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IMPROVING THE TECHNOLOGY OF BLADE PUNCHING MADE OF TITANIUM ALLOYS BY THE CALCULATION OF DEGREE OF RESOURCE UTILIZATION PLASTICITY

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ABSTRACT

The article states about how the rational modes of blank deformation, which allows getting the blades without disrupting the continuity of the material is defined through computer simulation of the process of forging in flat and combined strikers and also through the upsetting in the tool with the shape changing and punching.

Key words: Drawing, Strikers, Upsetting, Punching, Blade.

INTRODUCTION

The blade of an aircraft engine is one of the most important and massive parts of aeronautical engineering[1]. The blades of gas turbine engines (GTE) have significant differences of cross-sectional areas on the site of lock-pen, which makes it more difficult to manufacture.

Nowadays, the following technological schemes are widely used in the manufacture of forgings of GTE blades[2,3]: punching presses of crank hot, punching of pre-landing on horizontal forging machines (HFM) and electrical upsetting machines, pre-rolling punching and isothermal forging. At the same time, it should be stated that the application of these processes for the production of titanium forgings of GTE blades with a significant difference of cross-sectional areas is not effective: the blank rolling cannot be provided for moving

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such a small blade; the amount of deformation will be exceeded in the processes of upsetting and electrical upsetting, it means that there will be a need for a stress relief annealing, which leads to the increasing of gas-saturated layer; except this, upsetting of such blades will need as minimum 4 passages on HFM; isothermal forging avoids additional heat and it has a high coefficient of metal utilization, however it is more energy-intensive and has a low productivity, because of it the total economic effect will be minimal. For this reason, during the forging of such blades, the following technologies are used: minimum shaping of the blade is provided by means of extrusion process, where the final punching is used; or simply pressing in one transition followed by a high-speed milling.

It should be noted that during the punching of GTE blades, the special attention is paid to the careful preparation of the structure of blanks, i.e. obtaining forged blanks with ultra-fine-grained structure, which possesses unique physical and mechanical properties (high strength, super plasticity, high fatigue strength, wear resistance, etc.)[4]. Materials with ultra-fine-grained structure are considered as perspective structural and functional materials, which can be used in priority sectors such as the aviation industry, transport and energy, particularly for the manufacture of parts of aircraft engines and ground gas turbine plants.

In many cases, bars of titanium alloy BT6 (Ti-6, 5Al-5, 1V) with ultra-fine-grained structure with the length of 140 mm and with the diameter of 20 mm is used while manufacturing aircraft engine parts such as blade turbine engine as a source of initial blanks. Rods with ultra-fine-grained structure basically are received by the multiple isothermal forging (MIF)[4] in the temperature range of 800-630^{o}C with the strain rate of $10^{-3}c^{-1}$ and subsequent broaching at the temperature range of 630-650^{o}C. The blades are manufactured from a rod through the method of isothermal forging (ITF) at the temperature of 650°C.

However, the technology of MIF in getting the blanks with ultra-fine-grained structure is characterized by high labor intensity, low productivity and high material costs[5]. The reason for this situation is that the multiple precipitate and broaching process at 800-630^{o}C temperatures are used in order to obtain a re-crystallized structure through the existed technology, wherein the single compression does not exceed 15-40%.

The possibility of getting out blanks with ultra-fine-grained structure and the ways of producing the forging of GTE blades madeof BT6 alloy through high-performance and energy-saving technology are investigated in the present scientific paper. Therefore, a new technology for manufacturing the forgings of GTE blades is proposed: heating, drawn in the plane and combined strikers in the temperature range of 800-630^{o}C with a strain rate of $10^{-3}c^{-1}$, and the upsetting locked part in the tool with the changing shape and ITF at the temperature of 650°C.

The aim of the scientific paper is to define the rational modes of blank deformation, which allows getting the blades without disrupting the continuity of the material through computer simulation of the process of forging in flat and combined strikers and also through the upsetting in the tool with the changing shape and punching.

EXPERIMENTAL

Materials and methods

A specialized standard program called MSC. SuperForge was used for calculations of SSS[6]. A three-dimensional geometric model of the blank and striker was built through CAD program and it was imported into the CAE program of MSC. Super Forge. A three-dimensional volume element CTETRA (four-nodded tetrahedron) was used while creating a finite element model of the blank and striker.

A cylindrical sample with the size of Ø80*400 mm was used for calculations. A material of blank stretches made of the titanium alloy BT6 with thedeformation at the temperature range of 630-1100°C and tool steel is assigned from the database of materials. For simulating the plasticity of the blank, the elasto-plastic model of Johnson-Cook was chosen. The contact between the striker and the blank is modeled by the friction of Coulomb, and as the Coulomb friction coefficient 0.3 was adopted.

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

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

where ψ is a degree of resource utilization plasticity; Γ_i is a strain intensity; Γ_p is a limit plasticity; $k_r = \sigma/T$ is a stiffness coefficient of the stress state; T is the intensity of shear stress; σ is an average voltage.

It is known that when we have $1 < \psi$, forging material or blank material is not fractured, but it is fractured when we have $1 > \psi$.

Condition of fracture of titanium alloys during the upsetting and punching was evaluated by the formula (1), and during the broaching in flat and combined strikers, resource utilization plasticity level (RUPL) was calculated by formula[7]:

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

where Λ_p is a limited plasticity of metal, which depends on the state of stress; $\Lambda = \int_0^{\tau} H(\tau) d\tau$ is a level of shear deformation; H is the intensity of shear strain rate.

The level of shear deformation for the entire stage of the deformation can be calculated using the following formula $\Lambda = \Sigma\Gamma_i$.

The equation for titanium alloys based on limited plasticity from the heating temperature T_H, heating time τ_H, the index state of stress and strain rate σ/T and deformation speed ξ is provided in this work[5]. For BT6 alloy the regression equation is adopted, which is presented in the natural scale of variables is as follows:

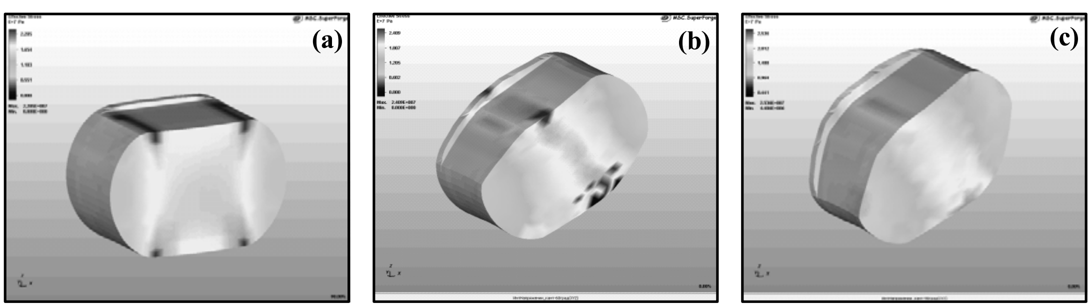
$$\Lambda_p = 6{,}26 + 0{,}0034 \cdot (T_H - 1150) - 4{,}32\ \lg\tau_H - 1{,}16 \cdot (\sigma/T) - 0{,}95] \\ + 0{,}023\ (T_H - 1150)\ (0{,}5 - \lg\tau_H) \qquad \ldots(3)$$

RESULTS AND DISCUSSION

Fig. 1 presents a picture of the intensity distribution of stresses over the section of the blank while broaching in the flat die with a single compression of 20%, the relative supply of 1.0 and 30° of tilting angle.

Based on the results of numerical simulations, it is revealed that:

- During the drawing of the round blank in flat dies with a relative pitch S = l/D = 0.6 ... 1.0 (where l is the length of deformation zone; D is a diameter of the blank), the intensity of localized stress and strain is localized at the initial stage of the first compression at the surface areas of the blank; and with an increase, the compression is localized on the forging cross;



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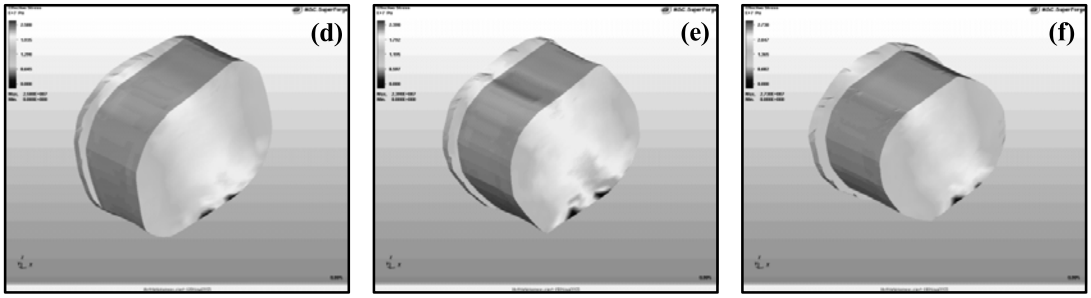


a – first compression; *b* – 30^o; *c*–60^o; *d*–90^o; *e*–120^o; *f*–150^o; *g*–180^o

Fig. 1: The picture of the intensity distribution of stress in the blank while broaching in flat die with a single compression of 20% , relative feed of 1.0 and tilting angle of 30^o, t = 800^{o}C

- While broaching in the flat die with increasing emphasis, the compression stress (Fig. 1, *a*) and the strain is transferred to the center of the blank (S = 1.0), or the maximum value of stress and strain is concentrated in the central zone (S = 0.8) or close to the surface area (S = 0.6) of blank;
- In drawing in the first pass with the relative feed of 1.0 and unit compression of 20%, due to the effect of contact friction forces, the part of the volume of geometric deformation zone will be in constrained deformation zones; and while broaching with the relative feed of 0.6-0.8 and compression unit of 20%, relatively small part of the volume of the geometric deformation zone will be in constrained deformation zones;
- Facing the blank at 30^o, 60^o, 90^o, 120^o, 150^o, 180^o and deformation with a reduction of 10, 15%, regardless of the relative supply leads to localization of the stresses and strains on the surface of the blank, and an increase in compression up to 20% allows focusing on voltage (Fig. 1, *b* , *c*, *d* , *e*, *f*) and deformation of the surface to the center, at the same time with an increase in compression occurs in reversal areas with the highest stresses and strains on the cross-section of the blank;
- While forging a round billet in the flat die with tilting angle of 30°, 60°, 90°, 120°, 150° and 180°, because of the turning areas with the highest stresses and strains on the cross-section of the blank, macro shifting deformations on the deformation zone is being intensively developed, which will lead to intense grinding of the grains in the metal structure (Fig. 1, *b*, *c*, *d*, *e*, *f*);

- Localization of stress and strain in the zone of the forging cross leads to increased heat and the risk of failure of the metal in the area and lack of deformation structures in the remaining volume of the blank, that is, different grain structure in the cross section of the blank.

A level of shear deformation Λ (accumulated strain) was calculated by summing the intensity of deformation for a number of technological modes of forging in combined and flat strikers (Fig. 2).

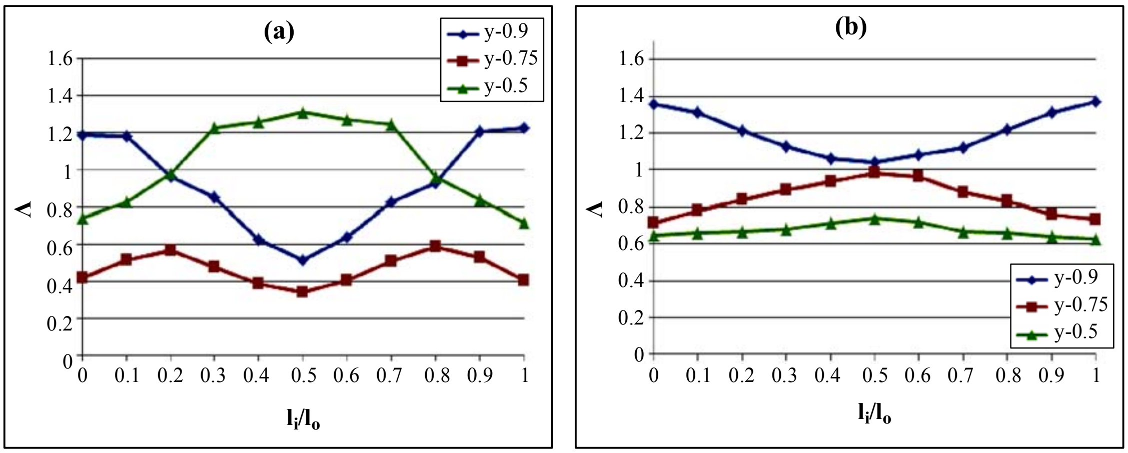
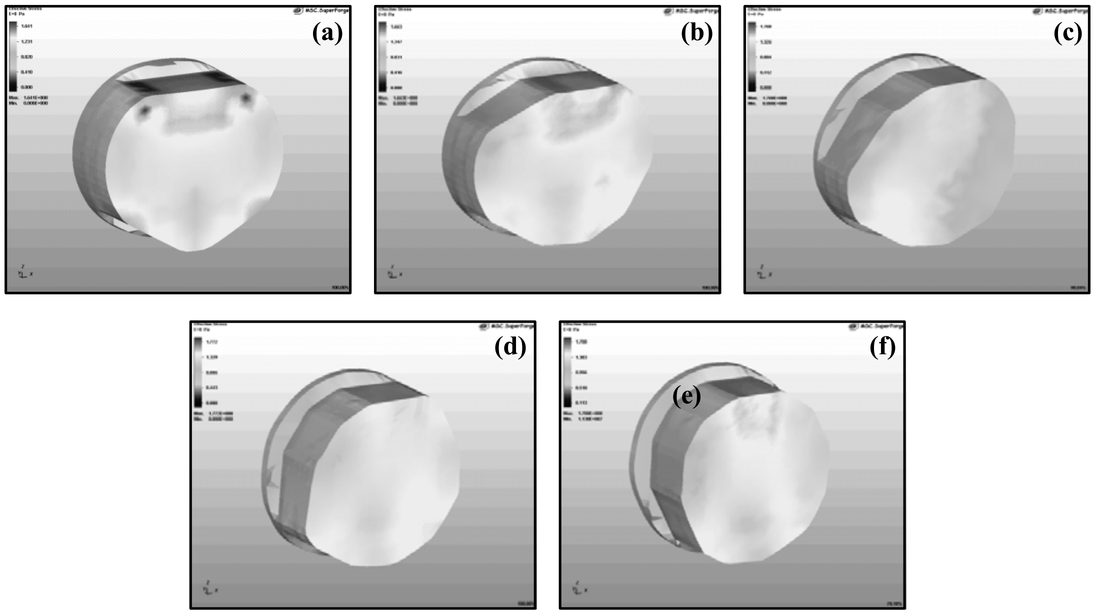


Fig. 2: The distribution of Λ on the longitudinal plane of the blanks while broaching in flat (a) and combined (b) strikers with the relative feed of 1.0

(◆- $D_i/D_0 = 0.9$; ■- $D_i/D_0 = 0.75$; ▲- $D_i/D_0 = 0.5$)

Analysis of Λ changes diagrams in the cross section with the blank while broaching with the tilting of 30°, 60°, 90°, 120°, 150° and 180° and with the relative feed of S = l/D = 0.8-1.0 shows that during the rational mode of deformation, the level of shear strain has the highest value in the adjacent zones of the blank to the tool; also in the central layers of the blank. In this case, the surface areas have the lowest values (Fig. 2, *a*, where l_i and D_i is the distance till the investigated point by the length and diameter; l_0 and D_0 are the length and diameter of the deformation, respectively).

Pictures of distributing the intensity of the stress on the cross section of the blank while broaching in combined strikers in the first compression and deformation from the angles of tilting of 30° are presented on the Fig. 3.



a – first compression; *b* – 30^{o}; *c* - 60^{o}; *d* - 90^{o}; *e* - 120^{o}

Fig. 3: The figure of distributing the stress intensity while forging in combined strikers with a single compression of 20%, relative feed of 0.6 (*a*) and tilting angle of 30^{o}, t = 800^{0}C

Based on the results of numerical simulations, it is revealed that:

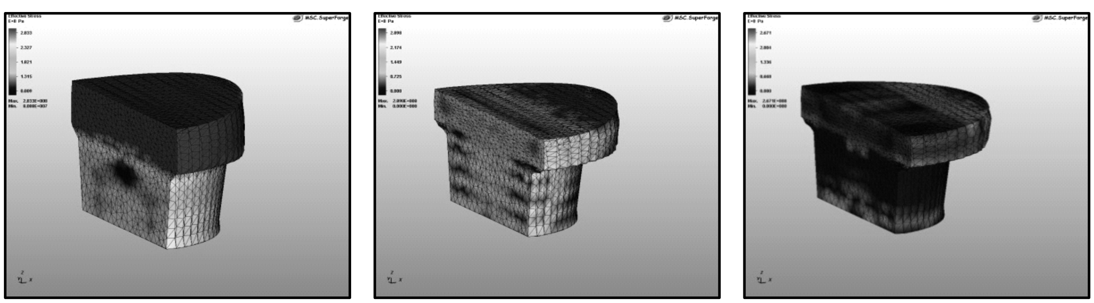
- During the first compression in combined strikers, the intensity of stresses and strains has a great importance in the areas adjacent to the site of contact of the tool with the blank, while in a load-free surface portion of the blank there can be seen a minimal deformation in magnitude;
- While broaching the round billet in combined strikers with the relative pitch of S = l/D = 0.6-0.8 , the intensity of stress and strain are concentrated at the initial stage of the first reduction in the surface areas of the blank, and with the increasing emphasis compression stress intensity and deformation is transferred to the closer part of the center of the blank (Fig. 3);
- Increase in the compression unit while broaching in combined strikers with relative feed of S = l/D = 0.6-0.8 leads to the expansion of localization zones of stress and strain intensity, and the maximum value of stress and strain are concentrated under a flat striker;

- Broaching with a relative feed of S = 1.0 leads to the transfer of localization zones of stress and strain from the area of contacting blank with the flat striker to areas of contacting blank with the patterned-striker;
- In the process of broaching with a tilting of 30^o, 60^o, 90^o, 120^o, regardless of the value of supply, the intensity of the stresses and strains focuses on the areas of metal contact with the tool, but the medium-sized stress and strain appears between the areas of contact of tool and blank (Fig. 3, *b*, *c*, *d*, *e*).

Analysis diagrams of Λ change in the cross section of the blank while broaching in combined strikers shows that during optimum operation of broaching with the relative feed of 0.6 and tilting angle of 30°, the level of shear strains will have a great importance in the areas adjacent to the blank surface, whereas in the central blank area has a minimum value (Fig. 2, *b*).

Thus, the results of calculating the level of shear deformation showed that in a co-planar deformation in flat and combined strikers, more uniform distribution of Λ over the cross section of the deformable blank can be achieved by broaching with the tilting angle of 30^o and relative feed of 1.0 in flat dies in the first phase, and with the angle of canting of 30^o and relative feed of 0.6 in combined strikers in the second phase. In this combined process of forging, we can obtain the forging with fine-grained structure with high mechanical properties.

Fig. 4 shows a picture of the intensity distribution of stresses over the section of the blank during the upsetting in the tool with the changing shape.



(a) ε = 15% (b) ε = 20% (c) ε = 25%

Fig. 4: The distribution of the stress intensity in the blank during the upsetting in the tool with a changing shape, t = 750^{o}C

Based on the results of numerical simulations, it is revealed that:

(i) At the initial moment of upsetting in the tool with the changing shape, the stress and strain intensity will be localized in the central zones of upsetting blank (Fig. 4,*a*);

(ii) An increase in the unit compression leads to a gradual shift in emphasis of stress and strain intensity from the central to the peripheral zones of the blank;

(iii) During the upsetting process, temperature rises in the localization zones of deformation;

(iv) Maximum value of the contact pressure is transferred from the axis to the periphery of the blank when the unit compression is increased;

(v) The nature of the flow rate of metal is similar to distribution of deformation intensity on the cross section of the blank;

(vi) During the landing in the tool with the changing form of the increment, the shear strain level is distributed equally over the cross section of the blank;

(vii) Thanks to lower contact of the surface and favorable friction conditions deforming force while upsetting in the tool with the changing shape, the working surface is almost 10 times less than during a conventional landing.

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

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

Analysis of the stress and strain intensity of distribution on the section of the blade, which was received while upsetting the forging die indicates that because of the execution of the incision on the contact surface of the punch, increases the coefficient of friction, decreases the intensity of the stresses and strains in the surface areas of the lock blade. In the deformation zone the inner layers move faster than the external layers and a small tightening of metal occurs in 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 caused a significant narrowing of the matrix.

The highest intensity of stress is observed not only in the transition zone from the source to the conical cavity, but also in the lower part of the pen, which is caused by extrusion of metal into a conical die cavity.

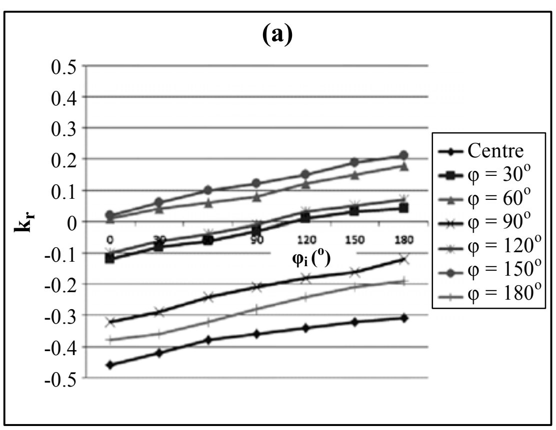
Fig. 5 and 6 shows the distribution pattern of SCCSS (stiffness coefficient of circuit stress state) and RUPL (resource utilization plasticity level) on the cross section of the blank while broaching in flat (*a*) and combined (*b*) strikers; while upsetting on the tool with the changing shape (*c*) and forging the blades (*d*) (where φ_i is the angle of rotation till the studied points, H_i and B_i is the distance till the studied point according to the height and width of the blank; H_0 and B_0 is the height and width of the deformation zone, respectively).

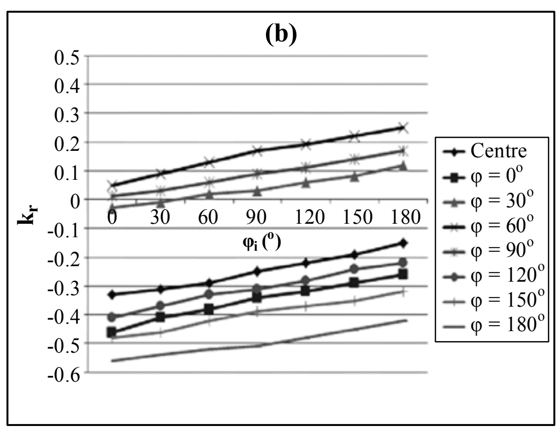
Based on the calculations of SCCSS and RUPL, it is revealed that:

(i) In the process of broaching blanks made of the titanium alloy BT6 at the flat and combined strikers, the maximum value of stiffness coefficient of circuit stress stateand the resource utilization plasticity leveloccurs in the free-load zones of the blank surface (Figure 5*a*, *b* and Figure 6*a*, *b*);

(ii) In the process of upsetting blanks in the tool with the changing forms and forging blades made of the titanium alloy BT6, the highest value of SCCSS and RUPL focuses on the central areas of landing or pressing parts of the blank (Figure 5, *c*, *d* and Fig. 6, *c*, *d*);

(iii) While broaching in flat and combined strikers and while upsetting on the tool with the changing shape and punching blades made of the titanium alloy BT6, the plasticity resource utilization is less than one, indicating no discontinuity of the blank material in the combined processes of metal forming (MF) (Fig. 6).





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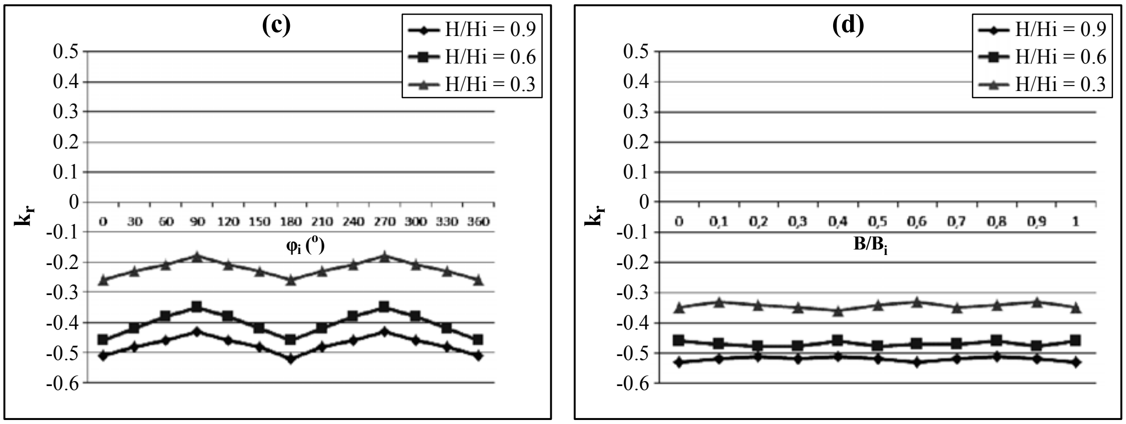
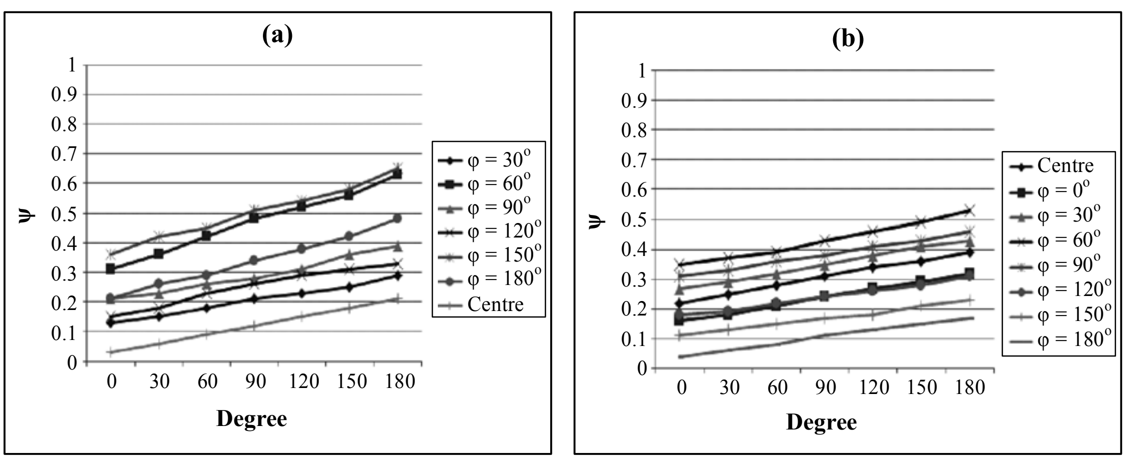


Fig. 5: Distribution of SCCSS on the cross section of the blank while broaching in flat (*a*) and combined (*b*) strikers; while upsetting on the tool with the changing shape (*c*) and forging the blades (*d*) (where φ_i, is the angle of rotation till the studied point, H_i and B_i are the distances of the point according to the height and width of the blank; H_0 and B_0 are the height and width of the deformation zone, respectively)

The foregoing statements show that in all conditions of the combined process of metal forming (MF), most part of the plastic zone is located under comprehensive uneven compression and in some circumstances in a small area of the zone, also in the peripheral layers of the blank there may be small tensile stresses in magnitude.



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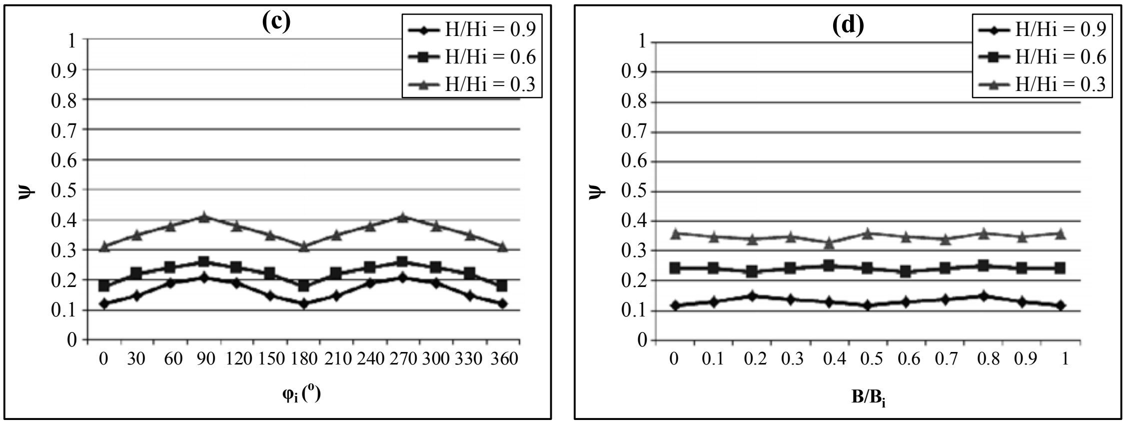

Fig. 6: Distribution of RUPL (resource utilization plasticity level) at the cross section of the blank while broaching in flat (*a*) and combined (*b*) strikers; while landing on the tool with changing shape (*c*) and forging the blades (*d*) (where φ_i is the angle of rotation to the studied point, H_i and B_i are the distances of the point according to the height and width of the blank; H_0 and B_0 are the height and width of the deformation zone, respectively)

CONCLUSION

(i) It was established that an equal distribution of Λ over the cross section of the deformable blank can be achieved while broaching with the tilting angle of 30^o and with the relative feed of 1.0 in flat strikers in the first phase; while with the tilting angle of 30^o and relative feed of 0.6 in combined strikers in the second phase;

(ii) Forging in flat and combined strikers, the landing in the tool with the changing shape and isothermal forging enables the manufacture of gas turbine engine blades without disrupting the continuity of material forgings.

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