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Computer simulation

VARIABLE DRAWBEAD HEIGHT AND VARIABLE CONTACT PRESSURE AS TRIBOLOGICAL INFLUENCES IN SHEET METAL STRIPE SLIDING TEST

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ABSTRACT

For this experimental research, electro-hydraulic computerised device for sheet metal stripes sliding was made. Its main property is realisation of contact pressure and drawbead height as functions dependent on time, i.e. stripe travel. In addition, it is also possible to measure drawing force, pressure, drawbead displacement, etc.

The paper presents the preliminary results of the investigation of decreasing drawbead height influence in combination with increasing-decreasing contact pressure function. The stripes are made of low-carbon steel sheet metal of 0.8 mm thickness. Contact conditions are influenced additionally in 2 ways – by mineral oil lubrication, and dry surfaces application. Drawbead geometry, with rounding radii of 2 and 5 mm, is also varied.

The results indicate that simultaneous influence of variable drawbead height, variable contact pressure, drawbead geometry and proper friction conditions can influence substantially the plastic flow process.

Keywords: deep drawing, variable friction conditions, variable drawbead height, variable contact pressure.

AIMS AND BACKGROUND

Due to the significance and complexity of the process of thin sheet metals deep drawing, the tendency to accomplish the control of forming process is the latest trend. In order to succeed in that, it is necessary to select out of a large number of influential factors, the ones which can be varied throughout the forming process, thus correcting it until it is completed successfully. There are only 2 such factors: contact pressure and drawbead height[1].

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Process control through active complex (closed-loop) systems requires permanent dynamic feedback between the given goal function, controlled and controlling variables. The goal functions and controlled variables can be different: wrinkle height, thinning in critical zone, flange motion, flange thickness change, friction force, forming force, stress in work piece wall, etc. The given goal functions are defined either by computer simulations or by previous experiments. Pressure on flange and drawbead height present the controlling variables. High velocity of reacting to control values change and robust controlling apparatus in hardware and software meaning are required, which implies significant investments[2,3].

There is also the alternative – a much simpler approach – used in this paper. However, first it is necessary to define optimum functions of pressure and drawbead height according to proper criterion (drawing depth, piece quality, etc.). This often requires comprehensive experiments[4,5] in order to identify the character of specified factors influence. With such information, it is possible to form the controlling apparatus for practical application whose main objective is to realise previously defined optimum functions of pressure and drawbead height. Such an equipment requires considerably smaller investments regarding hardware and software and is far more accessible to a wide range of users.

Application of constant height drawbeads is still most often applied and well known[6,7]. The same goes for application of constant blank holding force on flange. The main reasons for this are smaller forming process costs. However, due to the development of new materials of more complex formability properties, in most cases it is not possible to accomplish the satisfactory results by classical methods.

There are also some new ideas, such as application of drawbeads in which the angle between drawbead axis and sheet metal plane is different from 90° (Ref. 8). There is also the increased interest in many numeric simulations and virtual application of drawbeads in processes of complex work pieces forming[9].

The application of blank holding force without draw beads is the subject of separate researches based on the same previously mentioned principles[10–12].

In this paper, the emphasis is on investigation of the character of the connection between drawing force and various influences combinations. They include friction conditions (dry, application of lubricant), drawbead geometry (2 rounding radii), 1 variable function of pressure of increasing-decreasing character, 2 functions of drawbead of decreasing character and corresponding constant values both of pressure and drawbead height for comparison. The significance of the physical model applied in actual experiments is clearly seen in Fig. 1 (Ref. 7).

EXPERIMENTAL

Material. The material of which the stripes used in the experiment are made is classic low-carbon steel sheet metal of quality DC04 and 0.8 mm thickness. The main mechanical properties, properties of formability and roughness are given in Table 1.

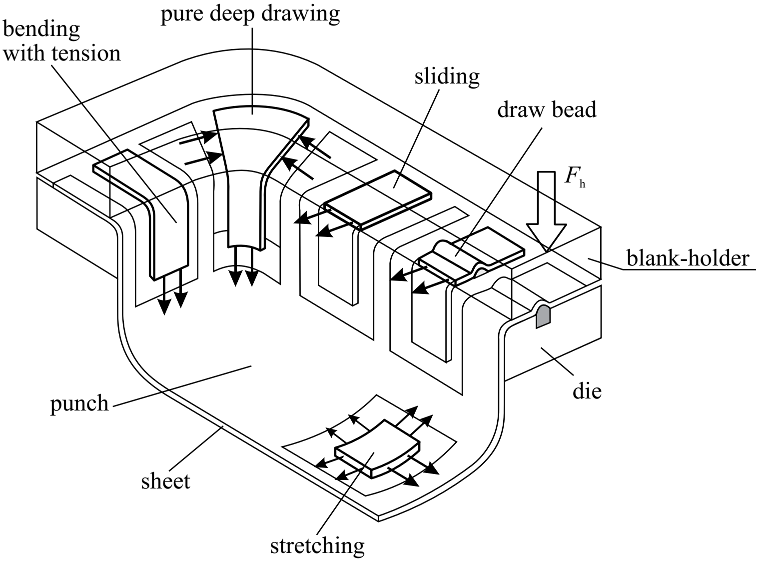

Fig. 1. Scheme of physical models at deep drawing of complex geometry parts

Table 1. Material properties

A. Mechanical properties, DC04					
	R_P (MPa)	R_M (MPa)	A_{80} (%)	n	r
Average	200.2	350.6	36.06	0.235	1.51
Strengthening curve (0°): $K = 204.9 + 388.9\varphi^{0.448}$ (MPa)					
B. Roughness properties					
R_a (μm)	R_t (μm)	R_z (μm)	R_p (μm)	Peak count (1/cm)	
0.5	3.9	2.9	1.6	57	

Mechanical properties: R_P – yield strength; R_M – tensile strength; A_{80} – fracture extension; n – strain hardening exponent; r – coefficient of the normal anisotropy.

Given are the average values due to planar anisotropy. Strengthening curve approximation function corresponds to sheet rolling direction.

Roughness properties: R_a – average absolute roughness height from the centre line; R_t – height from lowest valley to highest peak in roughness; R_z – average of 5 partial R_t; R_p – height of highest roughness peak measured from the centre line.

In one case, the friction conditions are dictated by dry surfaces – completely degreased and cleaned by acetone. In the other case, the contact surfaces were richly covered (by sponge) with oil for deep drawing of the following properties at 40°C: kinematic viscosity 45 mm^2/s, dynamic viscosity 42 mPa s and density 0.93 kg/dm^3.

Dimensions of applied stripes were: length 250 mm, width 30 mm and thickness 0.8 mm.

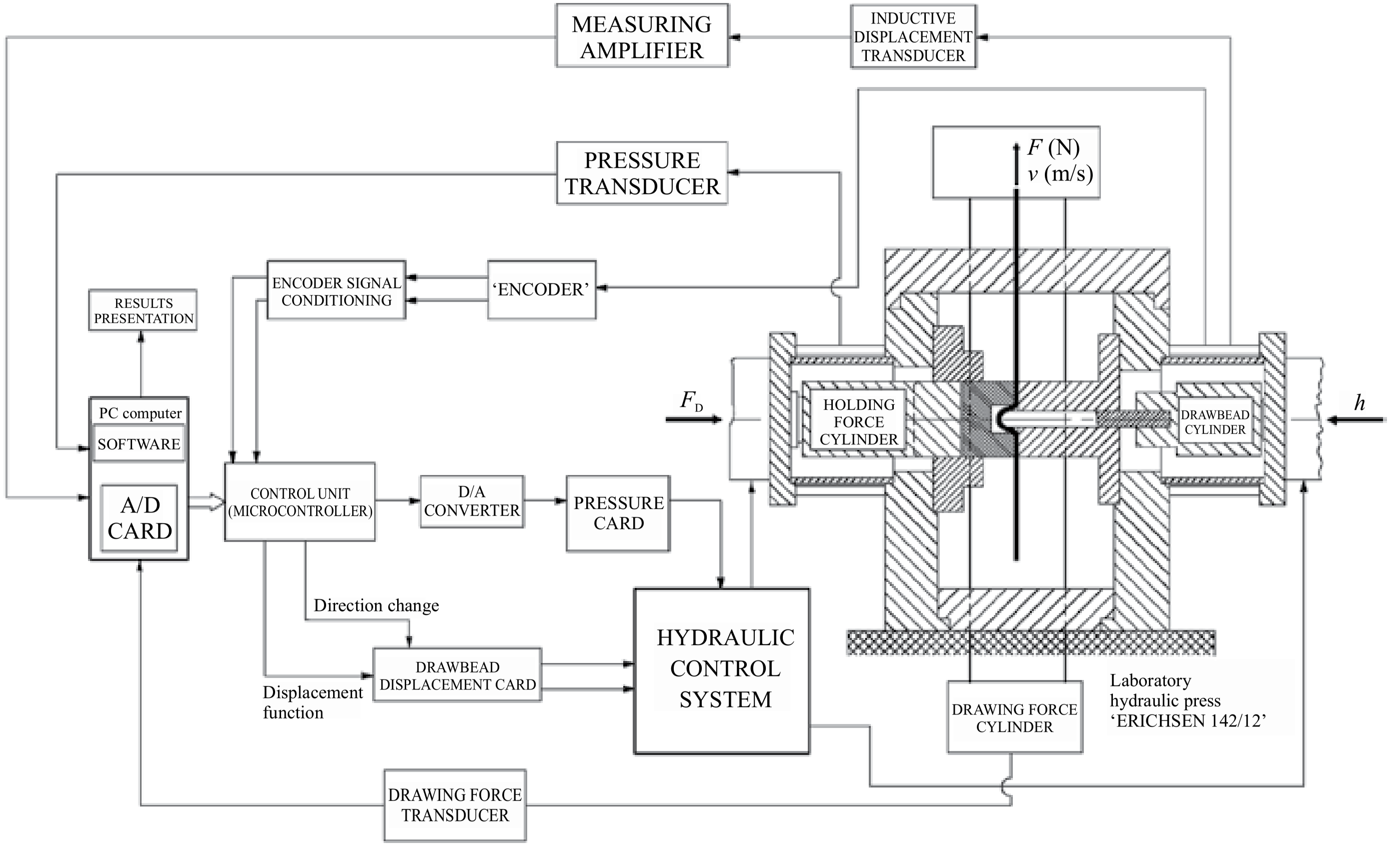

Fig. 2. Block scheme of experimental apparatus

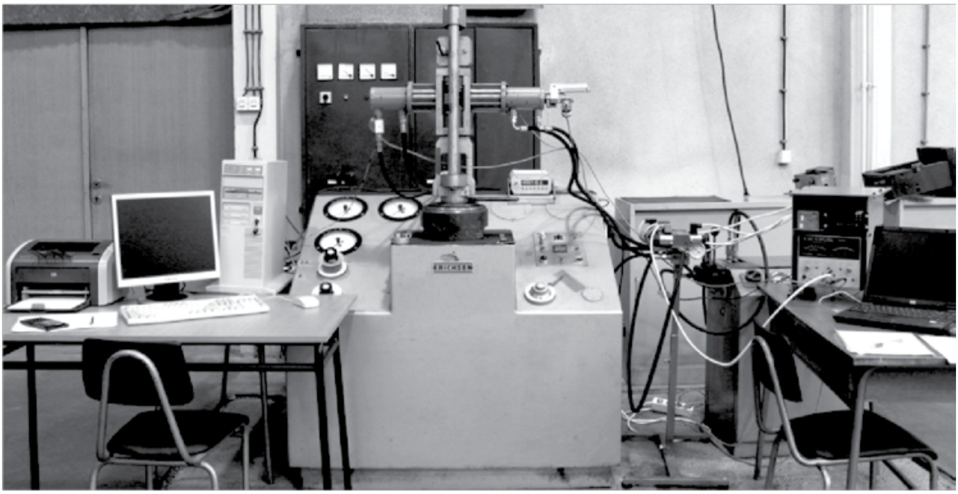

Fig. 3. Physical appearance of experimental equipment

Experimental device. The general scheme of the apparatus is shown in Fig. 2, and physical appearance in Fig. 3. Sheet metal stripe is positioned vertically between contact pairs, drawbead and die, which are variable. Drawing force is realised from laboratory press ERICHSEN 142/12 in range 0–20 kN, as well as voltage signal for measuring the force of proper sensor. Hydro-cylinders for drawbead displacement and pressure realisation are fed by aggregate ERICHSEN of nominal pressure 100 bars and flow 1.5 l/s. The oil from the aggregate runs through the series of controllable proportional hydro-valves to both cylinders.

Measuring and pressure controlling branch consists of pressure sensor which gives the current true value signal and control unit (micro-controller) which receives the given desired value from the software and sends signal to the D/A converter. The received analogous signal is transmitted to the control card of the proper hydro-valve connected to the pressure cylinder.

In controlling branch, due to drawbead motion, the current true drawbead position is read by rotation encoder. After processing, the signals are sent to the control unit (micro-controller), and then to the card for control of hydro-valve for drawbead cylinder. One signal is related to the direction change, and the other one to the value of drawbead motion function. For measuring and reading the true drawbead position, supporting branch with inductive sensor and proper amplifier is made.

All true values signals are brought into PC computer with integrated A/D card and proper original software, which enables monitoring of all its values, their memorising, presentation as well as generating of pressure and drawbead motion functions necessary for micro-controller performance.

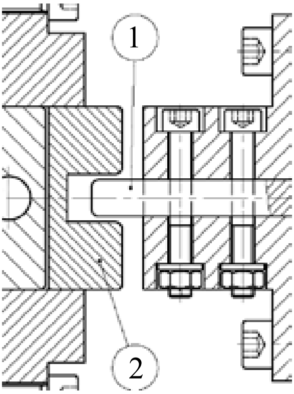

Fig. 4. Scheme of drawbead action

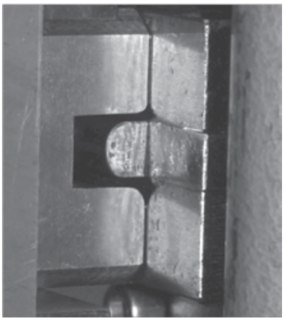

Fig. 5. Drawbead and die before contact

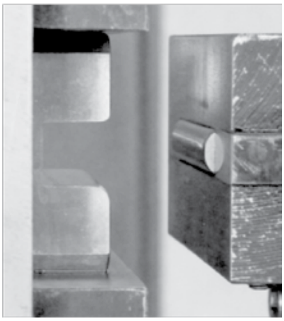

Fig. 6. Drawbead and die in contact

Figure 4 shows the drawing of drawbead (1) and die (2). Drawbead is 10 mm thick and is applied with 2 radii: 2 mm (shown in the sketch), and 5 mm (shown in Figs 5 and 6). Die rounding radius is 2 mm, and die opening is 12 mm. Both drawbead and die can be varied with the aim of monitoring the influence of drawbead geometry change. Active surfaces of drawbead and die are fine grinded and polished.

RESULTS AND DISCUSSION

Pressure and drawbead displacement functions. For the needs of planned comprehensive experiment, 6 variable dependencies both of pressure and drawbead motions on time, as given functions, were defined. In Figs 7 to 12, those functions are marked with numbers 1 to 6. Dependencies 5 and 6 are linear, and 1, 2, 3 and 4 non-linear – parabolic. Functions were defined based on empiric values of minimum and maximum pressure (0–20 MPa) and drawbead height (0–8 mm). Process duration was conditioned by limited stripe displacement and adopted sliding velocity of 20 mm/min. This conditioned maximum process duration of 3 min. Dependencies signed from 7 to 10 are related to constant values of pressure and drawbead height.

The purpose of the so-defined functional dependencies, which have different characters, is the inclusion of wide range of possible influences: decreasing, increasing, combined decreasing-increasing and increasing-decreasing, linear and non-linear. Monitoring of the response of drawing force regarding the performance of such dependencies together with friction conditions and drawbead geometry is the most important part of this research.

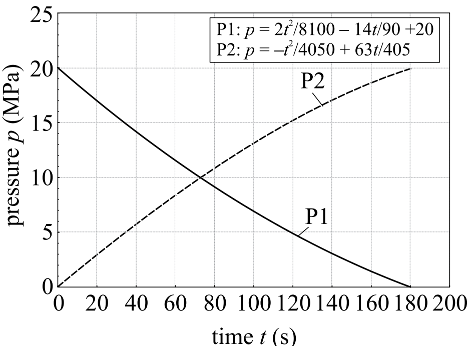

Fig. 7. Previously defined dependencies of contact pressure on time

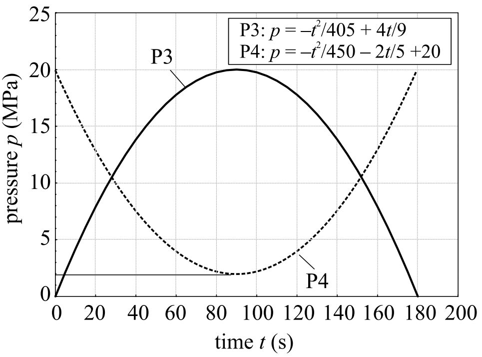

Fig. 8. Previously defined dependencies of contact pressure on time

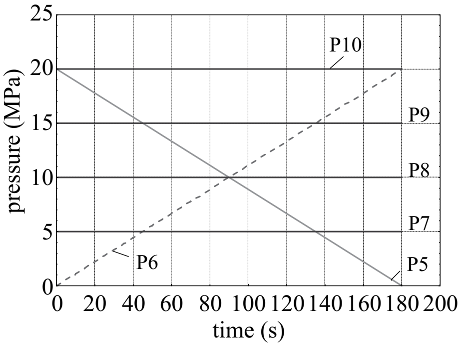

Fig. 9. Previously defined dependencies of contact pressure on time

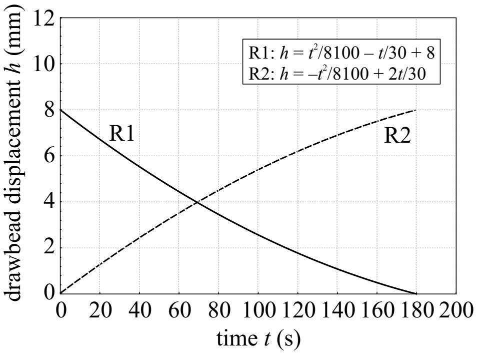

Fig. 10. Previously defined dependencies of drawbead height on time

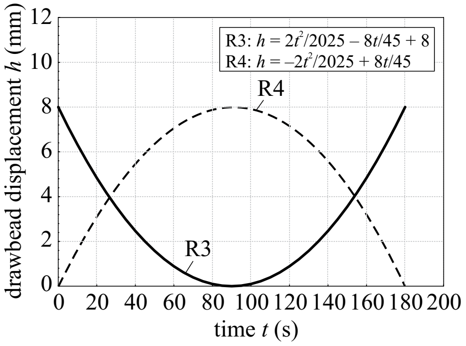

Fig. 11. Previously defined dependencies of drawbead height on time

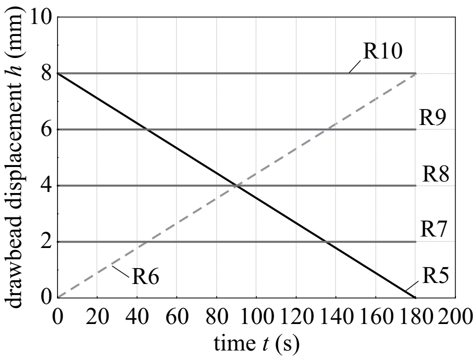

Fig. 12. Previously defined dependencies of drawbead height on time

Measured drawing force values. For this particular experiment adequate combinations of pressure and drawbead height functions were choosen. Such dependencies are presented in the following figures (Figs 13 and 14).

Figure 13 shows given (dashed line) and really achieved (full line) dependence of pressure P3 change according to marks from Fig. 8. Figure 14 shows given and truly achieved decreasing dependencies of drawbead height with marks according to Figs 10 and 12. Truly achieved constant values of pressure according to scheme P8 and constant drawbead height according to scheme R9 are corresponding, with insignificant deviations, to Figs 9 and 12 and are not shown here. Such a combination was selected with the purpose of checking the response of drawing force to complex increasing–decreasing dependence of contact pressure during the process together with decreasing functions of drawbead height.

The investigation of the following combinations was also carried out: constant pressure P8 – decreasing drawbead function R1 and variable pressure P3 – constant drawbead height R9. The purpose of such combinations is the evaluation of separate influences of variable pressure and drawbead height influence. In addition to that, it was necessary to estimate the influence of friction conditions and drawbead geometry.

Figure 15 shows the influence of drawbead functions R1 regardless of variable pressure. Constant pressure was applied according to scheme P8. Drawing force increases until it reaches the critical value, and then it decreases in proportion to drawbead height decrease. Oscillatory phenomena caused by drawing force sensitivity to gradual change of real function R1 can be observed. Drawbead geometry influence exceeds the varying of contact conditions (mixed to dry). The change of drawbead radius from 5 to 2 mm makes stripe sliding conditions more difficult than the change of friction conditions caused by oil application on dry surfaces. Curve character L2 (lubrication, $r = 2$ mm) is different compared with curve L5 (lubrication, $r = 5$ mm) and D5 (dry, $r = 5$ mm).

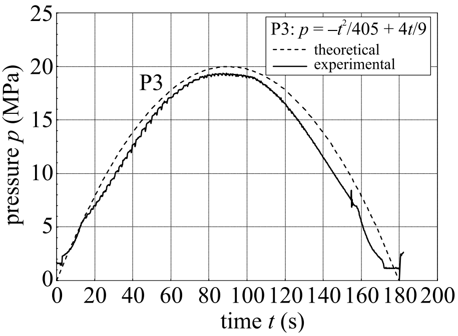

Fig. 13. True dependence of pressure on time

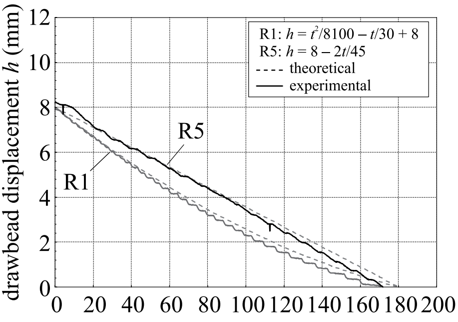

Fig. 14. True dependence of drawbead height on time

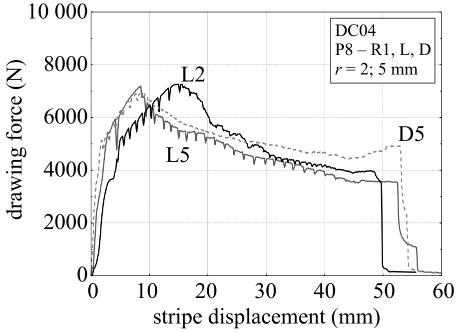

Fig. 15. Drawing force dependencies on stripe displacement

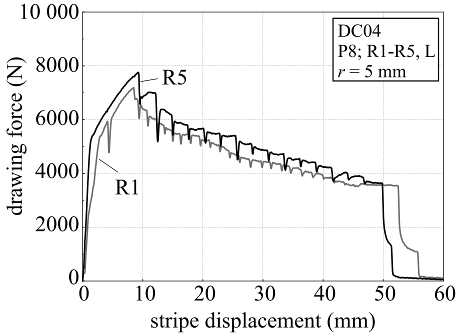

Fig. 16. Drawing force dependencies on stripe displacement

Figure 16 shows the influence of relatively small difference in character and intensity between functions R1 and R5 (Fig. 14). In line with somewhat higher intensity of R5 change, the reaction of drawing force is obvious and difference in comparison with function R1 application is shown.

The separate influence of pressure function P3 (at constant drawbead R9 from Fig. 12) in all 4 variants is shown in Fig. 17. The dominant influence of decreased drawbead rounding radius can be seen even more clearly than in Fig. 15. Drawing force dependencies for 2-mm radius are separate and of somewhat higher intensity. The change of friction type is noticeable, but it is of smaller intensity. The character of drawing force curves is proportional to the pressure function P3 and is very different from curves in Figs 15 and 16.

Figure 18 shows drawing forces at simultaneous actions of pressure functions P3 and drawbead functions R1, i.e. R5.

At 5-mm rounding radius, drawing force curves represent a combination of dependencies from Figs 15, 16 and 17. Larger stripe travel and oscillatory changes were caused by drawbead influence, and general curve form and maximum inten-

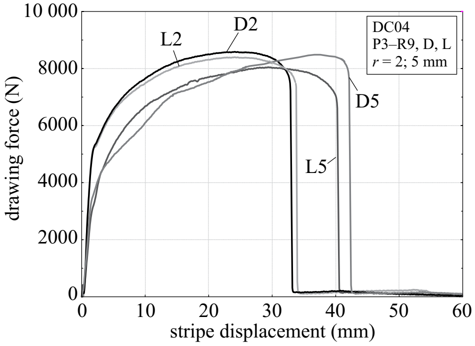

Fig. 17. Drawing force dependencies on stripe displacement

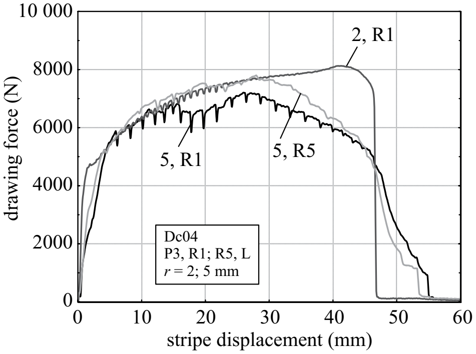

Fig. 18. Drawing force dependencies on stripe displacement

sities were caused by pressure influence. By making sliding conditions difficult due to the application of radius $r = 2$ mm, curve form changes and the influence of pressure P3 becomes dominant. Oscillatory disturbance is diminished, and intensity of maximum drawing force somewhat smaller in comparison with Fig. 17.

CONCLUSIONS

The presented apparatus for testing the tribological influence on drawing force in the process of stripe sliding over drawbead at variable contact pressure and variable drawbead height enables accurate measurement of the influence of drawbead geometry, friction conditions, pressure activity and drawbead height on drawing force.

This paper presents a part of experimental results for the sliding test for low-carbon steel sheet metal stripe. Based on the presented results, the following conclusions can be made:

(a) the response of drawing force is approximately equally influenced by simultaneously applied functions of pressure and drawbead height at milder sliding conditions, at larger drawbead rounding radius and smaller friction;

(b) under more difficult sliding conditions, at smaller drawbead radius, the influence of pressure function is more significant;

(c) drawbead rounding is more influential than friction conditions;

(d) reaction of drawing force is registered even at relatively small differences in drawbead height change during the process;

(e) the character of drawing force response shows that the favourable combination of simultaneous acting of contact pressure change, change of drawbead height, friction conditions and drawbead geometry makes it possible to influence and control the course of sheet metal-forming process;

(f) by such investigations, with relatively simple apparatus, it is possible to define significant data for numerical simulations and immediate application in practice at deep drawing of complex geometry parts.

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