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INFLUENCE OF CONTACT CONDITIONS ON THE PROCESS OF THE THIN SHEET SLIDING DURING THE FLAT DIE TEST

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Abstract: *Influence of tool contact surface type and lubricant in combination with variable contact pressure is recent research subject in field of deep drawing of thin sheet metals. For that purpose developed was original tribological model based in sliding process between flat contact surfaces in conditions of simultaneously variable contact pressure intensity and made was appropriate computerized device. Realized was multifactor experiment with steel sheets DC04 stripes applying. Also applied were four tool contact surfaces types, two lubricant types and two contact pressure functional dependencies on sliding length. Based on previously defined contact pressure-sliding length mathematical functions, for every above mentioned conditions obtained were tensile forces and friction coefficient dependencies. In that way there is possibility to evaluate tribological factors influence on process parameters. Also, significant influence have roughness of tool contact surfaces and their ability of appropriate lubricant accumulation in contact zone.*

Keywords: *flat-die test, deep drawing process, contact pressure*

1. INTRODUCTION

There are just a few options to influence the deep drawing process, mainly by the contact pressure effect on the thin sheet flange and by the draw beads action at the holder. In majority of research in this field, presented until now, the pressure within a die, was set as constant. This research is focused on the variable pressure, i.e. on its continuous setting during the sliding process via functions established in advance, as well as on development of the matching real model. Influence of the variable contact pressure is the actual subject of research, in order to discover the new possibilities for controlling this forming process. Analysis shown in paper did not take into consideration the other influential factors (the die, the contact conditions, material etc.).

For that purpose, various physical-tribological models were developed, of which the most present is the flat die sliding model [1-5]. The problem treated in those papers, was the modeling of the deep drawing process at the thin sheet flange, at the flat contact surfaces between the holder and the die. The tribological models were created taking into account all relevant factors like material, die, machine, and contact conditions enabling monitoring of variation of friction coefficient and drawing force. The tools of various surface roughness were applied. The contact conditions were realized, besides by the contact surfaces conditions, as well as by application of many types of the deep drawing lubricants and by thin sheets with different coatings. Besides that, variation of the sliding speed of the thin sheet was enabled, [6-8]. The objective was typically how to control the output parameters of the process in order to reduce deep friction coefficient and drawing forces as much as possible, on one side, and to get desired geometry without the wrinkles at the flange on the other side, [9-11].

2. EXPERIMENTAL INVESTIGATION

2.1 Tribological aspects of the flat die sliding

The deep drawing complex parts are accompanied by numerous influental parameters, making it one of the most complex and demanding forming processes. Therefore, the principle of physical modeling of this complex part characteristics is applied, which is used as a basis for complete tribological modeling of the process, [12]. The thin sheet sliding (strip pulling) between the flat surfaces of the holder and the die (Fig. 1) corresponds to zones of the working piece that are not subjected to lateral compression but only to stretching in the radial direction. The drawing force, as a consequence of the pulling action, is transferred via the die's edges rounding to the zones below the holder, Fig 2.

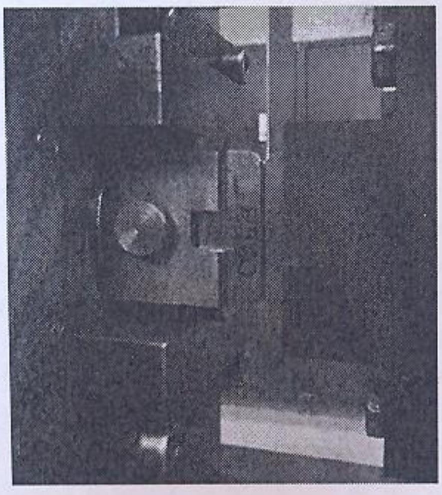

Figure 1. Photography of flat die test

The surface pressure during the sliding is lower than the yield strength, so deformation remains elastic. Changes on the contact surfaces (wear, glued particles) can disturb the stable course of the sliding process. Otherwise, the failure of the drawed part can occur [13, 14].

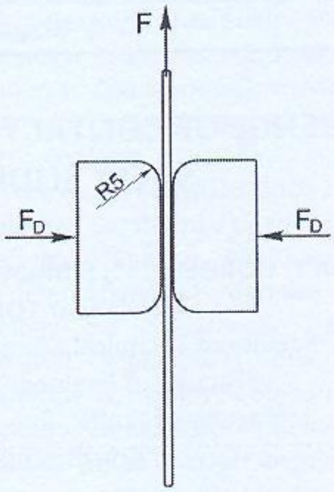

Figure 2. Scheme of flat die test

The coefficient of friction in this research was calculated based on the actual (measured) values of drawing forces and real contact pressure. Values of drawing forces and actual pressures were determined, for each specific case, on a stroke of a length of 60 mm. Given that the pulling process takes place between the flat contact surfaces (Fig. 2), the coefficient of friction μ was easy to determine, based on the known value of the actual contact surface of the exchangeable elements and sheet metal strips of 960 mm^2.

$$\mu = \frac{F}{2 \cdot F_D} = \frac{F}{2 \cdot p_D \cdot A} = \frac{F}{1920 \cdot p_D} \tag{1}$$

2.2 Experimental apparatus

The experimental apparatus, developed especially for this investigation and exchangeable sliding elements, are shown in Fig. 3 and explained in more details in [15].

The key element in the separate hydraulic module is the voltage proportional valve. For a certain value of the voltage signal from the control card one obtains the certain flow, namely the certain pressure in the cylinder which ensures the blank holding force. That force is transferred to the exchangeable contact elements in the hydraulic-mechanical part of the apparatus, which provides the holding of the sample – the thin sheet strip. The strip is clamped in the jaws at the top side of the holder is shown on Fig. 3. and Fig 4 shows the exchangeable sliding elements. Sliding elements are made of tool steel X37CrMoV5-1.

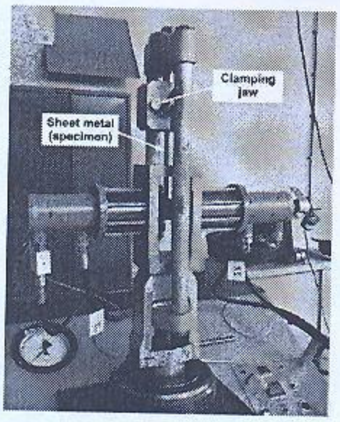

Figure 3. Mechanical part of the apparatus during the pulling

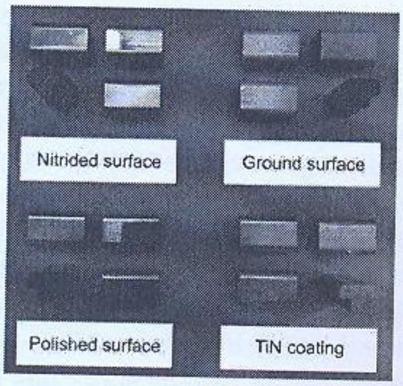

Figure 4. Exchangeable sliding elements

Each of the exchangeable sliding elements has a different roughness of the surface (table 1).

Table 1. Surface roughness of the contact elements before sliding process

Type of surfaces	Surface roughness, Ra [μm]
Nitrided	0.291
TiN coating	0.270
Ground	0.050
Polished	0.038

2.3 Previously defined pressure dependencies

Two variable dependencies of the contact pressure in terms of time were predefined for the needs of the planned experiment. Those non-linear parabolic dependencies (P3 and P4) are presented in Fig. 5. Functions are defined based on empirical values of the minimum and maximum pressure (0 to 20 MPa) [16, 17]. The pressure step is 60 mm, corresponding to the properties of the laboratory press [18, 19]. The pulling speed of 20 mm/min was chosen, what enabled solving the process parameters control. In that way, the maximum duration of the process of 180 s was obtained.

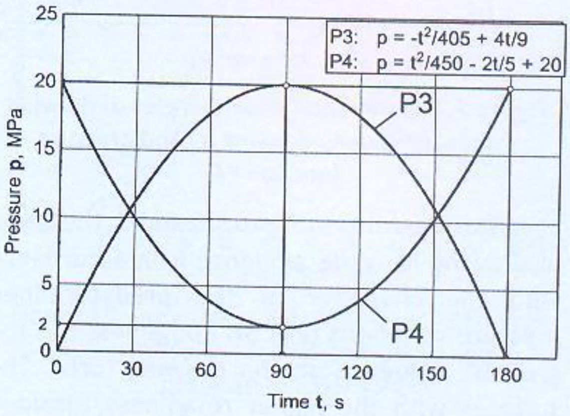

Figure 5. Analytically pre-defined pressure functions P3 and P4

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figures 6 to 9 show the dependencies of drawing forces for DC04 steel sheet strips, dimensions 250×30×0.8 mm, using two types of lubricants: oil for deep drawing and MoS_2 based lubricating grease. The dependencies were obtained for all four types of contact surfaces (Fig. 4).

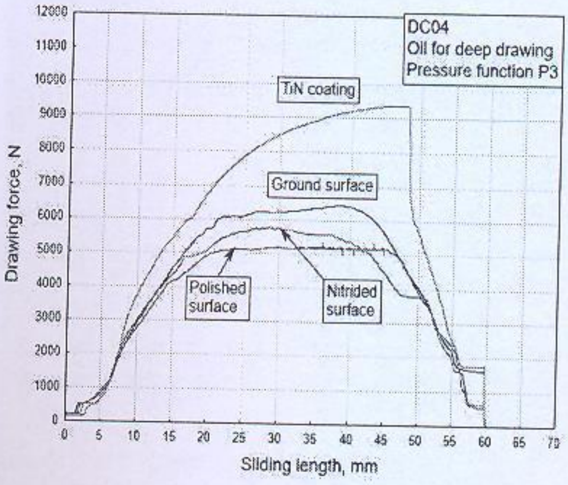

Figure 6. Experimental dependencies of drawing forces using deep drawing oil and pressure function P3

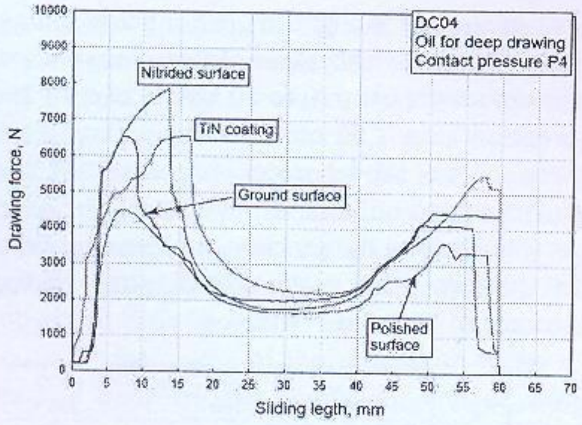

Figure 7. Experimental dependencies of drawing forces using deep drawing oil and pressure function P4

In the diagrams in Figures 6 and 7, the trend of drawing force dependence is in accordance with the character of the predetermined pressure variations (Fig. 5). Roughness has the greatest influence on the drawing force. The surfaces with the higher roughness (nitrided and TiN coating, table 1) have a lower ability to maintain a lubricating layer of oil (especially at higher pressure values) than the surfaces with a lower roughness (polished, ground).

With use of lubricants based on molybdenum-disulfide, there is a phenomenon of increasing the value of drawing forces on surfaces with the least roughness (polished surface, Figures 8 and 9).

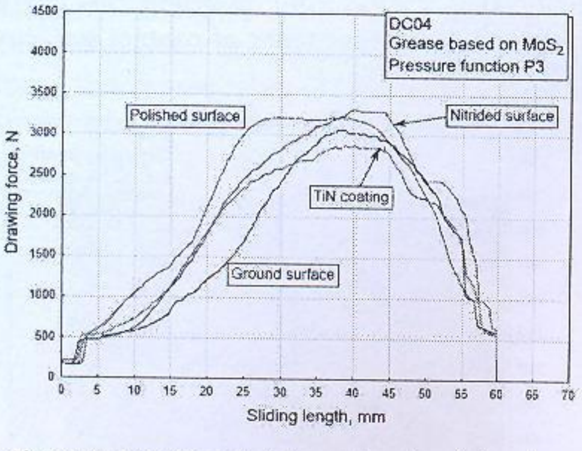

Figure 8. Experimental dependencies of drawing forces using MoS_2 based lubricant and pressure function P3

The polished surfaces with a lower roughness (table 1) in combination with lubricant based on MoS_2 (Figs. 8 and 9) have a greater affinity for rthe formation a glued layers in contact with sheet metal, which results an increase the drawing force.

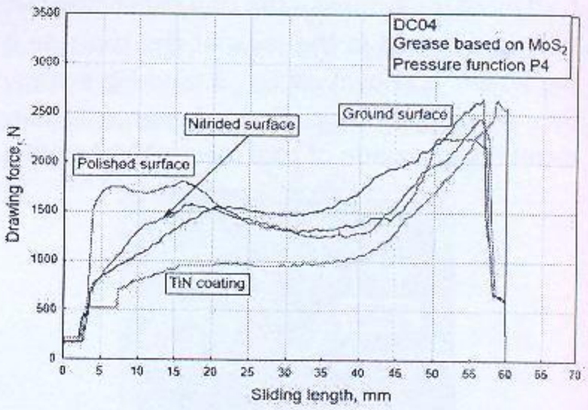

Figure 9. Experimental dependencies of drawing forces using MoS_2 based lubricant and pressure function P4

The coefficient of friction (equation 1), in addition to the drawing force, is one of the output parameters of the process by which it is possible to realistically see the influence of variable pressure, surface roughness and the type of lubricant on friction in the sliding zone. Figures 10 to 13 shof the dependencies of the friction coefficient on the sliding stroke length.

By analyzing the diagrams (Figs. 10 and 11) for all types of contact surfaces, a similar conclusion can be drawn as with the drawing force diagrams. It is noticeable that the coefficient of friction has lower values for ground and polished surfaces. The reason for this is a better combination of contact conditions (oil and less rough surfaces).

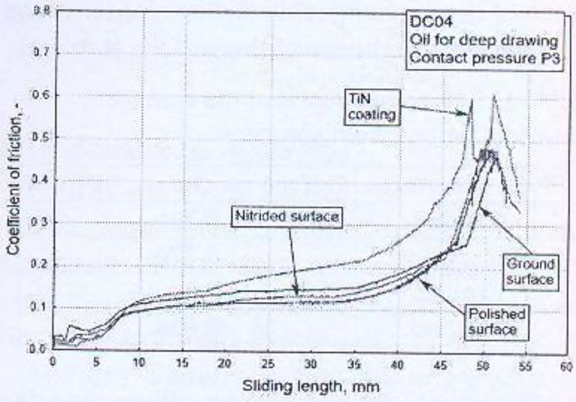

Figure 10. Experimental dependencies of friction coefficients using the deep drawing oil and pressure function P3

The change in P3 (Fig. 5) ends with an intensely decreasing trend (from the middle to the end of the stroke), so considering the tendency of pressure to zero (expression 1), unrealistic values of the friction coefficient were obtained. These are the values on the diagrams that have a jumpy trend (Figs. 10 and 11).

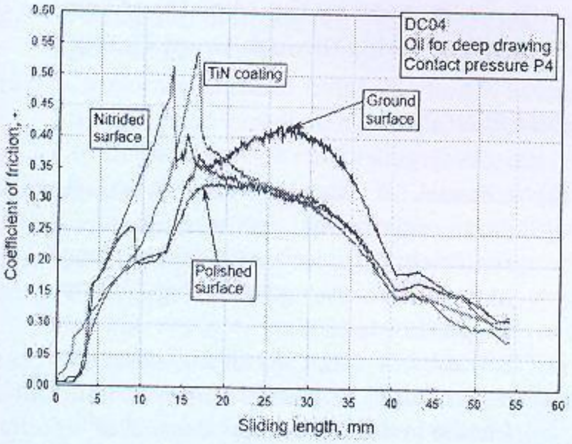

Figure 11. Experimental dependencies of friction coefficients using the deep drawing oil and pressure function P4

In the process of drawing steel sheet in combination nwith lubricating grease based on MoS_2, there is a problem of the formation of stickers on contact surfaces of less roughness (polished and partially ground). In addition, the viabillitz of the lubricating layed was compromised. On the drawing force diagrams, this was manifested by a disproportionate increase in drawing force for polished surfaces (Figs. 8 and 9). Exactly the same manifestation is represented in the diagrams of friction coefficient (Figs. 12 and 13).

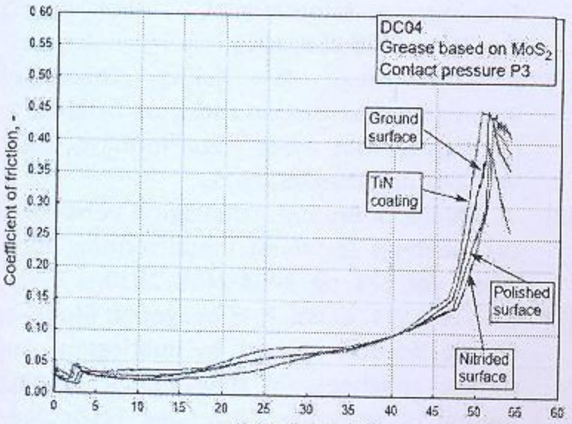

Figure 12. Experimental dependencies of friction coefficient using MoS_2 based lubricant and pressure functions P3

On the other hand, there is a problem of determining the real values of the friction coefficients for pressure change P3 that end in a downward trend (Fig. 5).

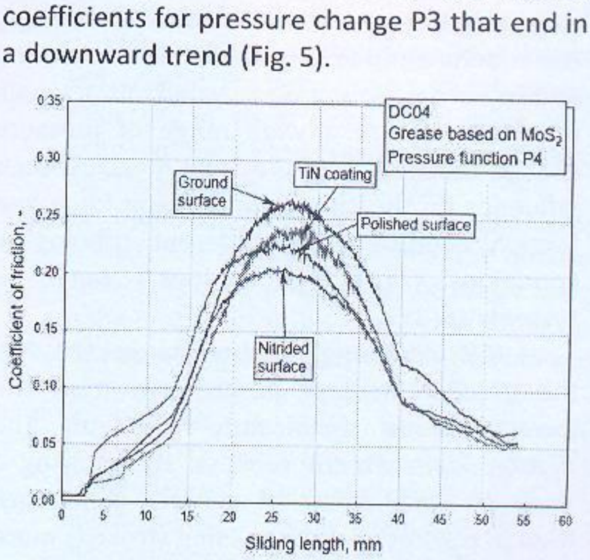

Figure 13. Experimental dependencies of friction coefficient using MoS_2 based lubricant and pressure functions P4

In that case, it is possible to control the friction until the moment when the pressure drops so much that the contact between the sheet and the sliding elements is called into question. These are values that are close to zero. On the diagrams, that moment is manifested by a sharp jump in the coefficient of friction (Figs. 10 and 12).

The problem of sustainability lubricating grease based on MoS_2 on polished surfaces can be illustrated by a photograph (Fig. 14).

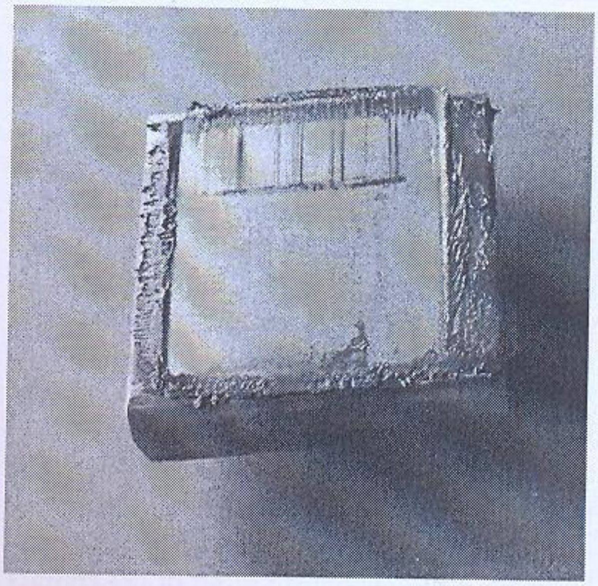

Figure 14. Photography of sliding element after the flat-die test

CONCLUSIONS

As the starting point on the work, the design, manufacture and testing of complex measuring and cotrol equipment was carried out. Its main task is to realize a wide range of pressure change functions and precisely measure their influence on the change in drawing force and friction coefficient for different tribological conditions. The conclusions can be systematized:

a) With increasing pressure changes (P3, P4), the gradual increase in pressure from the lowest values significantly facilitates the friction management process. By applying a suitable combination of contact conditions, friction control along the sliding stroke is more effective;

b) Application of contact surfaces of different roughness in combination with oil and lubricating grease has different effects on drawing force and friction coefficient. This is largely influenced by the character of the functional change in pressure. It is more siutable to use surfaces with less roughness (ground and polished) in combination with oil, while lubricating grease is recommended in combination with surfaces with higher roughness (nitrided surfaces and TiN coatings);

c) Titanium nitride coating, which is mainly used in metal cutting, is suitable for use in sheet metal forming by deep drawing in combination with lubricating greases, especially in conditions of a gradual increase in pressure from the lowest values;

d) Better retention of the lubricating grease in the depressions of the surface roughness was observed with the TiN coating, which makes the lubricating layer sustainable, even at higher contact pressure values. In such conditions, the formation of glued layers of sheet metal on exchangeable sliding elements is minimal;

e) Polished surfaces of the least roughness have an increased tendency to form of glued layers of sheet metal. This is especially pronounced under conditions of lubricating grease and high contact pressure, when the lubricant is partially pushed out of the contact zone. A lower affinity of polished and ground surfaces towards the formation of the glued layers is present when lubricated with oil.

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