Serbian Tribology Society

SERBIATRIB '19

16th International Conference on Tribology

Faculty of Engineering University of Kragujevac

Kragujevac, Serbia, 15 – 17 May 2019

ANALYSIS OF THE PROCESS PARAMETERS INFLUENCE ON THE CHANGE OF MEAN CONTACT PRESSURE IN IRONING PROCESS

Dragan ADAMOVIĆ[1]*, Jelena ŽIVKOVIĆ[1], Bogdan NEDIĆ[1], Fatima ŽIVIĆ[1], Slobodan MITROVIĆ[1], Miroslav ŽIVKOVIĆ[1],

[1] Faculty of Engineering, University of Kragujevac, Serbia

*Corresponding author: adam@kg.ac.rs

Abstract: *Friction that occurs in metal forming processes is significantly different from the friction in mechanical joints. Specific pressures in deep drawing with thinning of the wall thickness that occur on the contact surface between the deformed metal and the tool are very high and considerably exceed the yield stress of the workpiece. As a result of such high pressures there are significant changes in the friction conditions, the efficiency of the lubrication is reduced (the lubricant layer breaks and a direct contact of the surfaces occurs) and the wear process is intensified.*

This paper shows the analysis of the influence of different process parameters (the die angle, lubrication on die and punch, the punch surface roughness, tool material, etc.) on the mean contact pressure based on performed experimental tests on the model.

Keywords: *ironing, mean contact pressure, lubricant, tool material, roughness, steel sheet.*

1. INTRODUCTION

The occurence of friction in metal forming processes differs significantly from the friction that occurs in mechanical joints regarding the factors such as:

- High specific pressures (that exceed the yield stress of one of the metals in the contact pair),
- Large strain and hence the resulting difference in relation to the contact mechanisms,
- Continuous change of surfaces in contact,
- Function of lubrication, etc.

In metal forming processes the layers of the metal of a small hardness are shifting over the tool surface of substantially higher hardness, which is followed by release of energy of the contact pair that consists of a rigid and deformable body. In many cases, under the influence of significant pressures and corresponding high temperatures, the outer layers of the tool are deformed plastically, which is actually the occurence of the so-called plastic contact.

The specific pressures that occur on the contact surface between the deformed metal and the tool are very high and depend on the type of process and reach the values in the range of 100-3000 MPa, which means that they considerably exceed the yield stress of the workpiece and that they are close, and sometimes even higher, than the yield stress of the tool material. As a result of such high pressures there are significant changes in friction conditions, the efficiency of lubrication is reduced (the lubricant layer breaks and a direct contact of the surfaces occurs) which contributes to the intensification of the wear process.

2. DISTRIBUTION AND VALUES OF CONTACT PRESSURES

The load is one of the important values that characterizes friction. Therefore, all friction hypotheses usually give the dependence between the friction force and the normal force (load) where, so far, the friction science was taking into account the force under whose influence the contact elements were only elastically deformed (in terms of macro and not in terms of micro occurence). Friction has somewhat different character in case of metal forming processes, i.e., in such load conditions where one of the contact elements endures the final plastic deformation.

The process of cold deformation of most metals relates to the phenomenon of hardening (the process takes place below the recrystallization temperature). Based on this, metals can be classified using two basic mechanical models:

- Elasto-plastic model without hardening and
- Elasto-plastic model with hardening.

Hardening must be taken into account in the analysis of tribological phenomena because it is typical for this group of processes.

In metal forming processes a specific model of contact pairs consisting of a tool (rigid body) and deformed metal (plastic body) occurs. The pair tool-deformed metal has to be chosen in that way (with big difference in the resistance and hardness properties) to obtain a permanent deformations of workpiece at a given constant load that depends on the type of forming process. In contrast, the tool must not reach the plastic deformation at the same load (considering the strength and dimensions).

As a result of the fact that the pressure of one body (tool) to another (deformed material) is transmitted through micro-volumes of the actual contact, a complex stress state close to the state of three-axis pressure occurs, and in the points of actual contact there is a considerable exceeding of the yield stress and plastic deformation of the unevenness of the tool surface. With the increase in plastic deformation of the workpiece, the nominal surface area as well as the actual surface of plastic-shaped metal is growing, which causes a decrease in the value of normal pressures. On the other hand, the processes of shifting of workpiece layers over the tool surface are accompanied by significant shear stresses, and consequently a local increase in temperature occurs which results in a decrease of the yield stress in the micro-volume of the contact. Therefore, in the case of metal forming in macro sense, there is an elastic-plastic contact, and in a micro-volume a fully plastic contact can occur.

Considering these differences in load conditions, friction phenomena should be studied differently. Particularly significant importance should be given to the analysis and determination of the character of dependence between the friction force and the normal force in the area of higher pressures and finding out in which pressure area the *Amonton's* law is fulfilled, as well as the determination of other corrective quantitative relationships.

According to the studies carried out by Schey [1], dependence of the friction coefficient on the load has a nonlinear character, which means that the Amonton's law is not fulfilled, whereby it is characteristic that with the increase of the load the friction coefficient decreases (Figure 1).

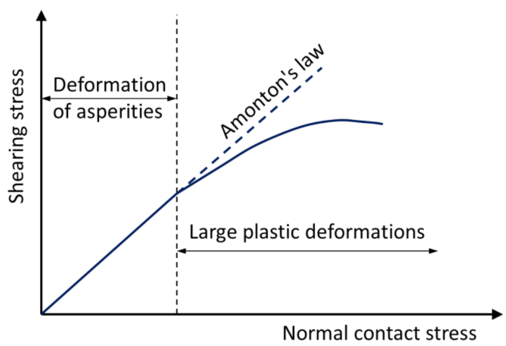

Figure 1. Amonton's law

Ziemba and Solski [2] found that in the general case, the curve that represents the dependence of the friction coefficient on the specific pressure can take the form shown in Figure 2, which means that in the field of low pressures the value of the friction coefficient decreases with increasing of the pressure, and in a certain area that dependence is linear. In the linear field of pressure, the friction coefficient does not depend on the load (it has a constant value), and at very high pressures there is a clear increase in its value.

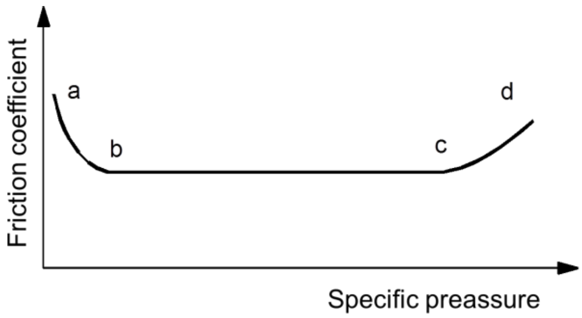

Figure 2. Dependence between friction coefficient and specific pressure [2]

Pavlov [3] examined the dependence of friction coefficient on the load during the rolling process and proved that together with the increase of the pressure the friction coefficient is decreasing. These tests, however, were related to the low pressure values. In the case of ironing process, the growth of the friction coefficient with increase of the pressure has been noted, with results referring to very high pressures (2000 MPa) which verifies the shape of the part of the general curve shown in Figure 2.

In this paper, presented results of friction analysis performed during the metal forming process show that the friction coefficient changes with increasing pressure, i.e., that the *Amonton's* law is not fulfilled in the entire load area. The friction coefficient is the proportionality coefficient and has a constant value independent of the load. After exceeding a certain load value, the dependence between F_{tr} and F_n is nonlinear and the friction coefficient (in the sense of *Amonton's* law) has no constant value and changes with increase of the pressure.

Decrease or, at very high pressures, increase of the friction coefficient with the increase of the pressure suggests that, in the case of higher loads, additional phenomena occurs which must be reflected on the friction law.

3. EXPERIMENTAL TESTS

The original strip ironing device has been developed at Faculty of Engineering, University of Kragujevac. It imitates the zone of contact with die and punch [4] with double-sided symmetry during modelling of ironing. This device enables the realisation of high contact pressures and respects physical and geometrical conditions of real process (material of die and punch, contact surfaces topography, different die angles α etc). The scheme of strip ironing device, with presentation of forces which act upon the workpiece, die and punch, as well as specimen shape is shown in Figure 3.

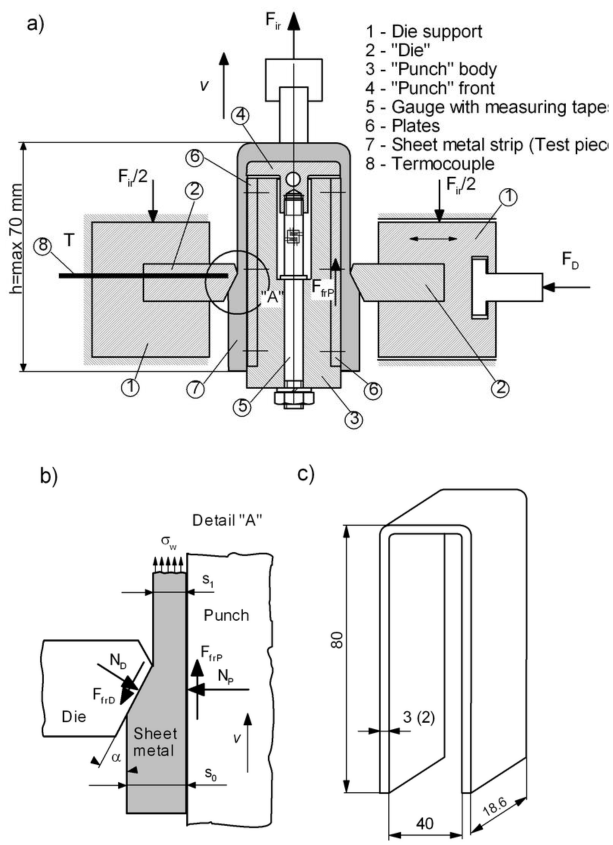

Figure 3. Scheme of strip ironing device with measuring chain for data acquisition (a), presentation of forces in deformation zone (b) and specimen shape (c)

Sheet metal strip 7 is bent (Figure 3c) and placed on the "punch". Dies 2 are placed in supports, whereat the left support is motionless, and the right one is movable together with the die.

The divided punch consists of body 3 and front 4 which are inter-connected by gauge with measuring tapes 5. The strip is ironed between dies due to the effects of force F_{ir} on the punch front. Throughout ironing, the outer surface of strip slides over die surface, which is inclined at an angle α. The inner surface of strip slides over plates 6, fixed onto the punch body. The main idea was to enable determination of friction coefficients, both on die side and on punch side at various contact conditions.

Total ironing force F_{ir} represents the sum of friction force F_{frP} between punch and workpiece, and force that acts upon the test specimen bottom, F_w, that is:

$$F_{iz} = F_{trI} + F_z \; . \qquad (1)$$

Mean contact pressure between die and sheet metal is the ratio between the normal force by which the die acts on the sheet metal, N_M, and the contact surface between die and the sheet metal S_k:

$$p_{sr} = \frac{N_M}{S_k} = \frac{2 \cdot F_D \cdot \cos\alpha \cdot \sin\alpha + F_{iz} \cdot \sin^2\alpha}{b \cdot (s_0 - s_1)} \qquad (2)$$

Based on analysis of researches and preliminary investigations, the following factors were selected, which will be the subject of experimental researches, shown in Table 1.

Table 1. Properties of investigated material and investigation conditions

		Material	Mechanical properties	Surface characteristics
Tool	Die (D)	▪ TS (Tool steel) ▪ TS + Cr plate ▪ TS + TiN plate ▪ HM (Hard metal)	TS Hardness 60÷63HRC HM Hardness 1200HV30	R_a≈0.01 [µm] (N1)
	Punch plate (P)	▪ TS ▪ TS + Cr plate ▪ TS + TiN plate		R_a≈0.01 [µm] (N1), R_a≈0.01 [µm] (N3) and R_a≈0.4 [µm] (N5)
Workpiece		DC04 (EN10130) Thickness: 2.0 [mm] width: 18.6 [mm]	R_p=186 [MPa], R_m=283 [MPa] A_{80}=37.3 [%] n=0.2066, r=1.09009	R_a=0.92 [µm] R_p=3.62 [µm] R_v=5.11 [µm]
Reduction degree: 1÷55 [%]			Angle of die gradient: α = 5°, 10°, 15°, 20°	
Sliding path: max 70 [mm]			Investigation temperature: room temperature	
Ironing speed: 20 [mm/min]			Blank holding force (F_D): 8.7; 17.4; 26.1 [kN]	
Applied lubricants	On die side		L1, L2, L3	
	On punch side		L4	
TS – Tool steel (DIN17006: X165CrMoV12) HM – Hard metal, WG30 (DIN4990: G30) L1 – Lithium grease with additive of the molybdenum disulfide (Li+MoS_2) – Grease, L2 – Mineral emulsifying water-soluble oil with EP, anti-wear and lubricating additives – Oil, L3 – Mineral emulsifying agency – Paste, L4 – Non-emulsifying mineral oil with mild EP qualities – Oil (v = 45 [mm^2/s]),				

4. RESULTS OF EXPERIMENTAL TESTS

As shown, the mean contact pressure on the die side represents the ratio between the normal force by wich the die acts on the workpiece and the contact surface between the die and the workpiece (equation 2). From equation 2 it can be seen that the mean contact pressure will depend on the holding force, the die angle, the resulting deformation and the ironing force. As the drawing force, among other things, depends on the contact conditions, it is logical to conclude that the mean contact pressure, to a certain extent, will also depend on the achieved contact conditions. Since the drawing force changes very little on the sliding path, the mean contact pressure will also have an approximately constant value for the entire time of drawing (Figures 4 and 7).

Dependence of the mean contact pressure on the sliding path is shown in the Figure 4, where diagram is made for three characteristic holding forces. From the mentioned diagram it can be seen that the mean contact pressure decreases with increasing of holding force. This happens due to the fact that with the increase of the holding force, the contact surface between the die and the workpiece is growing.

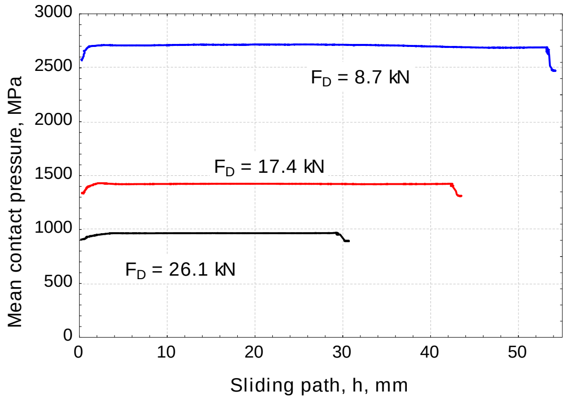

Figure 4. Dependence of mean contact pressure on the sliding path due to different holding forces

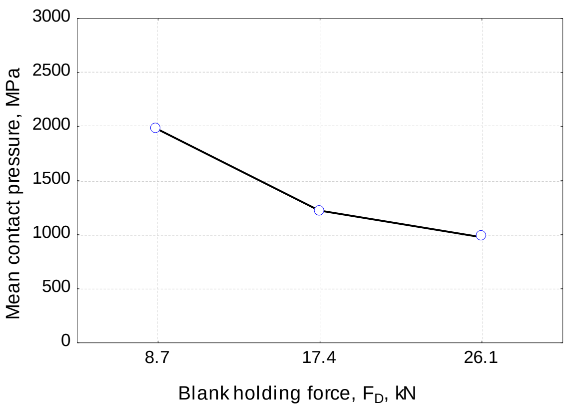

Figure 5. Change of mean contact pressure due to the holding force

The change of the mean contact pressure depending on the holding force is shown in Figure 5. With the increase of the holding force the mean contact pressure decreases more intensively at start, while with a further increase in the holding force the gradient of the pressure decreases considerably.

By increasing the holding force, at all die angles, the mean contact pressure decreases (Figure 6), wherein higher contact pressures correspond to greater angles. In the case of steel samples with the increase of holding force the differences in the pressure obtained with different die angles are decreasing (Figure 6).

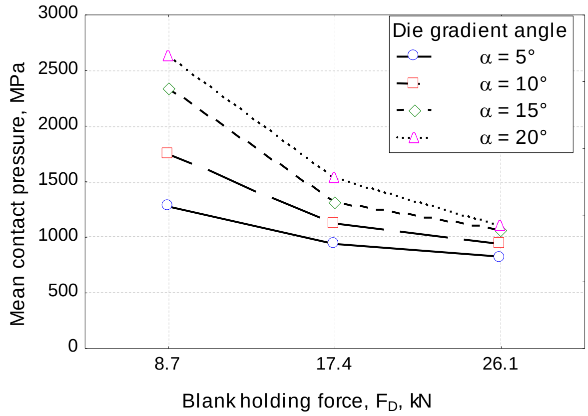

Figure 6. The change of the mean contact pressure due to the holding force at different die angles

As the die angle increases, as has already been said, the mean contact pressure increases. Dependence of p_{sr} on the sliding path for different angles α, when the lubricant is on the die - L1, tool material – tool steel (TS), the roughness of the punch - N1, and the holding force - 8.7 kN is given in Figure 7.

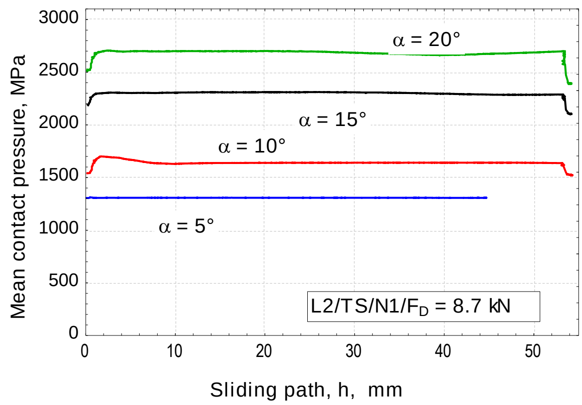

Figure 7. Dependence of the mean contact pressure on the sliding path at different die angles

Figure 8 shows the change of the mean contact pressure due to the die angle.

The influence of the lubrication type on the die on the value of the mean contact pressure is given in Figure 9. From the mentioned diagram it can be seen that in the case of all types of used lubricants almost the same values of p_{sr} are obtained, which points out to the small influence of the selected lubricants on the value of the mean contact pressure.

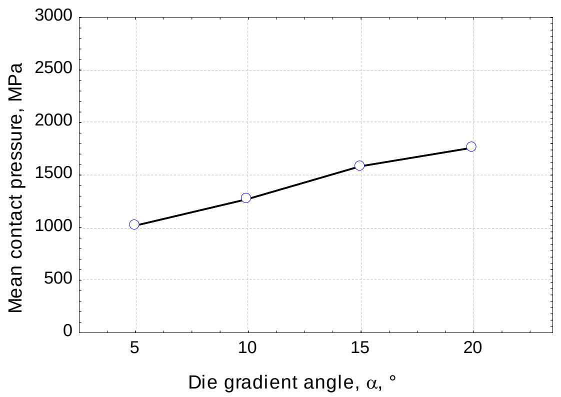

Figure 8. The change of the mean contact pressure due to the die angle

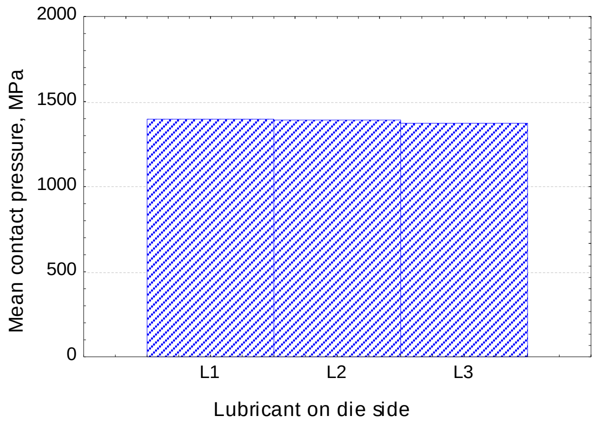

Figure 9. Dependence of the mean contact pressure on the lubricant type on the die

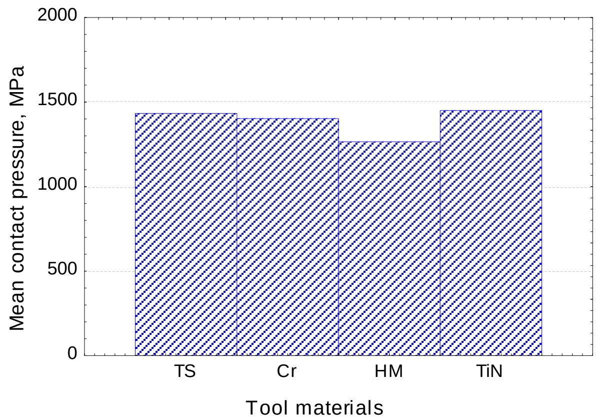

Figure 10. Dependence of the mean contact pressure on the tool material

The lowest value of the contact pressure is obtained by using tool made of hard metal, and somewhat higher values by using chromium-coated tools. The highest values of p_{sr} are obtained by using tools of alloyed tool steel and TiN coating (Figure 10).

As the roughness increases, there is a slight increase in the mean contact pressure, which is shown in Figure 11.

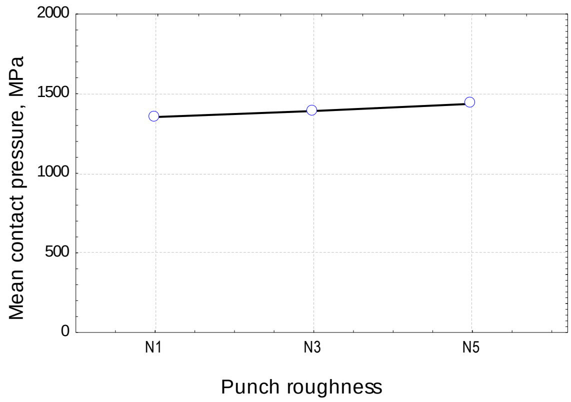

Figure 11. Dependence of the mean contact pressure on the roughness of the punch surface

Figures 12 to 14 show the dependence of the mean contact pressure on the die angle and the holding force for variations of different levels of the analyzed factors (lubricant on the die, tool material and roughness of the punch surface). In all combinations of the die angle and the holding force, approximately the same value of the mean contact pressure at all levels of lubricant on the die side are obtained. That indicates, as has already been said, a very small influence of the selected lubricants on the die to the value of p_{sr} (Figure 12).

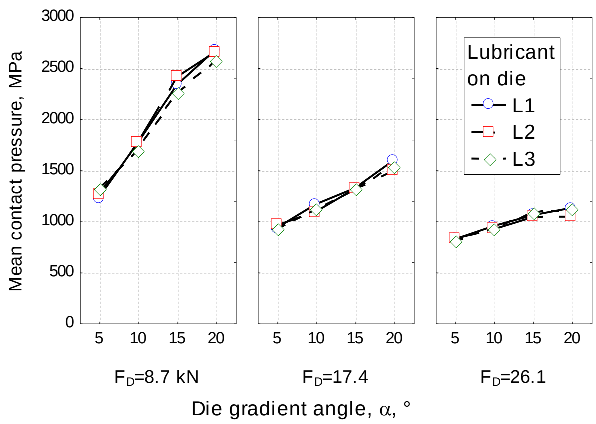

Figure 12. Change of the mean contact pressure due to the die angle and the holding force for different lubricant types on the die side

Diagrams in Figure 13 show that the lowest values of pressures are obtained with hard metal tools, and the highest values are obtained with tools made of tool steel and titanium nitride coating, for most of the levels of the die angles and the holding force. The influence of the punch surface roughness on the mean contact pressure, as shown in the diagrams in Figure 14, is very small.

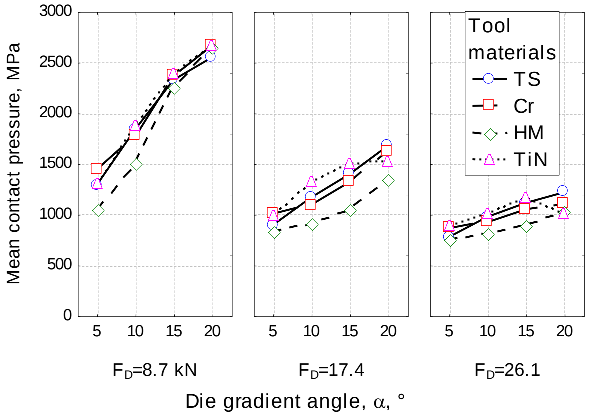

Figure 13. Change of the mean contact pressure due to the die angle and the holding force for different tool materials

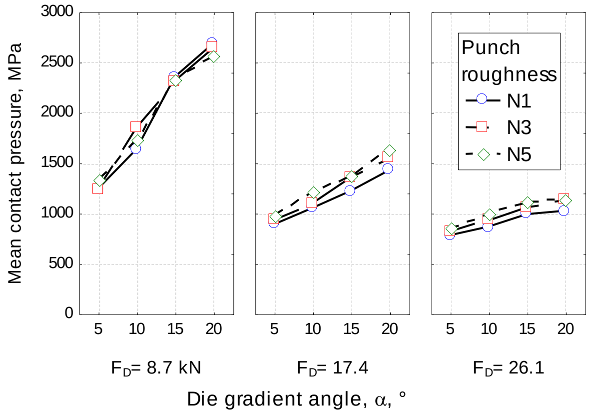

Figure 14. Change of the mean contact pressure due to the die angle and the holding force for different roughness of the punch surface

It has already been said that the mean contact pressure mainly depends on the holding force and the die angle, i.e., the degree of deformation, which is mostly determined by the angle α and the force F_D. In Figures 15 and 16 dependence of the mean contact pressure on the degree of deformation at different die angles and the holding forces, respectively, are given. From these diagrams, the dependence between stress and deformation are clearly observed at different die angles (Figure 15) and the holding forces (Figure 16). It can be concluded that the highest mean contact pressures are obtained with the low holding forces and large die angle.

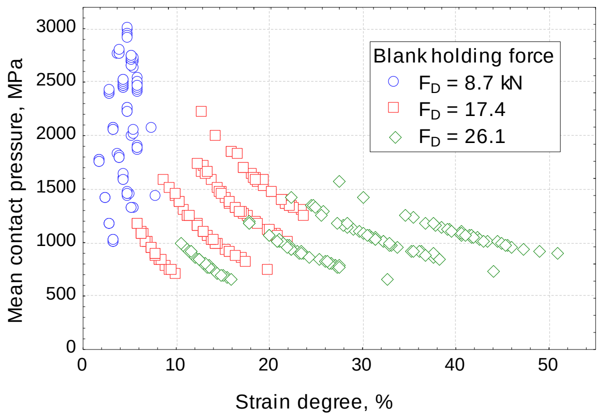

Figure 15. Dependence of the mean contact pressure on the degree of deformation at different die angles

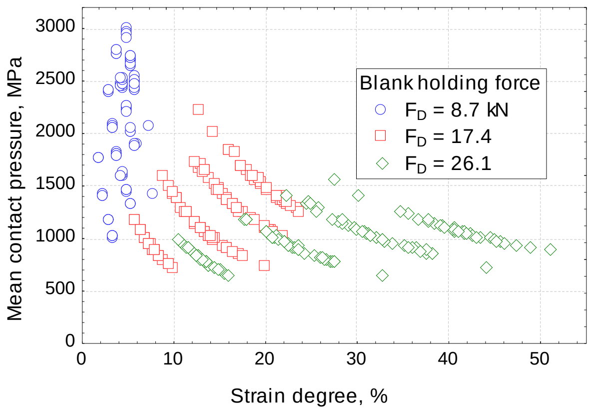

Figure 16. Dependence of the mean contact pressure on the degree of deformation at different holding forces

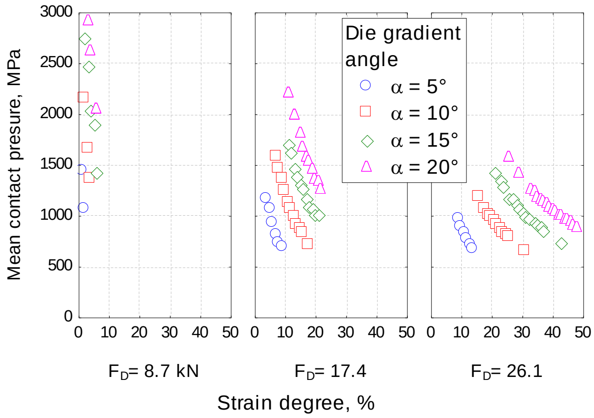

Figure 17. Dependence of the mean contact pressure on the degree of deformation at different holding forces and die angles

Previously described changes in the mean contact pressure due to the degree of deformation for different holding forces and the die angles could be presented in the form shown in Figures 17 and 18. In these diagrams, the points corresponding to the different values of holding force (Figure 17), and the die angle (Figure 18) are separated.

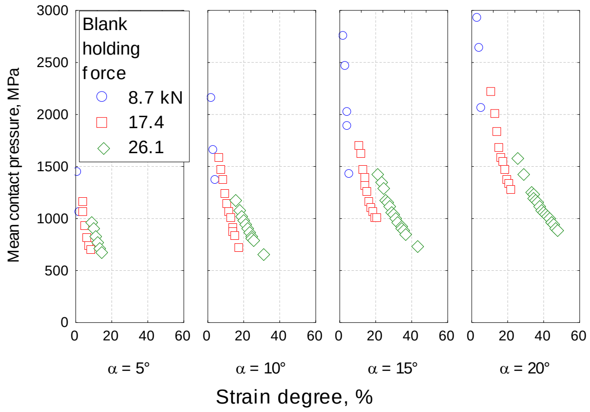

Figure 18. Dependence of the demium contact pressure on the degree of deformation at different die angles and the holding forces

5. CONCLUSION

The specific pressures that occur on the contact surface between the workpiece and the tool are very high and reach the value of the order of 400-3000 MPa, which means that their value significantly exceed the yield stress of one of the metals of the coupled pair, and it is close and sometimes even several times higher than the yield stress of the tool. As a result of such high pressures there are significant changes in friction conditions, the efficiency of lubrication is reduced (the lubricant layer breaks and a direct contact of the surfaces occurs) which contributes to the intensification of the wear process.

The mean contact pressure mainly depends on the holding force and the die angle, i.e., the degree of deformation, which is mostly determined by the die angle and the holding force.

ACKNOWLEDGEMENT

The part of this research is supported by Ministry of Education and Science, Republic of Serbia, Grant TR32036, TR34002 and TR35021.

REFERENCES

[1] A.J. Schey (Ed): *Metal Deformation Processes - Friction and Lubrication*, Marcel Dekker Inc., New York, 1970.

[2] P. Solski, S. Ziemba: *Zagadnienia tarcia suchego*, PWN, Warszawa, 1965.

[3] И.М. Павлов: *Теория прокатки, Металлургиздат*, Москва, 1950.

[4] D. Adamovic: *Behaviour of Materials in Contact in Cold Plastic Forming Processes with High Working Pressures*, Doctoral Thesis (in Serbian), the Faculty of mechanical Engineering in Kragujevac, Kragujevac, 2002.