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## STUDY ON THE INFLUENCE OF TEMPERATURE, VELOCITY AND SHAPE OF TOOLS ON THE COMBINED PROCESS OF EXTRUSION AND BROACHING OF THE DEEP SLEEVE WITH THE BOTTOM MADE OF THE AZ31 ALLOY

### BADANIE WPŁYWU KSZTAŁTU NARZĘDZI I PARAMETRÓW TEMPERATUROWO – PRĘDKOŚCIOWYCH NA PROCES POŁĄCZONEGO WYCISKANIA I PRZECIĄGANIA TULEI GŁĘBOKICH Z DNEM ZE STOPU AZ31

The article presents the results of a theoretical analysis of the manufacturing process of the deep sleeve with the bottom by means of a method of combining the indirect extrusion of a thick bush and broaching the blank through the conical die in one cycle of the stamp. The main advantage of application of the developed method for production of the sleeve is to reduce demand for energy and force compared to traditional methods of producing the deep sleeve. Moreover, the nature of the single operation of the extrusion process and extension of the sleeve eliminates the necessity of additional treatments: soft annealing, reheating the charge and reducing wall thickness of the sleeve by a second tool, which significantly reduce energy, labour and time consumption of production. Numerical calculations were performed in the Forge ® 2D using plane state of strain and the obtained results allowed to determine the forces necessary for the process and the strain limit, as well as die geometry and impact velocity on the process tool.

*Keywords:* complex extrusion, new method extrusion deep sleeves

W artykule przedstawiono wyniki z teoretycznej analizy procesu wytwarzania tulei głębokich z dnem z zastosowaniem metody polegającej na połączeniu wyciskania przeciwbieżnego grubościenniej tulei i przeciągania półwyrobu przez matrycę stożkową w jednym cyklu posuwu stempla. Zasadniczą korzyścią z zastosowania opracowanego sposobu wytwarzania tulei jest obniżenie zapotrzebowania na parametry energetyczno – siłowe w stosunku do tradycyjnych metod wytwarzania tulei głębokich. Ponadto jednooperacyjny charakter procesu wyciskania i wydłużania tulei pozwala na wyeliminowanie konieczności dodatkowych zabiegów: wyżarzania zmiękczonego lub dogrzewania wsadu oraz redukcji grubości ścianki tulei w drugim narzędziu przez, co ograniczy w znaczący sposób zużycie energii, pracochłonność i czasochłonność produkcji. Obliczenia numeryczne wykonano w programie Forge®2D stosując płaski stan odkształceń a uzyskane wyniki pozwoliły na określenie sił niezbędnych do przeprowadzenia procesu oraz określenie granicznej wartości zadawanych odkształceń, geometrii matrycy i wpływu prędkości narzędzi na przebieg procesu.

## 1. Introduction

Application of high values of the total strain during forming processes increases the demand for energy and force in the whole manufacturing process. This applies especially to the deep hollow extrusion of products, in particular ones with a complicated cross-sectional shape. Therefore, the design of extrusion process technology is an important issue to minimize the energy and force parameters. There are many methods to reduce the strength indicators processes by selecting appropriate parameters, *e.g.*: properties of extruded material, degree of processing and elongation factor, velocity of the extrusion process, initial temperature of the charge, prepara-

tion of the charge, lubrication and structure and shape of the matrix.

As it is presented in [6], a very effective method of reducing energy and force parameters of extrusion process is joining the patterns of metal flow and the distribution of a stream of the metal flow in such a way, that local increases in temperature in the first phase of the process will appear exactly in the places where, the greatest plastic deformation is observed in the second phase.

During the indirect extrusion, the working tools are subjected to the highest stress in the third phase of process [2], during the formation of the bottom. This phase in industrial practice is usually ignored, but as

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shown by results in [7], the extrusion force in relation to the value of the first phase of the process, where the rise until it reaches a local maximum is noted, increases by 15 to 20%. In extrusion processes of the deep products, where the total height of the product exceeds 2.5-fold its internal diameter, the tools (stamp and matrix) work at high temperatures and large long-term burden. To produce the deep sleeves on a massive scale using the conventional coextrusion method, the interoperational heat treatment should be applied, or alternatively additional heating of the charge, and complete the operation process under a separate finishing tool.

This paper presents an analysis of manufacturing of the deep sleeve by combination of the processes: concurrent extrusion of thick sleeve and broaching the blank through a conical die. Preliminary numerical studies have shown that demand for energy and force in the whole process are lower than in the conventional processes of producing the deep sleeve. An energy-consumption indicator of the process, which was the average force of extrusion of the whole process was reduced by about 35%.

The numerical study involved an analysis of the impact of variables such as:

- initial temperature of the charge ( $T_0 = 300, 350, 400$  [°C]);
- feed speed of a punch ( $V = 25, 50, 100$  [mm / s]);
- degree of strain ( $\varepsilon = 0.3$ );
- angle of the conical die ( $\alpha = 10^\circ, 12^\circ, 15^\circ$ )

on the combined process of extrusion and drawing of the sleeve.

The model material for the study was the AZ31 alloy. The characteristics of the material needed for the equations determining the values of flow stress by Forge ® software were obtained in plastometric tests performed at Gleeble 3800 system.

## 2. The concept of a new method of deep sleeve production

The deep sleeves are products used in metallurgical, machinery, aerospace, automotive and defense industry. They can be used as semi-finished products for the further production of pipes, manufacture of hydraulic cylinders, construction machinery parts, shells and bullets casings of medium and large caliber.

By definition, these are products characterized by the ratio of the total height  $H_t$  to the dimension of inner diameter  $D_w$  is greater than or equal to 2.5. ( $H_t/D_w \geq 2.5$ ).

In papers [4,6] the results of newly developed ways of extrusion of the deep sleeve from a whole charge are presented. They ensure completion of the process in one technological process by reducing the extrusion force by 40% as compared to the indirect extrusion. Moreover, substantial increase in strength/force during the formation of the bottom of the sleeve was eliminated. However, the proposed scheme of the metal flow in the described method make it necessary to design a tool with a rather complicated operational scheme [7].



Fig. 1. The product deep sleeve, where:  $H_c$  – total height,  $D_w$  – internal diameter,  $D_z$  – outside diameter

To produce such products without the need for additional operations listed in Introduction, and use simple assembly of the working tools, the authors proposed a new way of combining manufacturing extrusion and drawing the sleeve in one technological treatment/process. A scheme of the process is shown in Figure 1.

The process is basically divided into two stages. The first stage of the process of the indirect extrusion of a relatively shallow thick sleeve from a rolled charge (2) in a container (1) is by an action of the stamp (3). When the face of the stamp (3) reaches a distance from the face of the ejector (5) equal to the assumed thickness of the bottom of the sleeve, the second stage of the process begins, where both the punch (3) and holes (2) are moving in the same direction, with the same constant speed without changing the distance between them [3].

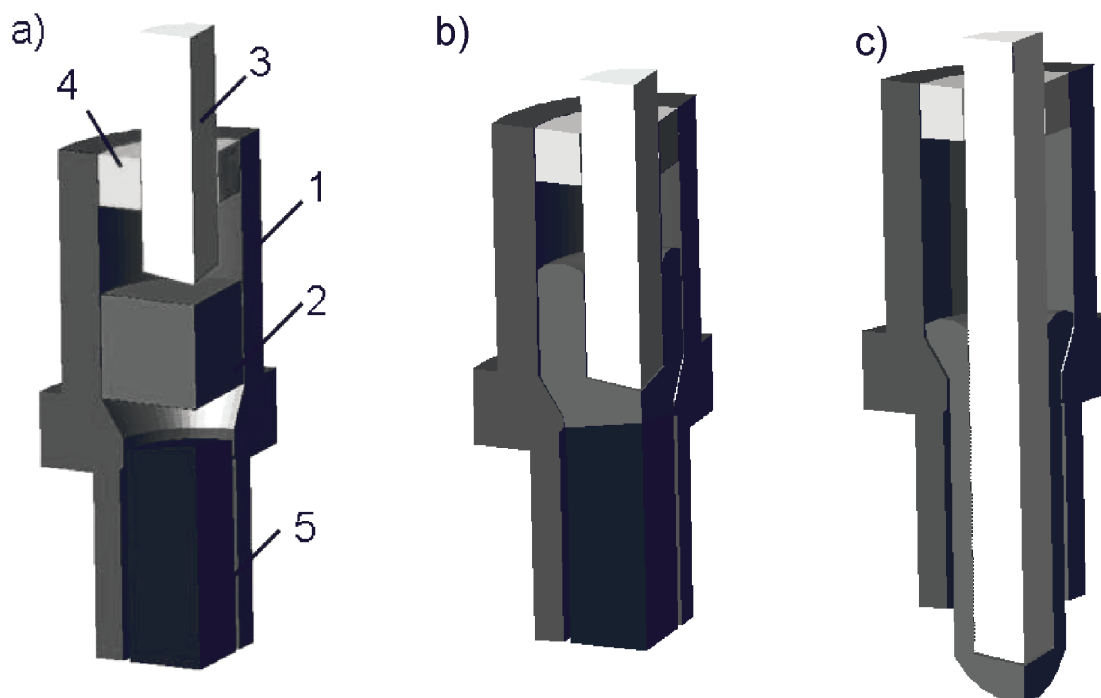


Fig. 2. Scheme of the process connected extraction and dragging the sleeve deep. 1) the container to the matrix 2) charge, 3) punch, 4) guide. a) the initial state of the process, b) Stage I c) Stage II

### 3. The material used in the studies

The model material used in numerical studies was magnesium alloy AZ31 with the chemical composition given in Table 1. The alloy was used for pressing as well as hot and warm extrusion [1].

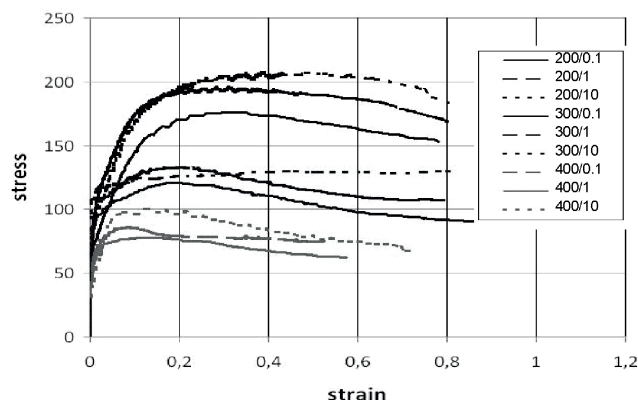


Fig. 3. The curves of strengthening obtained in studies on the GLEEBLE 3800 system

TABLE 1

The chemical composition of the tested alloy

Grade alloy	The content of ingredients, %							
	Mg	Al	Mn	Nd	Sb	Zn	Fe	Si
AZ31	96.284	2.58	0.12	0.005	0.017	0.99	0.002	0.02

To determine the rheological properties of the alloy and to generate the coefficients of the equation, which is used by the numerical program to determine the flow stress, the tests were performed at GLEEBLE 3800 physical simulation system. Figure 3 shows compression characteristics of the samples at temperatures of 200, 300 and 400°C and strain rates of 0.1, 1, 10 s<sup>-1</sup>.

After approximation of specified/obtained? data, the coefficients nap the equation were determined:

$$\sigma_p = Ae^{m_1 \cdot t} \cdot \varepsilon^{m_2} \cdot e^{m_4 \cdot \varepsilon} \varepsilon^{m_3} \quad (1)$$

where:  $\sigma_p$  – flow stress

A, m<sub>1</sub>, m<sub>2</sub>, m<sub>3</sub>, m<sub>4</sub> - coefficients  
have value:

A = 2624.315, m<sub>1</sub>= -0.00475, m<sub>2</sub>= -0.11510, m<sub>3</sub>= 0.18406, m<sub>4</sub>= - 0.00964

**4. Experimental method and assumptions for computer simulation**

Process of theoretical analysis was carried out based on the results obtained from computer simulations performed by means of Forge ® software. Due to the nature of the axially-symmetric process, calculations were carried out for a flat state of deformation. Two-step nature of the process requires application of the program function Multistep, which transport data from the last computational step of the first stage of the process to the first computational step in the second stage of the process. Thanks to this calculation in the second stage of the process conditions include temperature-velocity conditions and energy-force parameters present in the first stage of the process.

The main variable parameters in the process were the initial temperature  $T_0$  of feed, cone angle of the die  $\alpha$ , through which the semi-finished product was drawn in the first stage of the process, and the speed of extrusion and broaching.

During the operation of combined extrusion and drawing, the following angles of the conical die were used  $\alpha = 10, 12$  and  $15^\circ$ . Preliminary studies have shown that the limit of the angle of the conical die is  $\alpha = 15^\circ$ . After exceeding the angle of  $\alpha = 15^\circ$ , formation of constrictions was observed in the zone connecting the sleeve with the bottom wall during the second stage of the process. In the figure 4 the scheme of the tools used in the numerical tests is shown.

During the study, variable numerical temperature-velocity parameters were applied. The numerical calculations were performed for the following initial temperatures of the charge:  $T_0 = 300, 350, 400, 450$  [°C] and for the velocities of working tool  $V = 25, 50$  and  $50$  [mm/s].

A measure of the strain  $\varepsilon$  was degree of reduction of section  $S_0$  of a relatively shallow thick-walled sleeve received in the first stage of the process. Deformation diagram is shown in Figure 5.

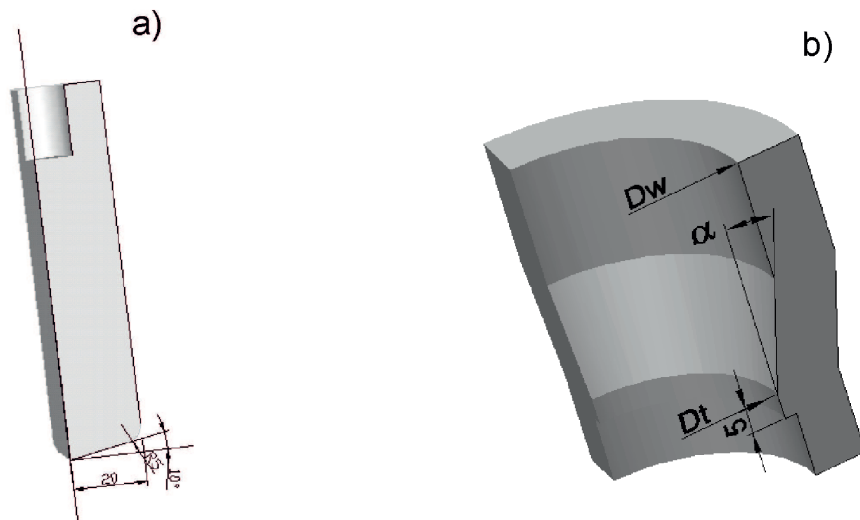


Fig. 4. Schemes of work tools. a) the stamp, b) a container with a matrix, where:  $D_w$  – internal diameter of the container,  $D_t$  – outside diameter of the sleeve,  $\alpha$  – the angle of the cone matrix

$$\varepsilon = \frac{S_0 - S_1}{S_0}$$

where:

$S_0$ -section after indirection extrusion,  
 $S_1$ -section after dragging

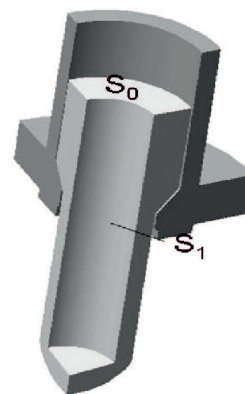


Fig. 5. Schematic deformation charge in the second stage of the process

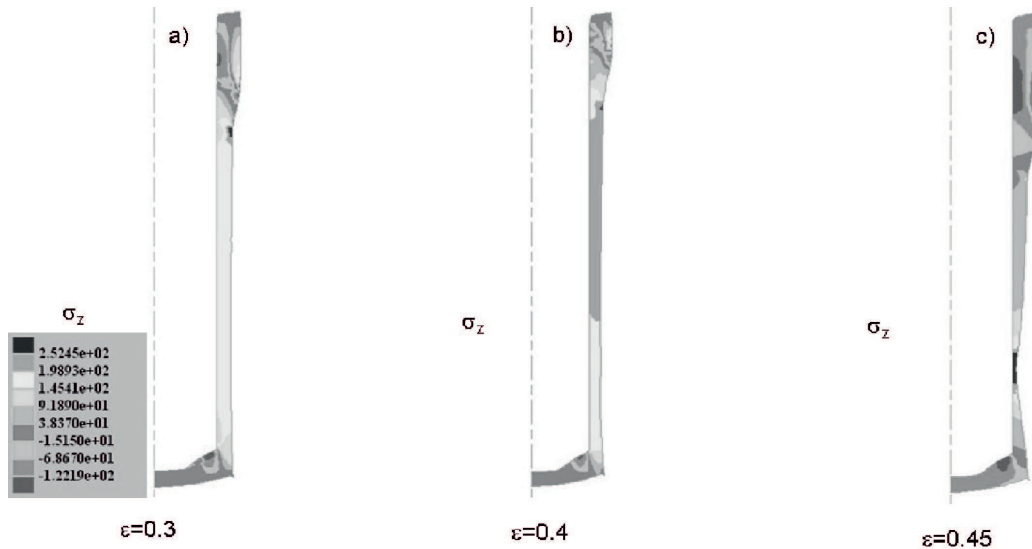


Fig. 6. Distributions of longitudinal stress  $\sigma$  of the deformation: a)  $\varepsilon = 0.3$ , b)  $\varepsilon = 0.4$ , c)  $\varepsilon = 0.45$  and initial temperature  $T_0 = 250^\circ\text{C}$ ,  $V = 25 \text{ mm/s}$

In the combined process of extrusion and broaching, the single variant of strain was used, which was the limiting value specified in a preliminary studies of the process and was  $\varepsilon = 0.3$ . The results are shown in Figure 6.

From the analysis of longitudinal stress distribution of  $\sigma$  arises, that applying the strain  $\varepsilon = 0.3$ , the value of stress in the wall of the sleeve during drawing does not exceed the flow stress determined during approximation of the plastometric results. Using the values of strain  $\varepsilon > 0.3$ . (Fig. 6), stress in the wall of the sleeve exceeds the value of flow stress  $\sigma_p = 170 \text{ MPa}$ , which causes the throat of the wall and the destruction of the product (Fig. 6 b, c).

## 5. Results of numerical calculations

Numerical studies were performed to determine the impact of variables of the process on the demand for energy-force parameters and a comparison of the determined extrusion forces with competing methods used to obtain the deep sleeve.

The calculations allowed for the determination of the basic characteristics of the extrusion process, which is the dependence of the force from the stamp path. Figure 7 shows a change of the press force during deformation of the charge.

In the first stage of the process, in which charge is extruded in a indirect way, the characteristic of force from the stamp path has a typical shape for such processes. After reaching the maximum value of the force, it slightly decreases and stabilizes (established state of ex-

trusion) and at the end of the process, when the bottom of the sleeve is formed it increases again. During the transition from the first to second stage of the process, the force drops to about 2% of the maximum force achieved in the first stage of the process. During the drawing operation of the sleeve, whilst reducing the wall thickness, the force reaches a maximum of 10 to 15% of the force from the first stage of the extrusion process (Fig. 7).

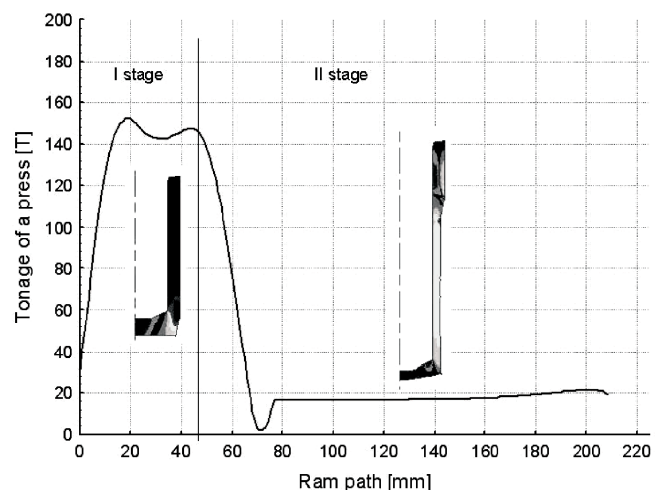


Fig. 7. Diagram changes in the presses force along the way stamp for:  $\varepsilon = 0.3$ ,  $V = 25 \text{ mm/s}$ ,  $T_0 = 400^\circ\text{C}$

The nature of the characteristic presented in Figure 7 is influenced by inflicted strain diagram and temperature distribution in cross-section during deformation of the metal sleeve. For the test process, it is characteristic

that in the first stage of the extrusion, the greatest local temperature increments exist in the wall of the sleeve. This is an area where during the second stage the largest amount of plastic deformation takes place, which allows

to impose a relatively large strain without losing the consistency of the material. Characteristic distributions of the temperature and impact velocity of the process is shown in Figure 8.

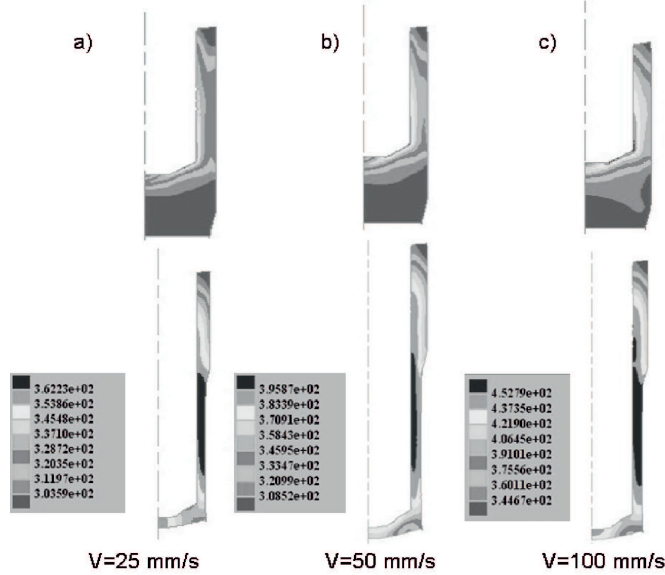


Fig. 8. The temperature distribution for the parameters:  $\epsilon = 0.3$ ,  $T_0 = 300^\circ\text{C}$  and  $V = 25, 50, 100 \text{ mm/s}$

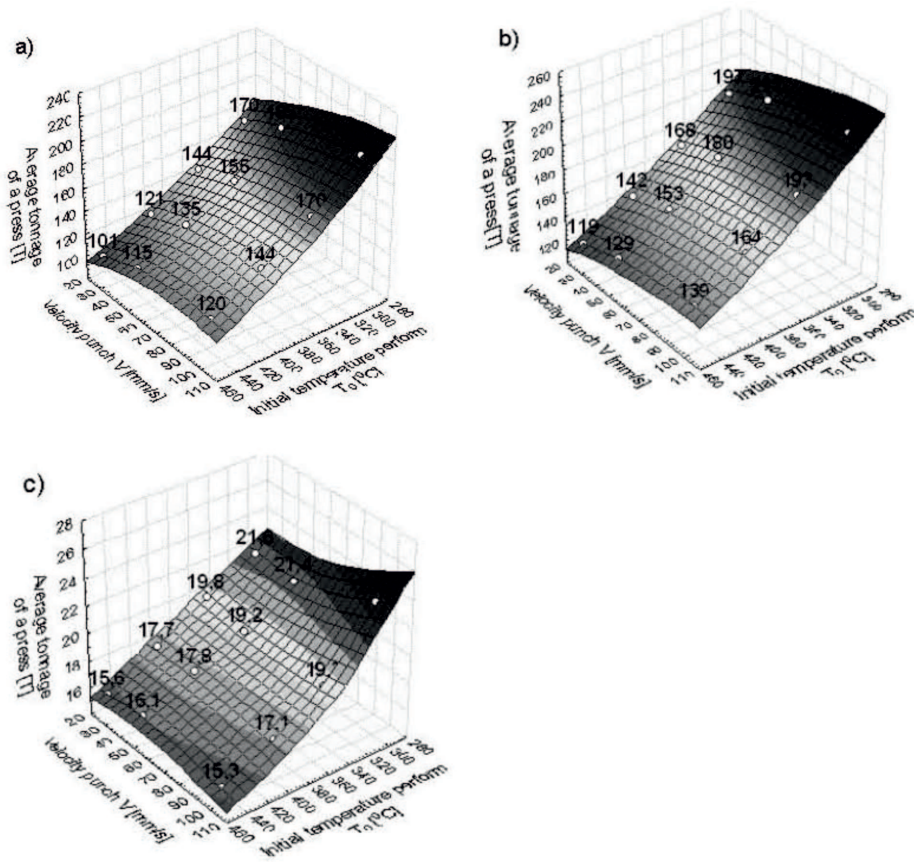


Fig. 9. Effect of feed rate stamp on the strength of the pressure press for  $V = 25, 50, 100 \text{ mm/s}$ ,  $T_0 = 300, 350, 400, 450^\circ\text{C}$ . a) stage I and II, b) Stage I, c) Stage II

As is apparent from the temperature distributions a significant impact on the process in the second stage is to speed extrusion. Threefold increase in speed causes an increase in temperature in the wall of the sleeve in the first stage by about 25% compared to the lowest speed  $V = 25$  mm/s. Similar proportions of temperature increase occur in the second stage of process (Figure 8).

Figure 9 shows the impact of feed speed gear in the pressure-press based on surface graphs.

From the graphs presented in Figure 9a shows, that increasing the tool feed speed from 25 to 100 mm/s in the whole range of average temperatures will increase the press force of about 10 to 15%. It is particularly evident in the first stage of process (Figure 9b), in the process of indirect extrusion, and the reason is the strengthening of the metal under the stamp. For higher temperatures the increase in pressure is less, which is a consequence of the lower value of  $\sigma_p$ . In the second stage of process the growth of the press force is the lowest temperature (Fig. 9c). For other variants of  $T_0$  at each value of  $V$  mean force, the press is on the same level and at the highest  $T_0$  shows a downward trend. A clear advantage of the temperature effect and the imposition of zones of deformation of the first stage, where he experienced the greatest increases in local temperature are the causes of decline in energy – force parameters in the second stage of the process.

In the processes of drawing or broaching a very significant impact on the course of deformation has a cone angle calibration tool. This parameter is responsible for the value of axial force and the distribution and value of the stresses in the cross product. The processes of drawing and broaching are generally conducted at ambient temperature and the angle of the cone is  $\alpha \approx 8^\circ$ . The large value of the angle of the cone causes the so-called matrix restrained deformation zone, resulting in a sudden strengthening of the metal and consequently increase the broaching tension and axial force. Analyzed the process was conducted in a temperature range corresponding to the hot processing of alloy AZ31, so was analyzed, a greater value than the angle  $\alpha$  in the processing of cold and determined their effect on the broaching force. Examined the impact of the cone angle sensor  $\beta = 10, 12$  and  $15^\circ$  on the broaching force in the second stage of the process shown in Figure 10.

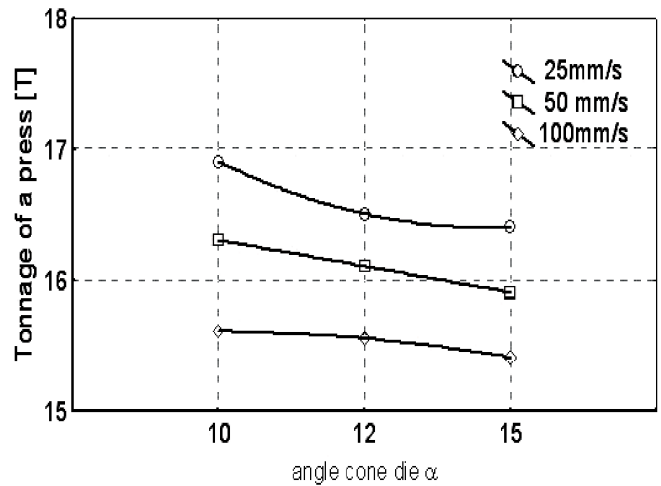


Fig. 10. Impact of angle of the cone matrix and tool feed rate the press on the pressure forcing at  $T_0 = 400^\circ\text{C}$

The calculation results showed that increasing the angle of the cone of the die obtained by a slight decrease of force of the press. The temperature rise in the first stage of the process in the walls of the device (Fig. 8) caused a decrease of flow stress, which was the result of edge effect of temperature on the consolidation of the metal deformation in the basin resulting in a slight decrease in the force needed to carry out the second stage of the process of broaching the sleeve.

## 6. Comparative analysis of energy and force parameters

Application of the combined extrusion process investigated and broaching into industrial practice is subject to, among others: whether the demand for energy - force performance is such that the test process can compete with alternative processes that enable the production of similar products. In papers [6,7] proposes extrusion process (Fig. 11 b), which enable the production of the sleeve with the bottom of the deep and have a much lower forces than extrusion the most widely used way of indirect extrusion. During the tests carried out numerical calculations for these processes using, as input material AZ31 alloy in order to obtain force versus pressure graphs from the way the press stamp and compare them with the process of extrusion from broaching. The results of calculations are described in Figure 11.

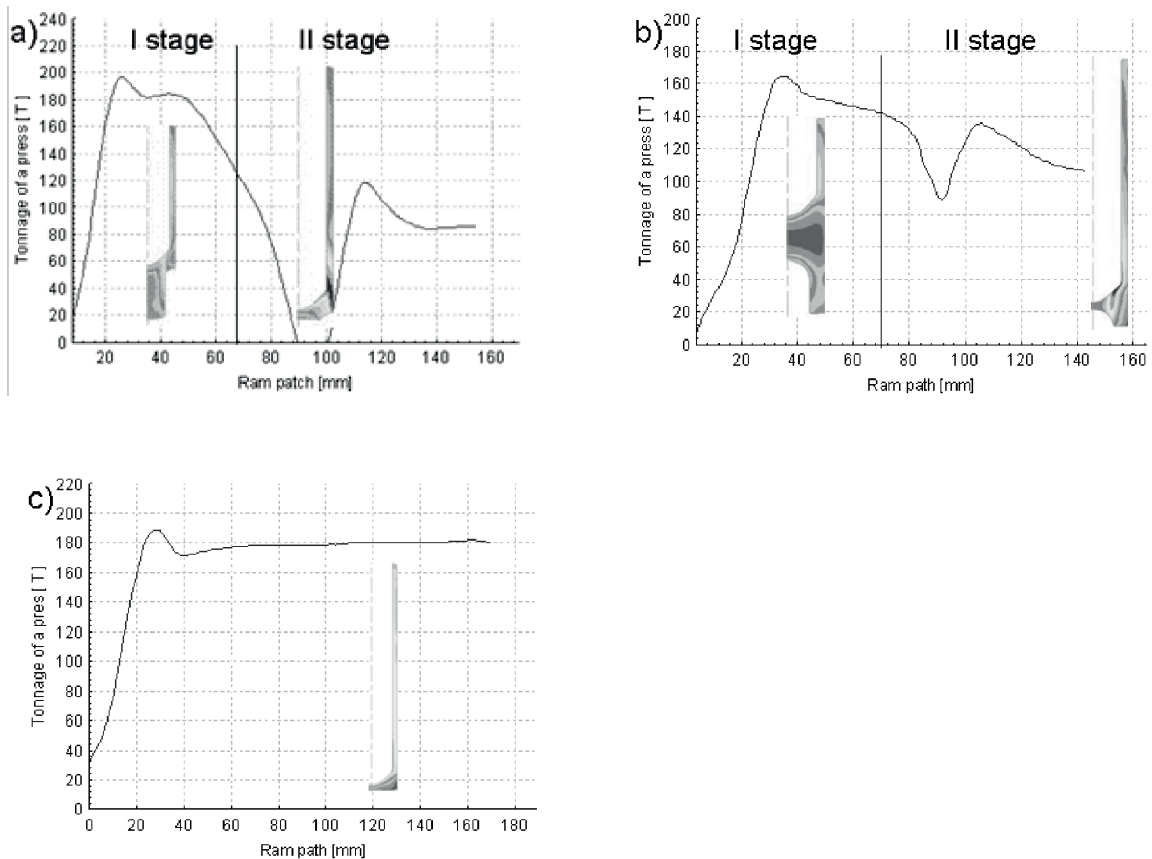


Fig. 11. Diagrams force changes in the way the press stamp for  $V = 25 \text{ mm/s}$ ,  $T_0 = 350^\circ\text{C}$ : a) extrusion complex, b) two-sided complex extrusion, c) indirect extrusion

A measure of energy consumption in the manufacturing process is the average force of extrusion, which takes into account the force of the process from beginning to end. Numerical calculations showed that the mean force, press the test combined extrusion process with broaching at  $T_0 = 350^\circ\text{C}$  and  $V = 25 \text{ mm/s}$  was 135 Tons. The results of calculations for the alternative processes for manufacturing the sleeve shown in Figure 11 were: complex extrusion (Fig. 11a) 121 Ton, two-sided extrusion complex (Fig. 11b) 130 Ton, indirect extrusion (Fig. 11c) 165 Ton.

## 7. Conclusion

The results shown in this study suggest that it is possible to carry out two-stage combined extrusion and broaching in one treatment technology, without moving the blank to the second gear after the first step to complete the operation by broaching the sleeve. As shown the numerical calculations of the demand for energy – force of parameters of the test process relative to competing methods of extrusion, which significantly exceed

the indirect extrusion the sleeve is at a similar level. The energy intensity of the process, which is the average force, the press has been reduced thanks to the work of the proposed process for the manufacture of the sleeve by about 25% compared to the conventional indirect extrusion. The maximum degree of reduction in cross-section of the sleeve after the first stage of the process is  $\varepsilon = 0.3$ , and limit the angle of the cone of the die  $\alpha$  may be the  $15^\circ$ . Threefold increase in feed rate causes an increase in average tools of the press force of up to 15%.

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