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RESEARCH

New Method of Defining of Process Parameters in Double Side Thinning Strip Ironing Test

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A B S T R A C T

New way for defining of 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 improved analysis for friction coefficient and contact pressure defining. Classical common so called "Schlosser model" and other similar models are not suitable in certain cases, and give unreal values for both of main process parameters. Expressions obtained here were verified in suitable examples which are, also, presented in the paper. Verification was performed on the base of experimental results. Realized was the single and four phases ironing process of mild steel DC04 in sheet stripes drawing test. 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 improved procedures enables more precise process monitoring and precise quantification of lateral force, contact pressure and thinning strain influence on friction.

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 numerous published papers. Here are chosen relatively small number of selected references [1–22] whose are representing short history of last nearly four decades ironing researches. Main reason is probably great appliance of ironing forming process in modern industry. It is sufficiently to notice that industry produce by ironing process only, more than two hundred billions pieces yearly of well known product: beverage cans [5,7,9] or other products .

There are many researches of ironing process modeling in literature. Only some of them are given here. Practically most of cited references give tribological approach, mainly because ironing is more 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 was 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 paper [19] introduced are engine pistons succesful manufacturing process of thick aluminium sheets with important ironing operation. Paper [20] give simulation and analysis of cylindrical parts ironing with profile inner plug indent onto inner surface of blank. Final estimation is favorable application in real conditions. In paper [21] experimental and numerical analyses were performed to explore the influence of DLC/TiAlN coated die surfaces in sheet-metal forming including ironing. The results indicated that the DLC/TiAlN coating strongly resists galling appearance and improve friction conditions. In paper [22] given is research of continuous micromanufacturing of the hollow flanged micropart with variable thickness. Microforming method was proposed by using an integrated hole flanging-ironing process. Conclusion is that hole flanging-ironing process is promising and efficient for micromanufacturing of micro-scaled parts.

In this paper authors exposed are their own complete mechanical model and new 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

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. Before drawing there is a need of initial indentation of tools (lateral elements) which makes appropriate thnining of strip. After that starts acting of drawing force F and starts ironing process. Drawing force F and two lateral (side) forces F_S acting on the sample are simulating the industrial tool die and perform the ironing. It is useful to notice that in Fig. 1 are shown active lateral force (outer tool side) and corresponding reactive forces (inner tool side). Also, it is important to notice for this model that existing of small vertical area (detail A, Fig. 2) which can be consider flat in first approximation (Figs. 1 and 2). Also note that view in Fig. 1 is like in real conditions, but in Figs. 2, 3, 4, 5 and 6 given are common schematic views.

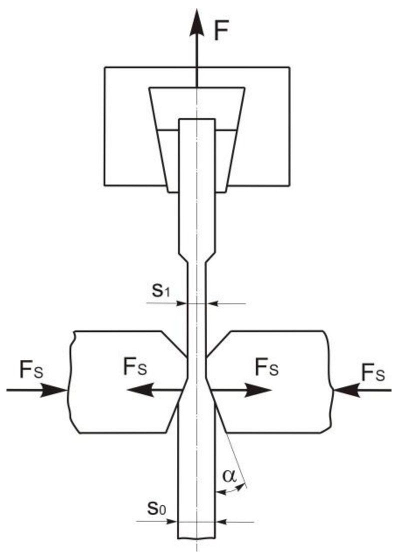

Fig. 1. Test tooling elements.

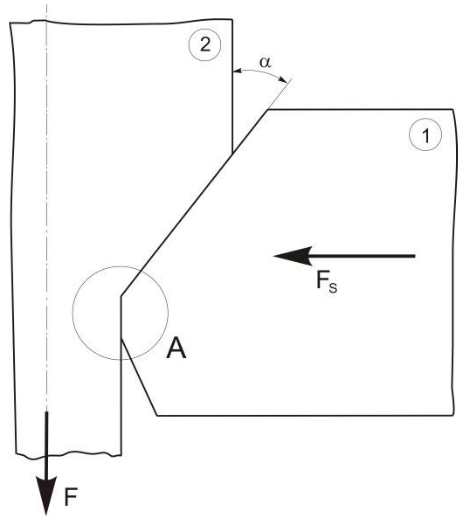

Fig. 2. Contact zones.

In real it is small arched surface of side element rounded edge i.e. part of cylindrical area with small radius (Fig. 3). Here, in particular case of used tools adopted is radius of about 1 mm and angle 10° (Fig. 4).

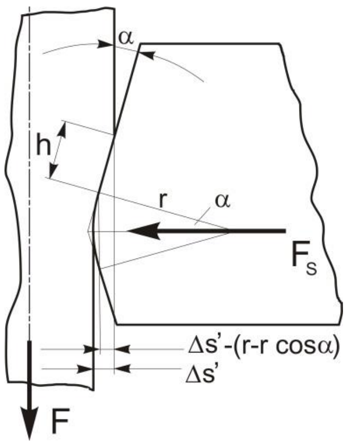

Fig. 3. More realistic model.

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:

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

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

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

where s_0 is initial sheet thickness, s_1 is thickness after forming process, ε is percentage deformation. With here adopted values (r=1, α=10°) given are:

$$\Delta s' = \frac{\Delta s}{2} \le 0.0159 \quad (4)$$

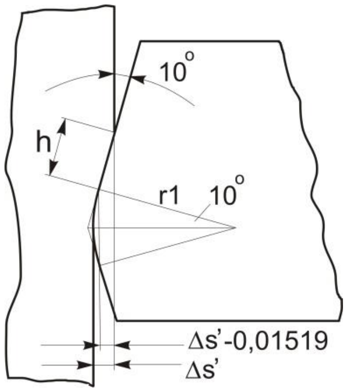

Fig. 4. Model with adopted values.

$$\Delta s = s_0 - s_1 \le 0.03038 \quad (5)$$

$$\varepsilon \le \frac{3.038}{s_0},\ \%;\ \textit{for}\ s_0 = 2.5\,mm\ \ \varepsilon \le 1.215\% \quad (6)$$

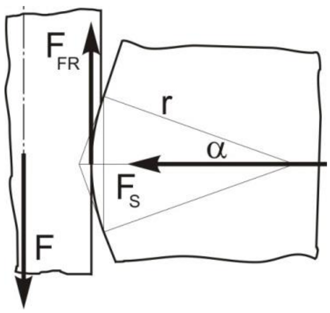

Fig. 5. First case acting forces (right side).

In such a case process is carrying out in conditions of contact established on rounded surface only (Fig. 5). There is no any flat contact. Mechanical model of acting forces is very simple: drawing force F, two side forces F_S and two friction forces μF_S (Fig. 5). 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.

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

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

$$\Delta s = s_0 - s_1 > 0.03038 \quad (9)$$

$$\varepsilon > \frac{3.038}{s_0},\ \%;\ \textit{if}\ s_0 = 2.5\,mm\ \varepsilon > 1.215\% \quad (10)$$

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

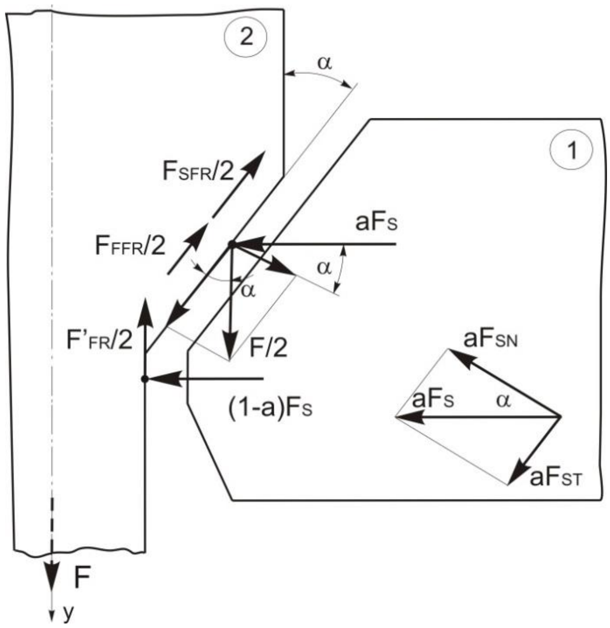

Fig. 6. Second case mechanical model of right side forces acting.

Mechanical model of acting forces is given in Fig. 6 (for right side only). Can be assumed that side tool element 1 is slightly moved right and his acting changed with the force F_S. Distribution of force F_S between flat inclined and small near vertical surfaces is determined by empirical parameter a. It was adopted a=0.7 after analysis in [7]. Friction force F_{SFR} depends on normal component (aF_{SN}) of side force part aF_S. Force F_{SFR} acting on flat inclined surface. Force F_{FFR} depends on normal component of drawing force F/2. Friction force F_{FR}' depends on (1-a)F_S part of side force 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 (Fig. 5). 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, Fig. 6) 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) like is given here. 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 and adopted 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, A_1=h·b=0, Fig. 5) and consequently not exist corresponding forces from Fig. 6 (expression 19). It is clear that:

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

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

where is:

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

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

Finaly

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

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 assumed 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 .

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

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

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

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

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

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

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

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

Can be noticed that small rounded area A_2 is adopted here like flat, inclined with angle α. 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, important is to notice that approach like previous isn't reasonable for friction analysis in sliding process where two areas (A_1 and A_2) 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 [1,5,7,8]. These are well known classic expressions:

$$\mu=\frac{\frac{F}{2F_S}-tg\alpha}{\frac{F}{2F_S}tg\alpha+1} \tag{31}$$

$$p=\frac{F\sin^2\alpha+2F_S\sin\alpha\cos\alpha}{b(s_0-s_1)} \tag{32}$$

All the details about experiment: equipment, tooling, material properties, geometry, lubricants properties, process properties etc. is not presented because of limited space and can be fined in [7], [8] and [10]. However, some data of materials, lubricants, process and equipment will be given here. In Figs. 7, 8 and 9 presented are tools elements and experimental equipment.

Material samples i.e. 2.5 mm thick, 20 mm wide and 200 mm long strips were made of mild steel DC04. Lateral forces were 5, 10 and 15 kN. Sliding speed was 20 mm/min. Applied were two lubricants from domestic producer: mineral oil (kinematic viscosity 170 mm^2/s at 40 °C, density 0.950 g/cm^3 at 20 °C) and special grease intended for drawing processes (viscosity 330 mm^2/s at 40 °C).

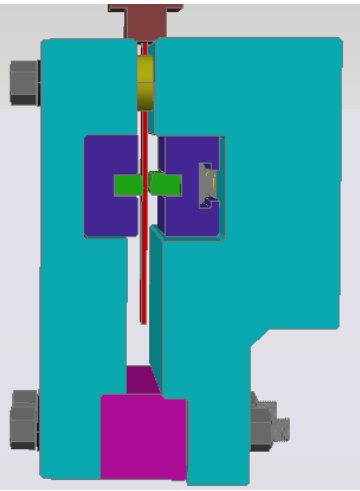

Fig. 7. 3D model of tool assembley.

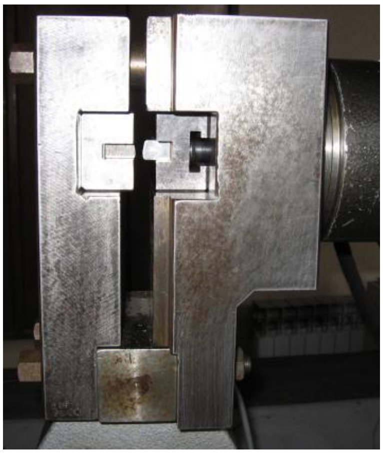

Fig. 8. Real tool assembley.

Fig. 9. Experimental equipment.

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

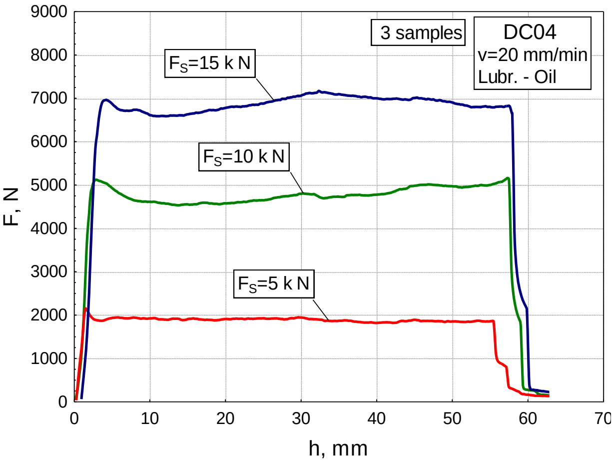

Fig. 10. Force dependence on sliding length.

Curves in Figs. 11 and 12 were obtained by application of classic formulas ((31), (32)) and can be seen that μ have very low values and pressure, quite opposite very high values in conditions of small deformations i.e. lower intensity of side force F_S [7,8,10]. Pressure p intensity is near 3000 MPa and friction coefficient μ near zero which are unreal.

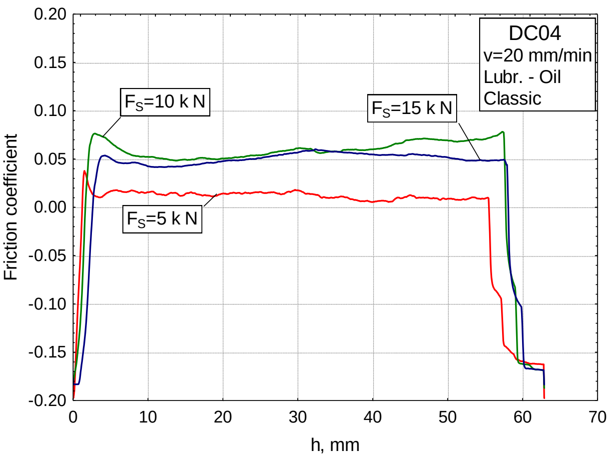

Fig. 11. Friction coefficient dependence on sliding length.

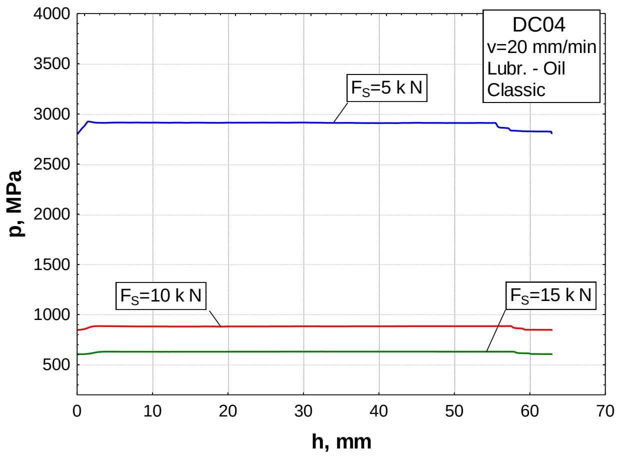

Fig. 12. Pressure dependence on sliding length.

In Figs. 13 and 14 shown are results of here proposed formulas, signed as corrected on the diagrams. Values are much more realistic.

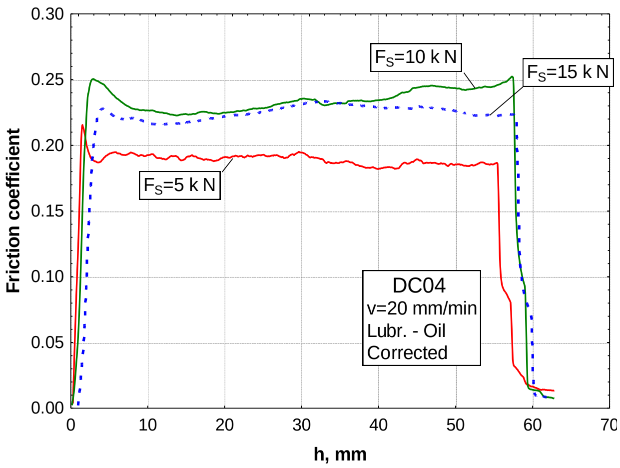

Fig. 13. Friction coefficient dependence on sliding length.

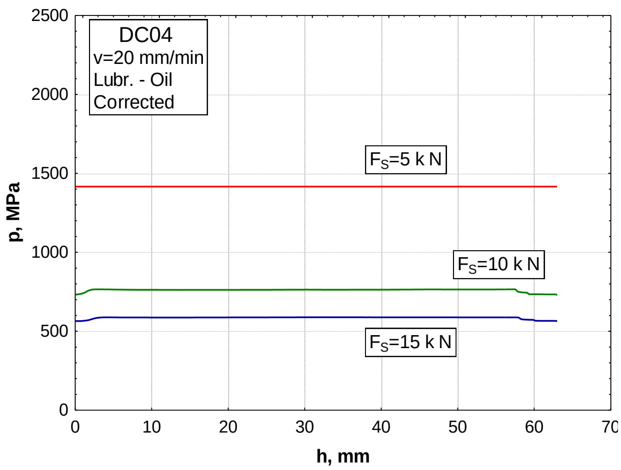

Fig. 14. Pressure dependence on sliding length.

Figure 15 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=5 kN. Figures 16 and 17 gives are results of classic formulas application with observations similar to previous case. In Figs. 18 and 19 shown are results of here proposed approach. Comments are like in previous case.

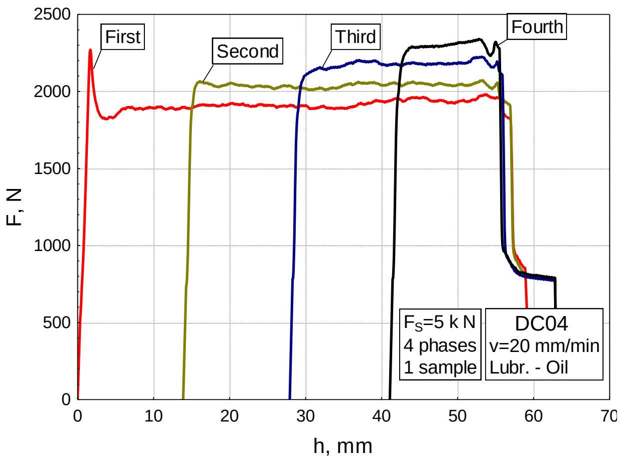

Fig. 15. Force dependence on sliding length.

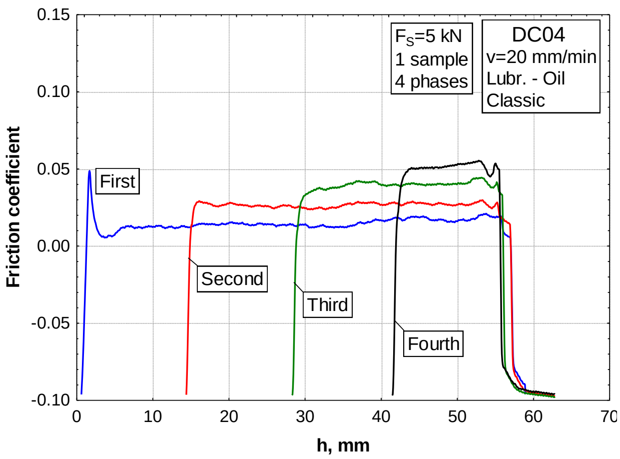

Fig. 16. Friction coefficient dependence on sliding length.

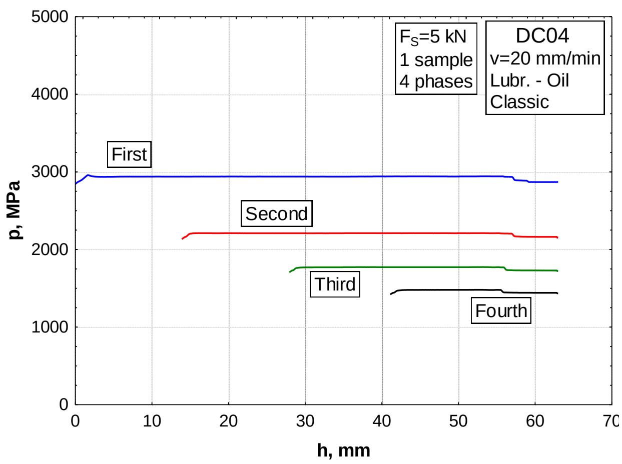

Fig. 17. Pressure dependence on sliding length.

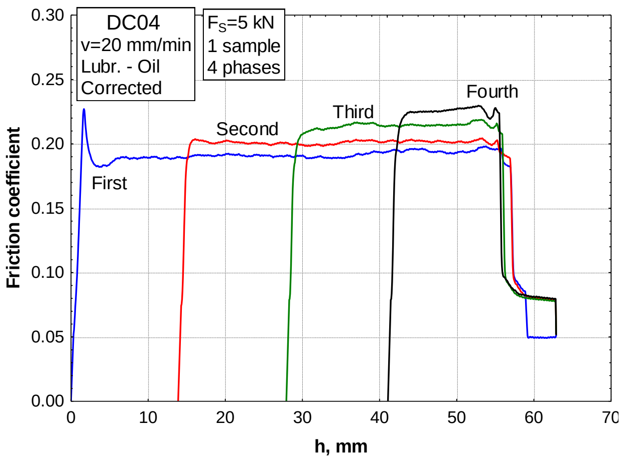

Fig. 18. Friction coefficient dependence on sliding length.

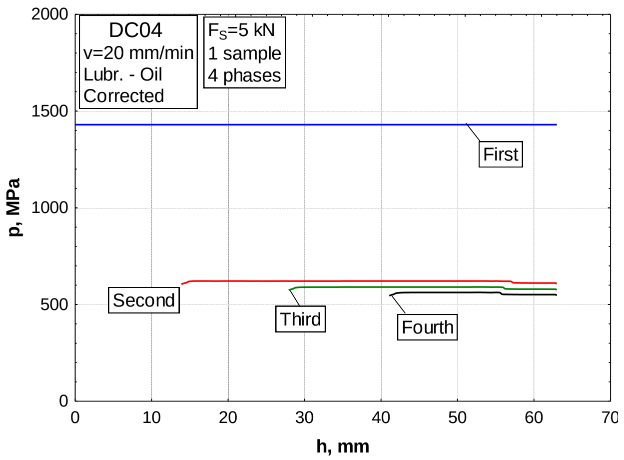

Fig. 19. Pressure dependence on sliding length.

3.2 Grease lubrication example

Figure 20 corresponds to Fig. 10. Different is only lubricant. There is used appropriate grease [8,10].

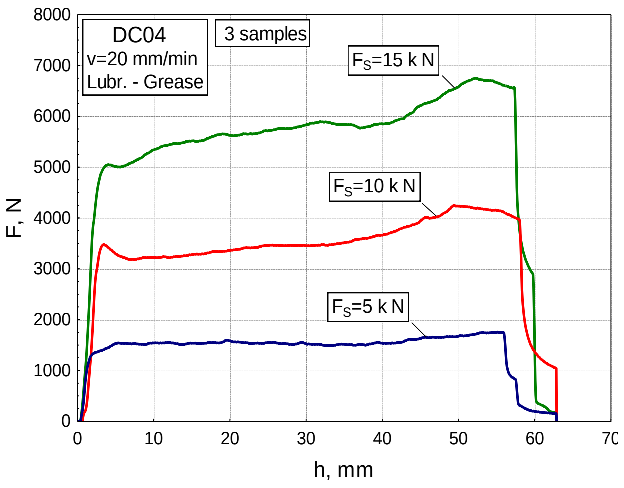

Fig. 20. Force dependence on sliding length.

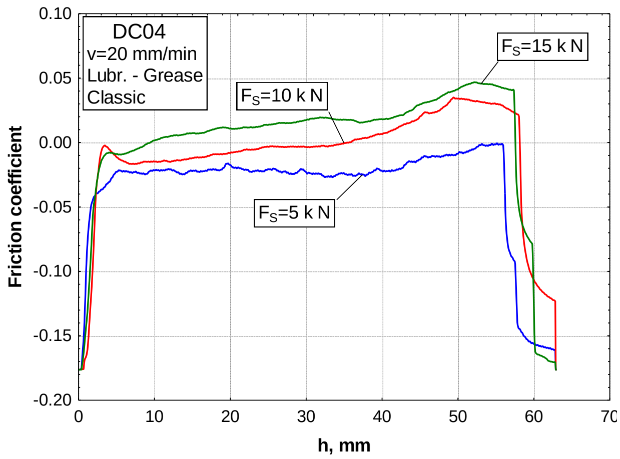

Fig. 21. Friction coefficient dependence on sliding length.

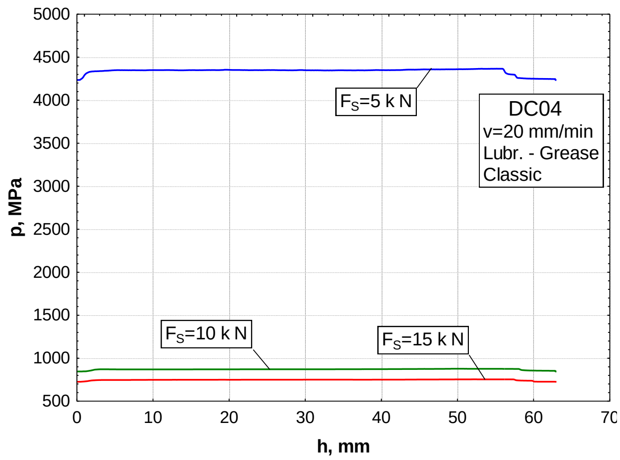

Fig. 22. Pressure dependence on sliding length.

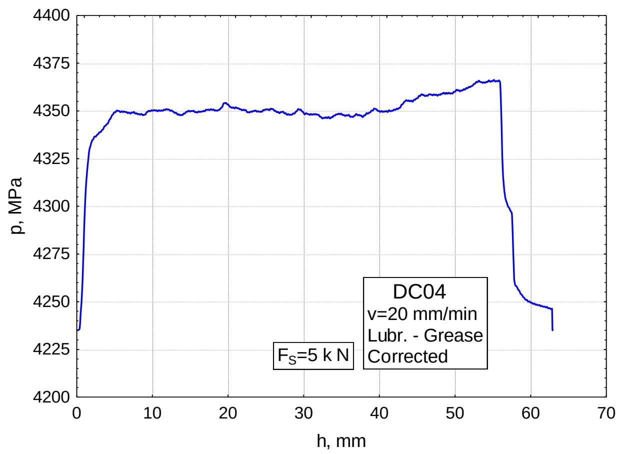

Fig. 23. Pressure dependence on sliding length.

Classic formulas gives unacceptable results (coefficient of friction $\mu<0$, and pressure $p\approx4500$ MPa) in Figs. 21 and 22.

In Fig. 23 are shown example where are illustrated small variation of pressure intensity. With appropriate scale it can be seen.

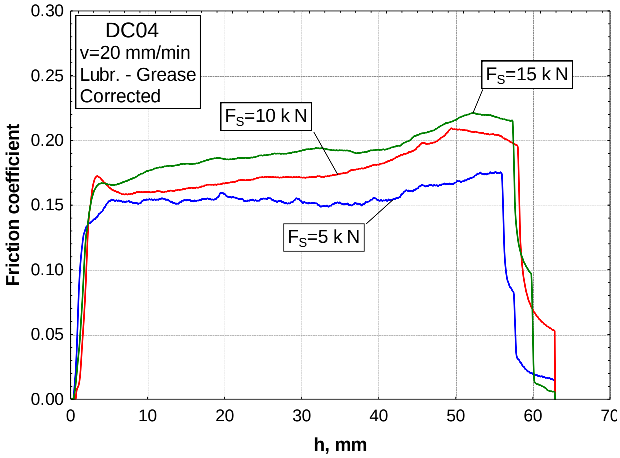

Fig. 24. Friction coefficient dependence on sliding length.

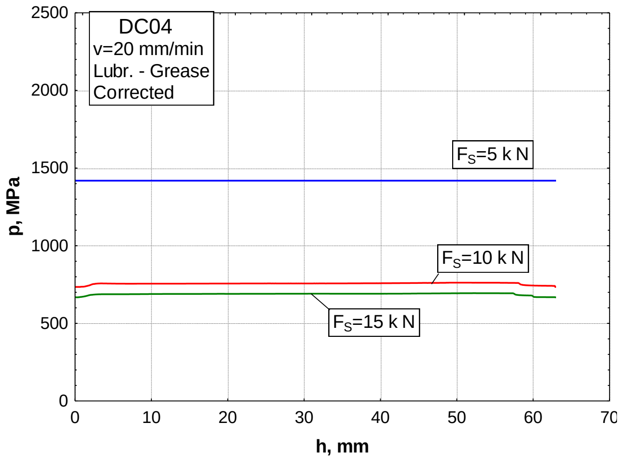

Fig. 25. Pressure dependence on sliding length.

Results with new formulas are much better (Figs. 24 and 25).

Last example in this paper given is in Fig. 26 and corresponds to example in Fig. 15.

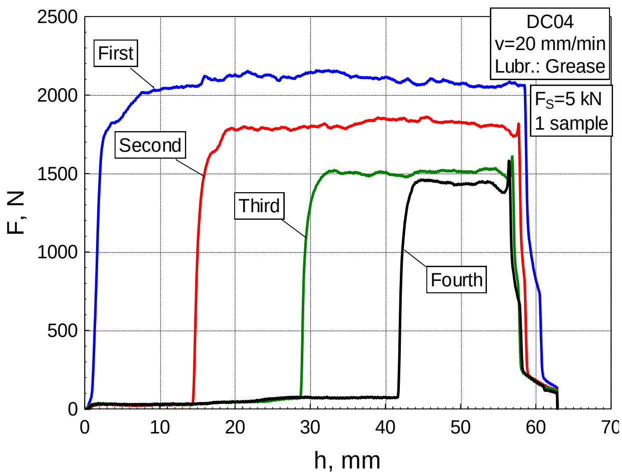

Fig. 26. Force dependence on sliding length.

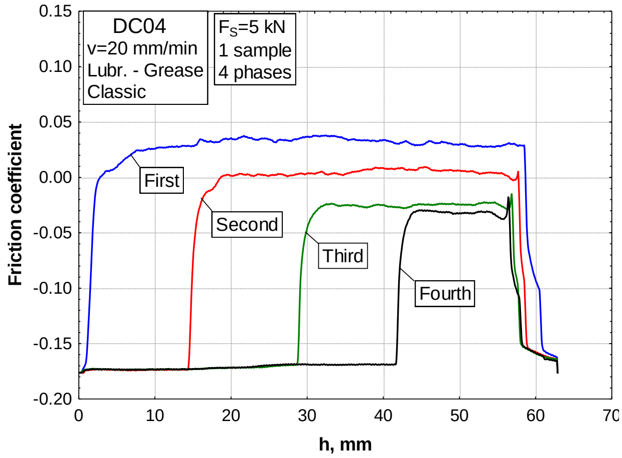

Fig. 27. Friction coefficient dependence on sliding length.

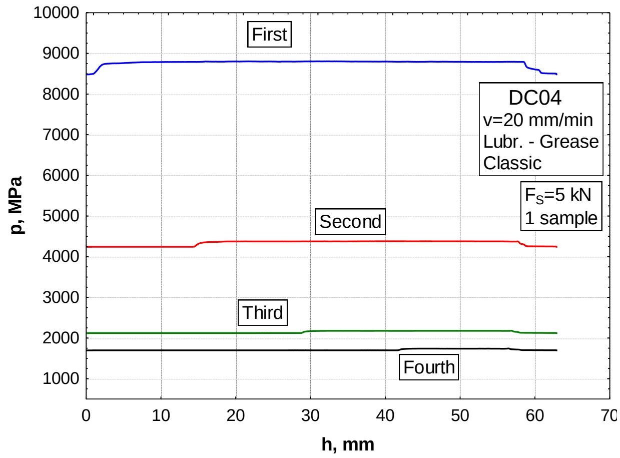

Fig. 28. Pressure dependence on sliding length.

Application of classic formulas gives in some cases negative values for friction coefficient and completely unreal values for pressure also (Figs. 27 and 28). It is clearly visible that results in Figs. 29 and 30 are more realistic.

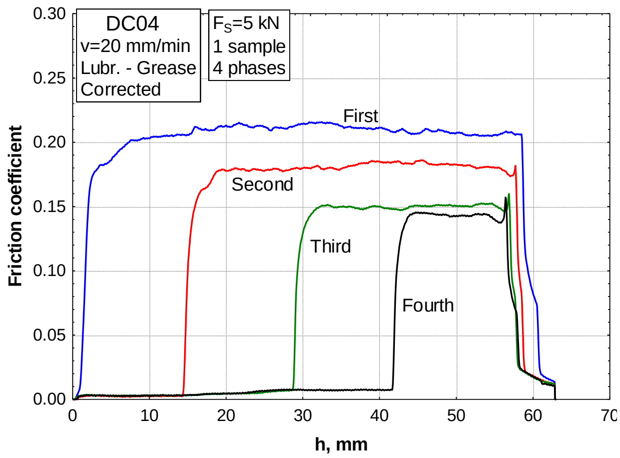

Fig. 29. Friction coefficient dependence on sliding length.

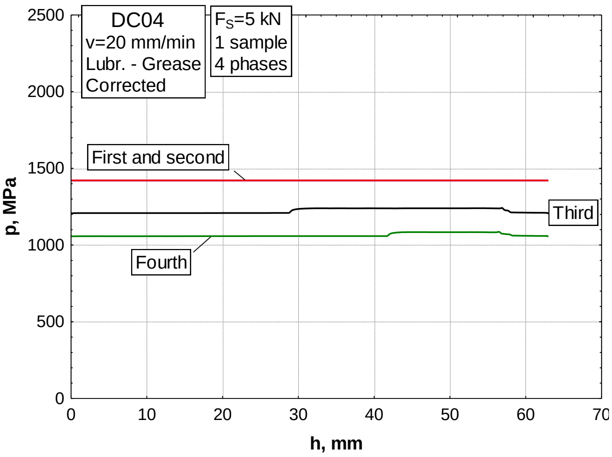

Fig. 30. Pressure dependence on sliding length.

4. CONCLUSION

Main goals in this study 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.

Acknowledgement

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