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Research on the Influence of Technological Forging Parameters on the Quality of Biphasic Titanium Alloys

Abstract: The deflected mode (DM) during the preparation of the broach in the flat and combined baizes and also on radial forging machine (RFM) was investigated for creating the rational technology of a broach and determining the optimum size of the angles of rotation and single squeeze reduction. The quantitative data was obtained by the method of final elements and the MSC. Super Forge program; the main consistent patterns of stress–strain state (SSS) distribution and temperature while modeling forging in flat and combined baizes, also on RFM with various angles of rotation and sizes of squeeze reduction were determined. The rational trial technology of forging of biphasic titanium alloys was developed and tested.

Keywords: broach, radial forging machine, deflected mode, numerical simulation, intensity of tension and deformation, squeeze reduction

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Introduction

Nowadays the need for products made of titanium has been increasing. A combination of high durability and plasticity, possibility of using them up to working temperatures of 600–650°C, lower density that provides high level of specific operational characteristics and excellent corrosion resistance in many natural and industrial environments are the common characteristics of titanium alloys. These properties of titanium alloys increase its high efficiency in its application [1–3].

However, at the present time, the technological processes of receiving workpiece for stamping made of titanic alloys are characterized by high labor input, low productivity and big material inputs [2, 4]. It is connected with the application of repeated deposit and the broach at temperatures which are higher and lower than the temperature of polymorphic transformation for receiving the recrystallized structure by the present technology, thus single squeeze reduction does not exceed 15–40%.

The perspective direction of developing the modern production of products made of titanium alloys is the application of resource-saving technological processes which increase the labor productivity and production quality [1–3]. These requirements satisfy the processes of combined workpieces or ingots. In recent times the studied broach has been widely adopted in flat, combined (top – flat, bottom – cut), cut baizes and on radial forging machine (RFM).

Broach in the combined and cut baizes, also on RFM, is widely used for reducing the cross section and increasing the length of the workpiece. It is used in forging by a scheme called as "circle circle." Research results of the deflected mode (DM) of metal while forging in combined baizes and on RFM show that the maximum deformation and tension concentrate in the central or superficial zone of the workpiece [5–9]. Thus planimetric stretching tension and deformations can occur in zones of forging adjacent to the tool; they can lead to violation of metal continuity at a broach of forgings from low plastic alloys.

It should be noted that the main deficiency of well-known works devoted to research of broach process is because of the consideration of unequal distribution of stress–strain state (SSS) on the section of stretched workpiece from single reduction positions [5]. It is known that the level and stability of forging material properties depend on tension and deformation after each reduction and manipulation; thus, their calculation is not given in well-known works. The criteria for 30°, 60°, 90°, 120°, 150° and 180° optimization of the angles of rotation are given differently by different researchers. As a result, the

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information about the angle of rotation of workpiece sizes stretched on RFM, also in flat, combined and cut baizes, is inconsistent; therefore, they need a specification.

Therefore, DM of a broach in the flat, combined baizes and on RFM was investigated for creating rational technologies of a broach and determining the optimum sizes of the angle of rotation.

The aim of the scientific work is to develop a rational technology for forging of titanium alloys by calculating the saved-up deformations at a broach on RFM, also in the flat and combined baizes, and by distributing them on the volume of metal equally.

Materials and methods

DM of forging in flat and combined baizes, also on RFM, was investigated for developing the technological process that allows to distribute the saved-up deformations equally, i.e., to receive the titanic forging of a high quality, and for determining the optimum sizes of angle of rotation of single reduction.

The specialized standard MSC.Super Forge program was used for calculating the DM [10]. Three-dimensional geometrical model of workpiece and bikes was constructed in CAD of Inventor program and it was imported to CAE of MSC.Super Forge program. The three-dimensional volume element CTETRA (four-nodal tetrahedron) was used while creating the final element model of workpiece and bikes; it was applied for modeling the three-dimensional subjects. The process took 20–30 min on the Pentium Duo computer, which has a clock frequency of 3.4 GHz and random access memory of 2 Gigabytes.

The cylindrical samples of diameter 60×300 mm size were used for calculations. The material of stretched workpiece was Ti6AL4V with the temperature range of 900–1,250°C. The material for workpiece deformation was appointed from the material database. Johnson-Cook's elasto-plastic model was chosen for modeling the plasticity of workpiece. Tools were accepted absolutely by the rigid way in MSC.Super Forge and attention was paid to the properties of heat conductivity and heat transfer, i.e., specific heat conductivity, specific heat and density; the mechanical properties were ignored. The material for strikes is steel for tool. The material of bikes, density and thermal properties were chosen by default.

Interaction between rigid brisk and a workpiece is modeled by means of contact surfaces that describe contact conditions between surfaces of bikes and a workpiece surface. Contact conditions are constantly updated in the modeling process; they reflect the movements of bikes and material deformation which allow modeling the sliding between the brisk and a material of processed workpiece. Contact between the brisk and the workpiece was simulated by friction on the pendent; the coefficient of friction was accepted as 0.3.

The temperature mode at a broach consists of heat exchange between brisk, workpiece and environment; it also consists of thermal effect due to metal deformation. Heat transfer is carried out at the convective and radiant exchange with environment and at the contact of bike and workpiece. Process of a broach takes place at room temperature; therefore, we accept the reference temperature of bikes as 20°C.

The industrial ingots of an alloy of BT9 with $\varnothing 750 \times 1{,}875$ mm size were used as the initial material.

Research on the metallographic section was done by the traditional technique of grinding and polishing circles. The concentrated solution of nitric acid in ethyl alcohol was used for etching of samples. The metallographic analysis was carried out by using "METAM LV-32" microscope.

Results and discussion

The SSS preparation was investigated at a broach in the flat and combined baizes, and also on RFM for creating the rational technology of forging and determination of optimum size of angles of rotation, relative giving and single reduction.

The pictures of distribution of the SSS preparation section at a broach in the combined baizes in the first reduction and at deformation with angles of rotation 30°, 60°, 90° and 120° (single reduction was chosen as 20%, 40%, 60% and 80% from a total time of deformation) are presented in Figures 1–3.

On the basis of results received by numerical modeling it is established that

- at a broach of round workpiece in the combined baizes with relative giving of $S = l/D = 0.6$ (where l is the length of the center of deformation; D is the diameter of workpiece), intensity of deformation concentrates at the initial stage of the first reduction in superficial zones of workpiece, and with increase in sinking intensity of deformation is localized on a forging cross (Figure 1);
- at a broach with angles of rotation 30°, 60°, 90°, 120° irrespective of the size of relative giving, intensity of deformation generally concentrates on sites of metal contact with the tool, but between sites of contact of the tool and workpiece there are averages in intensity of size of deformation (Figures 2 and 3).

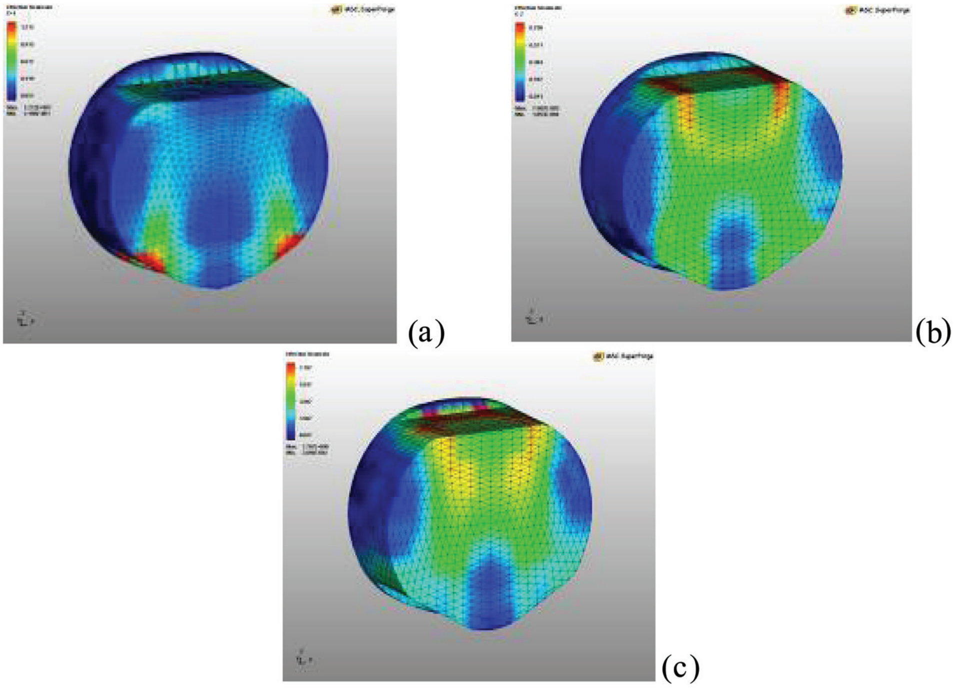

Figure 1 Picture of deformation intensity distribution when forging in the combined baizes with single reduction of 80%, $t = 960°C$. (a) $S = 1.0$; (b) $S = 0.8$; (c) $S = 0.6$

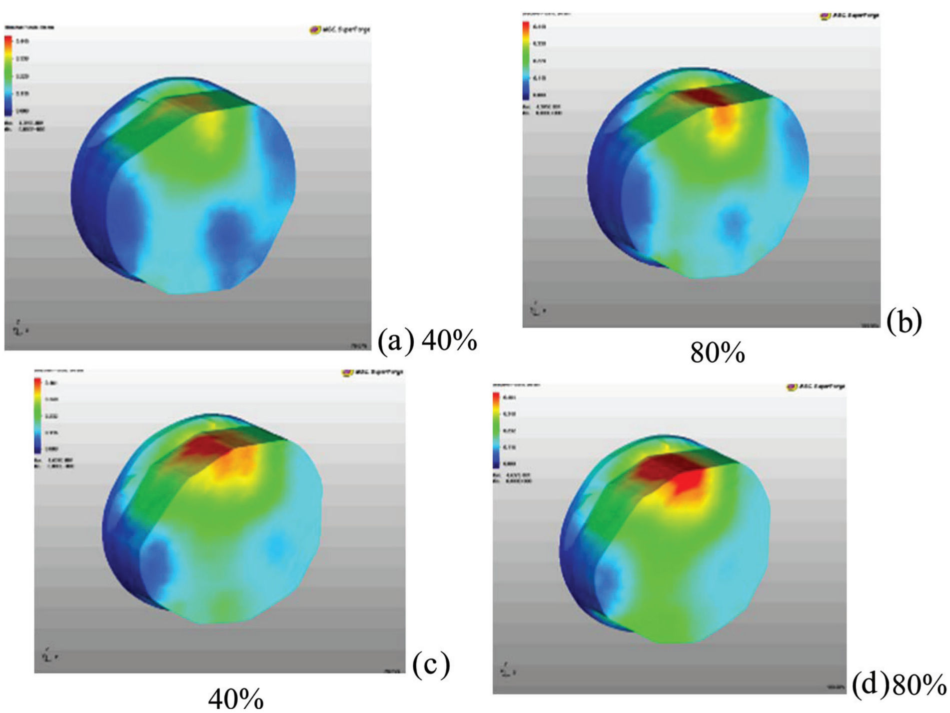

Figure 2 Picture of deformation intensity distribution when forging in the combined baizes with angles of rotation 30° (a and b) and 60° (c and d), $t = 960°C$

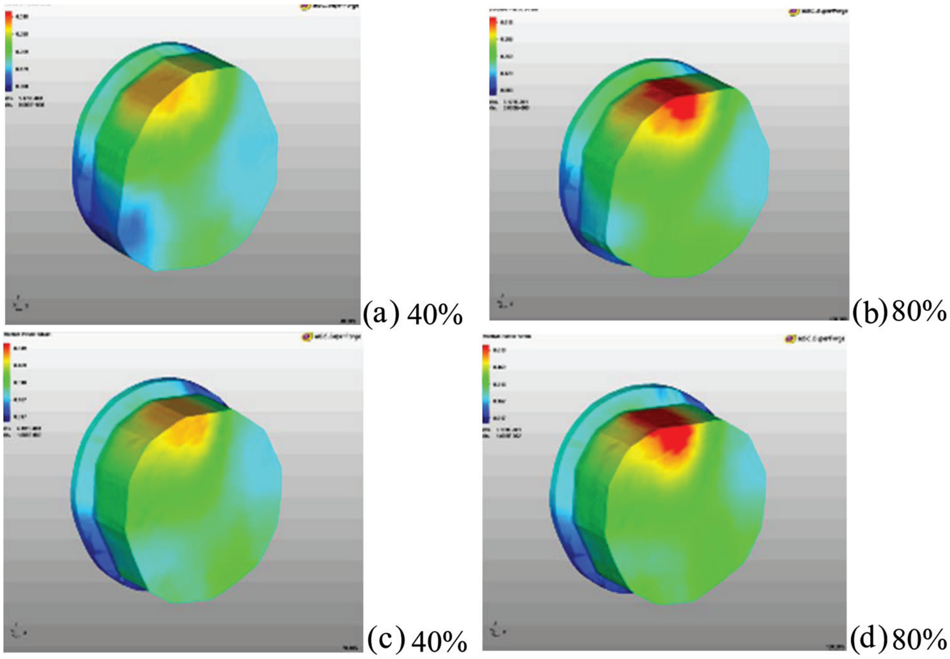

Figure 3 Picture of deformation intensity distribution when forging in the combined baizes with angles of rotation 90° (a and b) and 120° (c and d), $t = 960°C$

In this scientific work, the calculation was made by summing the intensity of deformation of shift Λ (the saved-up deformation), deformation extent for a number of technological modes of forging in the combined baizes.

The analysis diagram of Λ changes on preparation section at a broach in the combined baizes shows that the rational mode of a broach with relative giving of 0.6 and angles of rotation 30°, 60°, 90°, 120° extent of shift deformation (the saved-up deformation) has a great importance on the sites adjacent to a surface of workpiece, while in the central zone of workpiece it shows the minimum size (Figure 4).

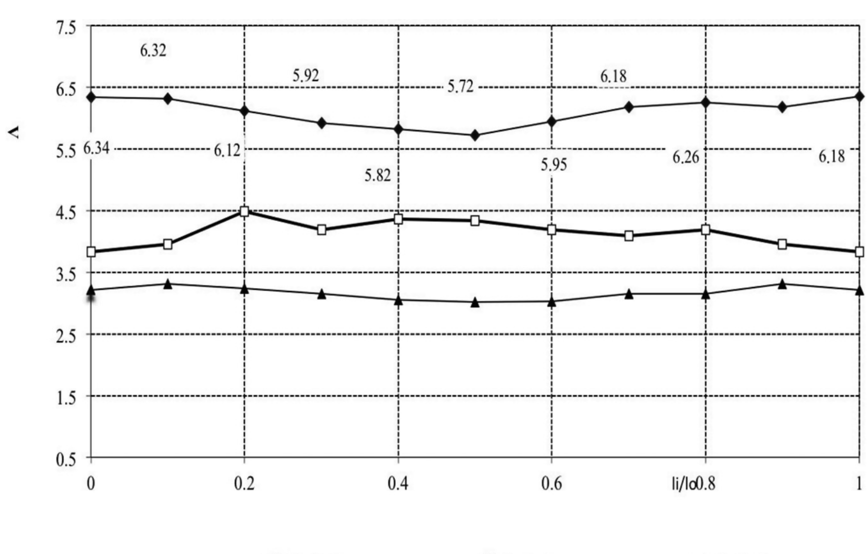

Figure 4 Distribution Λ on the longitudinal section of workpiece at a broach in the combined baizes with relative giving 0.6 (section 1 – $D_i/D_0 = 0.9$; section 2 – $D_i/D_0 = 0.75$; section 3 – $D_i/D_0 = 0.5$; l_i and D_i – distance to a studied point on length and diameter, respectively; l_0 and D_0 – length and diameter of the deformation center, respectively)

The pictures of deformation intensity distribution on workpiece section at a broach in flat baizes in vaporous reduction and at deformation with angles of rotation 30°, 60°, 90°, 120°, 150°, 180° are presented in Figures 5 and 6.

On the basis of results received by numerical modeling it is established that

- at a broach of round workpiece in flat baizes with relative giving of $S = l/D = 1.0$, intensity of deformation is localized in the initial stage of the first reduction in superficial zones of workpiece; because of force emergence friction intensity of deformation is localized on a forging cross with increasing reduction (Figure 5), thus accent of deformation is transferred to the workpiece center;
- at a broach with relative giving of 0.8 and 0.6, intensity of deformation is localized in the initial stage of the first reduction in superficial zones of workpiece, and with increase in sinking intensity tension and deformation are localized on a forging cross (Figure 5), thus the maximum in size of intensity of tension and deformation parts of workpiece concentrate in an average ($S = l/D = 0.8$) or superficial way ($S = l/D = 0.6$);
- irrespective of the size of relative giving, the workpieces with angles of rotation 30°, 60°, 90°, 120°, 150°, 180° and deformation with reduction of 20%, 40% from a total time of deformation lead to deformational localization on a workpiece surface, and the increase in reduction can be 60% and 80% from a total time of deformation which allows to concentrate intensity of deformation from a surface to the center (Figure 6); thus, the site turn with the maximum deformations on workpiece section occurs with the increase of reduction;
- macroshift deformations are developed on the deformational center when forging round workpiece in flat baizes with angles of rotation 30°, 60°, 90°, 120°, 150° and 180°; it occurs because of a turn of zones with the maximum deformations on workpiece section that will cause profound changes in metal structure for the account crushing of metal initial structure;
- the result of initial structure crushing of metal increases the level and uniformity of mechanical properties of metal and decreases their anisotropy properties.

The calculation was made by summing the intensity of deformation of shift Λ (deformation accumulation) for a number of technological modes of forging in flat baizes.

The analysis of Epirus changes Λ on workpiece section at a broach with angles of rotation 30°, 60°, 90°, 120°, 150° and 180° and relative giving of $S = l/D = 0.8–1.0$ shows that at a rational mode of shift, deformation has more values in zones of workpiece (Figure 7) adjacent to the tool. Thus the superficial sites have the smallest values.

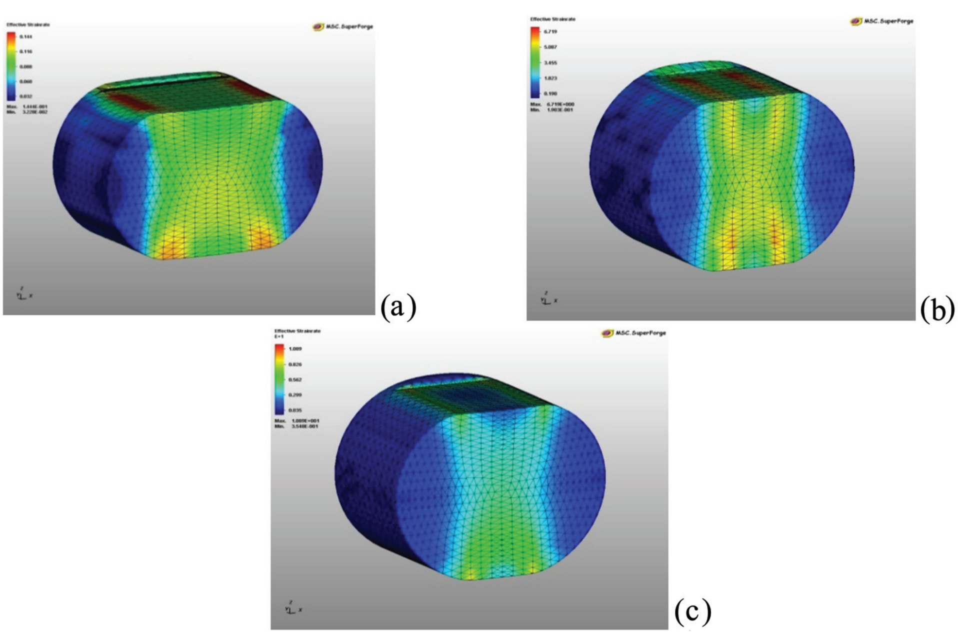

Figure 5 Picture of deformation intensity distribution in workpiece at a broach in flat baizes with single reduction of 80%, $t = 1{,}250$°C. (a) $S = 1.0$; (b) $S = 0.8$; (c) $S = 0.6$

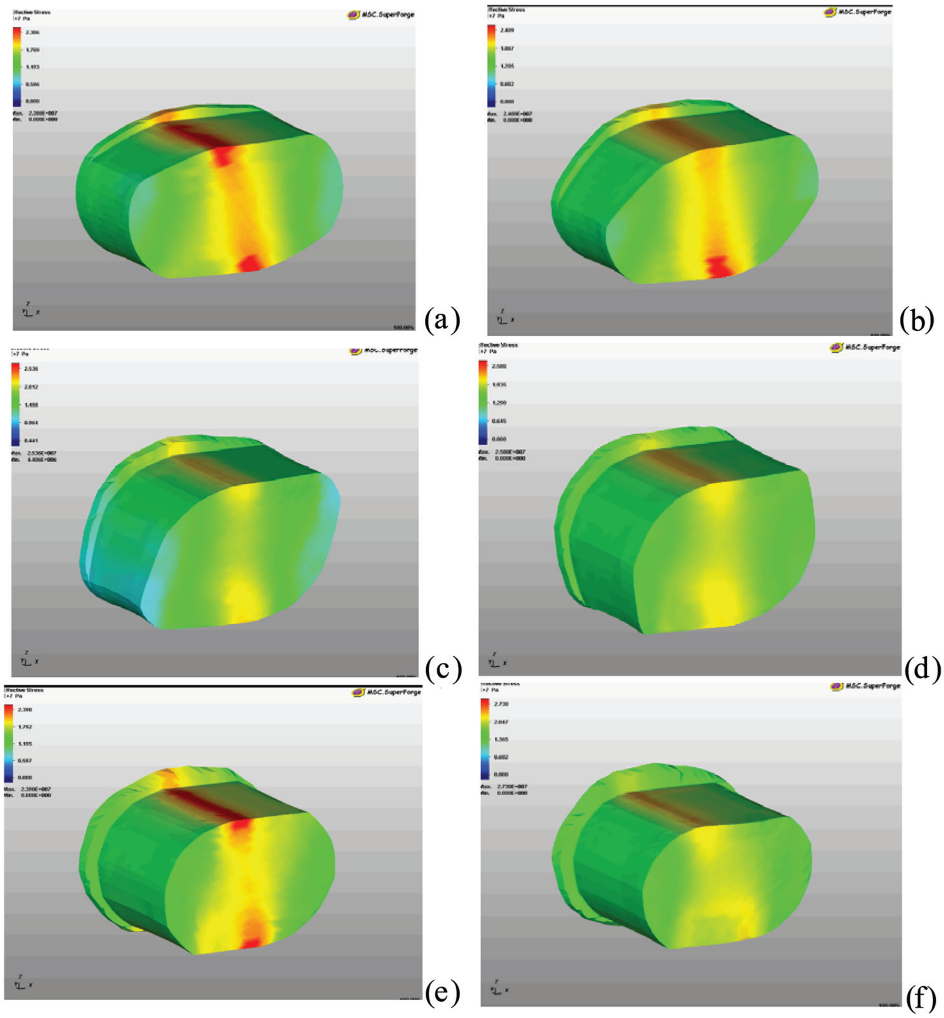

Figure 6 Picture of deformation intensity distribution in workpiece at a broach in flat baizes with single reduction of 80% and with angles of rotation 30° (a), 60° (b), 90° (c), 120° (d), 150° (e) and 180° (f), $t = 1{,}250°C$

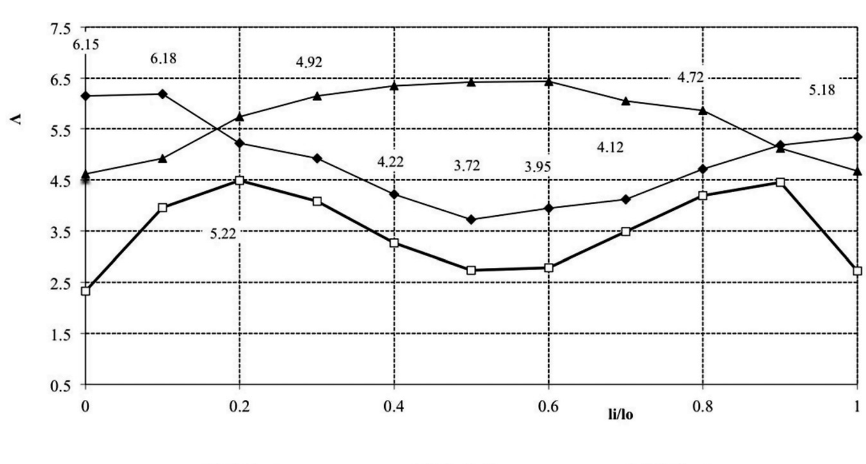

Figure 7 Distribution of Λ on the longitudinal section of workpiece at a broach in flat baizes with relative giving of 1.0 (section 1 – $D_i/D_0 = 0.9$; section 2 – $D_i/D_0 = 0.75$; section 3 – $D_i/D_0 = 0.5$; l_i and D_i – distance to a studied point on length and diameter, respectively; l_0 and D_0 – length and diameter of the deformation center, respectively)

The pictures of distribution of the SSS workpiece section are presented at a broach on RFM with reduction of 20%, 40%, 60% and 80% from a total time of deformation and angles of rotation 30° and 60° in Figures 8–10.

On the basis of the results received by numerical modeling it is established that

- at a broach of round workpiece on RFM, intensity of tension and deformation is localized at the initial stage of the first reduction in superficial zones of workpiece, and with increase in reduction because of friction force emergence, the accent of tension intensity is transferred from a surface to a middle part of the radius of workpiece (Figure 8);
- at the first reduction zones of a forging adjacent to the tool, in zones of contact of the flat tool with workpiece, intensity of tension and deformation shows the maximum size (Figure 8);
- deformation with angles of rotation 30° and 60° allows to concentrate intensity of tension in a zone of contact of metal with the tool on the initial stage of reduction; the increase in reduction is closer to the central part of workpiece to transfer a zone with the maximum size of tension intensity (Figure 9).
- the broach on RFM with angles of rotation 30° and 60° allows to concentrate also the intensity of deformation in a zone of contact of metal with the tool on the initial stage of reduction; the increase in reduction with the maximum size of intensity of deformation is transferred closer to the workpiece center; thus, from a surface to the middle of radius intensity of deformation is distributed evenly (Figure 10);
- temperature increases in the course of a broach on RFM in zones of localization of tension and deformation, thus in the central zone of workpiece temperature goes down.

The calculation was made by summing the intensity of deformation of shift Λ (deformation accumulation) for a number of technological modes of forging on RFM.

The analysis of Λ diagram change on the section of workpiece shows that at a broach on RFM with angles of rotation 30°, 60°, 90°, 120°, 150° and 180° extent shift of deformation has a great importance on the adjacent sites to a surface of workpiece, while in the central zone of workpiece it shows the minimum size (Figure 11).

Thus, when forging on RFM, intensity of tension and deformation of shift is concentrated in superficial and

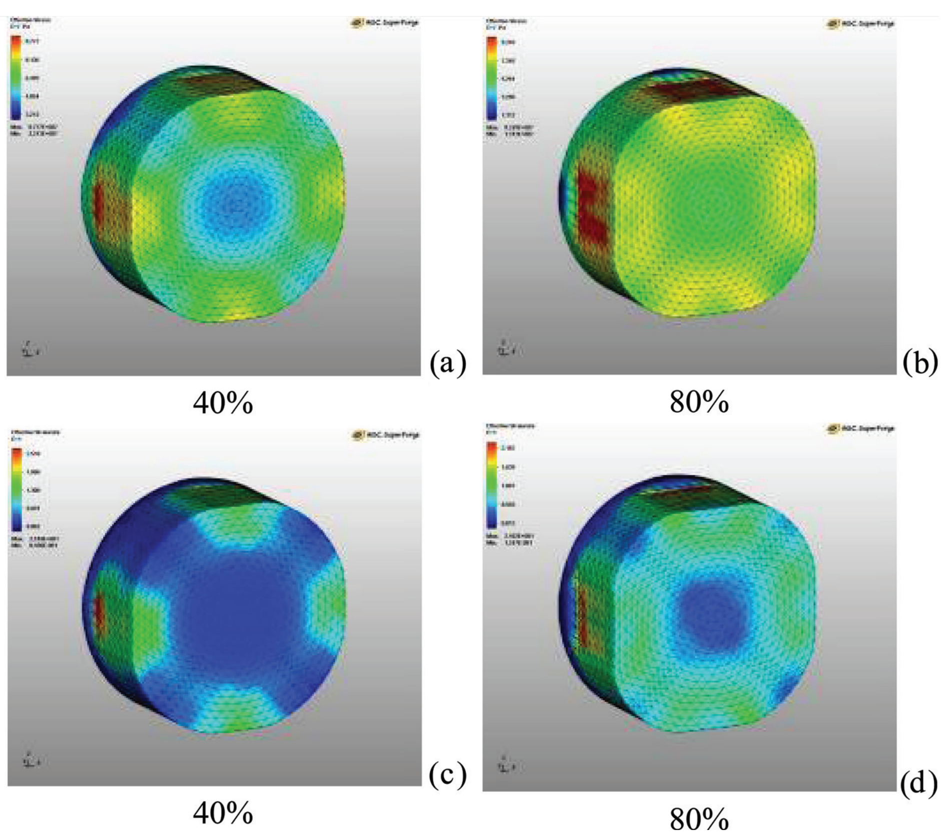

Figure 8 Picture of tension intensity distribution (a and b) and deformations (c and d) in workpiece when forging on RFM, $t = 1{,}150$°C

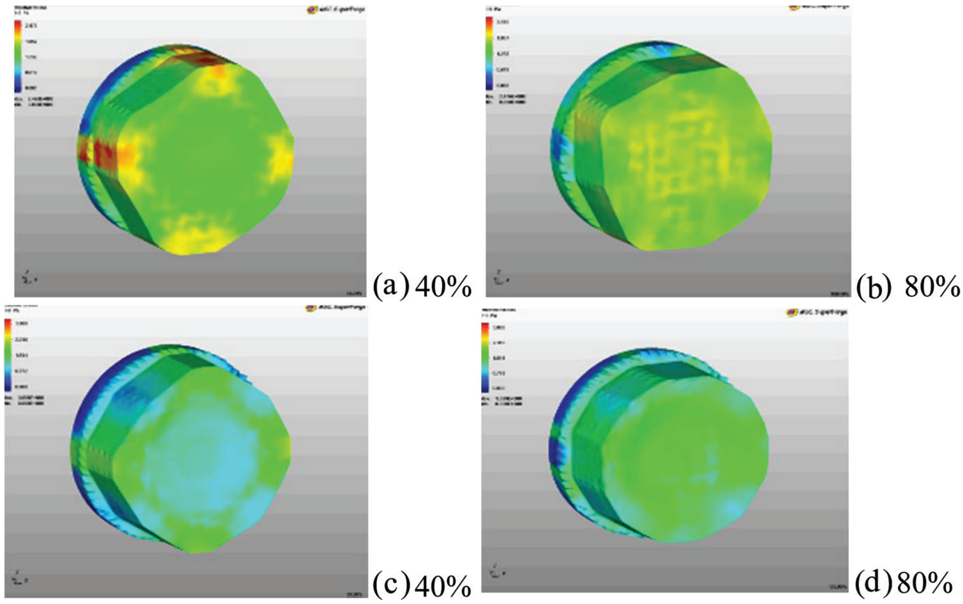

Figure 9 Picture of intensity tension distribution when forging on RFM with angles of rotation 30° (a and b) and 60° (c and d), $t = 1{,}150°C$

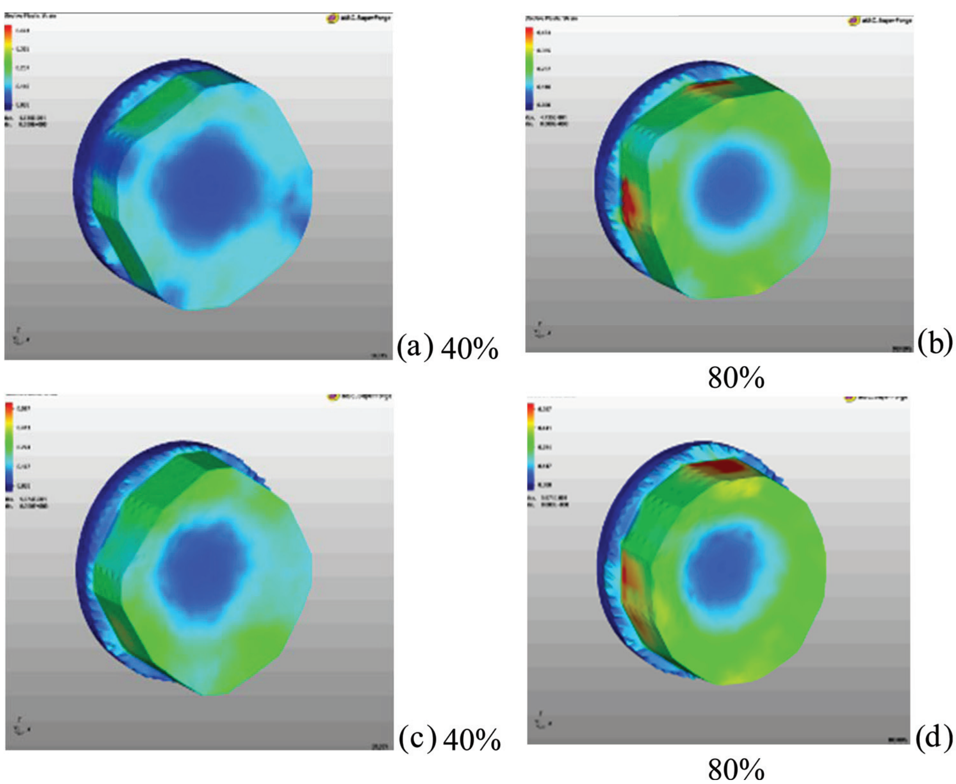

Figure 10 Picture of deformation intensity distribution when forging on RFM with angles of rotation 30° (a and b) and 60° (c and d), $t = 1{,}150°C$

average zones of workpiece. Therefore, for receiving a forging with uniform structure, it is necessary to use the combined way of RFM with other equipment, which allows to crush structure of initial workpiece evenly.

Calculation results of shift deformation extent showed that uniform distribution of Λ on the section of deformable workpiece can be reached at a broach with angles of rotation 30°, 60°, 90°, 120°, 150° and 180° and

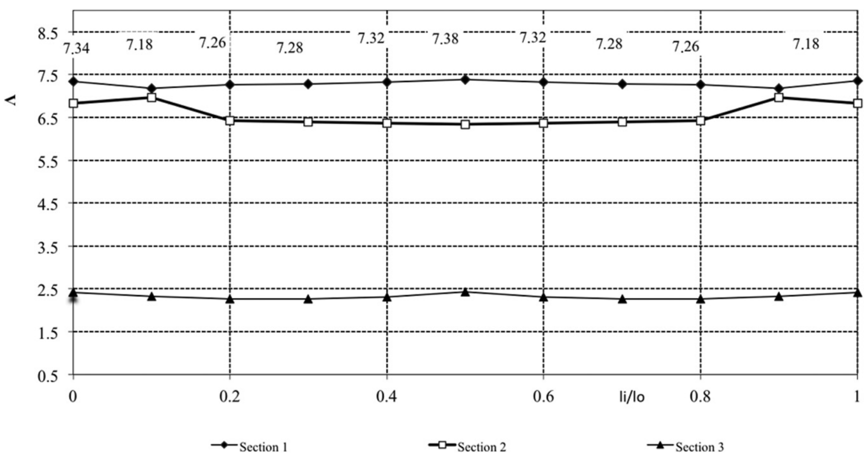

Figure 11 Distribution of Λ on the longitudinal section of workpiece at broach on RFM (section 1 – $D_i/D_0 = 0.9$; section 2 – $D_i/D_0 = 0.75$; section 3 – $D_i/D_0 = 0.5$; l_i and D_i – distance to a studied point on length and diameter, respectively; l_0 and D_0 – length and diameter of the deformation center, respectively)

relative giving of 1.0 in flat baizes at the first stage; with angles of rotation 30°, 60°, 90°, 120° and relative giving of 0.6 in the combined baizes at the second stage and with angles of rotation 30°, 60°, 90°, 120°, 150° and 180° on RFM at the third stage.

In the present work, a precipitation (Table 1) was investigated for the possibility of receiving fine-grained structure by a broach in the flat and combined baizes, also on RFM with elimination of labor-consuming operation. The industrial ingot of an alloy of BT9 with ∅750 × 1,875 mm size was served as an initial material.

Results of carried out experience show that a macrostructure of forgings of an alloy of BT9 is short-grained – 2–3 points (Figure 12). Forgings was forged in à-area in flat baizes, in (# # à)-area in the combined baizes and in à-area on RFM (Figure 12).

The analysis of a microstructure shows that the broach on offered modes leads to re-crystallization of β-phase by forming very small β-grain (20–30 μm). Dynamic transformation of lamellar α-phase took place in parallel to re-crystallization of β-phase (Figure 13).

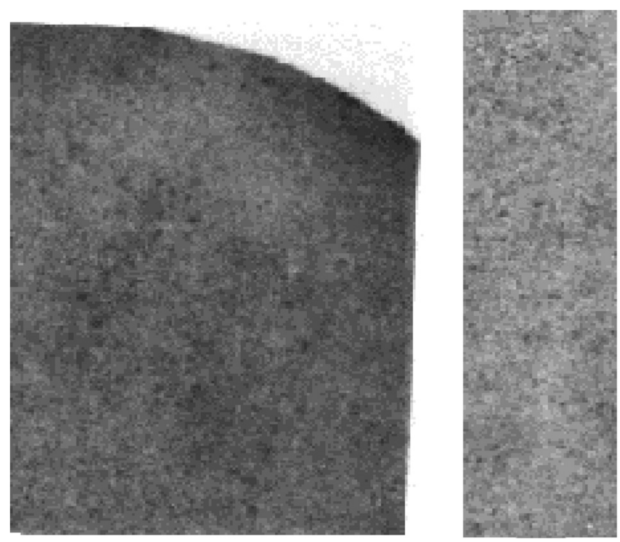

Figure 12 Macrostructure of an alloy of BT9 in cross and longitudinal sections after a broach in flat baizes at temperatures of β-areas, in the combined baizes of (α + β)-areas and on RFM in β-areas

Table 1 Broach modes in ingots from BT9 alloy

Temperature, °C	Configuration of bikes	Diameter of workpiece till a broach, mm	Diameter of workpiece after a broach, mm	Relative giving	Reduction, %	Manipulation temp.
1,250	Flat	750	520	0.8–1.0	10–30	30–60
1,100	Flat	520	420	0.8–1.0	10–30	30–60
960	Combined	420	350	0.4–0.6	10–15	30–60
1,150	RFM	350	250	0.6–0.8	10–15	30–60
1,150	RFM	250	200	0.6–0.8	10–15	30–60

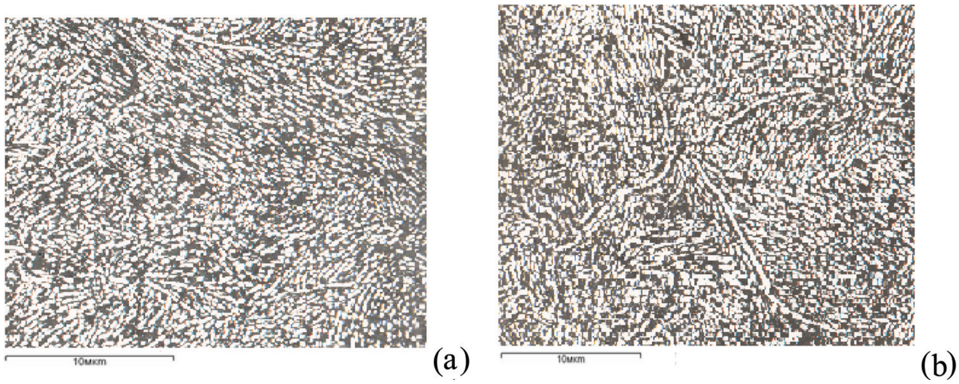

Figure 13 Microstructure of forgings from BT9 alloy after a broach in β-, (α + β)-, β-areas (a) in the cross section of forging; (b) in the longitudinal section of forging

Thus, the results show that a broach with a rational mode of forging as the usage of preliminary deformation in β-area, intermediate deformation in (α + β)-area and final deformation in β-area allows to receive the re-crystallized structure with the fine grain corresponding to 2–3 points on all sections of workpiece.

Mechanical properties of the forgings forged on skilled technology correspond to mechanical properties of the forgings received by comprehensive forging (Table 2).

Table 2 Comparative mechanical properties of the forgings made on skilled technology and the existing mode

No. of forging mode	Direction of cutting of a sample	σ_B, MPa	δ, %	ψ, %	KCV, kJ/m^2
Skilled technology	Axial	1,065	10.8	28.3	3,000
	Radial	1,035	9.1	24.6	3,300
	Tangential	1,035	9.2	25.3	3,500
The existing technology	Axial	1,050	9.0	25.0	3,000
	Radial	1,050	9.0	25.0	3,400
	Tangential	1,030	8.8	22.0	3,400

Conclusion

1. The quantitative data was obtained by the method of final elements and the MSC.Super Forge program; the main consistent patterns of distribution of the SSS and temperature are determined while modeling forging in the flat and combined baizes, also on RFM with various angles of rotation and sizes of reductions.
2. Equal distribution of shift deformation on the workpiece section occurs when forging in flat baizes with relative giving of 1.0 at the first stage; the combined baizes of 0.6 at the second stage; on RFM at the third stage of a broach.
3. The result of equal distribution of shift deformation extent is the increase of a level and uniformity of mechanical properties of metal and decrease of their anisotropy properties.
4. Results of calculation of deformation extent of shift and skilled forging allow making a conclusion that when forging in the flat and combined baizes which crush the structure of workpiece, it is possible to achieve the expense of relative giving at angles of rotation 30°, 60°, 90°, 120°, 150° and 180°.

So, it is possible to receive a forging with fine-grained structure with high mechanical properties on a landmark broach of round workpiece in the flat and combined baizes, and on RFM.

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