34th INTERNATIONAL CONFERENCE ON PRODUCTION ENGINEERING
28. - 30. September 2011, Niš, Serbia
University of Niš, Faculty of Mechanical Engineering

IMPORTANCE OF TRIBOLOGICAL CONDITIONS AT MULTI-PHASE IRONING

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Abstract: *The importance of tribological conditions in metal forming is well known and equal to other forming process factors – material, machine and tool. The results obtained in investigation of the effects of tribological conditions in cold metal forming are presented in the paper. A typical tribo-model is strip ironed between angled die surfaces. The changes in pressure, friction coefficient and surface topography in single and multi-phase sliding in the conditions of boundary lubrication were investigated. The low carbon mild steel sheet, suitable for plastic forming, was used. In dependence on conditions in contact, it is possible to realize various friction lows. In course of investigation the so called constant low friction has been realized in condition of high contact pressures. The results of multi-phase sliding, which simulates the moving of piece through dies, are especially significant.*

Key words: *cold forming, multy-phase 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.

In the closed system tool-lubricant-material numerous tribological factors are present, most of which are variable during the process and are in a particular interaction, which makes the entire problem extremely complex. These factors can be observed from macro-geometrical, rheological or some other aspect. Some factors which are very important are: properties of tool material and material being formed, thermal problems (temperature, heat transfer, …), micro- and macro-properties of forming process, relation of contact and free surface of the piece, friction properties, lubricant and lubrication method properties, contact surface roughness and its orientation, plasticity, fatigue, adhesion, diffusion, wear, stress and strain distribution, sliding speed, remaining stresses, damages, physical-chemical properties, condition of surface etc [3].

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. CHOICE OF TRIBOLOGICAL MODEL

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. Classical scheme of ironing is shown in Fig. 1, and different tribo-models of ironing are shown in Fig. 2.

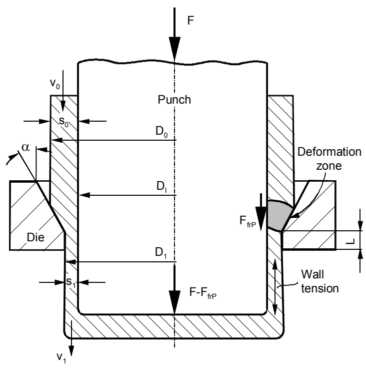

Fig. 1. Scheme of ironing

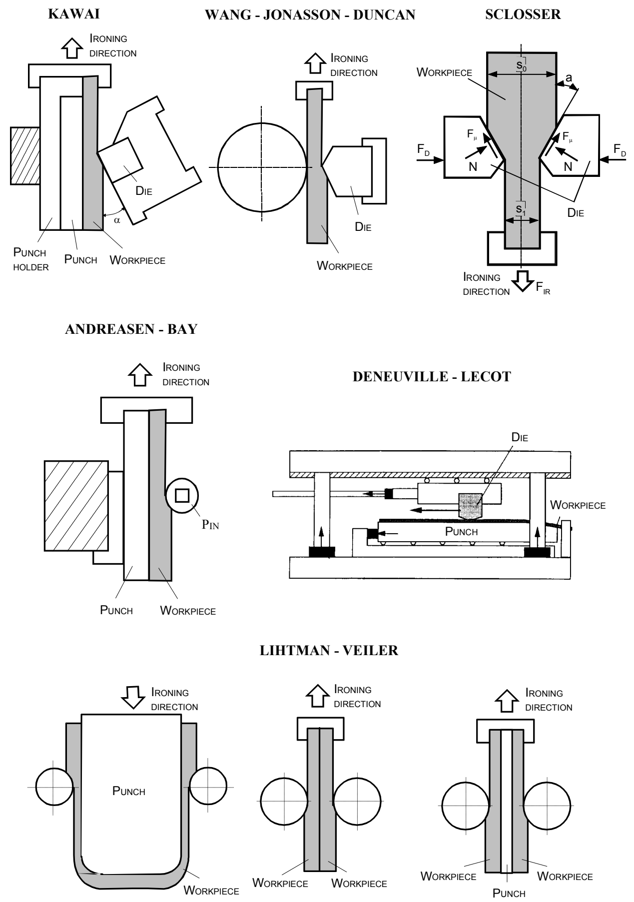

Fig.2. Tribo-models of ironing

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. 3. This is a classical model (*Schlosser)*, 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].

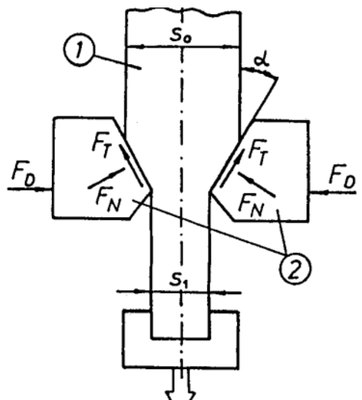

Fig. 3. Scheme of the tribo-model

Model applied in paper, according to fig.3, 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:

$$\mu = \frac{\dfrac{F}{2F_D} - tg\alpha}{1 + F\dfrac{tg\alpha}{2F_D}} \qquad (4)$$

$$\bar{p} = \frac{F\sin^2\alpha + 2F_D \sin\alpha\cos\alpha}{b_0(s_0 - s_1)} \qquad (5)$$

where is:

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

3. EXPERIMENTAL RESULTS

Ironing is realised in conditions close to plane strain 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: $b_0 \times s_0 \times$ *length = 20 × 2,5 × 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].

The investigations were made on a special device, ERICHSEN 142, according to the model in Fig.3 , which was placed on the machine for investigation of sheet-metals,

Side force F_D is realized by a special hydro-device, which enables measuring of the force. In the course of investigation, forces of 5, 10 and 15 kN were given. Drawing force, in dependence on the sliding path, was measured by a special measuring chain.

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. 4. Total drawing force consists of friction force and "ideal" forming force which depends exclusively on strain ratio [3], [4].

Sheet metal thinning at the same compression force F_D does not depend on tribological conditions in contact [4, 5]. Increase of the number of drawings worsens the lubrication conditions, which corresponds to real process of drawing through numerous dies-rings, Fig. 5.

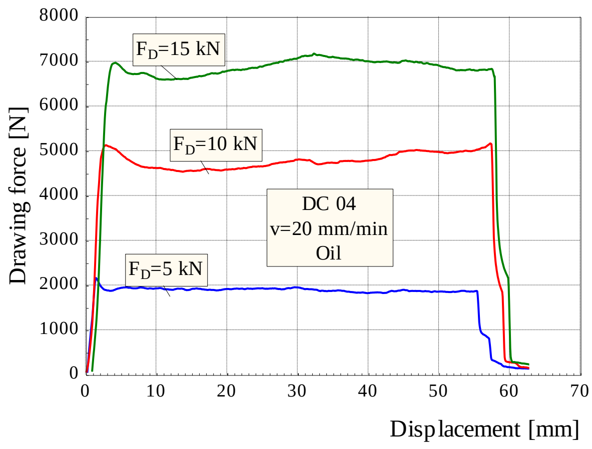

Fig. 4. Change of drawing force for different F_D

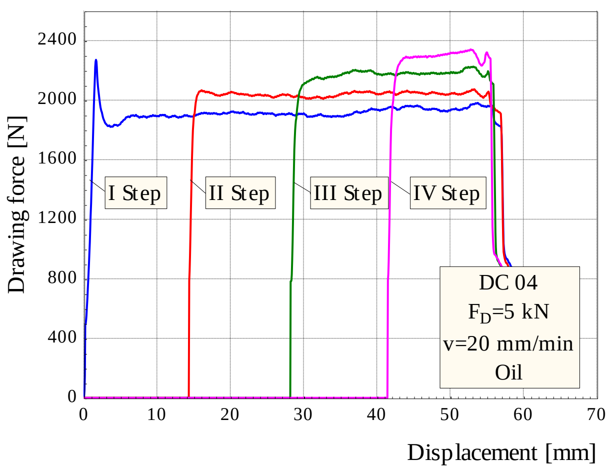

Fig. 5. Change of ironing force at multiphase drawing at F_D=5 kN

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.6.

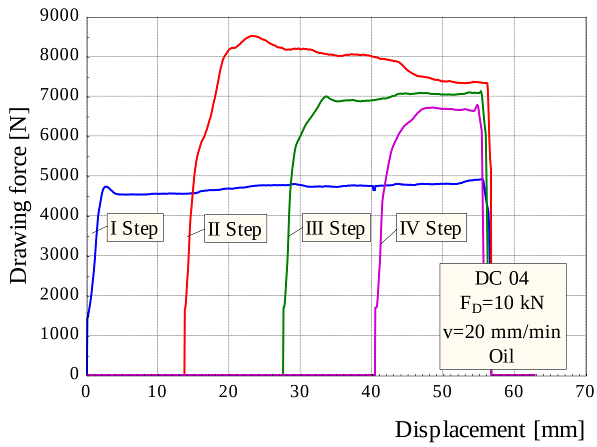

Fig. 6. Change of ironing force at multiphase drawing and F_D=10 kN

By using formula (1), it is possible to determine friction coefficient dependence on experimental conditions, Fig.7. 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 multphase sliding is shown in Fig. 8. and Fig.9.

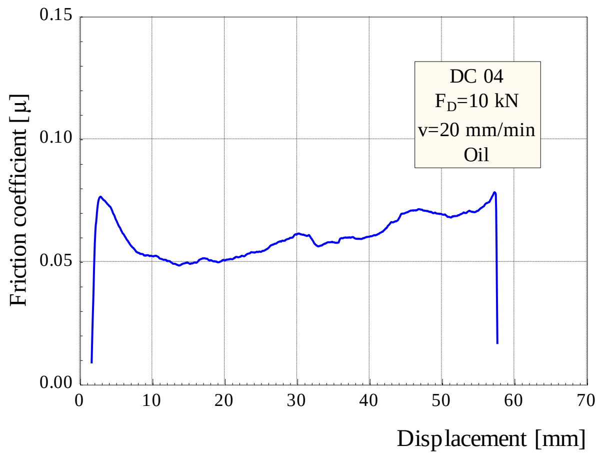

Fig. 7. Change of friction coefficient with sliding path at F_D=10 kN

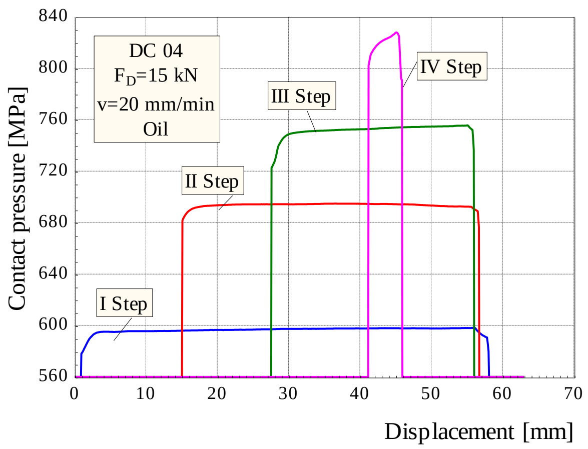

Fig. 8. Change of contact pressure at multiphase drawing and F_D=15 kN

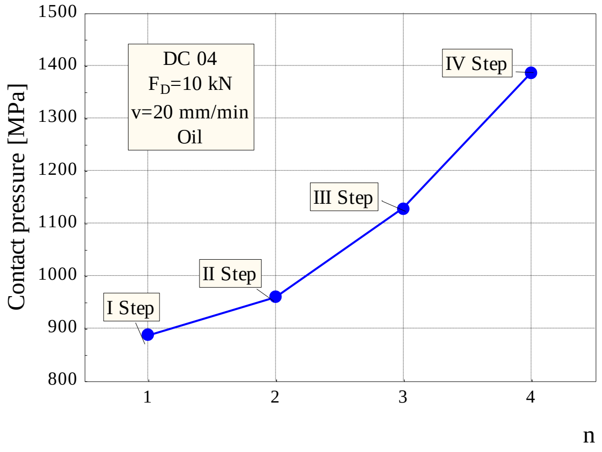

Fig. 9. Change of contact pressure at F_D=10 kN and n=4 phases of sliding

4. CONCLUSIONS

Cold plastic forming processes are characterized by unity of positive and negative influence of outer friction forces; on some areas of contact of tool and material, friction should be intensified (e.g. on movable die surface in indirect extrusion, on punch surface in ironing, etc..), and in some other zones (in general, on almost all surfaces) friction forces must be reduced by lubrication as much as possible.

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.

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