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DETERMINATION OF CORRECTED PARAMETERS IN STRIP IRONING PROCESS WITH DOUBLE SIDE THINNING

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Abstract: Determination of corrected main process parameters procedure in the strip ironing process with double side thinning, as well as appropriate experimental results are presented in this paper. Given is modified analysis for friction coefficient and contact pressure determination. Classical common so called "Schlosser model" is not suitable in many cases, and give unreal values for both of main process parameters. Formulas obtained here were verified in suitable examples which are, also, presented in the paper. Verification was performed on the base of experimental results. Realised was the single and four phase process of mild steel DC04 sheet stripes drawing. Stripes were 20 mm wide and 2.5 mm thick. Lateral force intensities were 5, 10 and 15 kN. Maximal obtained thinning deformation in one phase was about 17%. Appropriate lubrication with mineral oil and grease was used in conditions of lower speed of 20 mm/min.
Results shows that proposed corrected parameters enables more precise process monitoring and precise quantification of lateral force, contact pressure and thinning strain influence on friction.

Keywords: ***strip ironing test, corrected parameters, mild steel strips***

1. INTRODUCTION

Ironing is known as technological process which combine characteristics of sheet metal forming and bulk forming. Significance of ironing technology illustrate great interest of the researchers over the years. It is clearly visible in relatively small number of selected references ([1]–[18]) whose are representing short history of last four decades ironing researches. Main reason is probably great appliance of ironing forming process in modern industry. It is sufficiently to notice that by even ironing process industry produce more than two hundred billions pieces of well known product: beverage cans ([5], [7], [9]).

There are many researches of ironing process in literature. Only some of them are given here. Practically all cited references give tribological approach, mainly because ironing is most severe process in that sense. One of the significant tribological element is lubrication i.e. determination of the proper lubricants performance. In order to obtain tribological parameters and to quantify the performance of the individual lubricants, a different simulative tests has been developed. All the tests are modeling the process conditions in ironing, from old, now classic [1] to new ones ([12], [13]). All the tests considered mechanical models, parameters identification and experimental research of some selected factors influence on tribological phenomena's or specific parameters.

In papers [1] to [10] given were process analysis, modeling, parameters determination and particular experimental investigations of lubricants evaluation by friction coefficient determination mainly. In other cases used were specific materials, like in [3] and [4]. In [11] and [12] introduced was new test simulator and given were the results of tool characteristics influence on friction and lubrication. Papers [13] to [16] gives extensive researches of application of environmentally friendly lubricants. In papers [17] and [18] authors pays attention to some specific aspects of ironing process like acoustic emission, heat effects etc.

In this paper authors exposed are their own complete mechanical model and method for friction coefficient and contact pressure determination depending on drawing force, lateral force, tool and material sample geometry. Double sided strip reduction test was chosen in whole experiment. Conducted were extensive experimental investigations towards verifications of proposed procedures. With the reliable defined parameters can be perform different experimental investigations and, it is important, obtain more safer and precise results.

2. MECHANICAL MODEL OF ACTING FORCES

In this approach double sided thick strip reduction test was chosen like previously was mentioned. Figure 1 shows scheme of test tooling elements and main forces. The thick metal strip is being placed into the holding jaw. The jaw with the sample is moving in vertical direction, from down to up. On the sample acted drawing force F and two lateral (side) forces F_S which simulate the industrial tool die and perform the ironing. It is useful to notice that in Figure 1 are shown active lateral force and corresponding reactive forces. Also, it is important to notice for this model that existing of small vertical area which can be consider flat in first approximation (Figure 1 and 2).

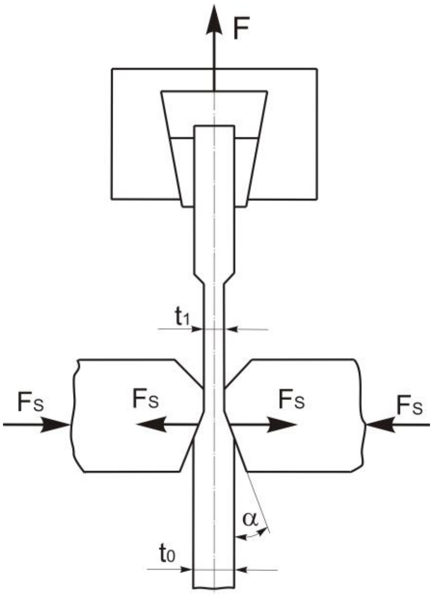

Figure 1. Test tooling elements

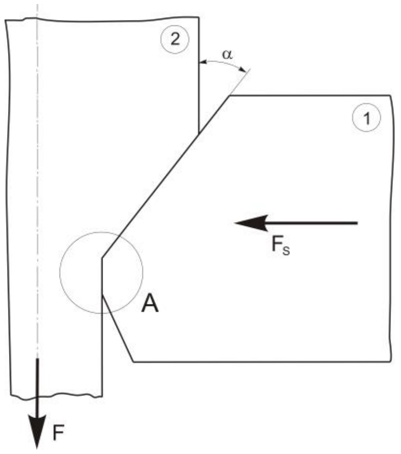

Figure 2. Contact zones

In real it is small arched surface of side element rounded edge i.e. part of cylindrical area with about 1 mm radius which is adopted here (Figure 3).

Forming and sliding process can be analyzed in two possible cases.

First case: ironing in conditions of very small deformation of thinning according to criteria:

$$\Delta s' = \frac{\Delta s}{2} = \frac{s_0 - s_1}{2} \le r(1 - \cos\alpha) \qquad (1)$$

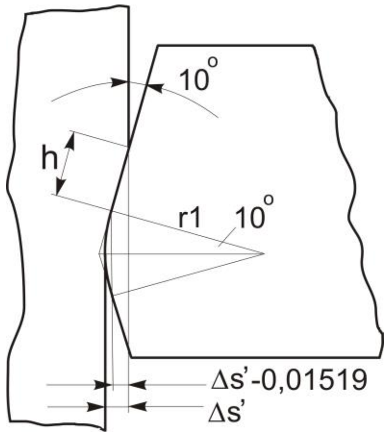

Figure 3. More realistic model

$$\Delta s = s_0 - s_1 \le 2r(1-\cos\alpha) \tag{2}$$

$$\varepsilon \le \frac{2r(1-\cos\alpha)}{s_0}100,\ \% \tag{3}$$

where s_0 is initial sheet thickness, s_1 is thickness after forming process, ε is percentage deformation. With here adopted values given are:

$$\Delta s' = \frac{\Delta s}{2} \le 0.0159 \tag{4}$$

$$\Delta s = s_0 - s_1 \le 0.03038 \tag{5}$$

$$\varepsilon \le \frac{3.038}{s_0},\ \%\ ;\ \mathit{for}\ s_0 = 2.5\ mm\quad \varepsilon \le 1.215\% \tag{6}$$

Process is carry out in conditions of contact established on rounded surface only (Figure 3). There is no any flat contact. Mechanical model is very simple: drawing force **F**, two side forces $\mathbf{F_S}$ and two friction forces $\mathbf{\mu F_S}$ (Figure 3). Friction forces can be consider vertical (like adopted here) or inclined. Difference is negligible because angle **α** is relatively small and cosα≈1.

Second case: Ironing in conditions of flat area formation above small rounded area.

$$\Delta s = s_0 - s_1 > 2r(1-\cos\alpha) \tag{7}$$

$$\varepsilon > \frac{2r(1-\cos\alpha)}{s_0}100,\ \% \tag{8}$$

$$\Delta s = s_0 - s_1 > 0.03038 \tag{9}$$

$$\varepsilon > \frac{3.038}{s_0},\ \%\ ;\ \mathit{if}\ s_0 = 2.5\ mm\ \varepsilon > 1.215\% \tag{10}$$

So, sliding process and forces acting can be monitored now in two zones, rounded and flat.

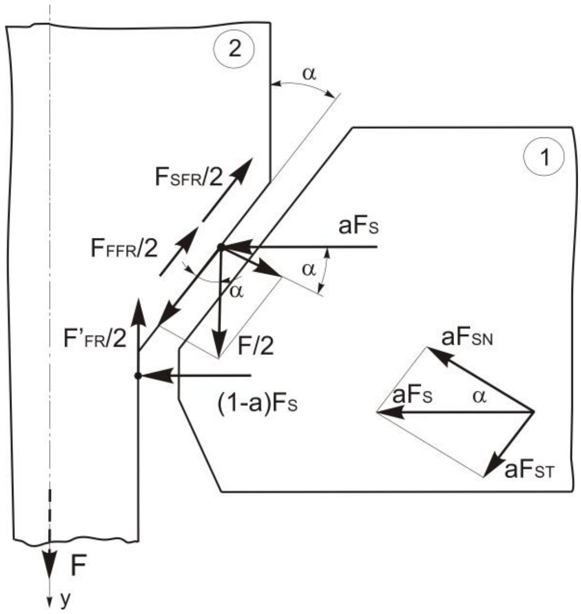

Figure 4. Mechanical model of right side forces acting

Mechanical model of acting forces is given in Figure 4 (for right side only). Can be assumed that side tool element 1 is slightly moved and his acting changed with the force $\mathbf{F_S}$. Distribution of force $\mathbf{F_S}$ between flat inclined and small near vertical surfaces determined by empirical parameter **a.** It was adopted **a=0.7** after analysis in [7]. Friction force $\mathbf{F_{SFR}}$ depends on normal component ($\mathbf{aF_{SN}}$) of side force part $\mathbf{aF_S}$. Force $\mathbf{F_{SFR}}$ acting on flat inclined surface. Force $\mathbf{F_{FFR}}$ depends on normal component of drawing force **F/2**. Friction force $\mathbf{F_{FR}}$´ depends on $\mathbf{(1\text{-}a)F_S}$ part of side force $\mathbf{F_S}$ which acting through small vertical surface. It is useful to notice that rounded area can be approximated by small vertical zone or not. That´s depends on particular case.

2.1 Friction coefficient determination

In first case of ironing (expressions (1) to (6)) three forces acting only, like is previously mentioned: drawing force and two friction forces, one on each side. If considered friction force is vertical coefficient of friction can be calculated by expression (11). Alternatively coefficient of friction can be calculated by expression (12) with negligible difference.

$$\mu = \frac{F}{2F_S} \tag{11}$$

$$\mu \approx \frac{F}{2F_S \cos\alpha} \approx \frac{F}{2F_S \cos\frac{\alpha}{2}} \tag{12}$$

In second case (criteria in expressions (7) – (10)) for all acting forces on material sample (part 2, Figure 4) can be written equilibrium equations (13), (14), (15).

$$\sum F_{iy} = 0 \tag{13}$$

$$F - F_{FR}^{'} - F_{FFR} \cdot \cos\alpha - F_{SFR} \cdot \cos\alpha = 0 \tag{14}$$

$$\begin{aligned} &F - 2\mu(1-a)F_S - \mu F \sin\alpha \cos\alpha - \\ &-2\mu a F_S \cos\alpha \cos\alpha = 0 \end{aligned} \tag{15}$$

It is better to use complete force system (both sides of sample). After relatively simple mathematical transformations (16) can be obtained expression (17) i.e. coefficient of friction. If particular values of inclination angle (α=10°) and parameter a=0.7 is considered ([8], [10]), can be obtained final expression for friction coefficient (18).

$$F = \mu\left(2(1-a)F_S + \frac{F}{2}\sin 2\alpha + 2aF_S \cos^2\alpha\right) \tag{16}$$

$$\mu = \frac{F}{\frac{F}{2}\sin 2\alpha + 2aF_S \cos^2\alpha + 2(1-a)F_S} \tag{17}$$

$$\mu = \frac{F}{0.17101F + 1.357785F_S + 0.6F_S} \tag{18}$$

Expressions (17) and (18) clearly shows that precise measuring of drawing force is essential for accurate determination of friction coefficient μ. Important also were: side force intensity, tool geometry and parameter a, but these are constant and previously set up values.

2.2 Procedure of contact pressure determination

According to previous consideration there exist two possible cases of ironing process, and that is related to contact pressure, also.

In first case there is no flat area (h=0, Figure 3) and consequently not exist corresponding forces (expression 19).

$$\text{if } h = 0 \text{ and } A_1 = 0 \rightarrow \Sigma F_{iA1} = 0 \tag{19}$$

$$p = \frac{F_S}{A_2} = \frac{F_S}{l \cdot b} = \frac{180}{\pi\alpha}\frac{F_S}{r \cdot b} \tag{20}$$

$$A_2 = l \cdot b = \alpha_r \cdot r \cdot b = \frac{\alpha^o \pi}{180} r \cdot b \tag{21}$$

$$l = \frac{10\pi}{180} \cdot 1 = 0.174533 \tag{22}$$

$$\text{if } \alpha = 10^o \text{ and } r = 1mm \rightarrow p = \frac{5.73F_S}{b} \tag{23}$$

So, contact pressure p can be calculated by expression (20) where A_2 is rounded surface which depends on arch length **l** and sample width **b** (21). With particular values, **l** is given by (22) and **p** by (23).

In second case can be assume that area A_1 and area A_2 are joined and continuous ((24) –(27)), and there are acting normal components of drawing force (F/2 for one sample side) and lateral force F_S.

$$\begin{aligned} A_1 = h \cdot b &= \frac{\frac{s_0 - s_1}{2} - r(1-\cos\alpha)}{\sin\alpha} \cdot b = \\ &= \frac{s_0 - s_1 - 2r(1-\cos\alpha)}{2\sin\alpha} \cdot b \end{aligned} \tag{24}$$

$$h = 2.879385(s_0 - s_1) - 0.08749 \tag{25}$$

$$A_2 = l \cdot b = \alpha_r \cdot r \cdot b = \frac{\alpha^o \pi}{180} r \cdot b \tag{26}$$

$$l = \frac{10\pi}{180} \cdot 1 = 0.174533 \tag{27}$$

$$p = \frac{\Sigma F_i}{A_1 + A_2} = \frac{\frac{F}{2}\sin\alpha + F_S \cos\alpha}{h \cdot b + l \cdot b} \tag{28}$$

$$p = \frac{F \sin^2\alpha + F_S \sin 2\alpha}{b\left[s_0 - s_1 - 2r(1-\cos\alpha) + \frac{\alpha\pi}{90} r \sin\alpha\right]} \tag{29}$$

$$p = \frac{0.03015F + 0.34202F_S}{b(s_0 - s_1 + 0.0302302)} \tag{30}$$

Pressure **p** can be calculated by starting expressions (28) and (29). Final expression is (30) for this particular case.

Can be notice here that small rounded area adopted like flat, inclined. This approximation is possible and reasonable because area A_2 is very small in comparison with A_1, and with lower significance in this case. Such approximation contributing to obtain simpler final expression for pressure **p**. Also, must be notice that approach like previous isn't reasonable for friction analysis in sliding process where two areas (A1 and A2) produce different friction forces each.

3. EXPERIMENTAL VERIFICATION

3.1 Oil lubrication example

Experimental verification of proposed approach, expressions i.e. formulas for coefficient of friction (**μ**) and contact pressure (**p**) presented were in this and next chapter.

Behind application of such formulas, monitoring and analysis of obtained results, given were results of comparison between new results and results obtained with classic, older formulas. Explanation of classic approach and classic formulas can be seen in [1], [5], [7] and [8].

All the details about experiment: equipment, tooling, material properties, geometry, lubricants properties, process properties etc. is not presented because of limited space here and can be fined in [7], [8] and [10].

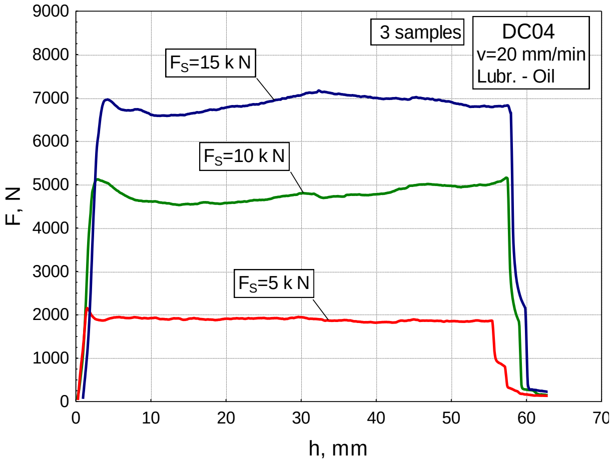

Figure 5. Force dependence on sliding length

Most important starting data gives dependencies of drawing (pulling) force on sliding length (sample travel). By using data acquisition system it is possible to obtain force dependence on sliding length in numerical form. That allows appliance of different formulas for friction coefficient (**μ**) and contact pressure (**p**) and obtaining corresponding dependencies during the ironing, i.e. sliding process. That also allows relatively simple comparison and evaluation of any particular approach.

Figure 5 shows force variation during the process for one phase ironing. Samples were deformed in one phase each, but with different lateral force F_S.

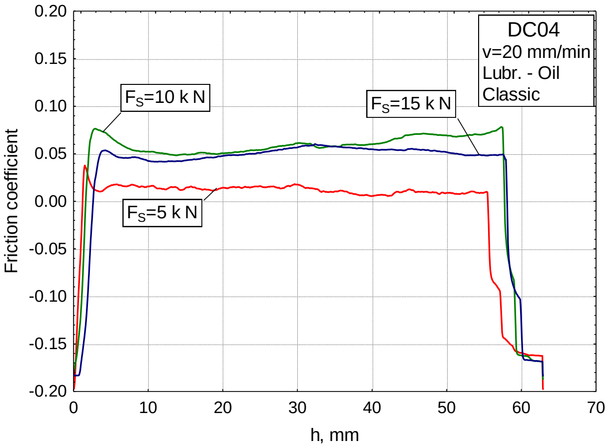

Figure 6. Friction coefficient dependence on sliding length

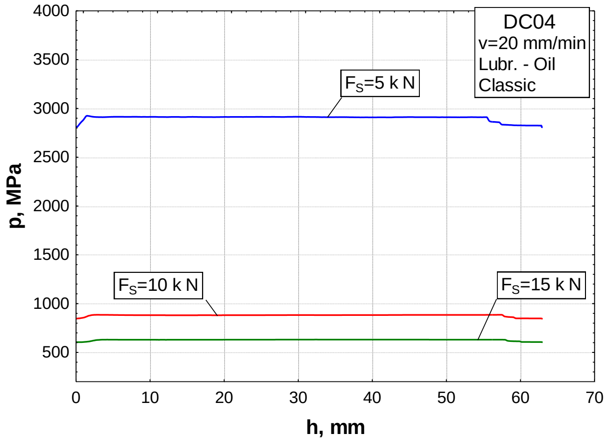

Figure 7. Pressure dependence on sliding length

Curves in figures 6 and 7 were obtained by application of classic formulas and can be seen that **μ** have very low values and pressure very high values in conditions of small deformations [7, 8, 10] i.e. lower intensity of side force F_S. Pressure **p** is near 3000 MPa and friction coefficient **μ** near zero which are unreal. In figures 8 and 9 shown are results of here proposed formulas. Values are much more realistic.

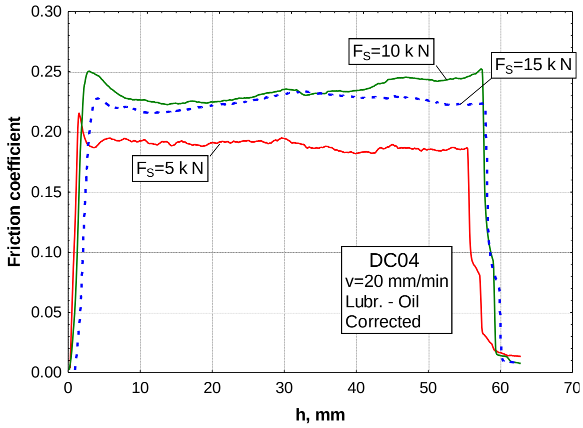

Figure 8. Friction coefficient dependence on sliding length

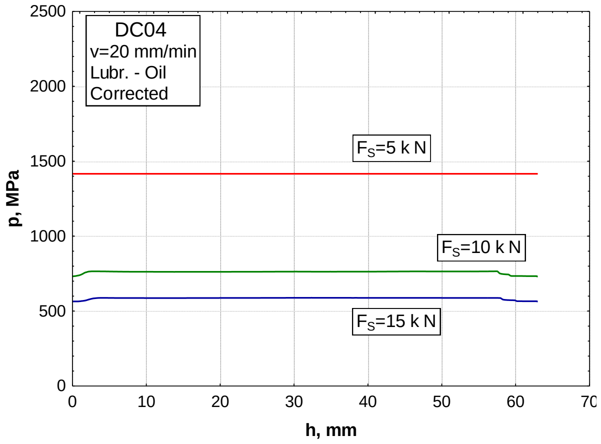

Figure 9. Pressure dependence on sliding length

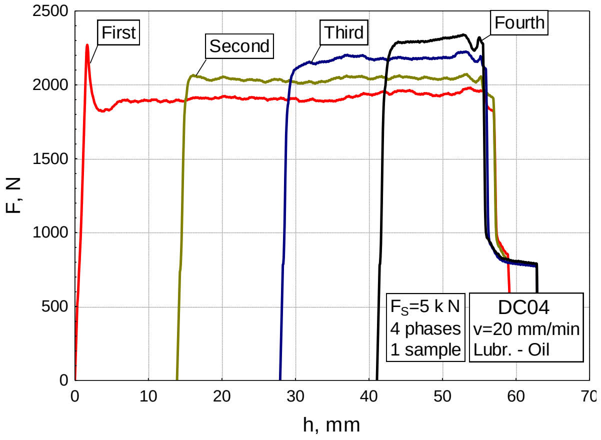

Figure 10. Force dependence on sliding length

Figure 10 illustrate second type of ironing process, multi phase sliding. On one and same sample makes four phase sliding process in conditions of side force F_S=5kN. Figures 11 and 12 gives results of classic formulas application with observations similar to previous case. In figures 13 and 14 shown are results of here proposed approach. Comments are like in previous case.

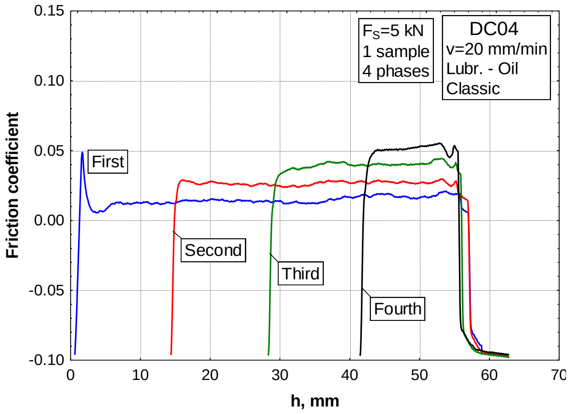

Figure 11. Friction coefficient dependence on sliding length

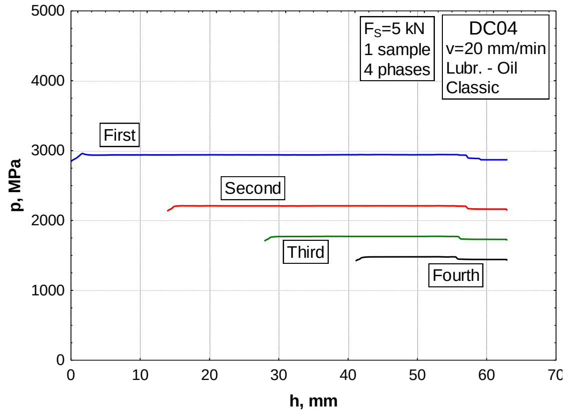

Figure 12. Pressure dependence on sliding length

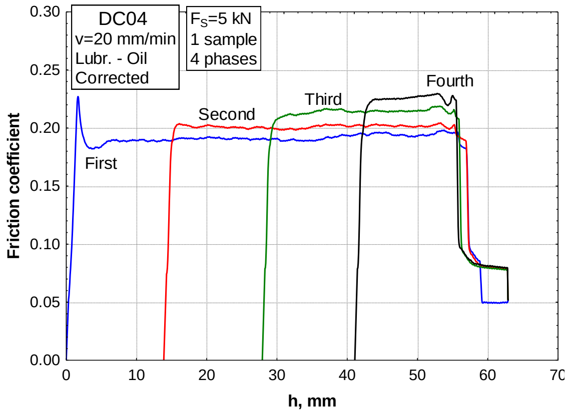

Figure 13. Friction coefficient dependence on sliding length

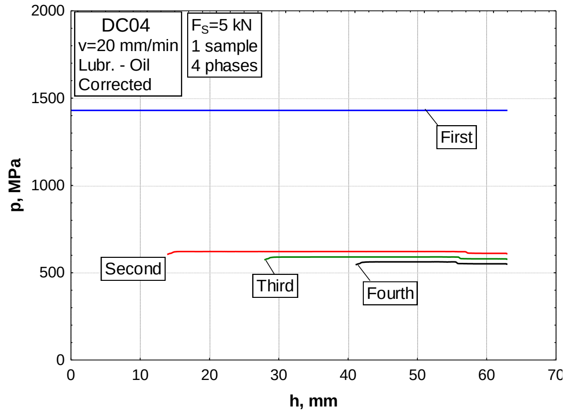

Figure 14. Pressure dependence on sliding length

3.2 Grease lubrication example

Figure 15 corresponds to figure 5. Different is only lubricant. There is appropriate grease [8, 10].

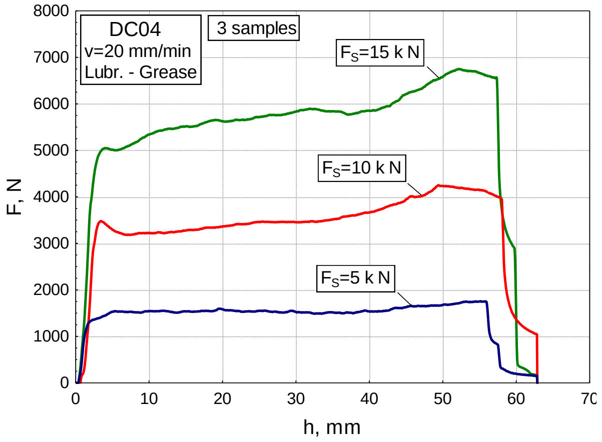

Figure 15. Force dependence on sliding length

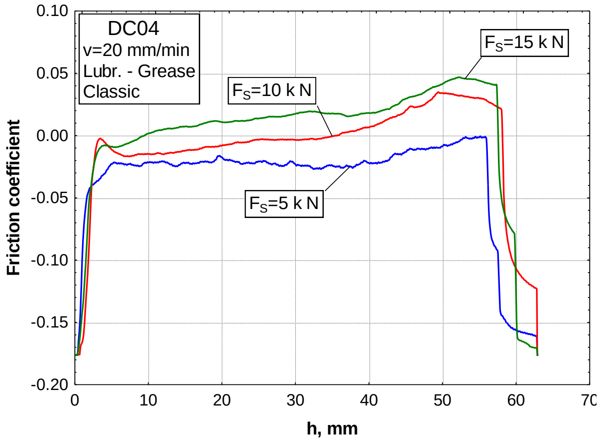

Figure 16. Friction coefficient dependence on sliding length

Classic formulas gives unacceptable results (coefficient of friction $\mu<0$, and pressure $p\approx 4500$ MPa) in figures 16 and 18.

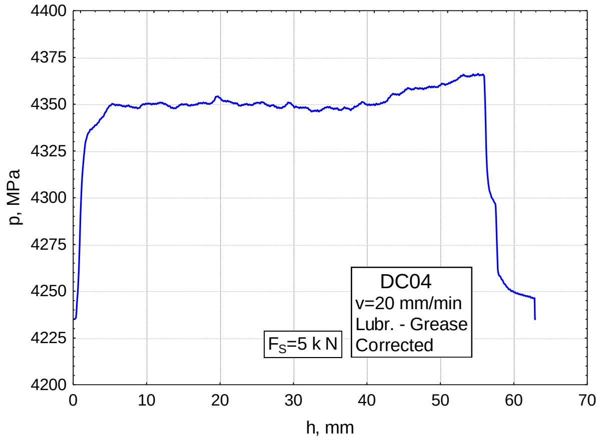

Figure 17. Pressure dependence on sliding length

In figure 17 are shown example where are illustrated small variation of pressure intensity. With appropriate scale it can be seen.

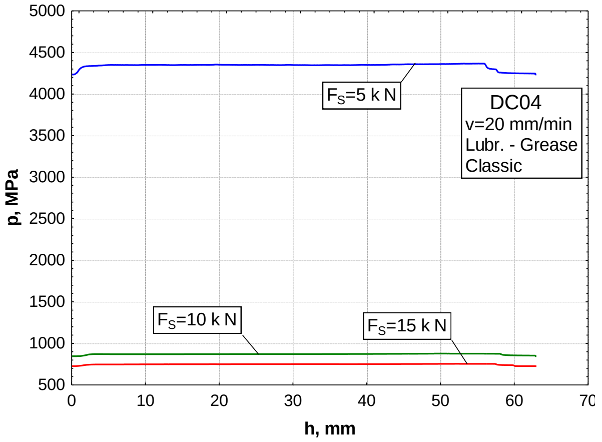

Figure 18. Pressure dependence on sliding length

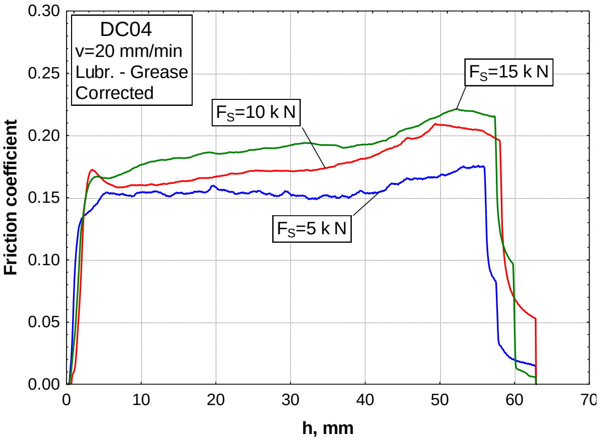

Figure 19. Friction coefficient dependence on sliding length

Results with new formulas is much better (Figs. 19 and 20).

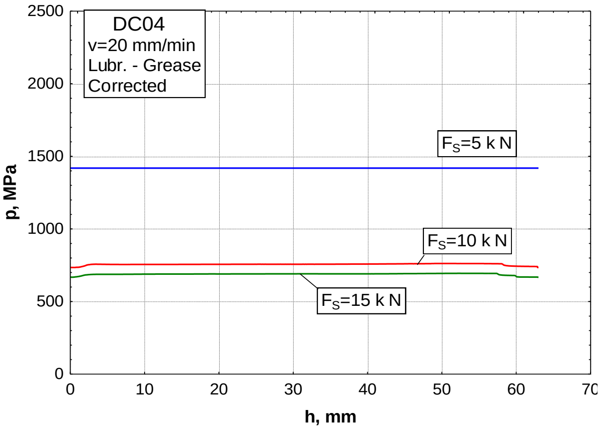

Figure 20. Pressure dependence on sliding length

Last example in this paper given are in figure 21 and corresponds to example in figure 10. Application of classic formulas gives in some cases negative values for friction coefficient and completely unreal values for pressure also (figure 22 and 23). It is clearly visible that results in figures 24 and 25 are more realistic.

4. CONCLUSION

Main goals in this research were: to establish mechanical model of ironing process with double side reduction , to define reliable expressions for coefficient of friction and contact pressure determination and evaluate applicability by experimental verification.

Obtained results presented in this paper, like others that’s not presented here, clearly shows that proposed approach is acceptable, and it can be reliable support in next experimental investigations of ironing process. Also, it can help in common experiments like the evaluations of the quality of lubricants, evaluation of influence of different sample materials etc.

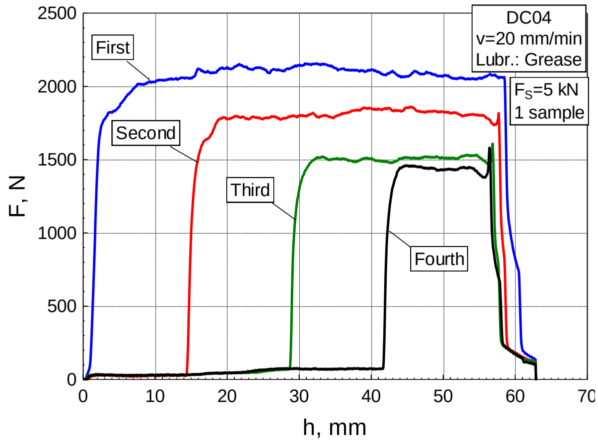

Figure 21. Force dependence on sliding length

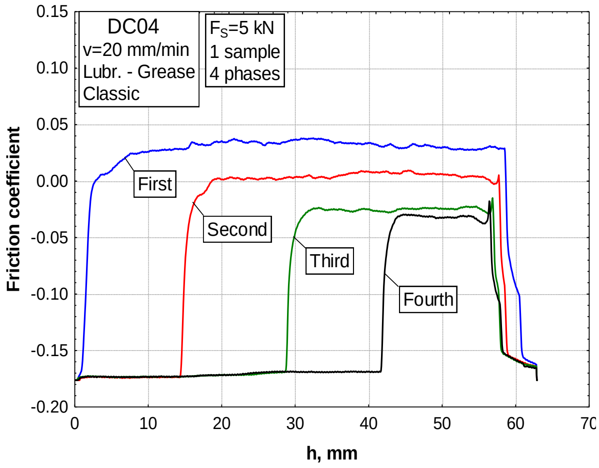

Figure 22. Friction coefficient dependence on sliding length

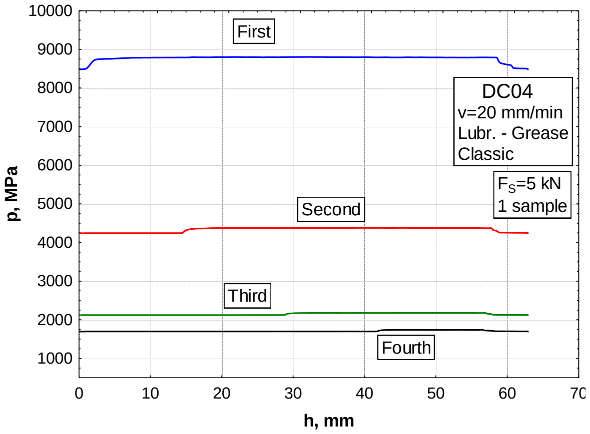

Figure 23. Pressure dependence on sliding length

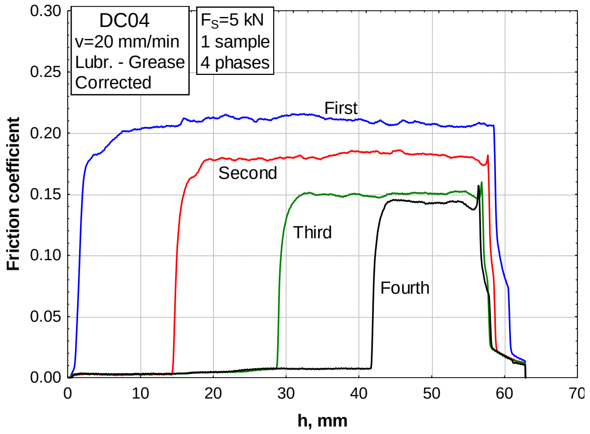

Figure 24. Friction coefficient dependence on sliding length

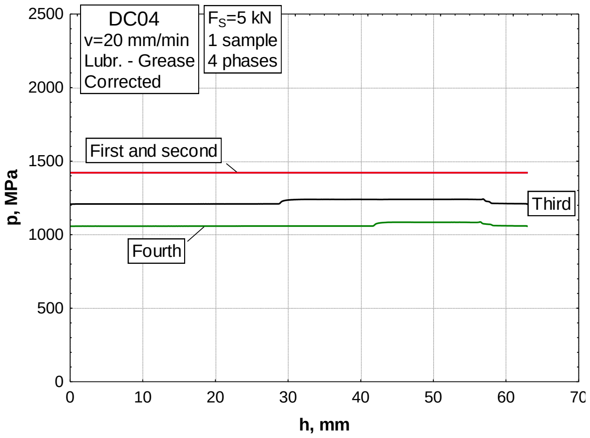

Figure 25. Pressure dependence on sliding length

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