J. MICHALCZYK*, V. DEVYATOV*

THE EFFECT OF STRAIN INTENSIFICATION ON THE SINGLE-OPERATION PROCESS OF EXTRUSION OF DEEP-BOTTOMED SLEEVES

WPŁYW INTENSYFIKACJI ODKSZTAŁCEŃ NA PRZEBIEG JEDNOOPERACYJNEGO PROCESU WYCISKANIA TULEI GŁĘBOKICH Z DNEM

In the article the authors present the results of a study on solving the problem occurring in the production of deep steel sleeves (H/d>2.5) from full preforms. The basic problem during the production of deep bottomed sleeves, e.g. during making sleeves by indirect extrusion, is that the punch operates under very difficult conditions (such as high temperature and high unit pressures), which causes a reduction in its lifetime and frequent failures. For this reason, deep sleeves are produced through at least two technological treatments. This involves the necessity of building two technological stands (often using two presses), which considerably increases the cost of production, its labour-consumption and, above all, reduces the productivity.

The new method of producing sleeves, proposed by the authors, combines the known and specific pattern of metal flow in the extrusion process, and aims at achieving the following: increasing the lifetime of working tools, increasing the productivity, lowering the production costs, reducing the material losses and decreasing the magnitude of extrusion forces.

The method under analysis consists in the simultaneous indirect extrusion and co-extrusion, which results in a semi-finished product in the form of a sleeve with a stem. These are known methods of the plastic working of full preforms. It is these schemes that are applied in the new method as the first stage of producing deep bottomed sleeves. The second stage in the process is a quite specific deformation pattern consisting in the formation of a finished sleeve wall from the stem formed in the first stage. By combining different extrusion schemes, both in the first and in the second stage of the process the strain intensities were increased, and the partitioning of the flowing stream and the change of the metal flow direction caused local temperature increases as a result of strain intensification, which resulted in a drop in the magnitude of forces needed for the single-operation extrusion of deep sleeves. Then, different variants of process rate and degree of deformation resulting from the geometry of the movable ring and its taper angle for four values of temperature were subjected to analysis and their effect on the extrusion force was determined.

A preliminary analysis of the process included computer simulations in the FORGE®2D program. As the model material, steel 45 was used. The process was conducted at different tool speeds: (25, 50, 100, 200, 300 mm/s), at different temperatures: (850, 950, 1050, 1150°C), for four degrees of deformation: (ε = 0.3, 0.4, 0.5, 0.75) and for three taper angles of the movable ring: (2 β = 120°, 140°, 160°).

Maximum extrusion forces were determined, graphs of the relationship of the extrusion force versus the above-mentioned parameters were plotted, and the maximum values of metal pressures on the punch, as dependent on the parameters analyzed, were determined. Also determined during analysis were the sizes of the zones of local increase in temperatures and their values, which are the result of strain intensification and strain rate intensification, the consequence of which is a reduction in the forces of metal pressure on the tools and a reduction in the extrusion force.

With the aim of performing the physical modelling of the process, a testing stand was build, which included a tool, whose operation allows the deformation pattern concerned to be carried out, and a modern testing press, type ZWICK Z100.

The model material for the extrusion of sleeves on the testing stand was lead.

Extrusion operations were performed in the tool, obtaining sleeves of an overall height of H=150÷200 mm, an outer diameter of D_z = 50 mm, an inner diameter of D_w = 40 mm, a wall thickness of 5 mm and a bottom thickness of 5 mm. Graphs of the relationship of the force P [kN] versus the punch path S [mm] were also plotted and compared with the graphs from computer simulations.

Keywords: extrusion, strain intensification, single operation of extrusion

W artykule autorzy przedstawili wyniki pracy nad rozwiązywaniem problemu występującego przy produkcji stalowych tulei głębokich (H/d>2,5) z pełnych wstępniaków. Podstawowym problemem podczas produkcji głębokich tulei z dnem np.

* INSTITUTE OF MODELLING AND AUTOMATION OF PLASTIC WORKING PROCESSES, 42-200 CZĘSTOCHOWA, 19 ARMII KRAJOWEJ STR., POLAND

przy wykonywaniu tulei poprzez przeciwbieżne wyciskanie jest to że, stempel pracuje w bardzo trudnych warunkach (wysoka temperatura i wysokie naciski jednostkowe), co powoduje obniżenie jego trwałości i częste uszkodzenia. Z tego powodu głębokie tuleje produkuje się poprzez conajmniej dwa zabiegi technologiczne. Wiąże się to z koniecznością zbudowania dwóch stanowisk technologicznych (często używania dwóch pras), co znacznie podwyższa koszt produkcji, jej pracochłonność a przede wszystkim obniża wydajność.

Zaproponowany przez autorów nowy sposób otrzymywania tulei łączy w sobie znany oraz specyficzny schemat płynięcia metalu w procesie wyciskania, a jego celem jest spowodowanie: podwyższenia trwałości pracy narzędzi roboczych, podwyższenia wydajności produkcji, obniżenia jej kosztów, zmniejszenia strat materiału oraz obniżenia wielkości sił wyciskania.

Analizowany sposób polega na jednoczesnym przeciwbieżnym i współbieżnym wyciskaniu dającym w efekcie półwyrób w postaci tulei z trzonem. Są to znane sposoby obróbki plastycznej pełnych wstepniaków. Właśnie te schematy są zastosowane w nowym sposobie jako pierwsze stadium otrzymywania głębokich tulei z dnem. Drugie stadium w procesie jest dość specyficznym schematem odkształcenia, polegającym na formowaniu gotowej ścianki tulei z powstałego w pierwszym stadium trzonu. Łączenie ze sobą różnych schematów wyciskania zarówno w pierwszym jak i w drugim stadium procesu pozwoliło na podniesienie intensywności odkształceń a podzielenie strumienia płynięcia i zmiana kierunku płynięcia metalu spowodowały lokalne wzrosty temperatury w wyniku intensyfikacji odkształceń, co wywołało spadek wartości sił potrzebnych do jednooperacyjnego wyciskania głebokich tulei. Następnie poddano analizie rózne warianty prędkości procesu, stopnia odkształcenia wynikającego z geometrii ruchomego pierścienia oraz jego jego kąta stożkowatości dla czterech wartości temperatur i okreslono ich wpływ na siłę wyciskania.

Wstępna analiza procesu polegała na komputerowych symulacjach w programie FORGE®2D. Jako materiał modelowy zastosowano stal 45. Proces przeprowadzano z róznymi prędkościami narzędzi: (25, 50, 100, 200, 300 mm/s), w temperaturach: (850, 950, 1050, 1150°C), dla czterech stopni odkształcenia: (ε = 0.3, 0.4, 0.5, 0.75) oraz dla kątów stożkowatości ruchomego pierścienia: (2β = 120°, 140°, 160°).

Wyznaczono maksymalne siły wyciskania, wykresy zależności siły wyciskania od wymienionych parametrów oraz maksymalne wartości nacisków metalu na stempel w zależności od analizowanych parametrów. W trakcie analizy określono również wielkości stref wzrostu lokalnych temperatur i ich wartości, które są efektem intensyfikacji odkształceń i intensywności prędkości odkształceń, czego skutkiem jest obniżenie sił nacisku metalu na narzędzia i zmniejszenie siły wyciskania.

W celu fizycznego modelowania procesu zbudowano stanowisko badawcze składające się z narzędzia, którego działanie zapewnia przeprowadzenie analizowanego schematu odkształceń oraz nowoczesnej prasy wytrzymałościowej typu ZWICK Z100.

Materiałem modelowym do wyciskania tulei w przyrządzie był ołów. W narzędziu przeprowadzono operacje wyciskania otrzymując tuleje o całkowitej wysokości H=150÷200 mm, średnicy zewnętrznej D_z = 50 mm, średnicy wewnętrznej D_w = 40 mm, grubości ścianek 5 mm i grubości dna 5 mm. Otrzymano również wykresy zależności siły P[kN] od drogi stempla S [mm] i porównano je z wykresami z symulacji komputerowych.

1. Introduction

Deep sleeves, and particularly bottomed sleeves, are very often elements for the construction of agricultural and aviation machines, and they are also used in the armaments industry for making shells and hydraulic and pneumatic cylinders.

A sleeve can be called deep, when the following condition is satisfied: $H \geqslant 2{,}5 D_w$.

The simplest method of producing a deep sleeve is to join the bottom to the cut-off tube length by welding. This technology is, however, burdened with two major drawbacks:

– the joining of the bottom with the tube length does not assure the uniformity of construction of the element, its tightness and strength in case of being subjected to large loads resulting from high pressures at low temperatures;

– the cost of making rolled tube in a rolling mill is by approx. 50% higher compared to making the hollow product by the extrusion method.[3]

The production of deep sleeves by the indirect extrusion method has a substantial engineering limitation:

– the longer punch path, the longer is the contact of the stock with the container bottom, which results in large zones of metal over-cooling in the location of forming the sleeve bottom, and hence a great increase in the extrusion force and the unit pressures of metal on the punch.

Therefore, the production of deep sleeves is recommended to be effected through at least two technological operations, which requires the use of two production stands, e.g. in the case of drawing of the pre-extruded "cup" through the tapered drawing die. In that case, inter-operation stock heating-up treatments are also recommended, which substantially increases the production cost and decreases productivity.

The proposed method allows the operation of extruding deep-bottomed sleeves in a single technological treatment without having to apply any treatments enhancing the plastic properties of the metal.

2. The essence of the process and assumptions for the theoretical analysis

The method under consideration includes two stages that are characterized by the following features:

– *Stage I* consists in the utilization of the known scheme of simultaneous indirect extrusion and co-extrusion (also referred to as the mixed or combined extrusion), as a result of which a semi-finished product is obtained, which is a sleeve with a stem. The metal stream flows in two directions, with part of the volume of the deformed preform flowing in the ring space and the remaining part flowing backward to the upper punch to form part of the sleeve already in the first stage.
– *Stage II* is the final phase of forming the deep sleeve, which consists essentially in the deformation of the stem formed in the first stage of the process. The ring, sliding down to form a free space in the container, gradually releases the stem metal which, under the action of the punch, is carried towards the recipient's walls and, at the same time, the sleeve wall of the preset thickness of formed. The sleeve bottom thickness depends on the setting of the distance of the punch from the movable ring. A process scheme is illustrated in Fig. 1.

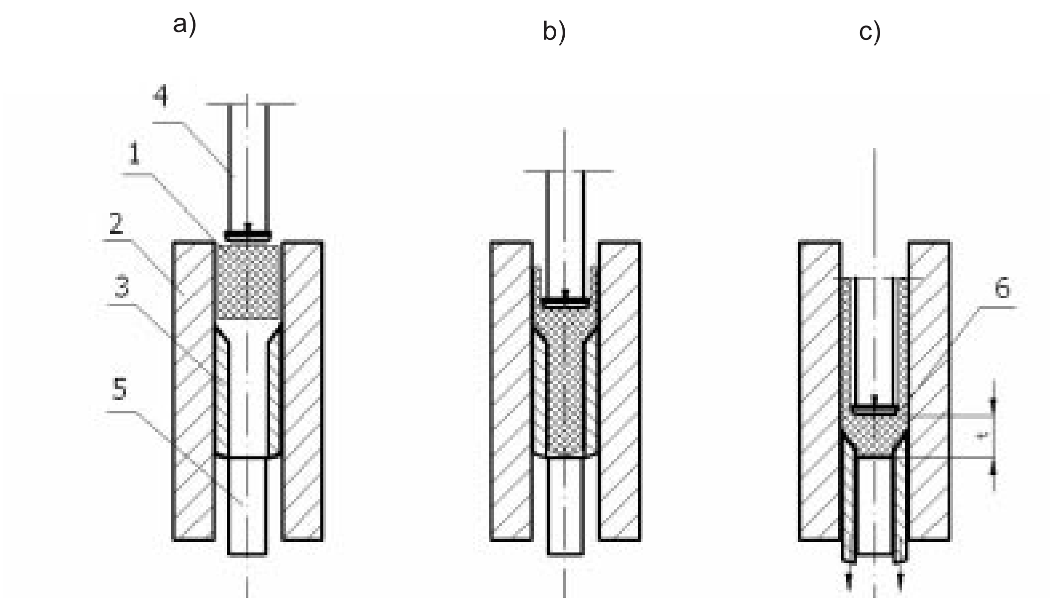

Fig. 1. Schematic diagram of the production of sleeves by the mixed extrusion method using a movable ring in the container. 1) preform, 2) container, 3) ring, 4) punch, 5) fixed punch

The preform in the form of a cylinder (1) is placed in the container (2) on the sleeve (3) which, in the initial stage, is immovable (Fig. 1a). Under the action of the punch (4), the metal of the preform (1) flows in two directions: into the gap between the walls of the container (2) and the punch (4) and into the opening of the tool sleeve (3). At the moment of contact of the preform metal with the face of the pusher (5) (Fig. 1b) the ring (3) starts moving down in accordance with the movement of the punch (4) and at the same speed. The pusher (5) at this stage is immovable and the punch (4) keeps moving down (Fig. 1b). The process is finished upon reaching the specified distance "t" between the face of the punch (4) and the pusher (5) equal to the sleeve bottom thickness. Then the blank (6) is removed from the container by the pusher (5) (Fig. 1c) [2]. Figure 2 and 3 shows a sample variant of the shape of tools used for computer simulations.

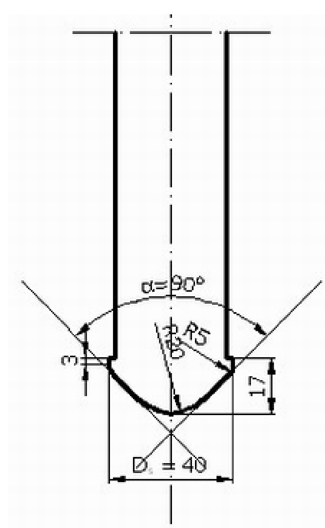

Fig. 2. Dimensions and shape of the punch of an angle of α = 90°

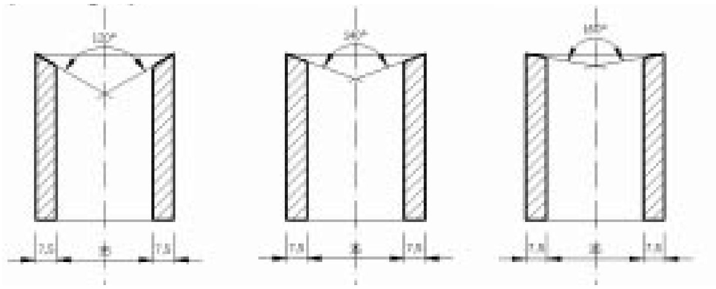

Fig. 3. Dimensions of the movable ring for the degree of deformation in the first process stadium equal to $\varepsilon = 0.5$; $2\beta = 120°, 140°, 160°$.

The assumed process parameters for computer simulations:

– the inner diameter of the movable ring, $D_w = 41$ mm($\varepsilon = 0.3$), 38 mm($\varepsilon = 0.4$), 35 mm($\varepsilon = 0.5$), 30 mm($\varepsilon = 0.75$);

– tool advance speed, V = 25, 50, 100, 200, 300 [mm/s];

– initial process temperature, T_0 = 850, 950, 1050, 1150 [°C],

– movable ring cone angle, 2β = 120, 140, 160[°C].

The model material was steel 45 in the form of rolled preforms of dimensions of ϕ48×75 mm.

3. Results of the theoretical process analysis

The analyzed sleeve extrusion scheme in the first stage is characterized by the two-directional flow of the stream. Part of the deformed metal flows countercurrently and the other part concurrently along the movable ring channel.

Two zones of local temperature increases are formed – in the punch head zone and in the zone of metal contact with the ring wall. The temperature of the metal flowing within the ring channel increases, depending on the process speed and the degree of deformation (ring diameter), which has a substantial influence on the course of the second stage of the process, in which the formation of the sleeve from the preformed stem takes place.

The characteristic zones of the most intensive strains and the highest local temperature increases, and the effect of the variable parameters of deformation degree and process speed on their formation, for sample variants, are shown, respectively, in Figs. 4, 5 and 6 and Figs. 7 and 8.

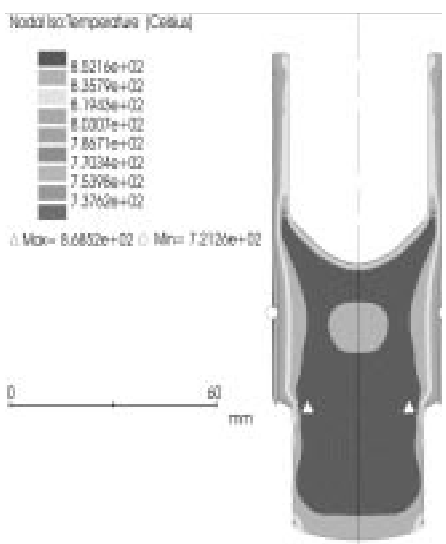

Fig. 4a. Distribution of temperatures in Stage I for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 25 mm/s,$\varepsilon = 0.4$, $2\beta = 120°$

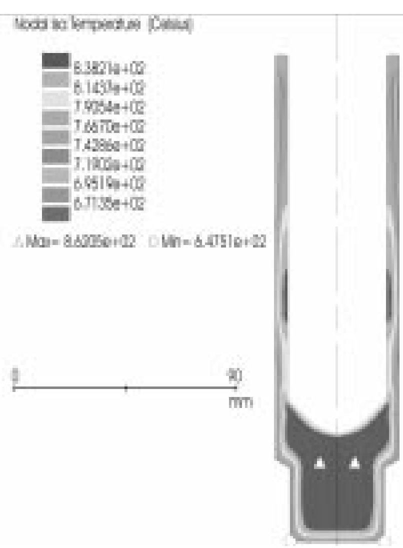

Fig. 4b. Distribution of temperatures in Stage II for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 25 mm/s,$\varepsilon = 0.4$, $2\beta = 120°$

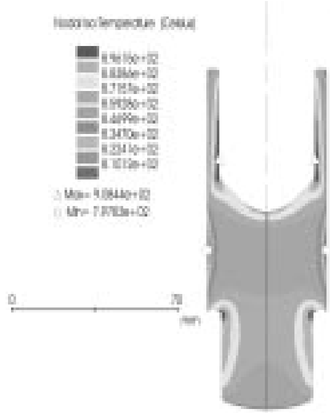

Fig. 5a. Distribution of deformation temperatures in Stage I for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 100 mm/s,$\varepsilon = 0.4$, $2\,\beta = 120°$

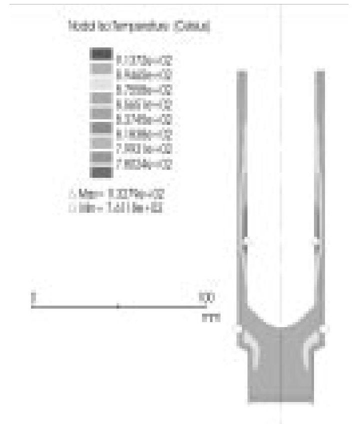

Fig. 5b. Distribution of deformation temperatures in Stage II for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 100 mm/s,$\varepsilon = 0.4$, $2\,\beta = 120°$

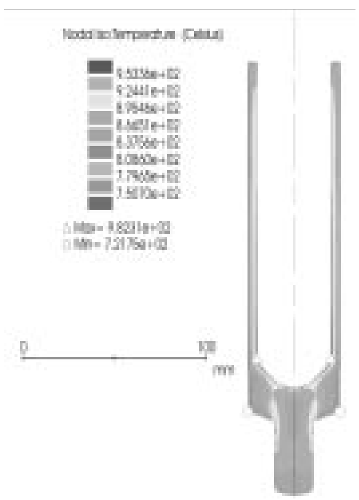

Fig. 6a. Distribution of deformation temperatures in Stage I for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 100 mm/s,$\varepsilon = 0.75$, $2\,\beta = 120°$

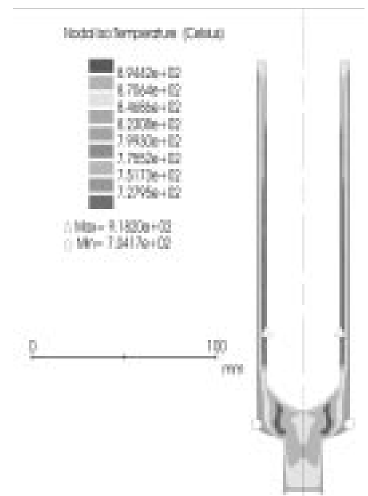

Fig. 6b. Distribution of temperatures in Stadium II for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 100 mm/s,$\varepsilon = 0.75$, $2\,\beta = 120°$

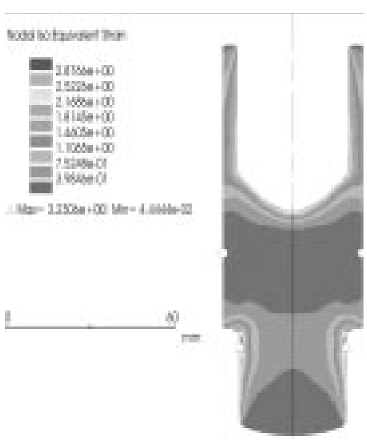

Fig. 7a. Distribution of strain intensities in Stage I for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 100 mm/s,$\varepsilon = 0.4$, $2\,\beta = 120°$

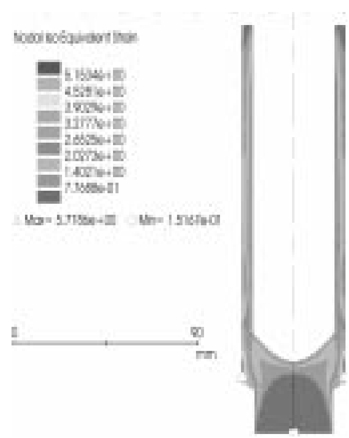

Fig. 7b. Distribution of strain intensities in Stage II for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 100 mm/s,$\varepsilon = 0.4$, $2\,\beta = 120°$

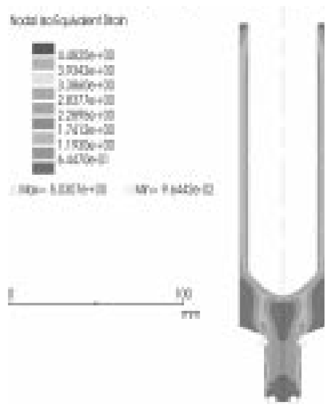

Fig. 8a. Distribution of strain intensities in Stage I for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 25 mm/s, $\varepsilon = 0.75$, $2\beta = 120°$

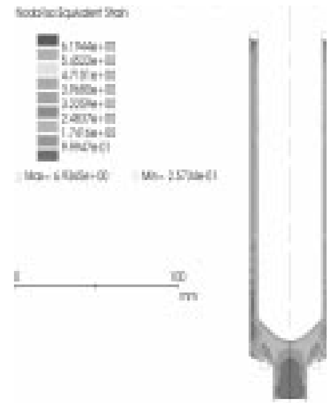

Fig. 8b. Distribution of strain intensities in Stage II for the following parameters: $2\alpha = 90°$, $T_0 = 850°C$, V = 25 mm/s, $\varepsilon = 0.75$, $2\beta = 120°$

The most important in this process is to maintain the temperature of the metal flowing into the ring channel at the level T_0 or to increase it. The stem temperature is decisive to the final process conditions.

At the minimum speed of 25 mm/s, the stem temperature is uniform and stays at the level of T0 throughout the process, with small zones of over-cooling of around 20°C in the zone of metal contact with the ring. By increasing the speed fourfold, a temperature increase by about 70°C was obtained, and with 300 mm/s – even by 250°C in the zones, where the greatest deformations occur in the second stage.

With the change of the deformation degree, there are no such distinct temperature changes, as in the case of indirect extrusion. This causes a two-directional behaviour of metal stream flow.

Figure 9 shows values for the dependence of the maximum unit pressure on the deformation degree and process speed, averaged from Stages I and II, for initial temperatures of T_0 = 850, 950, 1050, 1150 [°C].

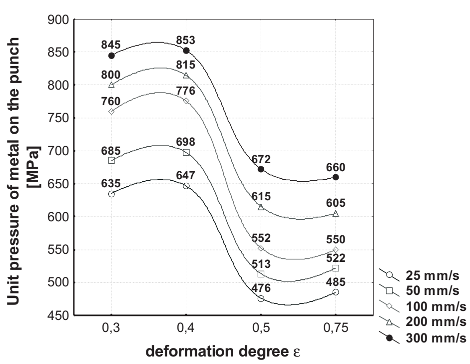

Fig. 9a. Unit pressure of metal on the punch from process Stages I and II for the variable parameters of V, ε and for $T_0 = 850°C$

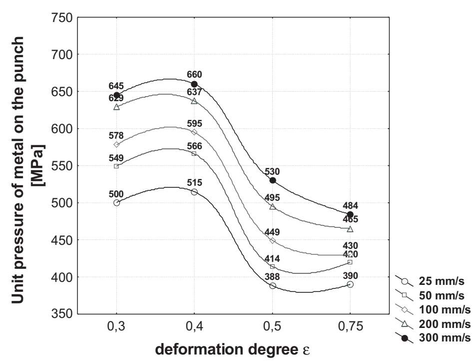

Fig. 9b. Unit pressure of metal on the punch from process Stages I and II for the variable parameters of V, ε and for $T_0 = 950°C$

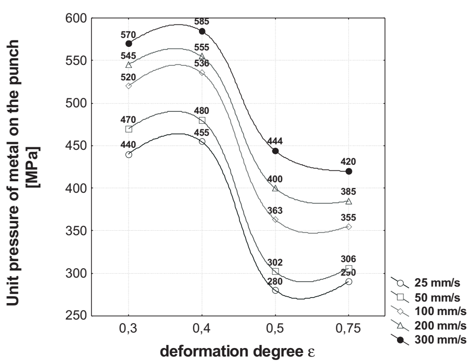

Fig. 9c. Unit pressure of metal on the punch from process Stages I and II for the variable parameters of V, ε and for $T_0 = 1050°C$

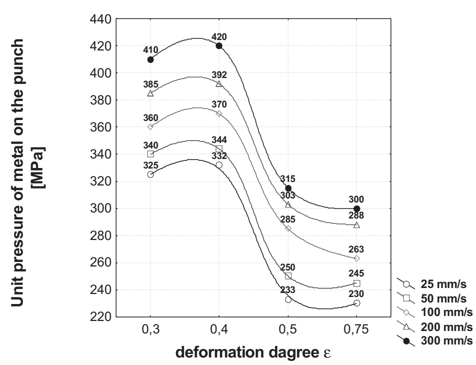

Fig. 9d. Unit pressure of metal on the punch from process Stages I and II for the variable parameters of V, ε and for $T_0 = 1150°C$

The average unit pressure from the both stages is the greatest for ε = 0.3 and ε = 0.4. In the first stage, the pressures are comparable for every value of ε. The large stem diameter creates a large surface of friction between the metal and the ring walls and causes the formation of a higher deformation resistance; for ε = 0.5 and ε = 0.75, on the other hand, the degree of cross-section reduction is the principal cause of the increase in pressures on the punch. In the second process stage, the pressures for ε = 0.3 and ε = 0.4 are still high, but in the case of ε = 0.5 and 0.75 the small stem diameter causes a drop in the forces and pressures. The small diameter of the formed stem does not require so high force to be used in order to deform the stem and produce the sleeve. Hence, after averaging the maximum pressures from the both stages, it can be seen that the greater ε, the smaller are the pressures on the punch.

Figure 10 shows approximated graphs of the relationship of the extrusion force P [kN] as a function of the punch path S [mm] from the computational program Forge®2D.

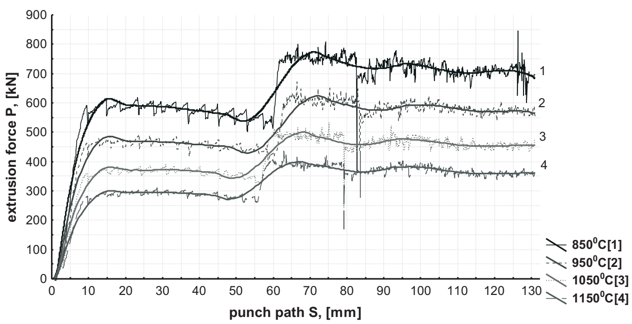

Fig. 10a. Graphs of the relationship of the extrusion force P [kN] as a function of the punch path S [mm] for: T_0 = 850, 950, 1050, 1150 [°C], V = 25 [mm/s], 2 β = 120°, ε = 0.3

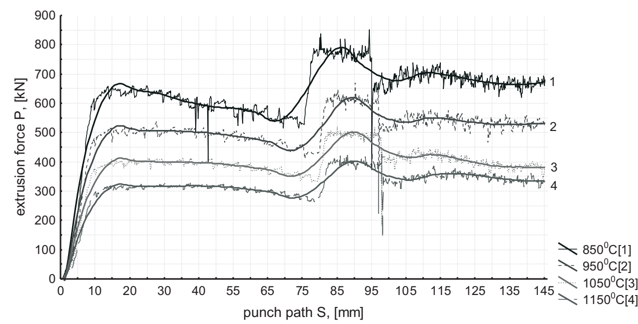

Fig. 10b. Graphs of the relationship of the extrusion force P [kN] as a function of the punch path S [mm] for: T_0 = 850, 950, 1050, 1150 [°C], V = 25 [mm/s], 2 β = 120°, ε = 0.4

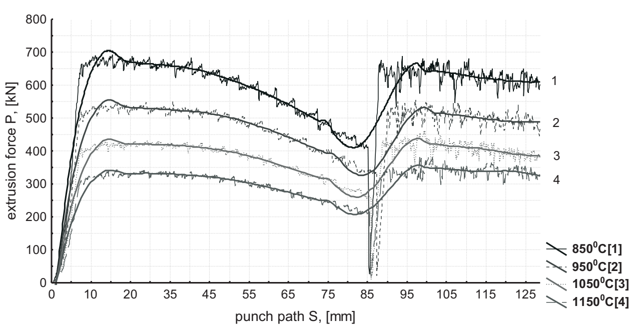

Fig. 10c. Graphs of the relationship of the extrusion force P [kN] as a function of the punch path S [mm] for: T_0 = 850, 950, 1050, 1150 [°C], V = 25 [mm/s], 2 β = 120°, ε = 0.5

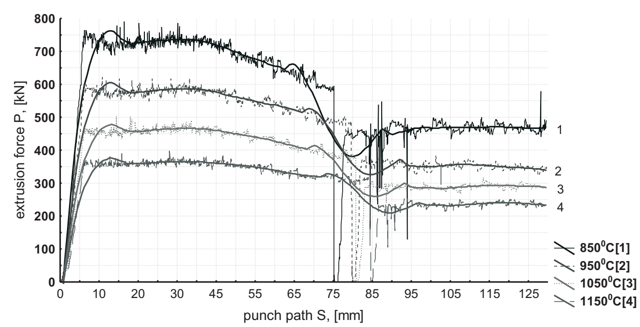

Fig. 10d. Graphs of the relationship of the extrusion force P [kN] as a function of the punch path S [mm] for: T_0 = 850, 950, 1050, 1150 [°C], V = 25 [mm/s], 2 β = 120°, ε = 0.75

It can be inferred from the graphs of the force-path relationship shown above that the mildest energy and force conditions occur in the process for the deformation degree of ε = 0.75. In principle, over the entire punch path under the stationary state of metal flow, a gradual decrease in the extrusion force was noted. This decrease is the most pronounced in the second stage of the process. At ε = 0.3 and 0.4, a rapid increase in the force occurs in the second stadium, which is the cause of momentary metal upsetting in the ring chamber. The forces in the second stage are greater also due to the relatively large stem diameter. The maximum extrusion force which was noted during extruding the sleeve in the movable ring amounted to 800 [kN] in the second process stage for ε = 0.3. Obtaining such a sleeve by the indirect extrusion method requires the application of a force of approx. 1070 kN.

4. The tool for the physical modelling of the process

The testing stand for physical modelling is composed of a specially designed extrusion tool and an electromechanical press of a pressure of 10 kN. The model

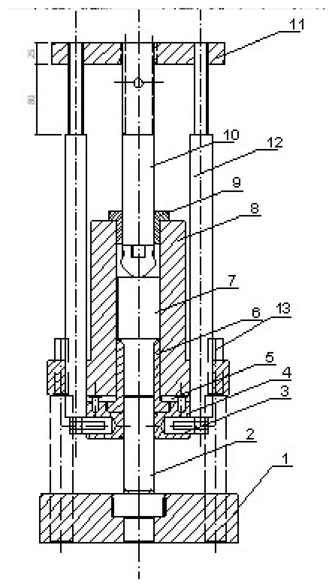

Fig. 11. The tool for the physical modelling of the process 1. plate, 2. mandrel, 2. connector, 4,5 ring drive, 6. ring, 7. preform, 8. container, 9. punch guide, 10. punch, 11. plate connecting the punch with the columns, 12. columns, 12. tool bracing columns

material for extrusion was lead in the form of rolled preforms.

Fig. 11 shows a schematic diagram of the tool for the extrusion of the sleeve in the contained with a movable ring.

5. The construction of the tool

The tool is mounted on the plate (1) and stiffened with the columns. The function of the container bottom is performed by the punch (2). The stock (7) is deformed by the punch (10) which travels up to the specified distance of its head from the ring (6). Then the disk (11), through the columns (12) and the assembly of the elements (3), (4) and (5), causes the ring (6) to move at the same speed as the punch. After the appropriate speed between the punch and the mandrel has been attained, the process will be ended.

The graphs of the relationship of the force P [kN] as a function of the path S [mm], as read out during the extrusion tests on the instrument, are shown in Fig. 12.

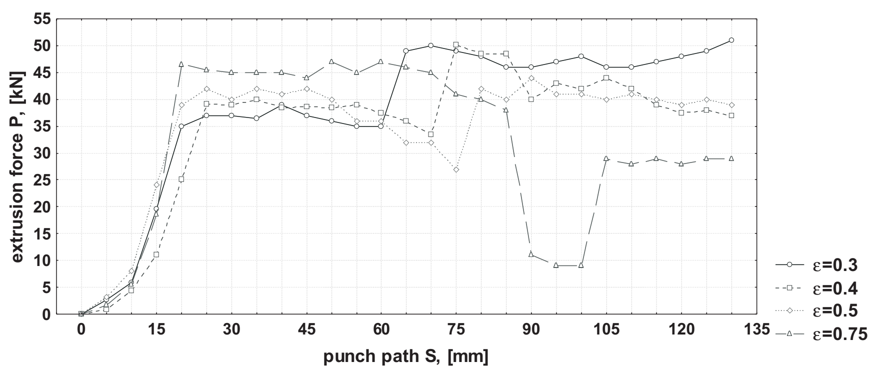

Fig. 12. Graphs of the relationship of the extrusion force P [kN] as a function of the punch path S [mm] for: ε = 0.3, 0.4, 0.5, 0.75

The graphs for the extrusion of the lead sleeve are shown in Fig. 12. They are very similar in shape to the graphs obtained by computer simulations. For the deformation degree of $\varepsilon = 0.75$, the same decrease in the forces is visible as in the second stage of the process. Similarly visible are rapid increases in the forces for smaller deformation degrees of $\varepsilon = 0.3$ and 0.4, **resulting from** the upsetting of the lead in the ring channel.

6. Conclusions

Comparison of the maximum values of metal pressures on the punch in the order of 1100 MPa and the maximum extrusion force on the level of 1070 kN for indirect extrusion by the presented extrusion method, where the maximum pressure was 850 MPa and the extrusion force was 800 kN, demonstrates how big a difference does exist in the energy and force parameters.

The reduction of the unit pressures on the punch by 10% results in an increase in punch life, as expressed in the number of extrusion cycles, by approx. 25% [1]. In the case analyzed, the difference between the indirect and the presented method of extrusion amounted to 20÷25%, which means an increase in punch life by 50÷60%.

The root cause of this phenomenon is the intensification of strains by the division of the metal flow stream, thus causing local temperature increases and metal flow velocity increases, which, as a consequence, resulted in a reduction in the pressures on the punch and in the force necessary for the single-operation extrusion of deep bottomed sleeves.

The constructed tool made it possible to produce a sleeve stamping from the model material and to obtain graphs of the P[kN]-S[mm] relationship, similar in shape to the graphs from computer simulations. This also proves that the model material, that is lead, reflects in this case the flow behaviour of steel 45.

REFERENCES

[1] Ju. P. Adler, E.V. Markova, Ju.V. Granovskij, Planirovanie ehksperimenta pri poiske optimal'nyh uslovij. – M. Nauka, (1971) – 283 s.

[2] V.V Devjatov, Matematicheskoe modelirovanie processov vydavlivanja s uchjotom temperaturnyh effektov. M. Sovershenstovovanie processov OMD. Meżvuzovskii sb. Nauchn. trudov. (1987) r., No 2.

[3] V. V. Dewiatow, H. S. Dyja, V. Y. Stolbow i in., Matematyczne modelowanie i optymalizacja procesów wyciskania Seria Metalurgia nr. 38 ISBN 83-87745-27-8.

[4] V. V. Devjatov, J. Michalczyk, Zgłoszenie o udzielenie patentu na wynalazek w Urzędzie Patentowym RP pt. „Sposób wytwarzania głębokich tulei z dnem" nr P 366255, Biuletyn UPRP nr 19/05.

[5] FORGE2® SETUP, Instrukcja obsługi, Transwalor S.A. of Sophia-Antipolis, (1996).

[6] StatSoft.: Statistica – A system description, edited by StatSoft, Cracow (2002).

Received: 5 February 2007.