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FORMATION OF THE STRUCTURE OF TITANIUM ALLOY DURING THE CHANGE OF STIFFNESS OF DEFORMING TOOLS

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ABSTRACT

In this paper, the reasons of non-uniformity of deformation on precipitation of VT3-1 titanium alloy was investigated by the theoretical finite element method. The quantitative data is obtained by Standard software MSC. Super Forge; the basic patterns of distribution of the stress-strain state on precipitation in the flat dies was established. The influence of rigidity of flat pins on the force, structure and properties of billet upset was investigated by the experimental methods. It was proved that the use of an elastic pad allows to develop the intragranular and intergranular deformation on the cross section of the billet; thus evenly distributed deformation over the cross section of the billet and upsetting forging receive a fine-grained structure with high mechanical properties.

Key words: Sediment, Flat die, The stress-strain state, Numerical simulation, The intensity of the stresses and strains, Elastic gaskets, Compression, Strain localization.

INTRODUCTION

Development, improvement and implementation of new equipment and tools in production require a new approach to all stages of the process improvement[1]. One of the weakest side of the existing technologies of metal forming is uneven deformation, instability and greater complexity of technology and zonal structural heterogeneity of manufactured products.

The heterogeneity of the structure is associated with a greater or lesser concentration of plastic deformation in different places of billet volume[2]. Therefore, it is believed that the heterogeneity of the structure is the result of uneven deformation. The appearance of uneven

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deformation during metal forming (MF) also associated with the deformation mode from the processing conditions of force, as well as the nature of the metal[3-5]. It should be noted that during the deformation process conditions, in which uneven deformation exhibit, does not remain constant, due to the changes in billet size of MF and other reasons, which exhibit uneven deformation. In this regard, it is important to know the conditions that lead to an unacceptable strain localization causing a large structural heterogeneity and the appearance of a line of intense flow in deformable billets.

It is known that the deformation zone is limited to active-moving and passive tool surfaces and the deformable body free surfaces of a draft blanks in a flat die, and is characterized by the passage of metal forging cross[1]. In this case, the localization of deformation along the forging cross manifested in the form of thin strips of intense currents, accompanied by a temperature-deformation phase of transformation.

Some of the researchers[6-8] believe that the cause of localization of plastic deformation is the change in stress state depending on the contact between friction and deformation, also the thermal effect during the deformation. At the same time, the heterogeneity of the strain increases as a result of the superposition of all kinds of uneven deformation (micro- and macroscopic origin).

Lin[9] has investigated the process of precipitation of a solid cylinder between the elastic plates. In this paper, finite element methods and finite differences were used for the study of stress-strain state (SSS) of precipitation. It has been shown that the quality of forgings largely depend on the basic parameters of the process deposits such as the elastic properties of the plate, the temperature, the shape and dimensions of flat plates. These studies were directed at optimizing the process parameters and forging forms in flat dies in order to gain a high quality of forgings.

Radic et al.[10] described the numerical simulation of cylindrical patterns in a flat die. Simulation is carried out by finite element method. Here, the software CATIA V5 R18 was used. It is shown that the study of precipitation process must take into account a single compression and contact friction, and stiffness of the tool. Results obtained by using the finite element method, and experiments have shown a high degree of similarity of the received data. The authors have shown that the simulation by finite element method can be used as the solution of complex technological problems.

In order to reduce the non-uniformity of deformation, we propose to use a draft of the instrument with textolite or rubber gaskets. The influence of rainfall on the instrument with textolite or rubber gaskets on the localization of deformation was not investigated in the above works. Therefore, the study of the influence of instruments with textolite or rubber gaskets on the uneven deformation should be recognized as one of the actual problems.

The aim of the work is to study the effect of precipitation in the tools with steel, textolite and rubber gaskets on the structure and properties of titanium alloy forgings.

EXPERIMENTAL

Initial materials and research techniques

Research of SSS of the billet on precipitate on process is contact, elastic-plastic, non-linear[5]. The strain and stress, and temperature gradient occur on precipitation. Therefore, the mathematical modeling of precipitation was produced by using the MSC. SuperForge software package, in other words SSS and temperature field of the deformable billet was investigated.

The symmetric plane in terms of round precipitation of billets was considered in mathematical modeling where the direction of metal flowing is uneven around the axis of symmetry. Thus, symmetric axial SSS was considered during the sinking strain. In this case, the plane of the metal flow is a meridional cross section of the billet. All cross-sections are symmetric according to the billet axis of the blank. In this regard, it is sufficient to investigate SSS with only one half of any meridian section blank in the simulation, that is in simulating the precipitation by MSC.SuperForge software; it is useful to consider a two-dimensional (2D) axisymmetric billet deformation.

The cylindrical billet with the size of Ø10 × 20 mm was used for studying the precipitation. The titanium alloy VT3-1 deformation with the temperature range of 1200-850°C and physical properties was chosen as the blank material: a modulus of elasticity is 112,000 MPa, a force coefficient is 0.3, density is 4.5 g/cm^3. The precipitate of billet was produced at the temperature of 1200°C. During the modelling the billet material was accepted as isotropic elastic-plastic with a non-linear hardening (BISO).

Contact conditions between the tool surfaces and the billet surface are modeled by the interaction surfaces between rigid and deformable tool material of the billet. Contact conditions are constantly updated reflecting the movement of the striker and the deformation of the material in the process of precipitation. This allows to simulate the slip between the boards and sedimentary material of the deformed billet. The simulation of contact conditions between the tool and the billet was produced by using Coulomb's law; 0.3 was adopted as the friction coefficient. 5 HNM steel tool with different modules of elasticity was chosen as a tool material: E_1 = 217000 MPa, E_2 = 204000 MPa, the coefficient of Punch was 0.3 and the density was chosen as 7,716 g/cm^3.

Two-dimensional geometric model of the tool and the billet was created in the CAD software Inventor, which was subsequently imported into the CAE of MSC.SuperForge software. Two-dimensional elements were used for creating a finite element model of the billet, which are used for the simulation of metal flow in axisymmetric deformation conditions. 2600 elements and 3200 node were required for modeling the billet and the tool.

The software was launched for the calculation after inputting all data and technological parameters of the precipitation process. Time of the calculation process took 22 mins on the computer Pentium Duo with 3.4 GHz and 2 GB of RAM.MSC. Super Forge software automatically generates all calculations. The software generates grid elements by taking into consideration the geometric features of complex metal flow. The solution automatically adjusts the grid elements at each step. It gives the best way to explore the features of the process such as barrel distortion precipitation during the deformation, and to predict the formation of folds and clips.

Series of experiments in the laboratory were conducted in order to investigate the influence of the stiffness of flat pins on the force, structure and properties of upset billets of titanium alloys VT3-1. For the experiments the samples with the size of Ø10.0 × 10.0 mm; Ø10.0 × 20.0 mm; Ø10.0 × 30.0 mm were produced of the above mentioned materials. VT3-1 alloy billets were pre-annealed in an electric furnace of the type of KS 600/25 at 650° C with 2 hrs for obtaining anequated structure. Three samples were deformed under identical conditions while the plates made of steel, textolite were placed under the steel plate, with the rubber of 15 mm thickness.

Test samples on hydraulic press with a single static compression to 60% was carried out at a temperature of 950°C. Loading was conducted at a constant speed of 1 mm/min, by maintaining a generally static load during the experiment.

Upset drives with the size of Ø10.0 × 20.0 mm were cut on cold-cutting mechanical saws to the transverse templates for further research. The metallographic analysis was performed in order to determine the changes in the macrostructure of metal precipitation. Samples for metallographic analysis were prepared by the standard method of manufacturing thin sections.

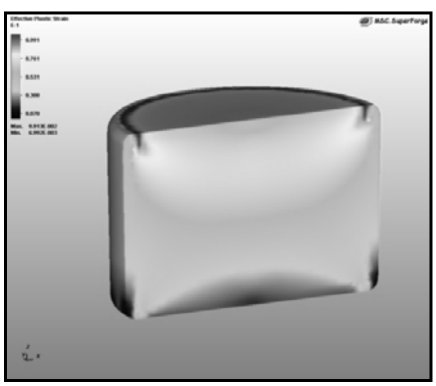
Metallographic analysis was conducted under the optical microscope ECMetam PB-21-1 at the magnifications of 50, 100, 200, and 500-fold. Quantitative analysis of the parameters of the defect substructure was carried out by standard methods[11].

RESULTS AND DISCUSSION

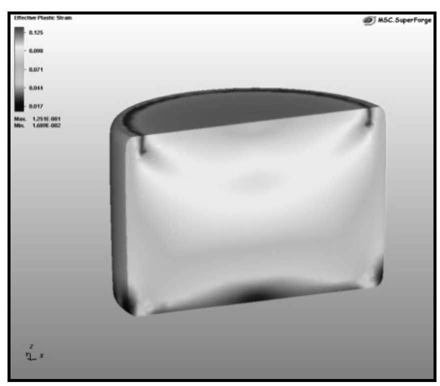
Figs. 1 and 2 show the distribution pattern of the equivalent plastic strain in the blank with the draft in a flat dies.

The followings are revealed based on the simulation results:

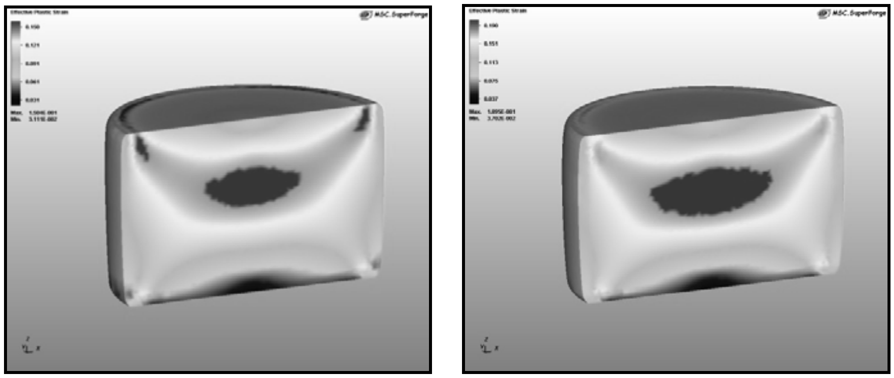
- With the increasing compression unit part of the volume of geometric deformation zone is occurred in the constrained deformation zones during the sinking strain process in a flat dies because of the action of touch friction forces (Fig. 1, a, b, c, d and Fig. 2, a, b, c, d);
- A consequence of the appearance of constrained deformation zones is localization of the most metal flow or shear bands in the form of forging cross (Fig. 1, a, b, c, d and Fig. 2, a, b, c, d);
- Localization of strain in the area of the forging cross increases the heat and the risk of metal failure in these areas, and leads to the lack of deformation in the structure of the remaining volume of the preform and assorted structure section;
- Equivalent plastic strain is concentrated in places of transition from a non-deformable to a deformable portion of the preform and forging cross during the sinking strain in the flat dies with increasing compression unit (Fig. 1, a, b, c, d, Fig. 2, a, b, c, d);
- The concentration of equivalent stress and the plastic strain can cause cracking, which deteriorates the quality of the metal.



(a) 40%



(b) 60%



(c) 80% **(d) 100%**

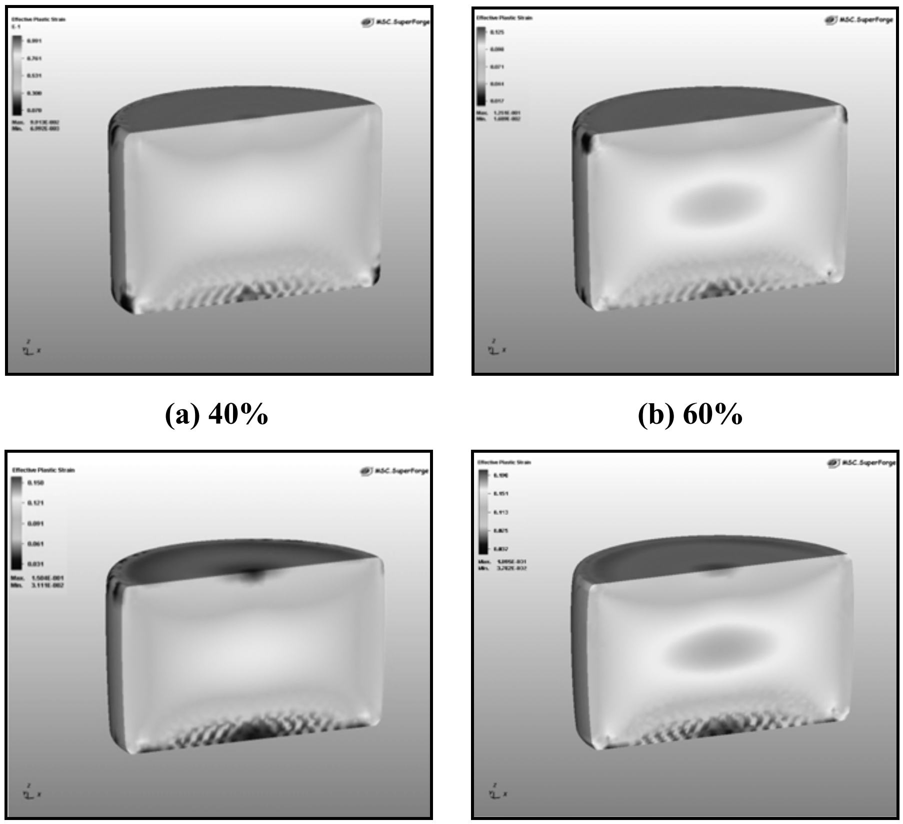
Fig. 1: The distribution of equivalent plastic strain in the blank with the draft of the flat dies (elasticity module E_1 = 217000 MPa)

The temperature gradient strongly influenced on the formation of the shear bands during the hot sinking strain. The initial stage of the formation of shear bands includes the development of refrigerated areas in hot blank, which is in contact with the cold tool. These areas also limit the uniform flow, since their deformation requires elevated local stresses.

The research showed that the non-uniformity of deformation increases with the increase in the elastic modulus of the instrument and shift bands are concentrated more in the central areas of the blank (Fig. 1, a, b, c, d and Fig. 2, a, b, c, d). In this case, the patterns of distribution of temperature field and equivalent stresses and their size remain almost unchanged.

Thus, during the sinking strain three main areas occur: upper and lower areas of constrained deformation; average plastic zone, which is located between the regions of constrained deformation; side plastic areas. In this case, the precipitate with small single crimps at elevated temperatures is followed by homogeneous deformation, but there occur the narrow bands of strain localization with the increasing unit compression, which are distributed by forging cross.

It should be noted that the area of the local flow occurs in those areas where equivalent stress has the maximal number in magnitude and reaches a limit of quantitation, and then spread under the action of stresses in the adjacent area. The conditions for enhancing the localization of deformation with a corresponding increase in temperature are created by exciting artificially in the deformation field with a significant quantity of shear stresses and spreading them throughout the deformation zone.



(a) 40% (b) 60%

(c) 80% (d) 100%

Fig. 2: The distribution of equivalent plastic strain in the blank with the draft of flat dies (elasticity module E_2 = 204000 MPa)

The intense heating zones are formed at the boundaries between the movable and stationary metal during the precipitation process. Even small deformations may cause a shift in the magnitude of several thousand percent since the thickness of the boundary layer can be infinitesimal. Originating, shear bands distributed independently due to adiabatic heating of the boundary layer. Wherein the deformation resistance of the boundary layer of metal is greatly reduced; it leads to a drastic reduction of the deforming force.

Thus, it can be noted that the reason for the localization of plastic deformation and reduction in the deformation forces is both the change in equivalent stresses depending on the strain, the modulus of elasticity and the appearance of precipitate under the effect of heat.

Investigation of power parameters of upsetting process showed that the change in stiffness of the tool from the sedimentary plates, under constant conditions on the surfaces of contact between deformable model and tool, in the absence of visible changes in the configuration of the deformed samples, can cause significant changes in deforming force. Installation textolite gasket causes an increase in efforts to 5...8% and installation of rubber increases to 12 ...15% (Figs. 3, 4 and 5).

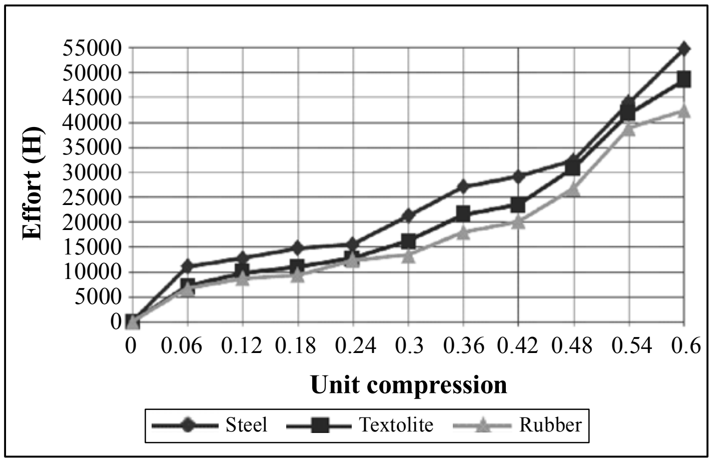


Fig. 3: Change in efforts on precipitation of titanium alloy VT3-1 in the flat dies with different gaskets (H/D = 1:1)

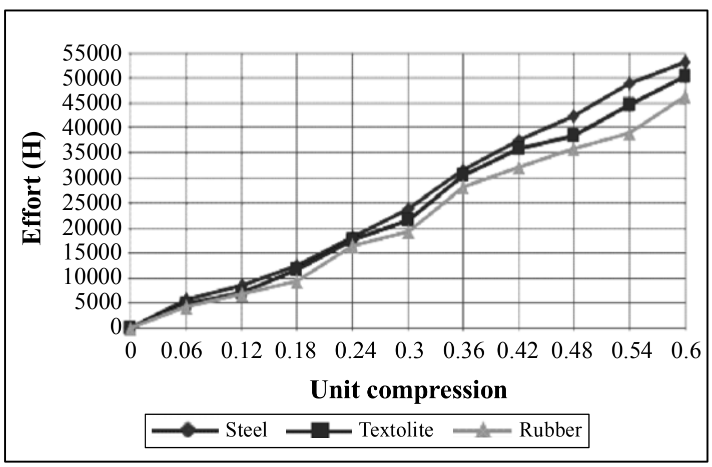


Fig. 4: Change in efforts on precipitation of titanium alloy VT3-1 in the flat dies with different gaskets (H/D = 2:1)

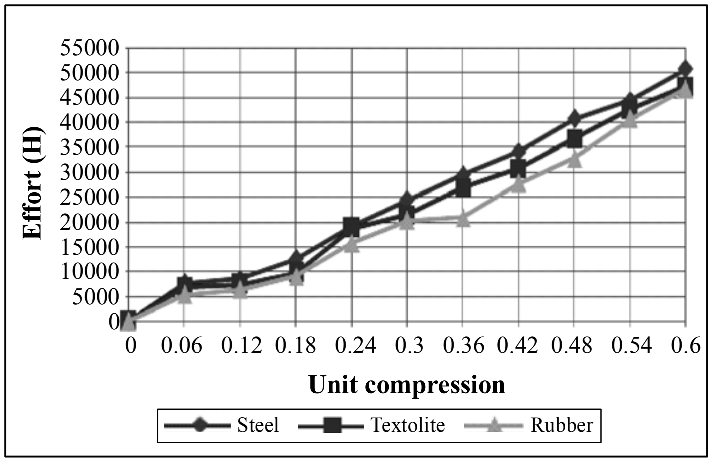
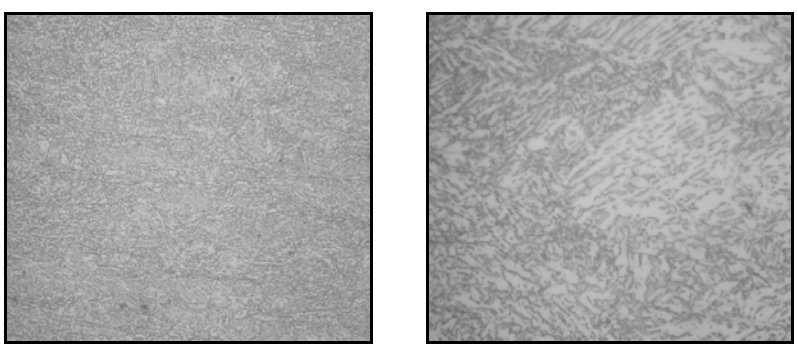
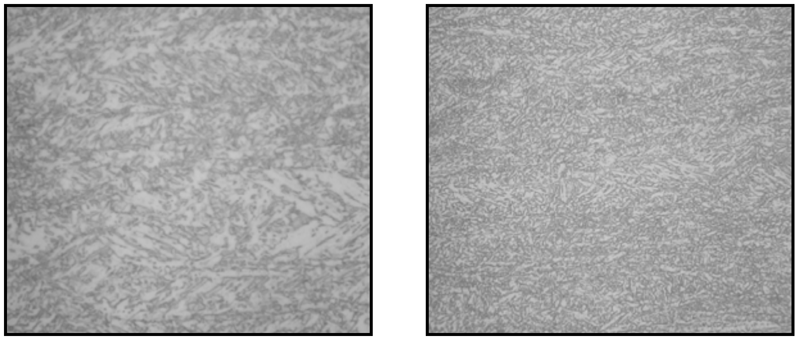


Fig. 5: Changes in efforts at draft titanium alloy VT3-1 in flat die with different gaskets (H / D = 3: 1)

Microstructural analysis of metal samples, which are upset without laying in a flat die, gives an evidence of heterogeneity in the structure of the cross-sections of the samples in the form of broad bands of the diagonal arrangement with a well-designed structure. It is very different from the structure of the base metal (Fig. 6). Deformation transformation occurs with the localization of deformation causing serious structural changes. If the structure of the main part of the metal core has the form of oriented α-particles along the flow direction with different degrees of elongation depending on the degree of local deformation, then the structure on the lines of the intensive flow will consist of β-fine grains where the disintegration occurred upon cooling to form dispersed α-plates. Obviously, the temperature of the metal in the localization area is close to the temperature of $\alpha + \beta \Leftrightarrow \beta$-transition due to the local heating, it is evidenced by a decrease in the number of primary α-phase flow in the line of intense and clearly identified converting grain of β-phase.



(a) **(b)**



(c) (d)

Fig. 6: The microstructure of titanium alloy VT3-1, which is upset without laying: (a) H_i/H_0 = 0.9 (extreme part of the blank); (b) H_i/H_0 = 0.9 (the central part of the blank); (c) H_i/H_0 = 0.5 (extreme part of the blank); (d) H_i/H_0 = 0.5 (the central part of the blank)

Analysis of the change of the grain size over the cross section blank at draft in flat dies without running shows (Fig. 7) that the size of the grains have the greatest value in the areas of contact between the metal billet with the tool. Thus, sizes of the grains become smaller in the central zone, the adjacent zones of the blank to the tool and the blank in the fibers, which is located between the central and surface areas.

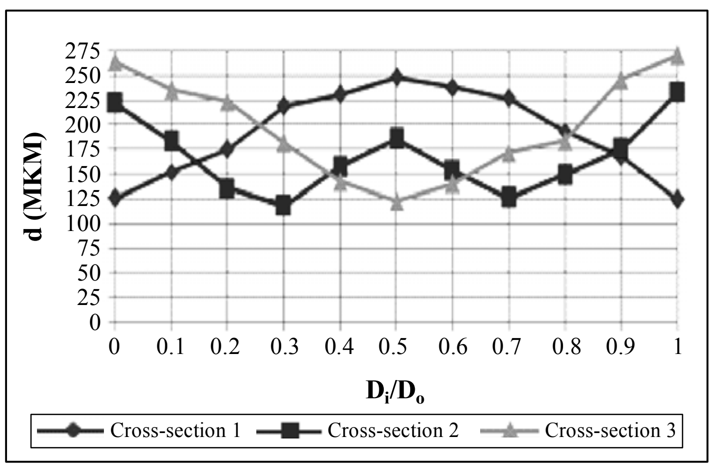
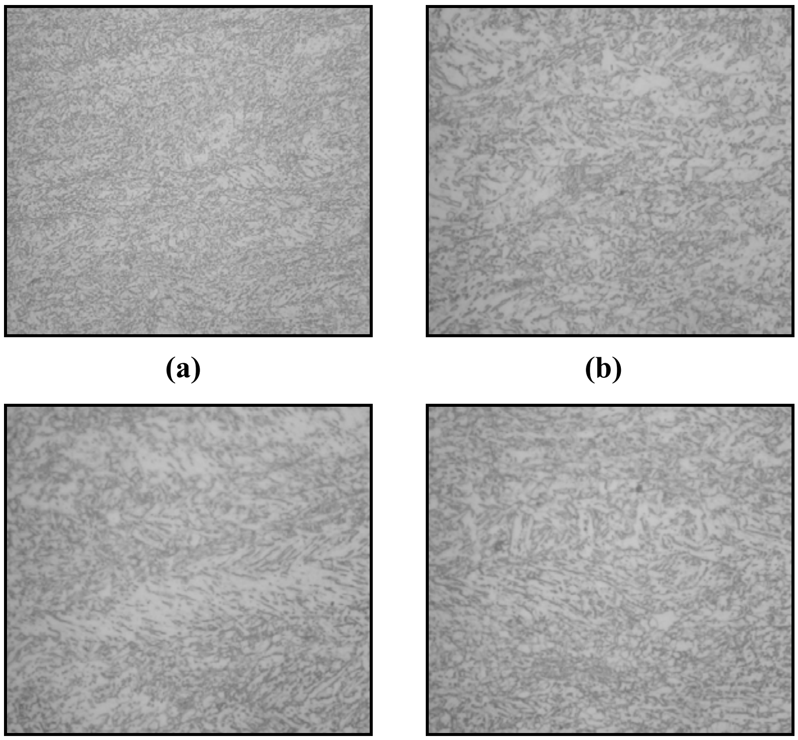


Fig. 7: Change in the size of the grains in the cross section blank on precipitation in the flat dies without laying (cross-section 1 - H_i/H_0 = 0.9, cross-section 2 - H_i/H_0 = 0.75; cross-section 3 - H_i/H_0 = 0.5; H_i - the distance from the end of the billet to the studied point; H_0 - height of the billet)

A smaller volume is observed on the samples deformed with textolite and rubber gasket, pronounced strain localization bands with a well-designed structure (Figs. 8 and 9). Thus, the macrostructure of blanks, which are upset with textolite and rubber gaskets, is relatively more uniform than the metal samples, which are upset without pads in the flat die (Figs. 10 and 11). The dimensions of the grains have a minimum value in the central layers of the billet.



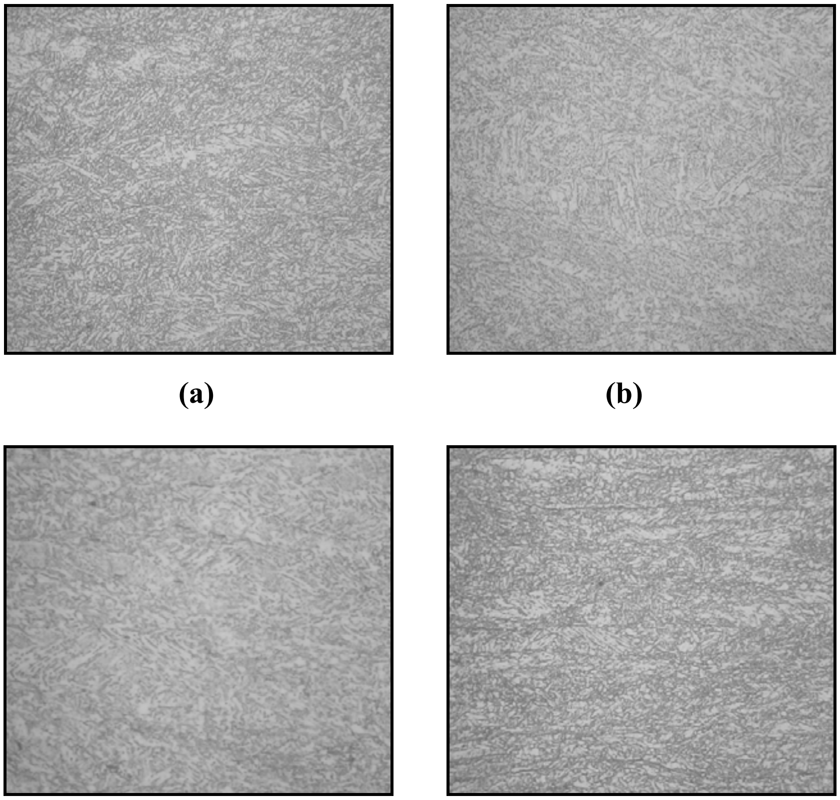
(a) **(b)**

(c) **(d)**

Fig. 8: The microstructure of titanium alloy VT3-1, which is upset by textolite gasket: (a) H_i/H_0 = 0.9 (extreme part of the blank); (b) H_i/H_0 = 0.9 (the central part of the blank); (c) H_i/H_0 = 0.5 (extreme portion of the blank); (d) H_i/H_0 = 0.5 (the central part of the blank)

The data is analyzed on the basis of literature data about the mechanism of plastic strain[12].

It is known[12] that intragranular shear movement of some parts of the crystal (crystallite) relative to the others is the main mechanism of plastic deformation of metals and alloys. Intragranular deformation is carried out by numerous species of dislocation motion.



(a) **(b)**

(c) **(d)**

Fig. 9: The microstructure of titanium alloy VT3-1 which is upset with rubber gasket: (a) H_i/H_0 = 0.9 (extreme part of the blank); (b) H_i/H_0 = 0.9 (the central part of the blank); (c) H_i/H_0 = 0.5 (extreme part of the blank); (d) H_i/H_0 = 0.5 (the central part of the blank)

Twenty percent of the plastic deformation at temperatures $T \geq 0{,}5\ T_{mp}$ (where T_m - melting point) is associated with the grain boundary slippage[12]. Diffusion processes play important role when slipping along the grain boundaries. These processes facilitate both intragranular and intergranular plastic deformation. All of this is connected with the diffusion of relief displacement (slip) of single crystals, facilitated vacancies, concentration and mobility, which increase significantly at high temperatures.

Temperature $0.4T_{pl}$ plays an important role during the strain. At that temperature, the strength of grain boundaries and the body becomes equal. When the temperature shows $T < 0.4T_{mp}$ then the grain boundaries become stronger than their bodies, at $T > 0.34T_{pl}$ – opposite things occur[12].

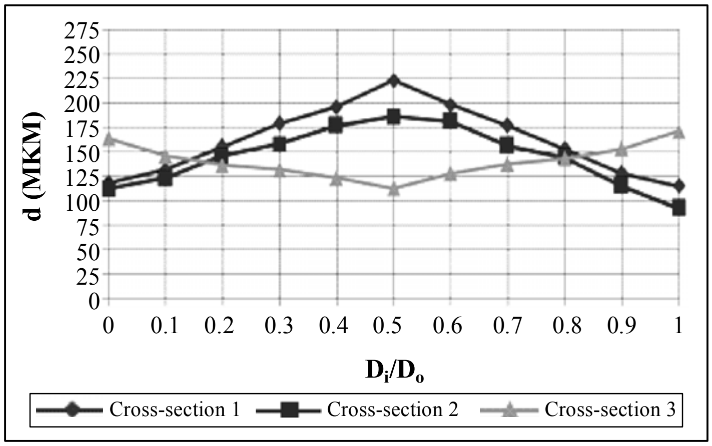


Fig. 10: Change in the size of grains on the cross section of the billet on precipitation in the flat die with textolite gasket (cross-section 1 - H_i/H_0 = 0.9, cross-section 2 - H_i/H_0 = 0.75; cross-section 3 - H_i/H_0 = 0.5)

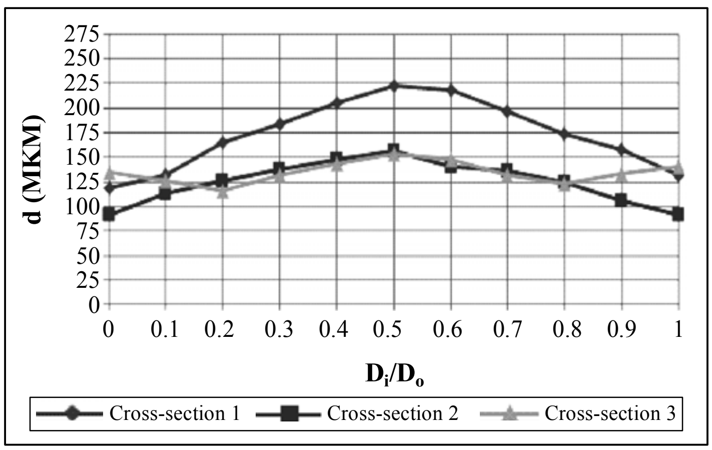


Fig. 11: Change in the size of grains of the section of the billet on precipitation in the flat dies with a rubber gasket (cross-section 1 - H_i/H_0 = 0.9, cross-section 2 - H_i/H_0 = 0.75; cross-section 3 - H_i/H_0 = 0.5)

Several mechanisms are implemented simultaneously in metal forming processes. Type of the crystal lattice, the chemical and phase composition, metal structure, degree, rate, type, temperature, strain, etc. determine the specific contribution of a deformation mechanism[12].

According to the Poluhin et al.[12], the grain boundaries in the metal is not flat, the slippage is carried out on a rough surface. Due to the presence of the projections, even on the atomic scale, it is impossible to direct the grain boundary sliding, because it requires high voltage cut-off ledges. Therefore, sliding along the grain boundaries is not an elementary act of plastic deformation. Its implementation depends on the possibility of accommodative processes. As a result of these processes, the grain boundary becomes flat, there is a possibility of sliding along the grain boundaries as crystallographic slip planes.

In turn, accommodation is controlled by[12]: the elastic displacements; diffusion mechanisms of plasticity; intragranular dislocation glide.

On the basis of numerous experimental data, the authors[12] concluded the following:

- Only the elastic accommodation of slippage is observed at low temperatures and low stresses. While internal stress is not balanced, external elastic accommodation occur slip;
- Accommodation can be diffused at high temperatures and low stresses: the stress across the border can cause diffusion, where the boundary becomes flat;
- Accommodation can occur as a result of plastic deformation at high temperatures and stress: both sides of the grain boundary dislocation motion is carried by slip and climb which removes the material from some parts of the border - projections, and adding it to the others - depression.

Analysis of the results[12] and our findings led to the conclusion that the precipitation samples made of the textolite and rubber create good conditions for intragranular and intergranular strains. This is due to the fact that during the precipitation process of pattern backup strips, deforming elastically, create good conditions for the processes of sliding at the grain boundaries, plastic accommodation and diffusion creep, etc. During the process of precipitation almost in all grains conditions for shear stresses are created. Under their influence inside the grain and on the boundary of it, stress of the shift (τ) occurs, which leads to intergranular and intragranular plastic deformation.

It should be noted that a large number of sliding systems are involved on precipitation with pads in plastic deformation for the following reasons:

(i) On the condition of maximum force occurs the elastic deformation pad creates good conditions for turning the grains at the maximum effort and it causes the maximal occurrence of shear stress in the slip planes of different metal grains and slip planes in the grain boundary zones, which leads to deformations of numerous grains. It contributes to the precipitation in conditions of uniform deformation;

(ii) Good conditions are created for the passage of plastic accommodation processes and diffusion creep, etc. at the time of maximum effort on the precipitation process of the samples with pads; it happens because of the elastic deformation of pads. All of this contributes to the involvement of a large number of grain deformation and conducting operations of precipitation in uniform deformation.

Based on the above data, we have concluded that the cause of increasing efforts on precipitation samples with the elastic gasket is the deformation of the metal, which gains not only intragranular shear displacement and also has a deformation of the grain boundary. It is believed that the combinations of deformation reduce the localization of deformation and heating of the metal in the areas of concentration of deformation by precipitation samples, which are developed in the deformation strain. All of this leads to the increased deformation forces.

Thus, the strain can be distributed even over the cross section of deformed billet by using an elastic pad and developing intragranular and intergranular deformation on the cross section of the billet; by this way forging with a fine-grained structure with high mechanical properties is obtained.

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