CODEN STJSAO
ZX470/1557

ISSN 0562-1887
UDK 621.983.3:539.37

Variable Contact Pressure and Variable Drawbead Height Influence on Deep Drawing of Al Alloys Sheets

***Srbislav ALEKSANDROVIĆ*[1)], *Tomislav VUJINOVIĆ*[2)], *Milentije STEFANOVIĆ*[1)], *Dragan ADAMOVIĆ*[1)], *Vukić LAZIĆ*[1)] and *Dragan TARANOVIĆ*[1)]**

1) Fakultet inženjerskih nauka, Univerzitet u Kragujevcu (Faculty of Engineering, University of Kragujevac), Sestre Janjić 6, 34000 Kragujevac, **Republic of Serbia**

2) FAM Jelšingrad, 78000 Banja Luka, RS **Bosnia and Herzegovina**

srba@kg.ac.rs

Original scientific paper

The process of deep drawing is influenced by many factors. During the forming process, only two of those factors can be controlled. They are blank holding force and drawbead height. Realisation of such control requires relatively complex computerized apparatus.
For this experimental research, electro-hydraulic sheet-metal strip sliding device has been constructed. Basic capacity of realized device is obtaining contact pressure and drawbead height as functions of time or stripe displacement. Additional features consist of the ability to measure drawing force, contact pressure, drawbead displacement etc.
Presented in the paper are the results of influencing of increasing and decreasing drawbead height functions in combination with increasing-decreasing function of contact pressure. Stripe material is aluminium alloy AlMg4,5Mn0,7 sheet metal. Contact condition are additionally influenced by application of mineral oil or completely dry tool and stripe surfaces. Drawbead geometry, with rounding radii of 2 and 5 mm, is also varied.
The accomplished results indicate that simultaneous effects of variable drawbead height, variable contact pressure, tool geometry and appropriate friction conditions can influence the plastic flow process in line with desired change of forming force.

Keywords
Deep drawing
Stripes sliding
Variable drawbead height
Variable contact pressure

Utjecaj promjenjivog kontaktnog tlaka i promjenljive visine zateznog rebra na duboko vučenje limova od Al legura

Izvornoznanstveni članak

Na proces dubokog vučenja utječe više faktora. Tijekom trajanja procesa oblikovanja moguće je upravljati samo s dva faktora. To su sila držanja i visina zateznog (vlačnog) rebra. Ostvarivanje takvog upravljanja zahtjeva relativno složenu kompjutoriziranu aparaturu. Za ovo pokusno istraživanje razvijen je elektro-hidraulički uređaj za klizanje traka od lima s kompjutorskim upravljanjem. Njegova osnovna karakteristika je ostvarivanje kontaktnog tlaka i visine zateznog rebra, kao funkcijskih ovisnosti o vremenu, odnosno hodu trake. Pored toga, moguće je mjeriti vučnu silu, silu pritiska, pomak rebra itd. U radu su izloženi rezultati ispitivanja utjecaja opadajuće i rastuće ovisnosti visine rebra u kombinaciji s rastuće-opadajućom funkcijom kontaktnog tlaka. Materijal trake je legura aluminija AlMg4,5Mn0,7 debljine 0,9 mm. Na kontaktne uvjete se dopunski utječe s dva tipa trenja. U prvom slučaju površine su suhe, a u drugom se primjenjuje podmazivanje odgovarajućim mineralnim uljem. Geometrija rebra se mijenja preko polumjera zaobljenja 2 i 5 mm. Ostvareni rezultati pokusa pokazuju istodobno djelovanje promjenljive visine rebra, promjenljivog kontaktnog tlaka, geometrije rebra i odgovarajućih uvjeta trenja, mogu utjecati na proces plastičnog tečenja u skladu sa željenom promjenom sile oblikovanja.

Ključne riječi
Duboko vučenje
Klizanje traka
Promjenljiva visina zateznog rebra
Promjenljivi kontaktni tlak

Primljeno (Received): 2011-10-10
Prihvaćeno (Accepted): 2012-02-04

1. Introduction

Deep drawing process is widely applied in modern industry, which makes it extremely important. That is the reason for ongoing tendencies to accomplish total control of forming process. In order to succeed in that, it is necessary to select, out of a large number of influential factors, the ones which can be influenced throughout the forming process, thus correcting it until it is completed successfully. There are only two such factors: contact pressure and drawbead height [1].

Process control through active complex systems requires constant dynamic feedback between the given goal function, controlled and controlling variables [2].

Symbols/Oznake

s	- sheet thickness, mm - debljina lima	t	- time, s - vrijeme
R_P	- yield stress, MPa - granica razvlačenja	R	- sign of drawbead function, R1 to R10 - oznaka funkcije pomicanja rebra, R1 do R10
R_M	- ultimate tensile strength, MPa - vlačna čvrstoća	P	- sign of pressure function, P1 to P10 - oznaka funkcije tlaka, P1 do P10
A_{80}	- elongation at break, % - istezanje pri prekidu	R_a	- average absolute roughness height from the center line, μm - srednje aritmetičko odstupanje mjernog profila
n	- hardening exponent, n-factor - eksponent očvršćivanja, n-faktor	R_t	- height from lowest valley to hightest peak in roughness, μm - najveća visina neravnina
r	- coefficient of normal anisotropy, r-factor - koeficijent normalne anizotropije, r-faktor	R_z	- average of 5 partial R_t, μm - srednja vrijednost 5 vrijednosti R_t
K	- equivalent stress in plastic field, MPa - ekvivalentno naprezanje u plastičnoj zoni	R_p	- height of highest roughness peak measured from the center line, μm - najveća visina neravnina mjereno od srednje linije
p	- contact pressure, MPa - kontaktni tlak	D	- sign for dry surfaces - oznaka za suhe površine
h	- drawbead displacement or height, mm - pomicanje ili visina zateznog rebra	L	- sign for lubricated surfaces - oznaka za površine s mazivom
l	- stripe displacement, mm - pomicanje trake lima	r_r	- drawbead roundness radius, mm - polumjer zateznog rebra
F	- drawing force, N - sila vučenja		

The goal functions and controlled variable 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 effects. High velocity of reacting to controlled values change and robust controlling hardware and software apparatus are required, which all implies significant investments [3, 4].

There is also the alternative – a much simpler approach – used in this paper. However, first it is necessary to define optimal functions of pressure and drawbead height according to proper criterion (drawing depth, piece quality etc.). This often requires comprehensive experiments [5, 6] 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 optimal functions of pressure and drawbead height. Such 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 [7, 8]. The same is valid 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.

The application of blank holding force without draw beads is the subject of separate researches based on the same aforementioned principles [9, 10, 11, 12].

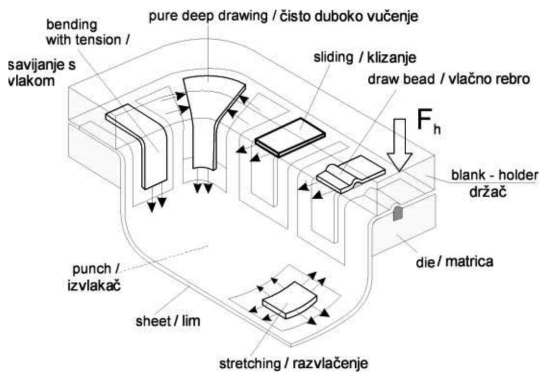

Figure 1. Scheme of physical models at deep drawing of complex geometry parts

Slika 1. Shema fizikalnih modela pri dubokom vučenju dijelova složene geometrije

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 (two rounding radii), one variable function of pressure of increasing-decreasing character, two functions of drawbead of decreasing and increasing character and corresponding constant values of both pressure and drawbead height. The significance of the physical model applied in actual experiments is clearly seen in Figure 1 [8].

2. Experimental conditions

2.1. Material

The material of which the stripes used in the experiment are made is Al alloy sheet metal from series 5000, AlMg4,5Mn0,7. Its thickness is 0.9 mm. Main mechanical properties and properties of formability are given in Table 1 (R_P – yield strength, R_M – tensile strength, A – elongation at fracture, n – strengthening exponent, r – coefficient of normal anisotropy, K – effective stress in plastic zone). Stripes material properties are related to the condition after the following thermal treatment: annealing at temperature of 350°C in duration of 3 hours.

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. Estimated coefficient of friction value was $\mu \geq 0.15$ [9]. In the other case, the contact surfaces were richly covered (by sponge) with mineral oil for deep drawing of the following properties at 40°C: kinematic viscosity $45 \cdot 10^{-6}$ m^2/s, dynamic viscosity $42 \cdot 10^{-3}$ Pas and density 0,93 kg/dm^3. Estimated coefficient of friction value in this case was $\mu \approx 0.1$ [9].

Dimensions of applied stripes were: length 250 mm, width 30 mm and thickness 0,9 mm.

Table 1. Material properties

Tablica 1. Svojstva materijala

A. Mechanical and formability properties /, AlMg4,5Mn0,7 - s=0,9 mm Mehanička svojstva i svojstva obradivosti					
	R_P, MPa	R_M, MPa	A_{80}, %	n	r
Average value / Srednja vrijednost	120.5	276.6	26.2	0.26	0.715
Strengthening curve approximation /: $K = 204.9 + 388.9\varphi^{0.448}$, MPa Aproksimacija krivulje očvršćivanja materijala					
B. Roughness properties / Parametri hrapavosti					
R_a, μm	R_t, μm	R_z, μm	R_p, μm	Peak count / Broj vrhova, 1/cm	
0.31	1.72	1.49	0.66	56	

2.2. Experimental device

The general scheme of the apparatus is shown in Figure 2, and physical appearance in figure 6. Sheet metal stripe is positioned vertically between contact pairs, drawbead and die, which are changeable. Drawing force is realized 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 realization are fed by aggregate ERICHSEN of nominal oil pressure 100 bars (10 MPa) and flow 1,5 dm^3/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 real 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 obtained 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 real 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 displacement function. For measuring and reading the real drawbead position, supporting branch with inductive sensor and proper amplifier is made.

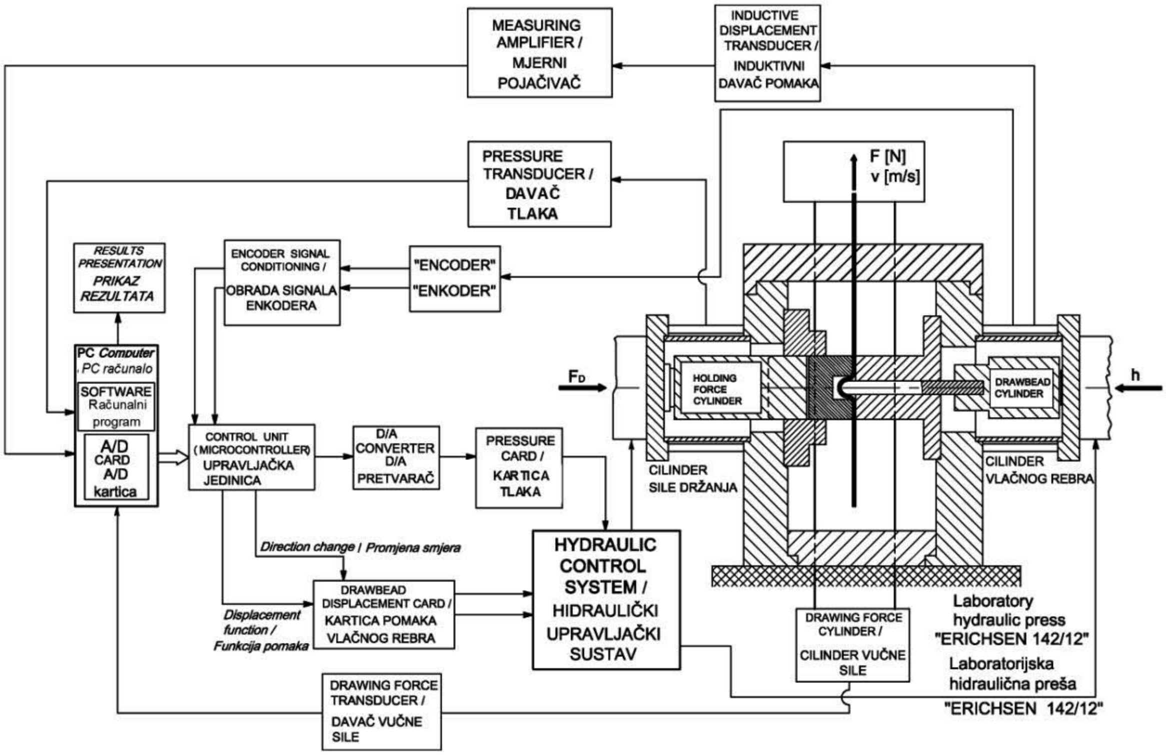

Figure 2. Block scheme of experimental apparatus

Slika 2. Blok shema eksperimentalne aparature

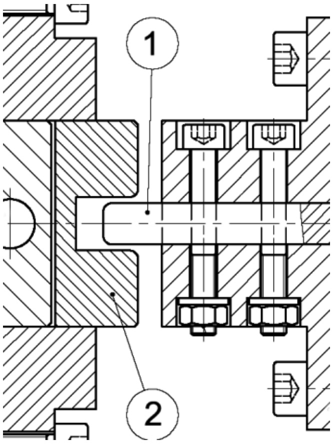

Figure 3. Scheme of drawbead

Slika 3. Shema zateznog rebra

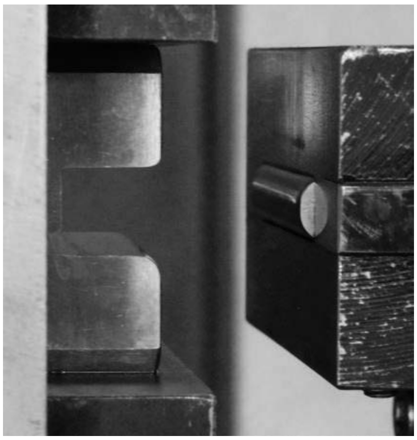

Figure 4. Drawbead and die before contact

Slika 4. Rebro i matrica prije kontakta

Figure 5. Drawbead and die in contact

Slika 5. Rebro i matrica u kontaktu

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

Figure 3 shows the drawing of drawbead (1) and die (2). Drawbead is 10 mm thick and is applied with two radii: 2 mm (shown in the sketch) and 5 mm (shown in the photo, Figures 4 and 5). 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. Drawbead and die material is steel X210Cr12 (EN 10027) with 60 HRC hardness after thermal treatment. Active surfaces of drawbead and die are fine grinded and polished with average absolute roughness height $R_a \approx 0.06$ μm

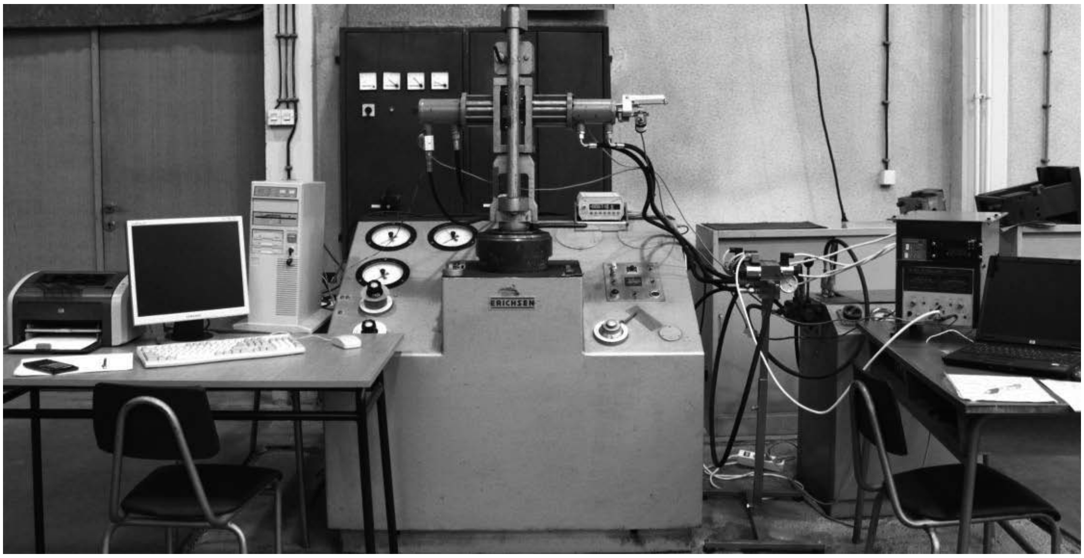

Figure 6. Physical appearance of experimental equipment

Slika 6. Fizikalni izgled eksperimentalne opreme

3. Results and discussion

3.1. Pressure and displacement functions

For the needs of planned comprehensive experiment, 6 variable dependencies of both pressure (P) and drawbead motions (R) on time, as goal functions, were defined. Those functions are marked with numbers 1 to 6. Dependencies 5 and 6 are linear (Figure 8 and 10), and 1, 2, 3 and 4 non-linear – parabolic (Figure 7 and 9). Functions were defined based on empiric values of minimal and maximal 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 maximal process duration of 3 min or 180 s.

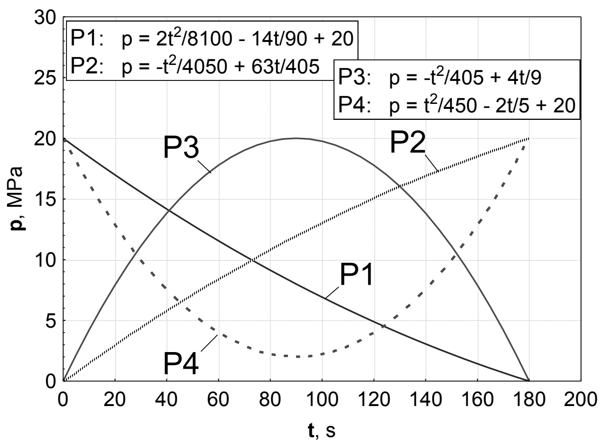

Figure 7. Contact pressure dependencies on time

Slika 7. Ovisnosti kontaktnog tlaka od vremena

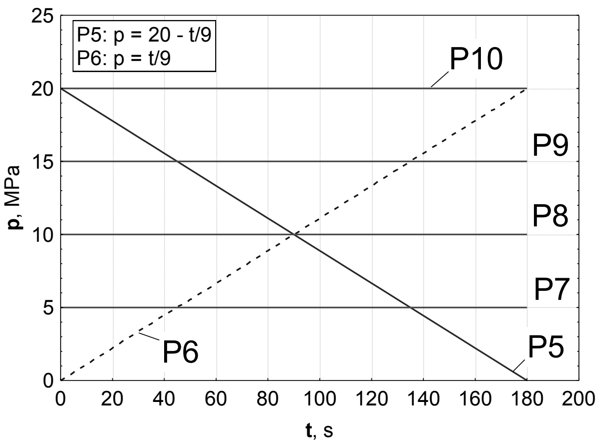

Figure 8. Contact pressure dependencies on time

Slika 8. Ovisnosti kontaktnog tlaka od vremena

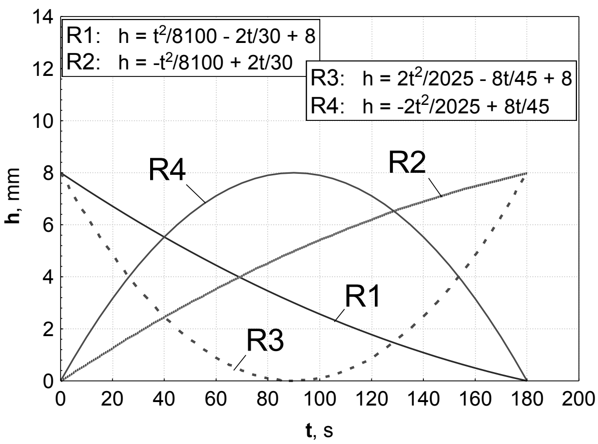

Figure 9. Drawbead height dependencies on time

Slika 9. Ovisnosti visine zateznog rebra od vremena

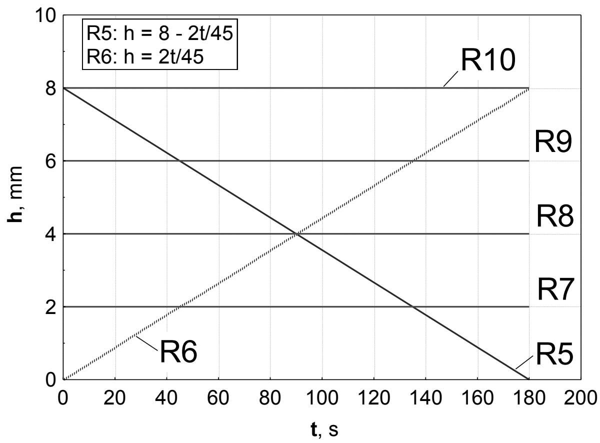

Figure 10. Drawbead height dependencies on time

Slika 10. Ovisnosti visine zateznog rebra od vremena

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

In Figures 7 to 10 review of all dependencies were shown, but for this paper following functions were used: constant pressure P7, P8, P9 and P10; variable pressure P3; constant drawbead height R9 and variable drawbead height R1 and R2.

3.2. Experimental values of drawing force

For this particular experiment adequately combinations of pressure and drawbead height functions were choosen. Such a dependencies are presented in following figures (Figures 11 and 12).

Figure 11 shows given and really achieved dependence of pressure P3 change. Figure 12 shows given and truly achieved decreasing and increasing dependencies of drawbead height. Really achieved constant values of pressure according to schemes P7, P8, P9, P10 and constant drawbead height according to scheme R9 are corresponding, with insignificant deviations to Figure 8 and Figure 10 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 and increasing functions of drawbead height.

The investigation of the following combinations was also carried out: constant pressure P7 to P10 – constant drawbead height R9, variable pressure P3 – constant drawbead height R9, as well as constant pressure P8 – variable drawbead height R1 and R2. 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. There are used two type of friction which where explained in chapter 2.1. Drawbead geometry was defined by rounding radius of 5 mm and it was not changed here.

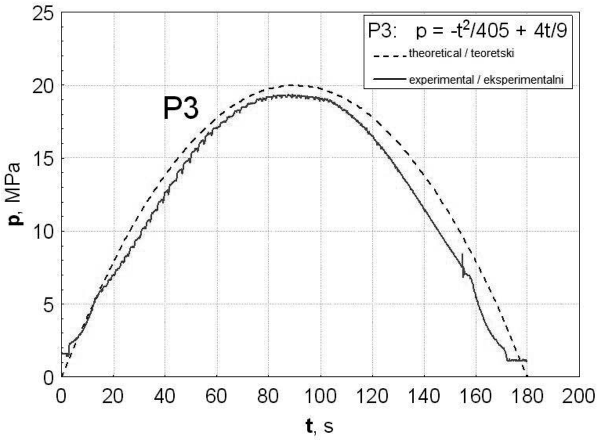

Figure 11. Given and real pressure dependence on time

Slika 11. Zadana i stvarna ovisnost tlaka od vremena

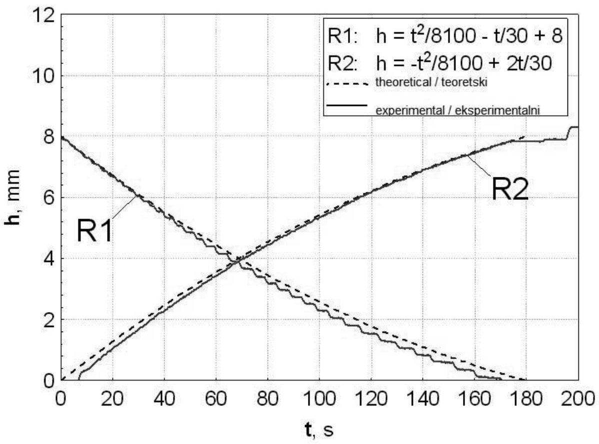

Figure 12. Given and real drawbead height dependencies on time

Slika 12. Zadane i stvarne ovisnosti visine zateznog rebra od vremena

Figure 13 confirm the known dependencies of drawing force on stripe travel at constant pressures and constant drawbead height [8]. In Figure 13, contact pressures are 5, 10, 15 and 20 MPa, and drawbead height is 6 mm. Dependencies were obtained in conditions of dry friction (sign D). The influence of extremely intensified friction is obvious. The intensity of force increases. In addition to that, stripe fracture before the end of process in 3 cases can be noticed, at pressures P8, P9 and P10. The combination of unfavourable friction conditions and contact pressures leads to critical sliding conditions and forming, which results in stripe fracture. At pressure P7, the process runs successfully until the end in both cases, and at extremely high pressure P10, fractures occur for both friction types.

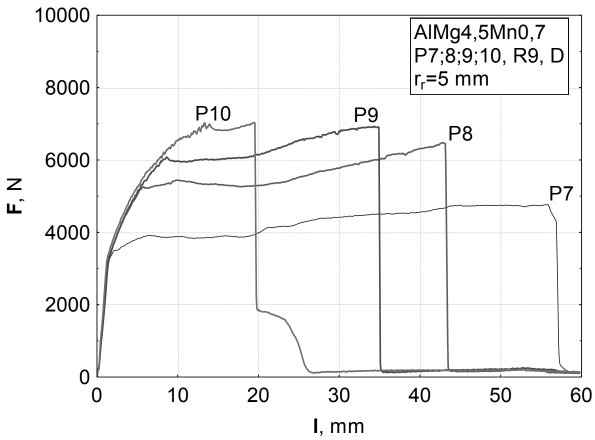

Figure 13. Drawing force dependencies on stripe travel

Slika 13. Ovisnosti sile vučenja od pomaka trake

Figure 14 shows drawing force at combination of influence of variable pressure P3 and constant drawbead height R9. Drawing force response is, in a way, similar with pressure function P3. At smaller friction (sign L) such a conclusion is valid until the end of the entire stripe travel, while unfavourable conditions of strong friction (sign D) lead to fracture in travel smaller than half of the total travel.

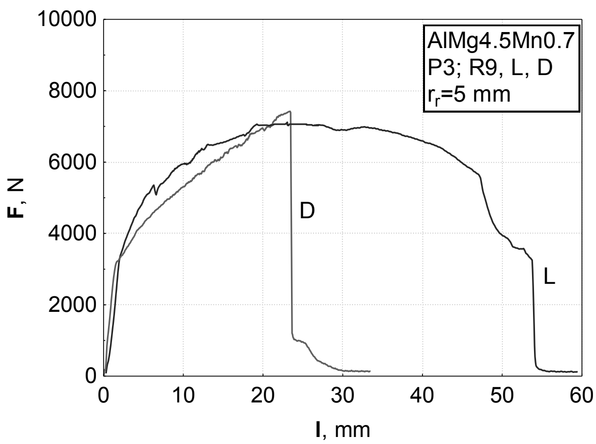

Figure 14. Drawing force dependencies on stripe travel

Slika 14. Ovisnosti sile vučenja od pomaka trake

If constant pressure value is fixed at 10 MPa, and drawbead height is varied (R1 and R2), dependencies in Figure 15 will be obtained, at oil lubrication. Due to the initial drawbead height of 8 mm for function R1, drawing force increases and only after approximately 10 mm of travel it begins to decrease less intensively than drawbead height decrease. In the case of increasing drawbead function (R2), drawing force increases almost proportionally to the increase of drawbead height. The initial force increase is conditioned by pressure P8.

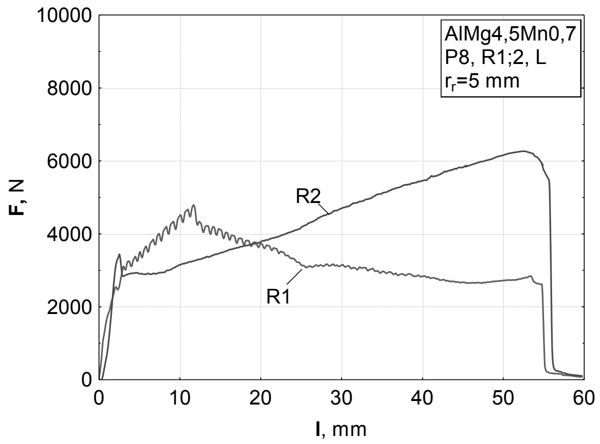

Figure 15. Drawing force dependencies on stripe travel

Slika 15. Ovisnosti sile vučenja od pomaka trake

Finally, in Figure 16, the effects of simultaneous influence of variable pressure (P3) and variable drawbead height (R1 and R2) at oil lubrication can be seen. According to the intensity and shape of drawing force curves, it can be seen that the intensity of influence of pressure P3 and change of drawbeads height R1 and R2 is equal. At the beginning of travel, combination P3R2 has small values of pressure and drawbead height, which results in weak intensity of drawing force which increases slowly. On the contrary, when function R2 is replaced with R1, large initial height of drawbead causes initial increase of force which lasts until drawbead height decreases sufficiently and sliding process enters a rather stable phase, with smaller oscillatory changes.

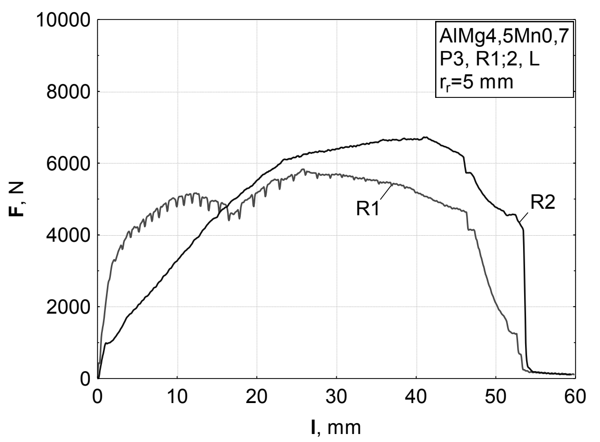

Figure 16. Drawing force dependencies on stripe travel

Slika 16. Ovisnosti sile vučenja od pomaka trake

4. Conclusions

Computerized device for testing the various influences on drawing force in the process of stripe sliding over drawbead at variable contact pressure and variable drawbead height enables accurate monitoring and measuring of the influence of pressure action, drawbead height, drawbead geometry and friction conditions on drawing force.

This paper presents a part of experimental results for the sliding test for aluminium alloy AlMg4,5Mn0,7 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 variable pressure and variable drawbead height in mild sliding conditions, which are realized by application of 5 mm drawbead rounding radius and oil lubrication,

b) more difficult sliding conditions realized by using of dry surfaces are unfavourable and lead to fracture,

c) reaction of drawing force is registered even at relatively small differences in drawbead height change during the process,

d) the character of drawing force response shows that the favourable combination of simultaneous performance of contact pressure change, change of drawbead height and friction conditions makes it possible to influence the course of sheet metal forming process according to the desired forming force criterion,

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

REFERENCES

[1] WAGNER, S.: *Tribology in drawing car body parts,* 11th International colloquium: Industrial and automotive lubrication, Technische Akademie Esslingen, 1998., Proceedings, Vol. III, pp. 2365-2372.

[2] ALEKSANDROVIĆ, S.; STEFANOVIĆ, M.: *Significance of blank holding force in realization of deep drawing process control*, 31. Conference on production engineering of Serbia and Montenegro, 2006., Kragujevac, Proceedings, pp. 139-146. (in Serbian).

[3] LIEWALD, M.: *Current trends in research on sheet metal forming at the institute for metal forming technology (IFU) at the University Stuttgart,* Papers of the International Conference on ”New Developments in Sheet Metal Forming”, IFU Stuttgart, 2008., pp. 263-288.

[4] BLAICH, C.; LIEWALD, M.: *New approach for closed-loop control of deep drawing processes,* Papers of the International Conference on ”New Developments in Sheet Metal Forming”, IFU Stuttgart, 2008., pp. 363-384.

[5] MICHLER, J.R.; WEINMANN, K.J.; KASHANI, A.R.; MAJLESSI, S.A.: *A strip-drawing simulator with computer-controlled drawbead penetration and blankholder pressure,* Journal of Materials Processing Technology, 43 (1994), 177-194.

[6] HU, S.G.; BOHN, M.L.; WEINMANN, K.J.: *Drawbeads and their potential as active elements in the control of stamping,* Papers of the International Conference on ”New Developments in Sheet Metal Forming”, IFU Stuttgart, 1998., pp. 269-303.

[7] WALLER, J.A.: *Press Tools and Presswork,* Portcullis Press Ltd, Great Britain, 1978.

[8] STEFANOVIĆ, M.: *Tribology of Deep Drawing,* monograph, Yugoslav Society for Tribology and Faculty of Mechanical Engineering, Kragujevac, 1994, (In Serbian).

[9] ALEKSANDROVIĆ, S.: *Blank holding force and deep drawing process control,* monograph, Faculty of Mechanical Engineering, Kragujevac, 2005, (In Serbian).

[10] ALEKSANDROVIĆ, S.; NEDELJKOVIĆ B.; STEFANOVIĆ, M.; MILOSAVLJEVIĆ, D.; LAZIĆ, V.: *Tribological properties of steel and al-alloys sheet metals intended for deep drawing,* Tribology in Industry, Faculty of Mechanical Engineering (now Faculty of Engineering), Kragujevac, ISSN: 0354-8996, 31(3&4) (2009), 11-16.

[11] ALEKSANDROVIĆ, S.; MARUŠIĆ, V.; VUJINOVIĆ, T.; MAGLIĆ L.: *Influence of variable blank holding force and nonmonotonous process of deep drawing on formability of coated sheets,* Strojarstvo, 52 (2010) 2, 159-168.

[12] GRIZELJ, B.; CUMIN, J.; GRIZELJ, D.: *Effect of spring-back and spring-forward in v-die bending of St1403 sheet metal plates,* Strojarstvo, 52 (2010) 2, 181-186.