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ENGINEERING OF THE COMBINED PROCESS OF PUNCHING THE COMPRESSOR BLADES WITH AN ESTIMATE OF THE PLASTICITY RESOURCE OF THE WROUGHT ALLOY

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ABSTRACT

The article clarifies the ways of defining the rational modes of blank deformation which allows obtaining the compressor blades with a fine-grained structure without discontinuity of the material by the method of computer simulation of the technological process of rolling in smooth rolls and the process of upending in convex strikers; also the isothermal forging.

Key words: Rolling, Upending, Strikers, Rolls, Stamping, Blades.

INTRODUCTION

Combined processes of the contour of metal forming (MF) are widely used in forging-stamping manufacture (FSM)[1]. For the combined process of MF, it is significant to engineer the material structure with good mechanical and performance properties.

It is known that the engineering of combined processes of MF is closely connected with the solutions of technical and technological tasks like the choice of temperature, speed modes of deformation and power-plant parameters of contour, the estimate of the influence of deformation distribution according to structure and properties of resulting product and also construction of the tool[2]. Despite the ambition of engineers to working out the technology with the uniform distribution of stress-strain state (SSS) on the volume of deformed blank, the uniform distribution of SSS cannot be reached during the real process of FSM. It leads to the nonhomogeneous engineering of the material structure, the anisotropy of mechanical properties and material discontinuities.

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In the connection with the above information, the contemporary investigations in the sphere of combined processes of MF should be held in the direction of technology engineering, which allows controlling the structure and properties of material of received details in different phases of developing the combined processes; moreover this happens without the material discontinuity[3].

According to the opinions of Paltiyevich[4], the most perspective directions of studied processes of metal forming are application of means of mathematical modeling. According to this opinions, firstly, it allows providing detailed and multi-factor analysis of the influence of SSS and deformation of temperature speed modes on the property of the product and secondly, it significantly decreases the amount of expenses and saves time for providing investigations.

Nowadays, CAE systems (Computer-aided engineering) are widely used as the means of mathematical modeling of technological processes, which are based on the finite element method (FEM)[5]. The following method allows investigating SSS with pinpoint accuracy, which is located in any point of the plasticity deformation sample taking into consideration rheological characteristics of the materials. The application of FEM allows building improved mathematical and volume models without significant quantity of mistakes and limits. Therefore with the help of FEM, received results will be more objective. Finite element method is the universal method, which have simple physical base realized by the flexible algorithm that is well-adapted for making solutions on electronic computers.

By using CAE-systems, the processes of metal forming are being actively investigated in last 15-20 years. During this period, powerful program complexes have been occurred; the examples are ANSYS, LS-DYNA, NASTRAN, COSMOS, De Form and Q Form, which allow modeling the processes like metal forming, and also pressing, volume stamping, upsetting etc.[5] Nowadays, the researchers have an enormous experience in engineering the geometrical models of tools and blanks; determining components of stress and strain tensors, deformation speeds, and temperature fields at each point of deforming blank considering the power-plant parameters of the tool. The obtained experience of using mathematical modeling allowed the engineering of technological processes of metal forming to raise it to the new level, particularly, it led to the occurrence of actual task, which is making a hypothesis and controlling the properties of resulting product by changing the parameters of SSS, temperature and speed.

The purpose of the present work is to engineer the technological process of the combined process to produce compressor blades without any defects by calculating the resource utilization plasticity level (RUPL). The base of the method is quantitative defining the RUPL depending on the volume and SSS distribution in the blank during the combined methods of metal forming.

It should be stated that for realizing the present methodology, it is needed for the functional dependencies, which link the parameters of heating process and SSS with the resource utilization plasticity level and material properties. For obtaining such dependencies, it is demanded to provide big amount of experimental investigations. Except this, found dependencies will be correct only for each separate group of studied materials.

Despite the statements given above, nowadays CAE-systems (MSC. Super Forge program) have been already invented; it has program models, which allows providing such analysis[6] and functional dependencies[7] and despite the fact that the blending characteristics are used as the initial parameters for used material, the given program and functional dependencies give reliable results. The reliability of the calculations and the efficiency of the application of MSC. Super Forge for computer modeling of the processes of rolling, broaching and stamping confirm the experience of leading industrial companies of Japan, USA and EU.

EXPERIMENTAL

Materials and methodology of the experiment

The paper proposes a new technology for manufacturing forged compressor blades: the heating, rolling in smooth rolls in the temperature range of 1000-950°C, the sediment in the convex smartly in a temperature range of 800-750°C and isothermal forging at a temperature of 650°C.

In order to calculate SSS, a specialized standard program MSC.Super Forge was used[2]. A three-dimensional geometric model of the blank and the tool has been constructed in the CAD program and imported into Inventor CAE program of MSC.SuperForge.

For investigating the combined process of manufacturing compressor blades as a smooth rolling of the rollers, the precipitation in the convex tool and stamping was used a rectangular billet with the size of 5 × 20 × 50 mm. Combined process was modeled in three-dimensional environment with a partition of the blank on 4-node elements (CTETRA). For modeling the blank, it is required 2439 elements and 3096 nodes. Material of the blank made of the titanium alloy BT6 with the deformation temperature range of 630-1200°C. From the database of «MSC. Super Forge» software system, the rheological properties were set. In this case, blank material took isotropic elastic-plastic with a non-linear hardening (BISO). On the surface of the tool with the blank, the friction coefficient adopted to 0.3. Tools were regarded as an absolute rigid body.

The program «MSC. Super Forge» was run. By the step method were calculated the following: a movement of the *U*, the strain tensor components *ε*, strain rate tensor components *ξ*, the components of the stress tensor *σ*, the intensity of deformation, stress intensity, temperature distribution over the volume of the preform. In this case, for clarity, for displaying the calculation results, the data was taken for the four stages in the percentage of full-time deformation, i.e., the following intervals were chosen: the first stage 10, second stage 40, third stage 70 and fourth stage 100 percent of the total deformation time.

In theory of the damage accumulation in the analysis of destruction of metals in non-monotonic deformation, Kolmogorov[7] obtained the kinetic equation for damage in the form of:

$$d\psi = \frac{d\Gamma_i}{\Gamma_p(k_г)} \qquad \ldots(1)$$

Where ψ – Resource utilization plasticity level; Γ_i – intensity of deformation; Γ_p – plasticity limit; $k_г = \sigma/T$ – stiffness coefficient of the circuit stress state (SCCSS); T – the intensity of the shear stress; and σ – medium voltage.

It is known that when $1 < \psi$, the material of the blank or forging is not destroyed, but when $1 > \psi$, it will be destroyed.

The conditions of the titanium alloy fracture were calculated by the formula (1), and with a smooth rolling at draft rolls of RUPL of stamping were calculated by the given formula [2]:

$$\psi = \int_0^t \frac{H(\tau(\tau)}{\Lambda_p[k_ж(\tau\tau)} = \frac{\Lambda}{\Lambda_p[k_ж(\varepsilon)]} \qquad \ldots(2)$$

Where Λ_p – Limit of the plasticity of metal, depending on the state of stress; $\Lambda = \int_0^\tau H(\tau)d\tau$ – The level of shear strain; and H – the intensity of shear strain rate.

The degree of shear deformation for the entire stage of the deformation can be calculated by the formula:

$$\Lambda = \Sigma\Gamma_i \qquad \ldots(3)$$

In the paper, the equation for titanium alloys depending on the plasticity limit of the heating temperature $T_н$, heating duration τ_H, index of the state of stress σ/T and the strain rate ξ is given[3]. For the alloy BT6, the received regression equation, which is presented in the natural scale has the following form:

$$\varLambda_{\text{p}} = 6{,}26 + 0{,}0034\cdot(T_{\text{н}} - 1150) - 4{,}32\ \lg\tau_{\text{H}} - 1{,}16 \cdot (\sigma/\text{T}) - 0{,}95] + 0{,}023\ (T_{\text{н}} - 1150)\ (0{,}5 - \lg\tau_{\text{H}}) \qquad \ldots(4)$$

RESULTS AND DISCUSSION

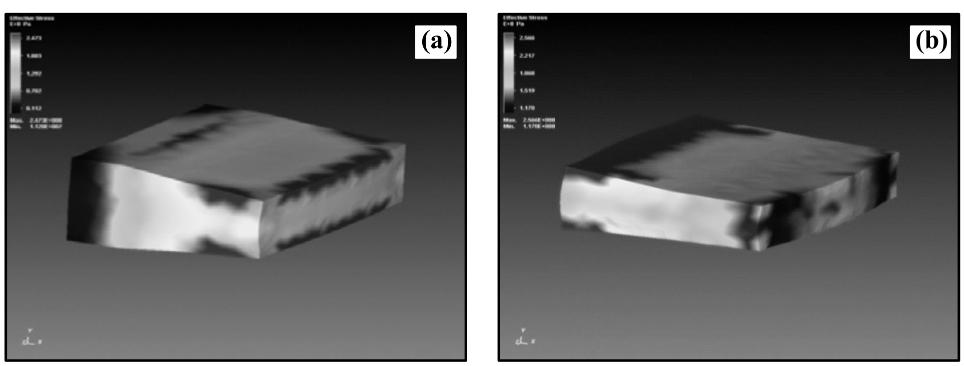
Fig. 1 shows the pattern of distribution of stress intensity and deformation during rolling billet of rectangular section on smooth rolls.

From the numerical simulation results, it is revealed that:

(i) During rolling in smooth rollers in the initial time of rolling (the first phase), the intensity of deformations ($\varGamma$) and the stress (σ_i) are concentrated in areas of the metal mill by rolls grip. With the increasing time of deformation, (the second phase), the maximum value of σ_i and $\varGamma$ are concentrated on the edges of the deformable blank (Fig. 1*a*, *b*). At the center of the blank, the intensity of deformation and stress increases;

(ii) In the next step of rolling (the third and fourth stages of rolling), emphass is that the stress and strain intensity are transferred from the edge of and the center of the blank to the zone of contact roller with deformable blank (Fig. 1, *b*, *d*). Such distribution of stress and strain intensity by rolling stages leads to more even distribution of the total $\varGamma$ and σ_i along the deformation zone;

(iii) The temperature drops in the contact zone called "hot metal - the rolls" during the process of rolling in smooth rolls.



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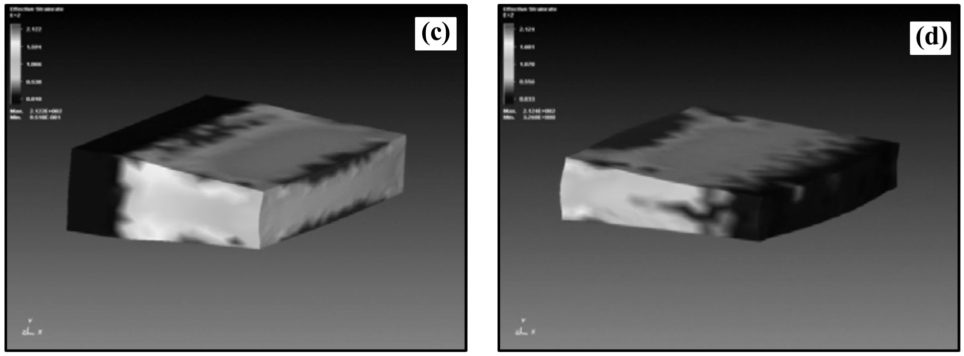


a – Second phase; *b* – Third phase; *c* – Second phase; d–Third phase

Fig. 1: The distribution of stress intensity (*a*, *b*) and strain (*c*, *d*) on the cross section of the blank during rolling in smooth rolls withε = 20%

By summing the deformation intensity, the level of shear strain Λ (cumulative strain) was calculated for the combined process of metal forming (MF) (Fig. 2).

Analysis diagrams of Λ change on the section of the blank during rolling in smooth rolls showing that when deforming a single compression ε = 20 %, the level of shear deformation becomes the greatest on the surface zone of deformable blank (Fig. 2, *a*, where H_i and B_i is the distance to the investigated point according to the height and width of the preform; H_0 and B_0 is the blank height and width, respectively).

Fig. 3 shows the intensity distribution of stresses and strains in the blank during the operations of rainfall in convex strikers.

On the basis of numerical simulation results, it is revealed that:

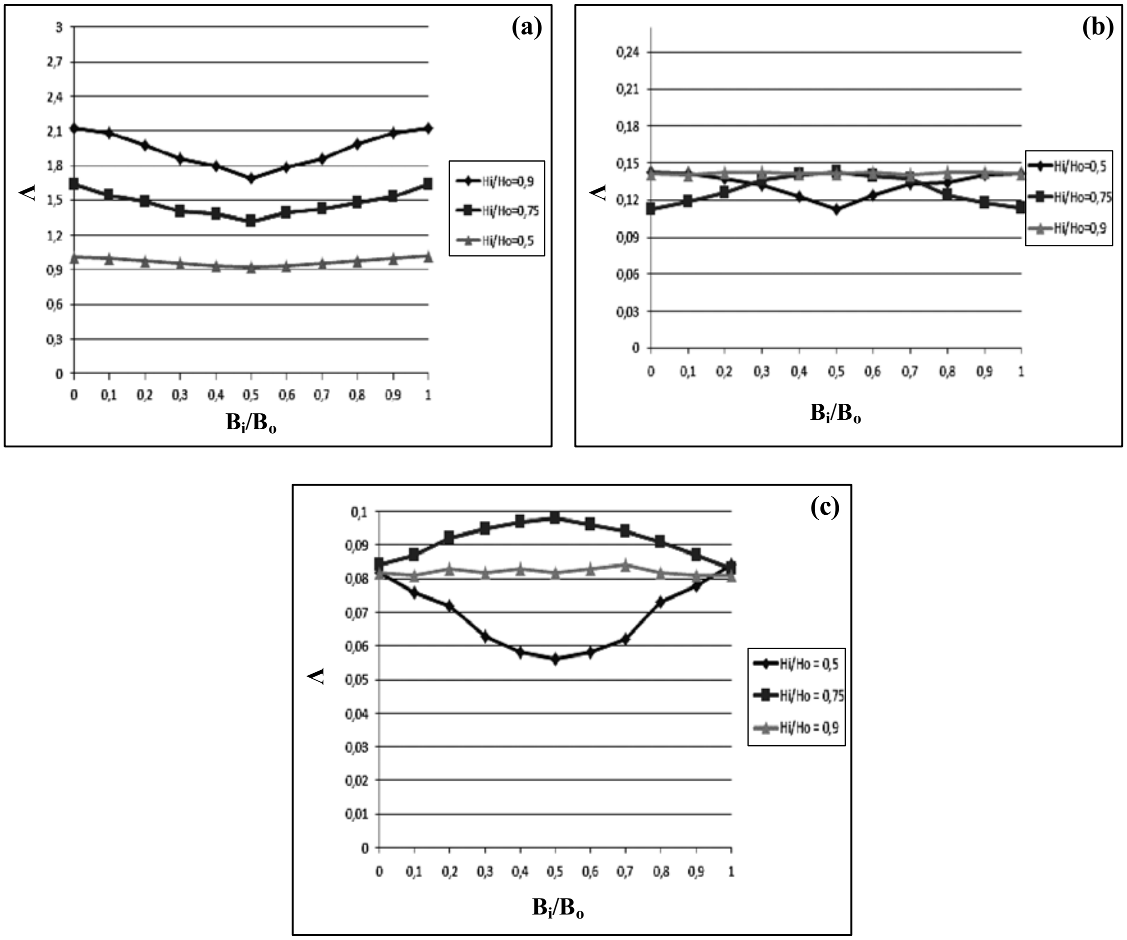
(i) At the initial time of precipitation in a convex striker, the stresses and strains intensity is mostly localized in the contact zones of the blank with the tool (Fig. 3, *a*, *b*);

(ii) Increasing of single compression leads to a shift in focus of intensity of stress and strain on the contact surface to the center and the periphery of the blank (Fig. 3, *b*, *d*);

(iii) The temperature rises in the areas of localization of deformation during the process of precipitation in convex strikers;

(iv) With the increase of the maximum value of a single crimp, the contact pressure is transferred from the axis to the periphery of the blank.

The nature of the metal flow rate is similar to the development of the intensity in a time warp.



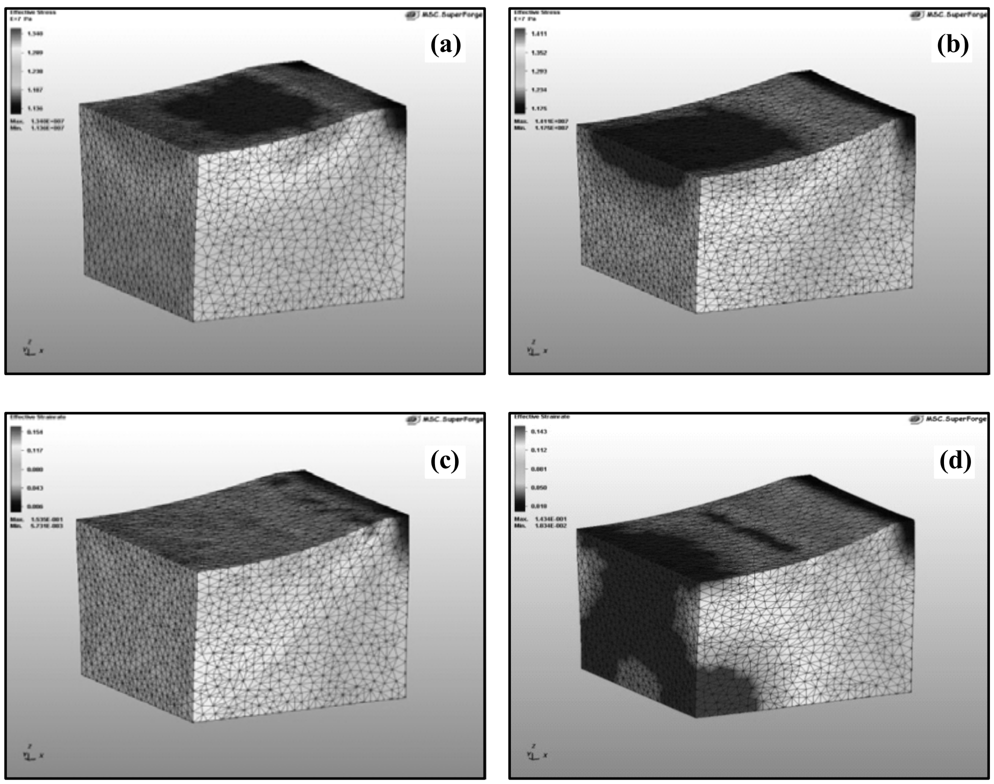
a–Rolling in smooth rolls; *b* – Precipitation in convex strikers, $L_i/L_o = 0.5$; *c* – Precipitation in convex strikers, $L_i/L_o = 0.8$

Fig. 2: Distribution of Λ along the cross section of the blank while rolling in smooth rolls and sediment in the convex strikers (L_i – the distance to the studied point according to the height of the blank; L_0– the height of the blank, respectively)

Analysis of the diagrams changes of Λ over the blank section at a draft in convex strikers smartly shows that the level of shear has a great importance in the central areas adjacent to the vertical axis of the blank and in areas adjacent to the contact zone called as "hot metal-tool" (Fig. 2, *b*, *c*).

The investigation of metal flow during forging the blank shows that punching process can be divided into processes of pressing and squeezing in the conical cavity. Pressing is carried out in the joint part of the blade, and squeezing is realized in the conical cavity of pen blades.

It should be noted that contamination and defects may cause undesired product structure and reduce the strength properties of the blades; because of it on the surface of the punch the incisions are made by milling[8]. They increase the frictional force in the contact area of the punch of the blank and prevent contamination and defects in the deformation zone.



a – Second phase; *b* –Fourth phase; *c* –Second phase; d – Fourth phase

Fig. 3: The distribution of stress intensity (*a*, *b*) and strain (*c*, *d*) in the blank during upsetting in a convex tool

Fig. analysis of distributing the intensity of stresses and strains on the cross section of the blade obtained by stamping the blank upset, which indicates that execution of the incision on the contact surface of the punch; thereby, the coefficient of friction increases, the intensity of the stresses and strains decreases on the surface areas of the joint blade. The inner layers of the deformation zone are moving faster and there is a small external tightening of the metal at the center of the hearth to the pen blades in the axial direction. The greatest intensity of the stresses and strains is observed in the transition from the deformation zone to the conical cavity, which is caused by a significant narrowing of the matrix. The highest intensity of stress is observed not only in the transition zone from the center to the conical cavity, but it is also observed in the lower part of the pen, which is caused by extrusion of metal in the conical die cavity.

Figs. 4 and 5 show the distribution of SCCSS and PUPL on the blank section during rolling in smooth rolls (*a*), the sediment in the convex tool (*b*, *c*) and punching blade (*g*) (H_i and B_i are the distance of the point according to the height and width of the blank; and H_0 and B_0 are the height and width of the deformation zone, respectively.

On the basis of the calculation and SCCSS and RUPL it is revealed that:

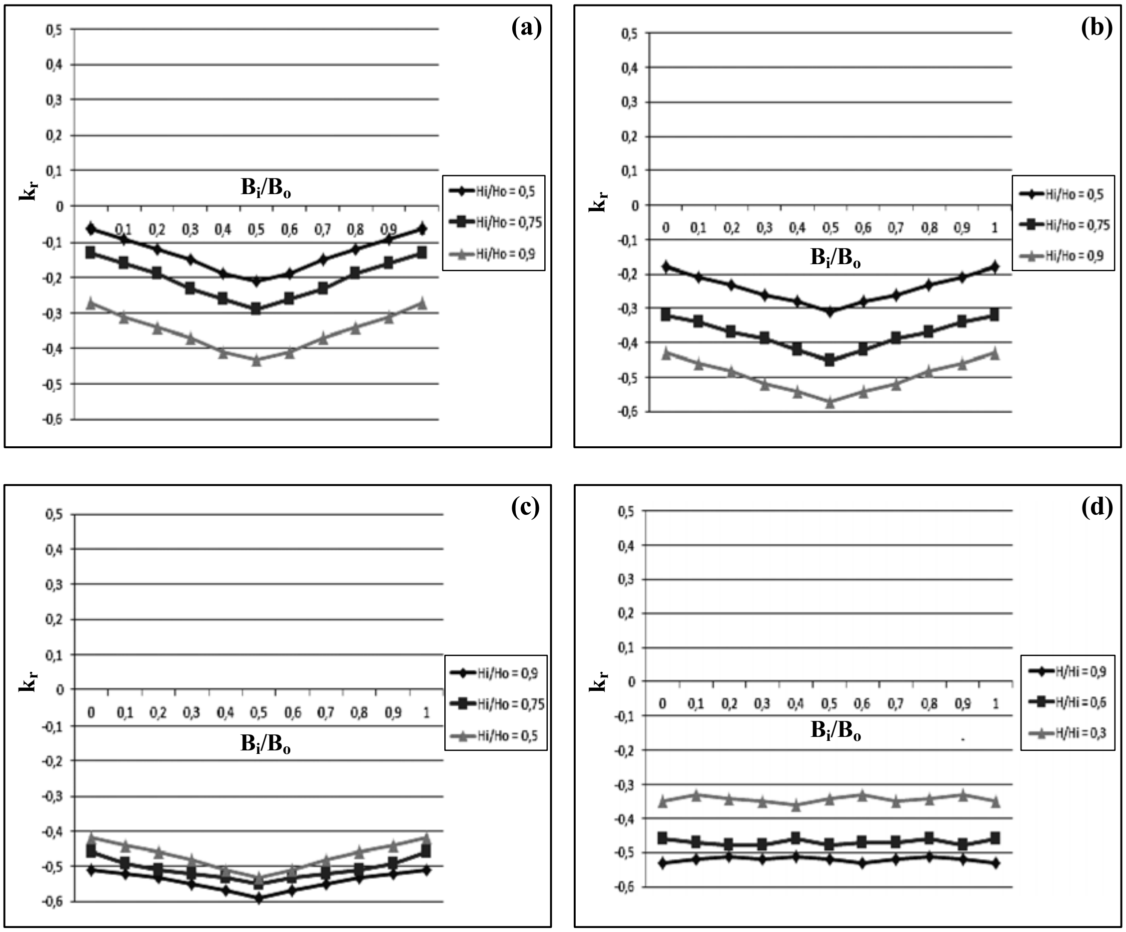
(i) In the process of rolling blanks made of the titanium alloy BT6 in smooth rolls, the highest value of the coefficient of stiffness of the stress state and the resource utilization plasticity level occur in the peripheral areas of the blank (Fig. 4, *a* and Fig. 5, *a*);

(ii) In the process of precipitation of blanks in a convex tool and while forging the blades made of titanium alloy BT6, the highest value of the coefficient of stiffness of the stress state and RUPL focuses in the central and peripheral zones of upsetting or the pressed part of the blank (Figs. 4, *b*, *c*, *d* and Figs. 5, *b*, *c*, *d*);

(iii) During rolling in smooth rolls, the sediment in the convex tool and stamping of blades made of the titanium alloy VT6, the resource utilization plasticity level is less than one, indicating no discontinuity of the blank material in the combined processes of metal forming (MF) (Fig. 5).

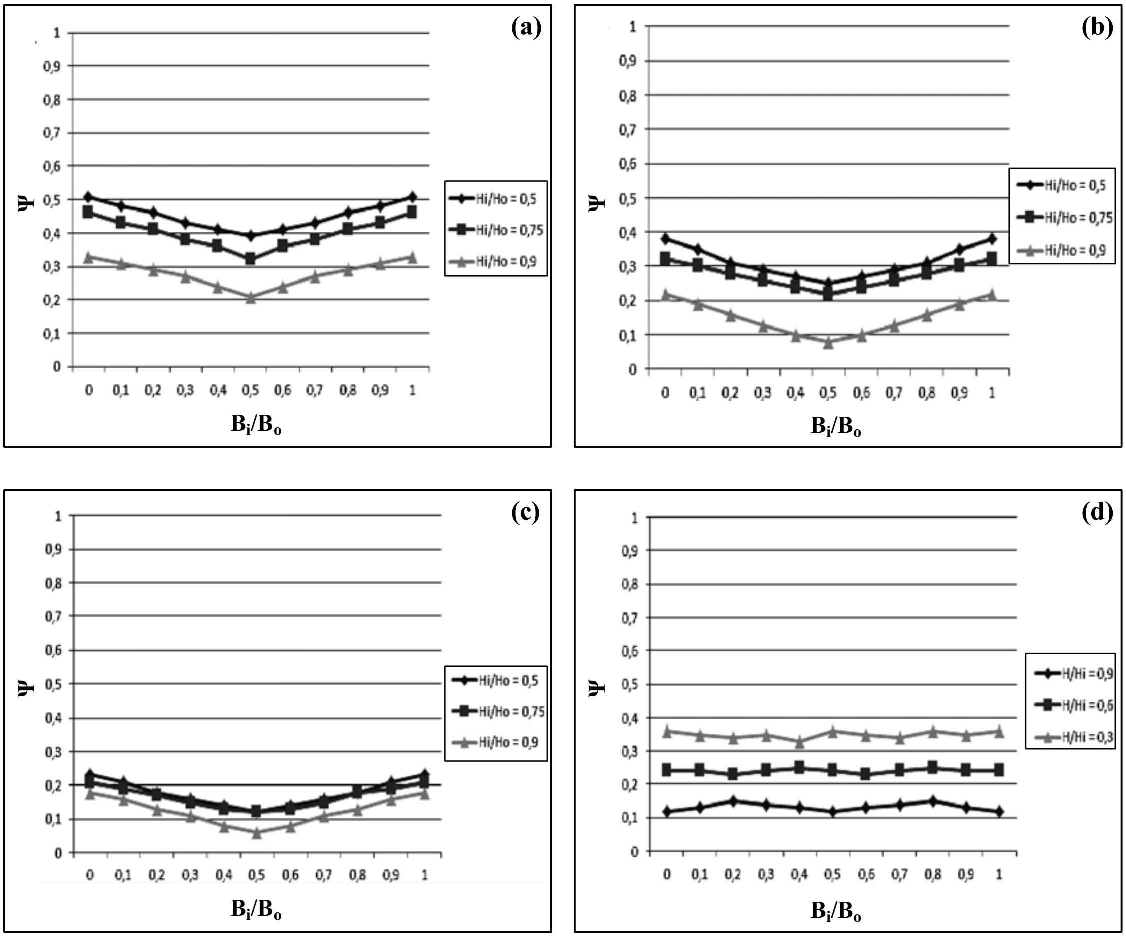
Thus, the process of stamping by the proposed manufacturing process avoids the discontinuity of the material of blank and forging. Thus, due to the even distribution of the level of shear deformation after stamping it is expected to receive fine-grained and homogeneous microstructure that enhances ductility, toughness and strength.

It should be noted that the previous shaping of the initial sheet blank in the convex strikers allows regulating the deformation intensity during stamping through this effective method. The application of cone-shaped blank allows not only distributing the blank material qualitatively, but also it allows balancing the shear forces in the blank; thus, to get rid of the special dragged grooves and increase the resource of stamp[9].



a–Rolling in smooth rolls; *b* – Precipitation in convex strikers, $L_i/L_o = 0.5$; *c* – Precipitation in convex strikers, $L_i/L_o = 0.8$; *d*–Stamping

Fig. 4: The distribution of SCCSS on the cross section while rolling in smooth rolls (*a*), precipitation in the convex tool (*b* and *c*) and stamping of blades (*e*) (H_i andB_i – the distance to the studied point according to the height and width of the blank; H_0 and B_0– height and width of the deformation zone, respectively)



a–Rolling in smooth rolls; *b* – Precipitation in convex strikers, $L_i/L_o = 0.5$; *c* – Precipitation in convex strikers, $L_i/L_o = 0.8$; *d* – Stamping

Fig. 5: The distribution of RUPL along the cross section of the blank while rolling in smooth rolls (*a*), precipitation in the convex tool (*b* and *c*) and stamping of the blades (*d*) (H_i and B_i – the distance to the studied point according to the height and width of the blank; H_0 and B_0– the height and width of the deformation zone, respectively)

From this, it follows that for compressor blades of responsible appointment made of BT6 alloy, it can be recommended their stamping from the previous shaped initial sheet blank. Previous shaping in the form of precipitation of the initial sheet blank in the convex strikers allows redistributing the material of initial blank. It minimizes the value of shear deformations, which cause the deformation heating, and which are invalid in causing inaccuracy in the metal structure; it also decreases the risk of forming cracks and stagnant zones, which are generic to the previous stamping.

CONCLUSION

(i) It is found that an even distribution Λ over the cross section of the deformable blank can be achieved with smooth rolls during rolling in the first phase; and it is achieved with the upending in convex strikers at the second stage and isothermal forging at the third stage;

(ii) In the process of deformation at temperatures above and below the temperature of polymorphic transformation (T_{pf}) in the smooth rolls and convex strikers, as well as isothermal forging below T_{pf} the fine-grained structure can be achieved;

(iii) The simplicity of rolling in smooth rolls, previous shaping in convex strikers and stamping allows getting the titanium forgings in dies without increasing their stamping slopes;

(iv) Rolling in smooth rolls, sediment in the convex strikers on hydraulic press and stamping ensures even distribution of the level of shear deformation, thereby obtaining forgings with fine-grained homogeneous microstructure without discontinuity of material and high mechanical properties.

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