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CHARACTERISTICS OF FRICTION IN SHEET METAL SLIDING WITH THICKNESS REDUCTION

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Abstract: *Presented in the paper are results obtained in investigation of the effects of tribological conditions in cold metal forming. A characteristically tribo-model is strip ironing between angled die surfaces. Investigated were the changes in ironing force, pressure, friction coefficient in single and multy-phase sliding in the conditions of boundary lubrication. The low carbon mild steel sheet, suitable for plastic forming was used. In course of investigation the so called constant low friction has been realized in condition of high contact pressures. Especially significant are the results of multi-phase sliding, which simulates the moving of piece through dies.*

Keywords: *cold forming, ironing, friction coefficient, sheet metal*

1. INTRODUCTION

In cold metal forming processes, characterized by high pressures, local tool loads, generating of new piece surfaces etc., realisation of the convenient lubrication regime and elimination of micro-welding are of extreme importance. Distribution and intensity of shearing stresses on piece surface influence the possibility for plastic forming, i.e. the size of active force, energy consumption, tool life, piece surface quality etc. Taking into consideration the complexity of specified factors, tribological investigations in MF processes are extremely important and equal with investigations of other forming system segments - machines, tools and materials.

Proper selection of tribological conditions and identification of boundary relations on contact surfaces enables controlled flow in surface layer, whereat this layer has sufficiently lower flow limit than basic material and can be defined without fracture. By combination of main tribo-factors in forming system – speed, load (strain ratio), type of materials in contact (topography, content), preparation of contact surface and lubricant type, it is possible to realise mixed, i.e. boundary friction. In that way, contact between tool and piece material, tearing of softer material particles and rough disruptions of forming conditions are reduced to minimum.

At ironing, pieces of considerable height in relation to diameter are obtained, with bottom thickness larger than wall thickness. In forming, which is most often multi-phase for one stroke, inner diameter slightly changes. Total thinning, i.e. number of rings and geometrical relations of work surfaces of tool elements are important in forming.

2. TRIBOLOGICAL MODEL DESCRIPTION

Modelling of tribological conditions at ironing implies satisfying of the minimum of necessary criteria considering the similarity in stress strain properties, temperature-speed conditions, properties of tools surface and material. In researches, the results of which are presented in this paper, the basic ironing model, which imitates zone of contact with die with biaxial symmetry, was used as tribo-model, fig.1. This is a classical model, which enables realisation of high contact pressure and takes into account real geometrical conditions of forming process. It was used in many researches, especially in the area of tribology of stainless steel sheet metals and in Al- alloys forming [1] , [2].

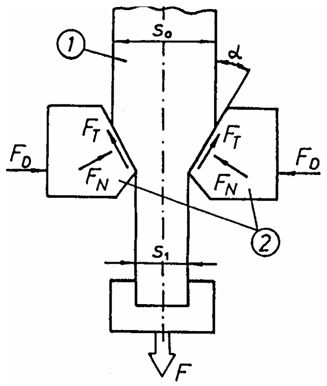

Figure 1. Scheme of the tribo-model

Model applied in paper, according to fig.1, requires measuring of holder force F_D and drawing-sliding force F. If the test-specimen dimensions and die angle are known, it is possible to determine friction coefficient and average pressure in contact:

$$\mu = \frac{\dfrac{F}{2F_D} - tg\alpha}{1 + F\dfrac{tg\alpha}{2F_D}} \tag{1}$$

$$\bar{p} = \frac{F\sin^2\alpha + 2F_D \sin\alpha\cos\alpha}{b_0(s_0 - s_1)} \tag{2}$$

where is:

b_0 - specimen width,
s_0 - initial test-specimen thickness ,
s_1 - thickness after drawing.

3. EXPERIMENTAL RESEARCHES

Ironing is realised in conditions close to plane stress state. The investigated material is low-carbon steel sheet metal of quality DC04, convenient for plastic forming. Mechanical and other properties are specified in Table 1. Dimensions of test-specimen being investigated are: b_0 *x* s_0 *x length = 20 x 2,5 x 200 mm.*

Table 1. Material properties

R_p, MPa	R_m, MPa	A, %	r	n
185,2	284,5	35,3	1,68	0,215

Contact pair is made of tool steel, hardness 60 HRC, highly-polished to mean roughness Ra =0,06 µm. Gradient angle is $\alpha=10^0$, as recommended in literature. Drawing speed is 20 mm/min. In investigations, mineral oil for cold forming was used [3].

In dependence on specified conditions, it is possible to carry out certain classification of friction types, taking as a criterion the value and change of friction coefficient and appearance of test-specimen surface after investigation [1]:

I - constant low friction,
II - increase of friction after realisation of type I,
III - constant increase of friction,
IV - constant high friction.

Proper contact surfaces have the following descriptions:

- flat (smooth)
- lightly polished
- with abrasions
- lightly scratched
- heavily scratched

At drawing at sliding length of 60 mm, there are no changes in friction character, as a rule. In addition, drawing force records at successive investigations are shown, with shorter sliding paths. Dependence of force on sliding path practically remains constant during investigation period, which corresponds to I friction type. Dependence of drawing force on travel at various working pressures is shown in Fig.2. Total drawing force consists of friction force and "ideal" forming force which depends exclusively on strain ratio [3].

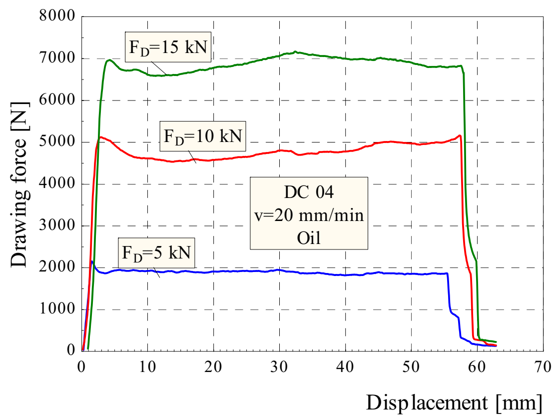

Figure 2. Change of drawing force for different F_D

Sheet metal thinning at the same compression force F_D does not depend on tribological conditions in contact [4]. Increase of the number of drawings worsens the lubrication conditions, which corresponds to real process of drawing through numerous dies- rings, Fig.3.

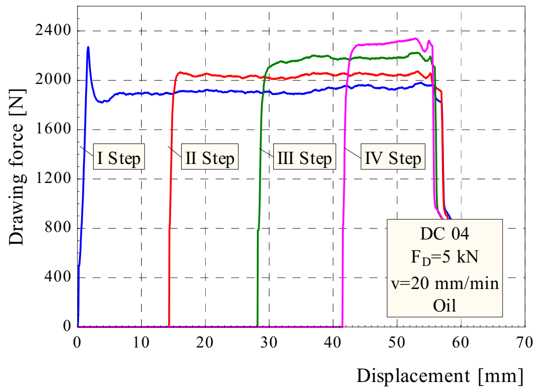

Figure 3. Change of ironing force at multiphase drawing at F_D=5 kN

Important changes in contact occur in the first and second forming phase, and then the process becomes stationary in the subsequent phases, if friction conditions do not change, Fig.4.

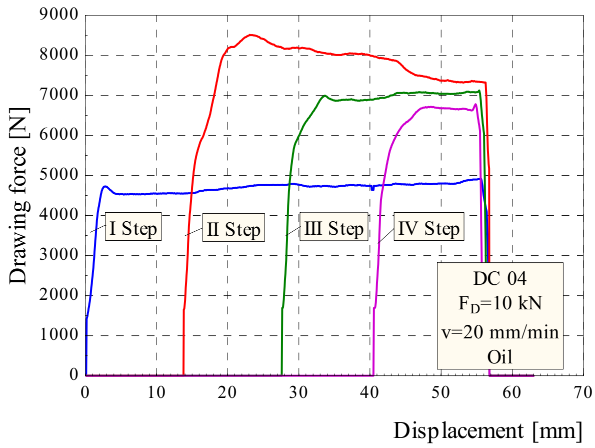

Figure 4. Change of ironing force alt multiphase drawing at F_D=10 kN

By using formula (1), it is possible to determine friction coefficient in dependence on experimental conditions, Fig.5.

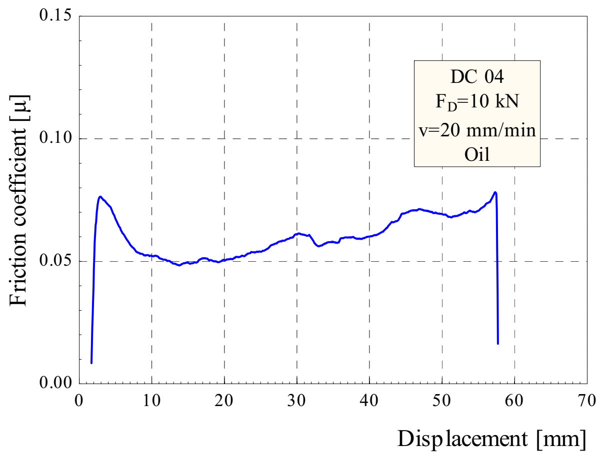

Figure 5. Change of friction coefficient with sliding path at F_D=10 kN

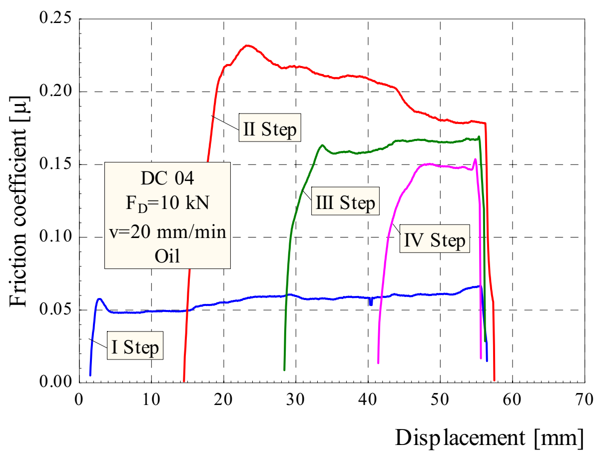

Figure 6. Change of friction coefficient at multiphase drawing at F_D=10 kN

Due to faster increase of contact surface in dependence on compression force, at bigger F_D forces, smaller pressures are realised and vice versa. By using formula (2), it is possible to determine average contact pressure in sliding zone. Dependence of contact pressure on travel at F_D=10 kN is shown in Fig. 7.

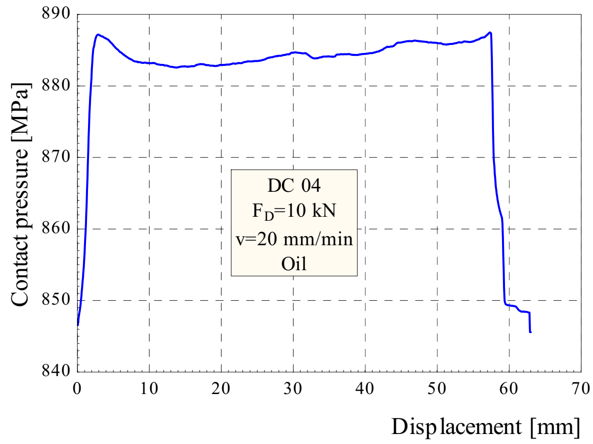

Figure 7. Change of contact pressure at F_D=10 kN

4. CONCLUSION

At model investigations of ironing, presented in the paper, stationary process with "constant low friction" was realised in conditions of high contact pressure. Friction coefficient values are the lowest at the first drawing and do not depend on sliding length.

At consecutive drawing-sliding, specific pressure in contact increases with the constant holder force, with realisation of boundary friction.

In the course of investigation, a new surface is generated, so the total length of test-specimen is increased.

At sliding lengths that are considerably larger than those in the experiment, the appearance of friction force increase is possible, as well as the appearance of the third or fourth friction type. a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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