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DIFFERENT WAYS OF FRICTION COEFFICIENT DETERMINATION IN STRIPE IRONING TEST

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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 formulas which gives relation between active forces and reactive friction forces. In application of such formulas some difficulties occurs because of improper friction coefficient values, especially at small intensities of tensile or drawing forces. In this paper for literature approaches were analyzed and after that defining of new formula were proposed. New formula was tested numerically and experimentally. Obtained results indicated that the suggested improvements give much more acceptable values of friction coefficient. That fact is particularly significant in lubricant evaluation process.*

Keywords: *Thick sheet metal, stripe ironing test, friction coefficient*

1. INTRODUCTION

Ironing is technological process which combine characteristics of sheet metal forming and bulk forming. Thinnig strain 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) are 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 fomability materials such as stainless steel, high strength steel, etc. [3]. Because of that, use of proper performace lubricants is very significant. In order to quantify the performance of the individual lubricants, a different simulative test methods has been developed. All the tests are modelling 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 [4]. By analysis of acting of drawing force, side forces and friction forces well known formula was determined. This particular formula established the connection between tool geometry, forces and coefficient of friction. The formula was used in different researches, [4, 5, 6, 7, 8] in genuin or modified form.

However, by more accurate measurements of the drawing force was shown that formula gives negative friction coefficient values in range of force smaller intensities. That fact was indicated yet in article [5]. That was motive for making analysis of several approaches with goal to obtain more convenient formula 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.

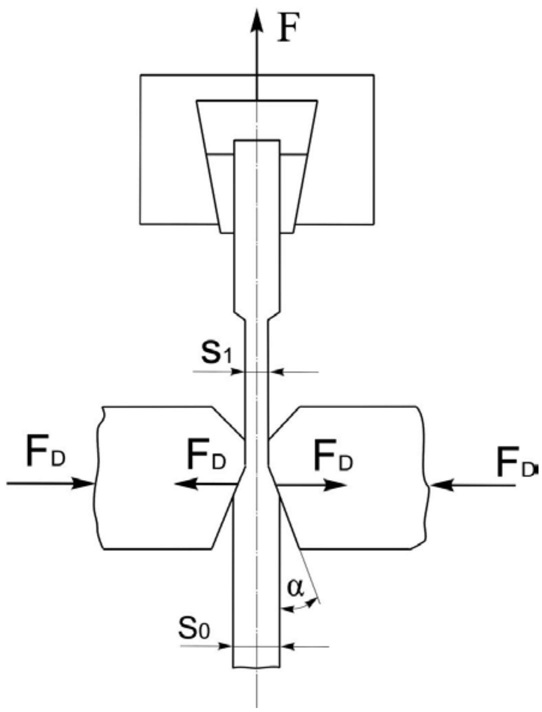

Figure 1. Stripe ironing test model

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 formula [4].

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

Similar term (2) was proposed in article [6]. 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 formulas give negative friction coefficient values for smaller intensities of drawing force in the sliding process starting phase. This notice was given yet in article [5] 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 [9]. After force analysis friction coefficient is given by:

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

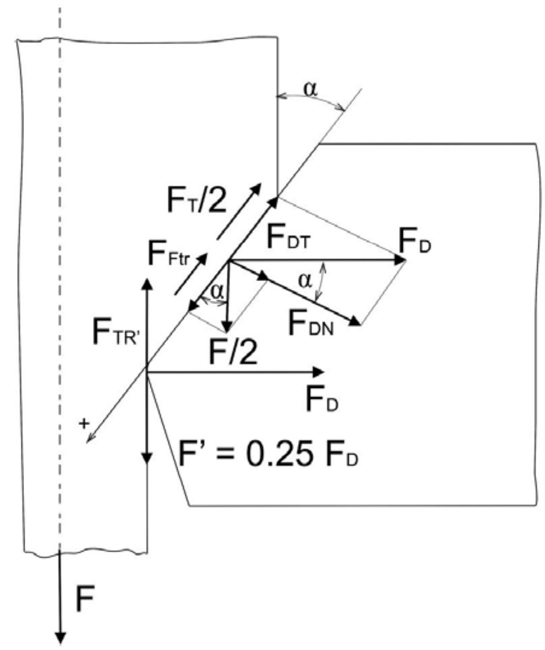

Figure 2. Force acting scheme [9]

Within a framework of the same study [9] 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 conditions another version of previous formula was given.

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

After analysis of the previous formulas 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:

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

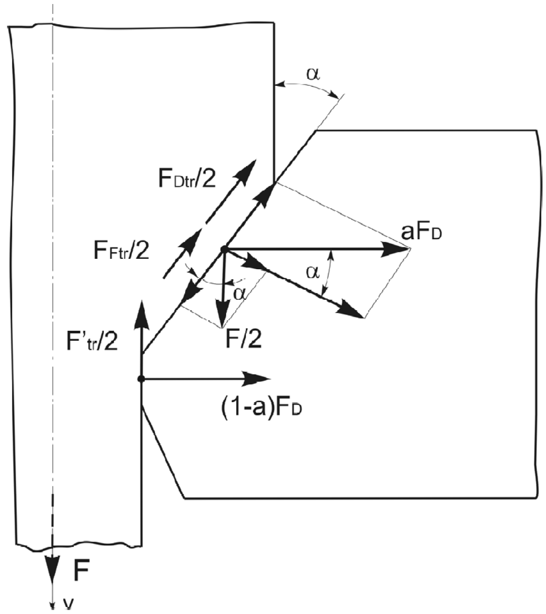

Figure 3. Modified force acting scheme

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 formulas whereat was adopted F_D=10 kN (fig. 4) and F_D=0 kN (fig. 5). Inclination angle was 10°. Drawing force is linearly increasing from 0 to 9500 N and lies on x axis. Clearly can be seen that formulas 1, 2 and 3 gives unreal negative friction coefficient values for smaller force F intensities. Use of 4 and 4a formulas is solving this disadvantage, but at the sliding process beginning friction coefficient have positive nonzero also unreal values. Only formula 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 then real.

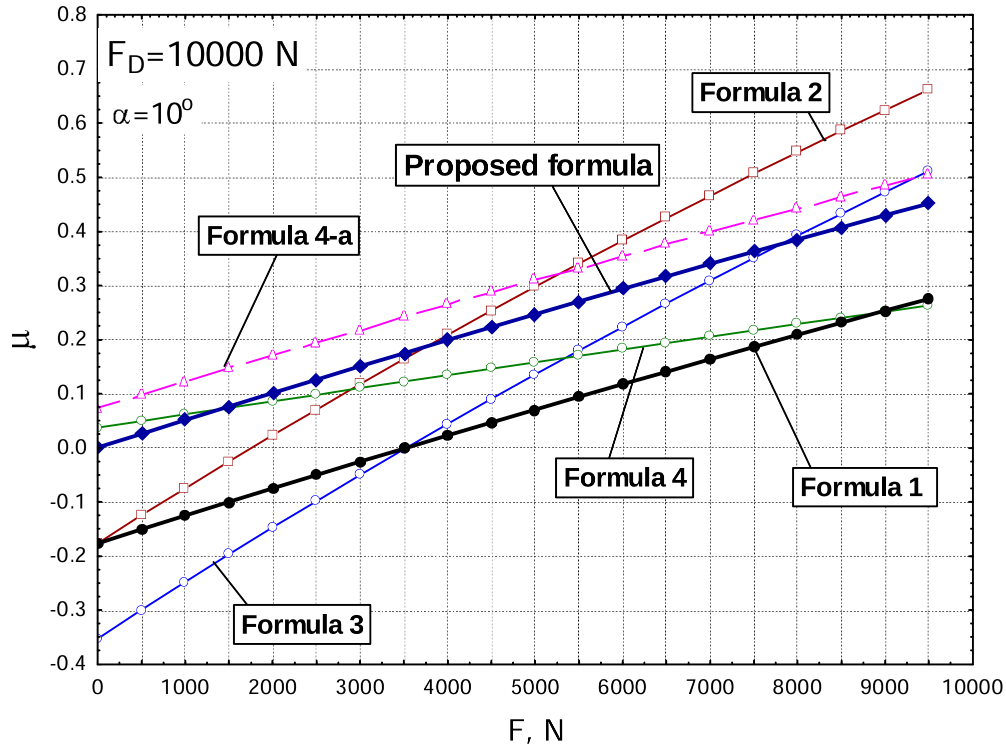

Figure 4. Friction coefficient dependencies on drawing force

As a example of formula (5) application in lubricants quality evaluation experiment giving are the figures 6 and 7. Experimental equipment is based on tribo model from fig. 1 and described with more details in [9]. 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. 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 MoS_2.

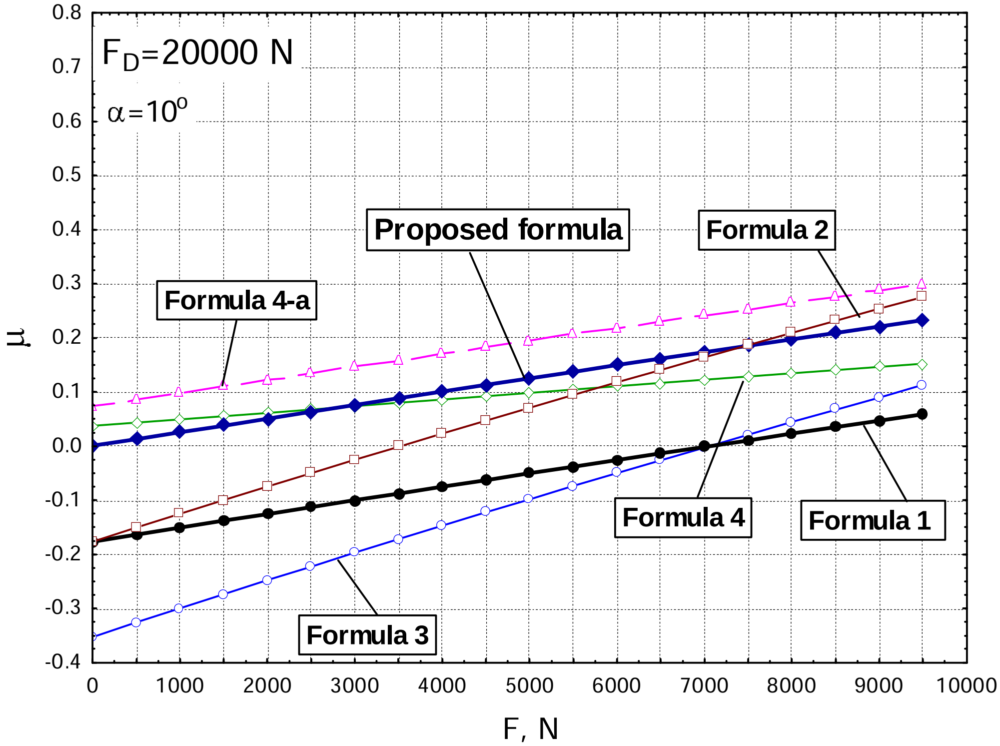

Figure 5. Friction coefficient dependencies on drawing force

By fig. 6 and fig. 7 comparison can be seen that for lubricant L3 contact pressure has no substantial influence on friction coefficient. In the case of lubricant L3 application friction coefficient is decreasing with side force decreasing.

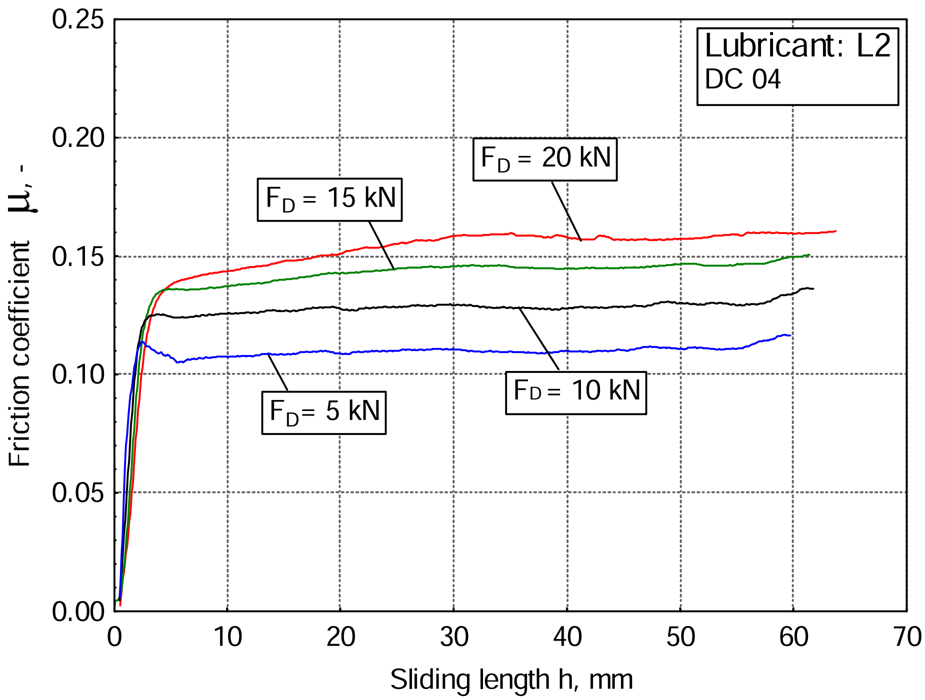

Figure 6. Friction coefficient dependencies on sliding length

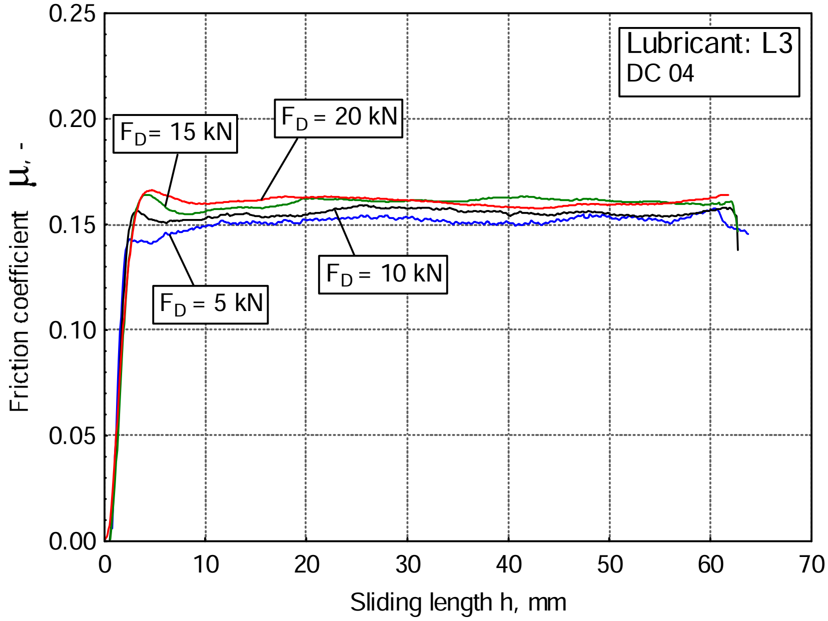

Figure 7. Friction coefficient dependencies on sliding length

3. CONCLUSION

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

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

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