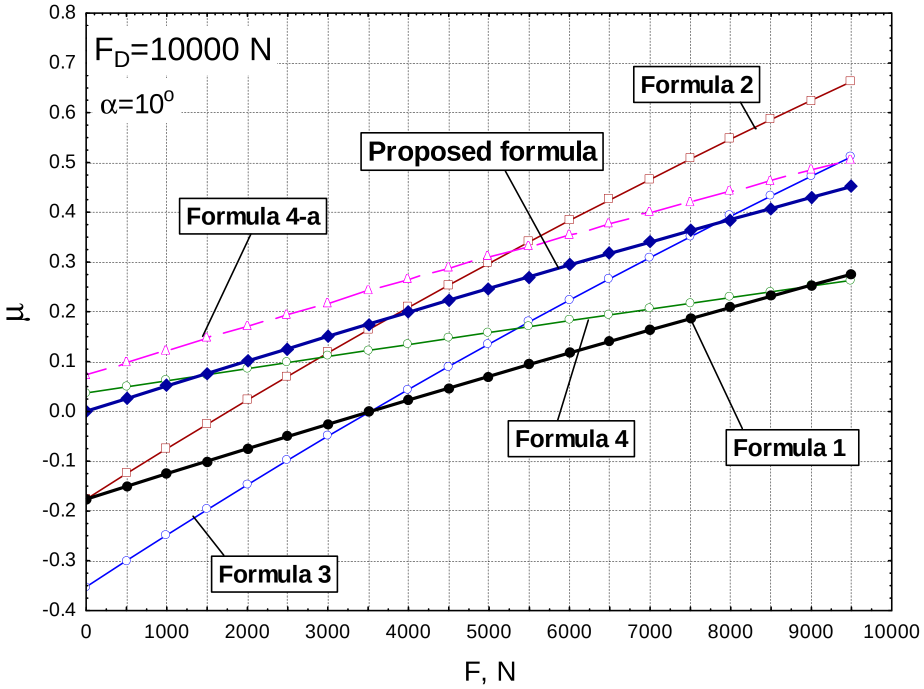

Fig. 4. Friction coefficient dependencies on drawing force.

Within a framework of the same study [11] intuitively was proposed different scheme of side forces F_D acting. It assumes that at inclined surface acting force $F_D/2$ and at narrow vertical surface also the same force $F_D/2$. In such a conditions another version of previous equation was given.

$$\mu = \frac{F + 2F_D(0.25 - 2tg\alpha)}{Ftg\alpha + 2F_D} \qquad (4a)$$

After analysis of the previous equations scheme of forces in Fig. 3 was formed. Based on equilibrium equation of all the forces (for contact surfaces at both sides) in vertical direction, friction coefficient is given by:

$$\mu = \frac{F}{2aF_D\cos^2\alpha + F\frac{\sin 2\alpha}{2} + 2(1-a)F_D} \qquad (5)$$

Parameter a is determining distribution of side force F_D between inclined and small vertical contact surface and his value is in the range 0 to 1. It was adopted a=0.7 in this case. Parameter a influence on friction coefficient value is very small (about 1 %).

Figures 4 and 5 gives comparative overview of all the 6 equations whereat was adopted F_D=10 kN (Fig. 4) and F_D=20 kN (Fig. 5). Inclination angle was 10°. Drawing force is linearly increasing from 0 to 9500 N and lies on x axis.

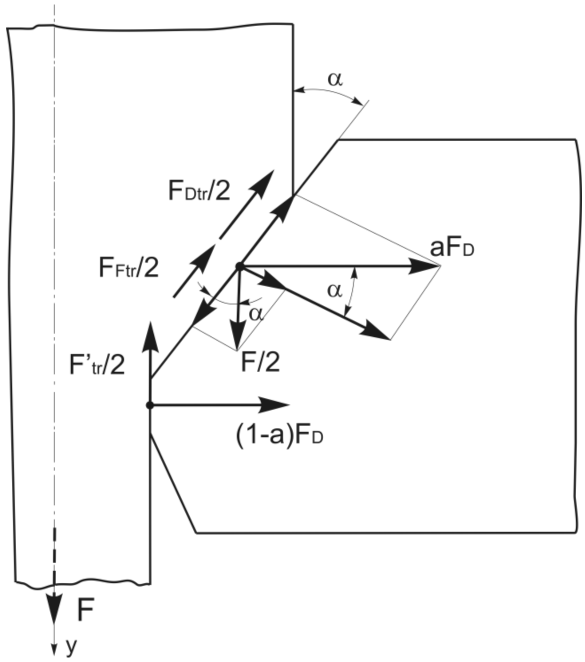

Fig. 3. Modified force acting scheme.

Clearly can be seen that equations 1, 2 and 3 gives unreal negative friction coefficient values for smaller force F intensities. Use of 4 and 4a equations is solving this disadvantage, but at the sliding process beginning friction coefficient have positive nonzero also unreal values. Only equation 5 gives friction coefficient values which starts from 0. That is in accordance with ironing process course. At smaller intensities of side force F_D friction coefficient values are probably higher than real.

As a example of equation (5) application in lubricants quality evaluation experiment giving are the Figs. 6-9. Experimental equipment is based on tribo model from Fig. 1 and described with more details in [11]. Sliding process was one phase with side forces 5, 10, 15 and 20 kN. Sliding length was approximately 60 mm at speed of 100 mm/min. Stripe material is low carbon steel sheet with 2.5 mm thickness. The first lubricant (L1) is the classical phosphate layer of zinc phosphate, with a thickness of approximately 10 μm, over which the mineral oil was deposited. The oil was applied considering the less strict requirements for the ironing process with respect to cold forming.

L2 is special dry ecological lubricant based on wax and metallic soap. Lubricant layer was obtained by dipping into bath with proper solution and than drying. L3 is lithium grease with MoS2.
The fourth lubricant (L4) is classical mineral oil, containing the EP sulphur-based additives, which uses in thin sheets forming. It should be mentioned that the same oil was used in L4 and in the additional lubricant over the phosphate layer (L1).

When the phosphate layer with mineral oil was applied (L1, Fig. 6), the values are similar to those for lubricant L3, ranging from approximtely 0.14 to 0.17. The influence of the lateral force variation is somewhat greater than that for L3. The most probable cause is the worse lubricating properties of the mineral oil. The coefficient of friction was much higher when the mineral oil (L4) was applied, with a range of approximatelly 0.16 to 0.2, Fig. 9. This confirms that this lubricants lubricating properties are worse than those of the other three.

Variation of the friction coefficient for the lithium grease with MoS_2 (L3) is presented in Fig. 8. The values are relatively low, ranging from 0.15 to approximatelly 0.165. The increase in the lateral force from 5 to 20 kN does not significantly influence the increase in the friction coefficient.

The results for the environmentally friendly single-bath lubricant (L2) are presented in Figure 7. Its friction coefficient is the lowest (0.11 to 0.16), but it is more sensitive to the lateral force intensity. It is clear that the lubricating properties of the environmentally friendly lubricant (L2) are good and that it can replace any of the other lubricants tested in this study, especially at lower lateral forces intensities.

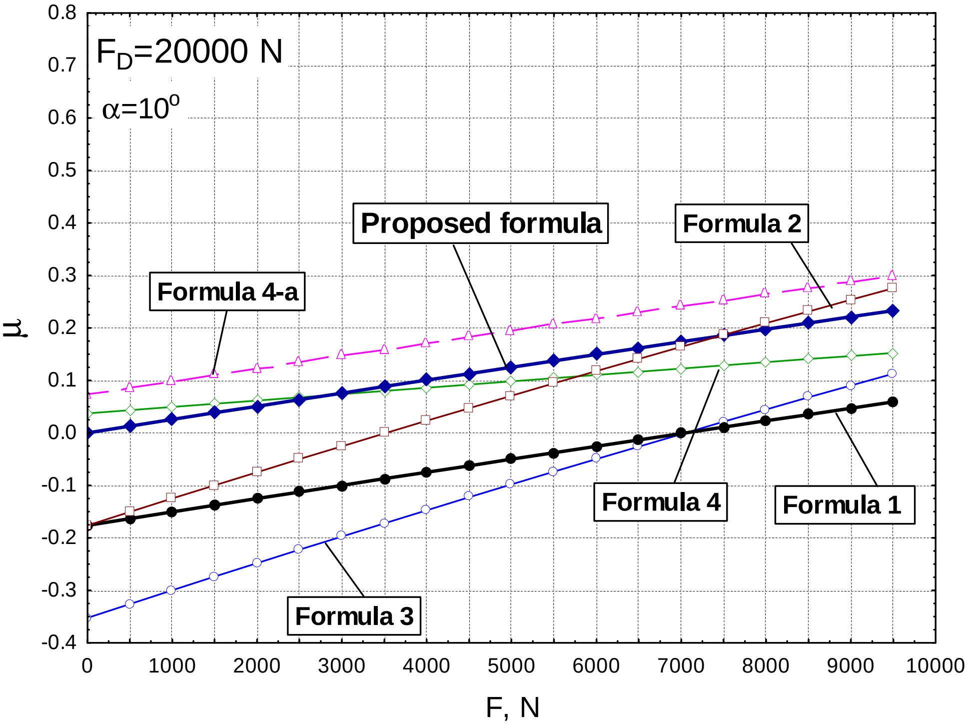

Fig. 5. Friction coefficient dependencies on drawing force.

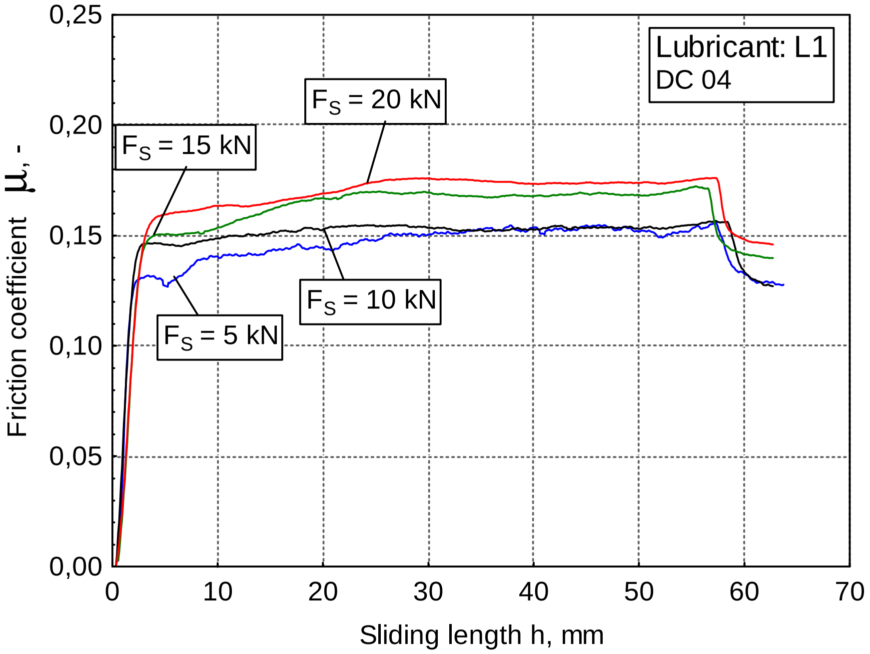

Fig. 6. Friction coefficient dependencies on sliding length for lubricant L1.

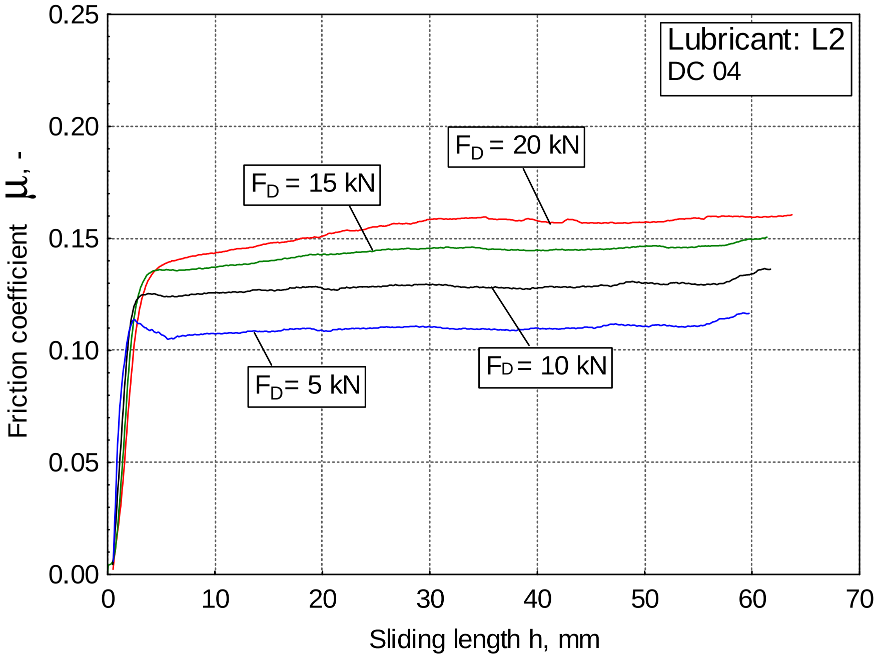

Fig. 7. Friction coefficient dependencies on sliding length for lubricant L2.

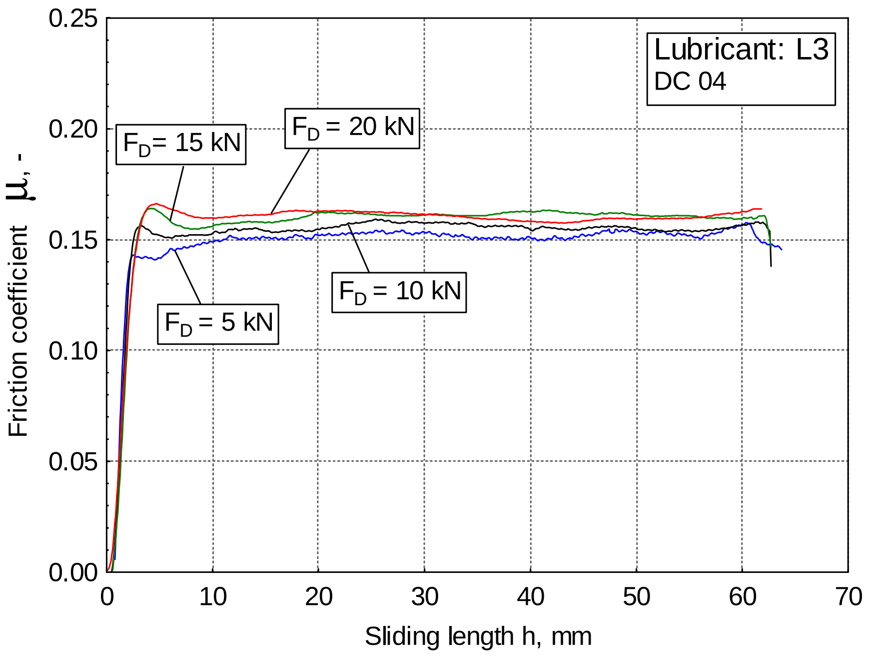

Fig. 8. Friction coefficient dependencies on sliding length for lubricant L3.

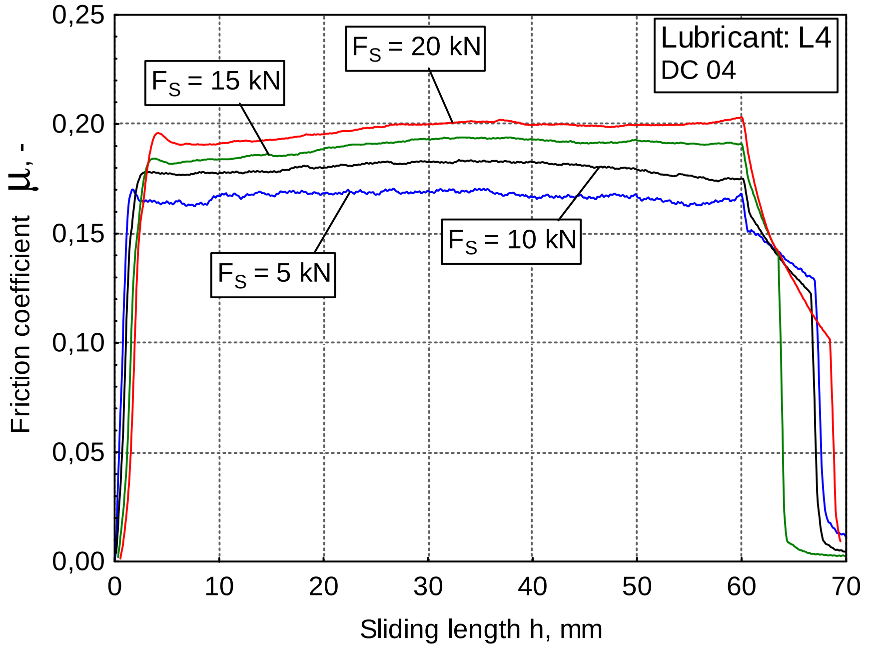

Fig. 9. Friction coefficient dependencies on sliding length for lubricant L4.

3. CONCLUSION

Comparative analysis of application of the four literature equations for the friction coefficient determining in stripe ironing test was accomplished in the first part of this study. Three equations give negative unreal friction coefficient values for smaller intensities of drawing force in the sliding process starting phase. For one equation (in two versions) friction coefficient has positive nonzero but also unreal values at the sliding process beginning. These notices are indicating that previously mentioned equations are inaccurate.

Different equation was suggested in the second part of this study. Proposed equation enables to determine acceptable friction coefficient values and dependencies. After performing of trial experiments the results are indicating that proposed equation can be successfully applied in the lubricant evaluation during chosen stripe ironing test process.

Acknowledgement

The work reported in this paper was partially financially supported by the Serbian Ministry of Education and Science, through contract TR 34002. The authors are very grateful for this funding.

REFERENCES

[1] N. Bay, A. Azushima, P.Groche, I. Ishibashi, M. Merklein, M. Morishita, T. Nakamura, S Schmid, M. Yoshida: *Environmentally benign tribo-systems for metal forming*, CIRP Annals-Manufacturing technology, Vol. 59, No. 2, pp. 760-780, 2010.

[2] D. Adamović, M. Stefanović, V. Lazić, M. Živković: *Estimation of Lubricants for Ironing of Steel Pieces,* Tribology in Industry, Vol. 26, No. 1&2, pp. 12-20, 2004.

[3] J.L. Andreasen, N. Bay, M. Andersen, E. Christensen, N. Bjerrum: *Screening the performance of lubricants for the ironing of stainless steel with a strip reduction test*, Wear, Vol. 207, No. 1-2, pp. 1-5, 1997.

[4] S. Aleksandrović, B. Nedeljković, M. Stefanović, D. Milosavljević, V. Lazić: *Tribological properties of steel and Al-alloys sheet metals intended for deep* drawing, Tribology in Industry, Vol. 31, No. 3&4, pp. 11-16, 2009.

[5] S. Aleksandrović, M. Stefanović: *Significance and limitations of variable blank holding force application in deep* drawing, Tribology in Industry, Vol. 27, No. 3&4, pp. 48-54, 2005.

[6] D. Adamović, M. Stefanović, V. Mandić: *Modelling of Ironing Process*, Monograph, Faculty of Engineering, Kragujevac, 2013.

[7] P. Deneuville, R. Lecot: *The study of friction in ironing process by physical and numerical modelling*, Journal of Materials Processing Technology, Vol. 45, No. 1-4, pp. 625-630, 1994.

[8] H.C.E. van der Aa, M.A.H. van der Aa, P.J.G. Schreurs, F.P.T. Baaijens a, 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.

[9] S. Đačić, M. Stefanović, S. Aleksandrović, D. Adamović: *Characteristics of Friction in Sheet Metal Sliding with Thickness Reduction*, in: *International conference SERBIATRIB 2011*, 11-13 May 2011, Kragujevac, Serbia, pp. 366-369.

[10] M. Stefanović, S. Đačić, S. Aleksandrović, D. Adamović: *Importance of tribological conditions at multi-phase ironing*, in: *34th International conference ICPE 2011*, Niš, Serbia, pp. 503-506.

[11] M. Đorđević, S. Aleksandrović, V. Lazić, M. Stefanović, R. Nikolić, D. Arsić: *Influence of lubricants on the multiphase ironing process*, in: *SEMDOK 2013*, 30 jan-01 feb 2013, Zilina-Terchova, pp. 22-26.