Phase transitions in titanium alloys at high-speed mechanical effect

Nikolay A. Krylov, Margarita A. Skotnikova
skotnikova@mail.ru

Abstract

TEM, SEM-technique and X-ray diffraction analysis are used to investigate the structural and phase changes occurring in a material of chip after turning treatment of blanks from titanium alloys PT-3V, VT-23, VT-6 in speed range of cutting 2...275 m/mines and plane targets-samples from VT-6 ($\alpha + \beta$) titanium alloy, processed by a shock wave with the help of a pneumatic gun, within impact velocity range of 400...600 m/s (at speeds of deformation 10^5 – $10^6 s^{-1}$) were investigated. It is shown, that the compressing shock wave modulates a material structure, breaking it on mezo-volumes by the size 100...400 microns, under which boundaries the unloading wave, connecting rotational (rotary) modes, makes located adiabatic shears. Is shown, that on an input the loading wave resulting in decomposition β-phases and enrichment by a vanadium of α-phase up to formation soft orthorhombic of $\alpha^{//}$-phase, braking a shock wave was formed. The shock wave was reflected in an output from the back party and the unloading wave was formed. Here there was a change of the mechanism of plastic deformation, from shift to rotational.

1 Introduction

The high-speed deformation is a modern high-efficiency way of metal materials treatment. In various fields of the industry with success energy of explosion and other methods of reception of shock waves for are ductile, press forming, welding and cutting treatment of materials is used. In practice most difficultly treated the titanium alloys, especially, two-phase of martensite class. It is possible to believe, what is it occurs because of localization of plastic deformation in blank metal in a zone of contact to the instrument, that is caused by their low heat conduction, high contact temperatures, high propensity to structural and phase transformations at deformation are considered.

2 Experiment

2.1 Cutting Treatment of Titanium Alloys

The treatment of titanium alloys PT-3V and VT-23 was carried out by a hard-alloy cutter VK8 without lubrication with a feed speed $S = 0,26$ mm/revolutions and cutting depth $t = 3$ mm, in a range of cutting speeds 2...120 m/mines. The geometrical parameters of a cutter made corners: $\varphi = 45^0$; $\varphi_1 = 15^0$; $\alpha = 6^0$; $\gamma = 12^0$.

2.2 Morphology of Chip

As it is visible from Fig. 1a, at increase of speed of cutting treatment blank from titanium alloy VT-23, the linear wear of the tool was much higher, in comparison with treatment of steel HVG or aluminium alloy AMz. Thus it was formed chip local (adiabatic) shear with traces of localization of plastic deformation (ε_{local}), Fig. 1b. The period of localization (width of chip segments) on the average 300...400 microns.

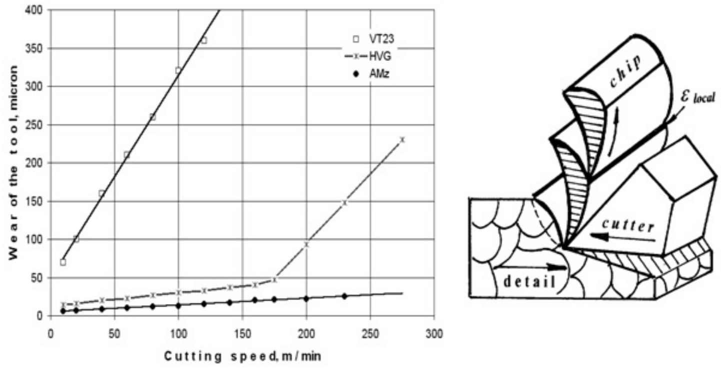

Figure 1: Wear of tool with increase of speed cutting treatment of alloys VT-23 (1), HVG (2), AMz (3), (a). The scheme of Bкadiabatic shiftBњ chip formation (strong localization of plastic deformation) (b).

2.3 Structure of Chip Metal

The structure of blank from titanium alloy VT-23 in an initial state represented colonies of parallel plates of α-phase, disjointed interlayers of β-phase, Fig. 2c. At cutting treatment, beginning already from speed 2 m / mines, the inhomogeneous plastic deformation, its strong localization in narrow iterating with a period 300...400 microns volumes of metal on the mechanism of formation of a superfine structure, Fig. 2d, took place.
As have shown results of scanning electronic microscopy, free surfaces of chips from alloys VT-23 (Fig. 2b) and PT-3V (Fig. 2a) were formed on the rotational mechanism with attributes of destruction in conditions local adiabatic shear.

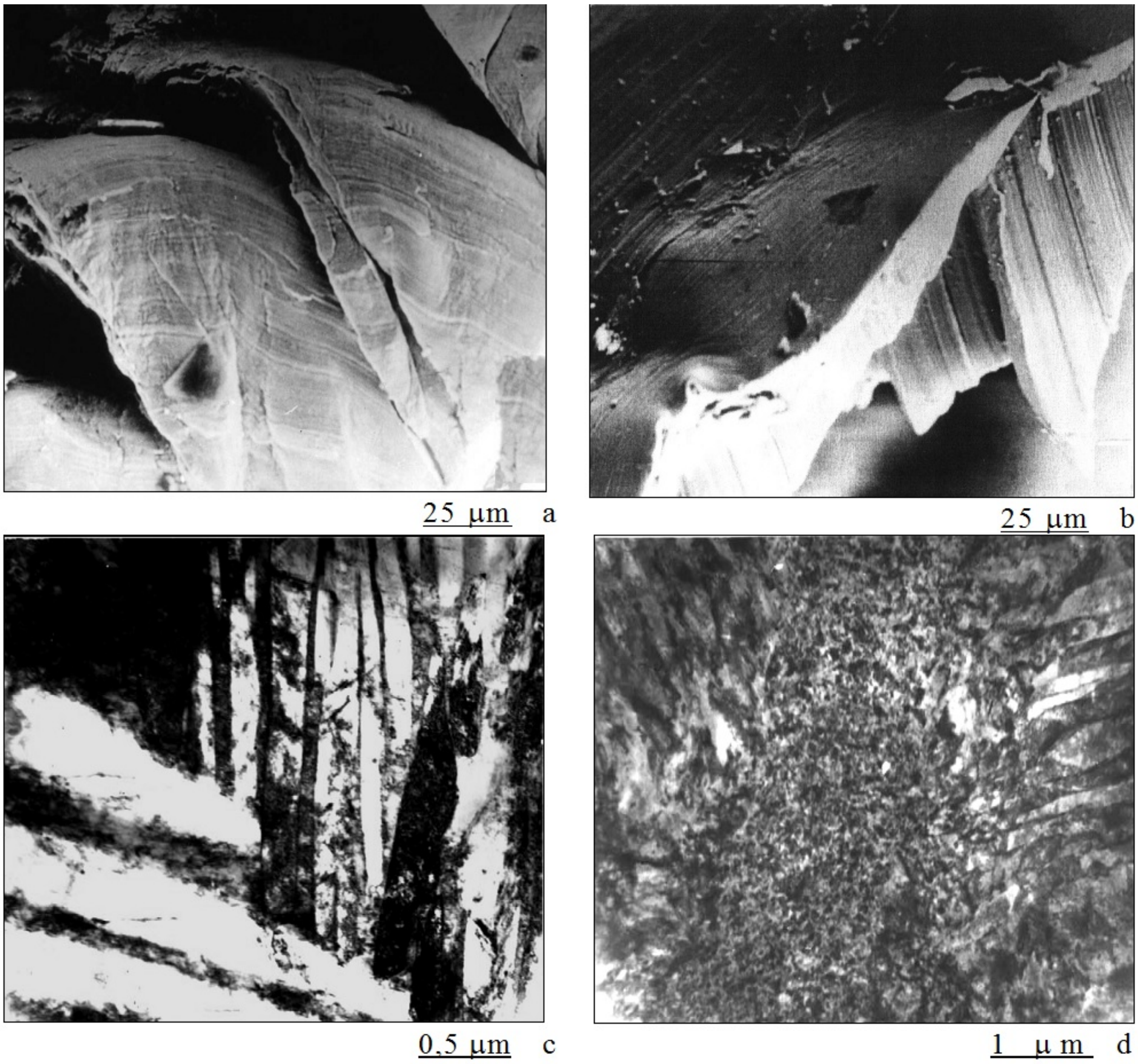

Figure 2: Reference photos of chips surface from alloy VT-23 (b) and PT-3V (a). Structure of chip from alloy VT-23 before (c) and after (d) cutting treatment with speed 120 m/min.

2.4 Estimate of Chip Microhardness

The microhardness testings were made in chip metal from alloy VT23 along a direction of movement of cutter in with speed 120 m/min, with an interval 20 microns at loading of 20 grams. Results of microhardness testing of chips had wavy character, is especial close their free edge, Fig. 3.

The maximal values of microhardness had on places of an articulation of segments of chips, in which with the help of transmission electronic microscopy the localization of plastic deformation on the mechanism of formation of narrow zones has been earlier found out by a superfine structure. Here absolute values of microhardness for alloys VT-23 reached 4381 MPa at average hardness of chips and metal in an initial condition, accordingly 3761 and 3903 MPa. It is necessary to note, that the specified

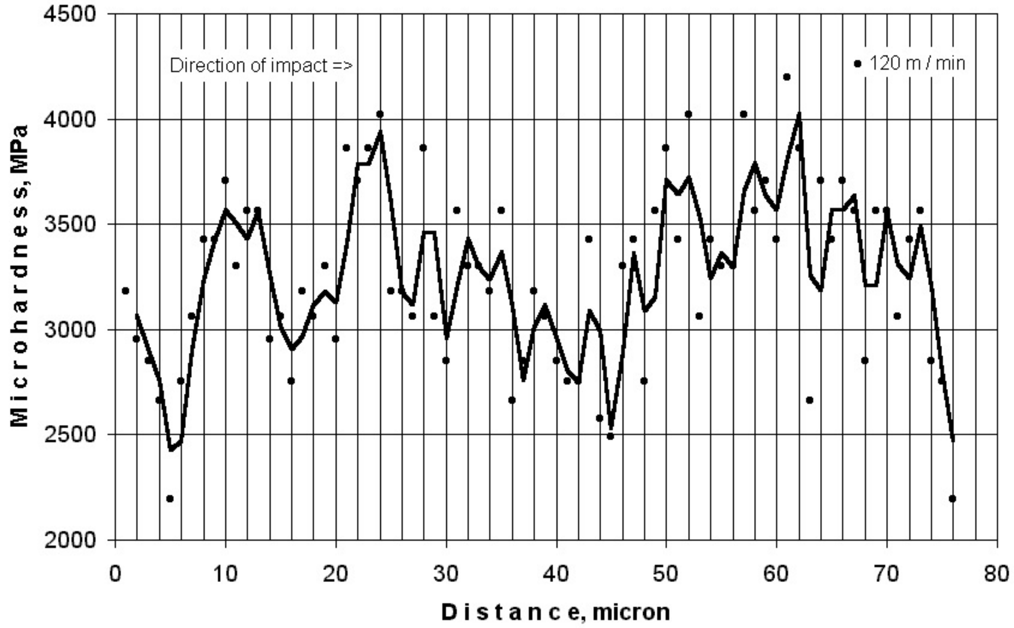

Figure 3: Distribution of microhardness in chip metal from alloy VT23 along a direction of movement of cutter in with speed 120 m/minutes.

changes of structure, Fig. 2d and modulation of microhardness, Fig. 3, near to free edge of chip were more essential, than in at cutter zone that testified to passage there more intensive relaxation processes. Thus, the cutter at the movement along treated blank material forms a wave of compression which modulates material structure, dissecting it on mezo-volumes by the size 300...400 microns. Having reflected from a surface of blank material, the unloading wave of the plastic deformation providing connection of rotational (rotary) modes of plastic deformation and making located adiabatic shears along the boundaries educated mezo- volumes is formed. Dissipative modulation of structure and microhardness in titanium alloys could be the reason of decrease of tool wearproofity.

3 Shock Stressing of titanium alloys

The treatment by a shock wave was carried out in a material of plane blanks - samples from two-phase ($\alpha + \beta$) titanium alloys OT4, VT6 and VT-23, tested by anvil block, or blast wave [1]. Thus blanks have been finished with full destruction with education of two free surfaces or cavities.

3.1 Morphology of destruction of targets- blanks after shock loading

In Fig. 4, the photos and the scheme of destruction of target- blank №2 from the VT6 alloy tested over impact velocity of 568 m/s are submitted. It is visible, that formed turnpike the crack was parallel to a free surface of a target and had the step form.

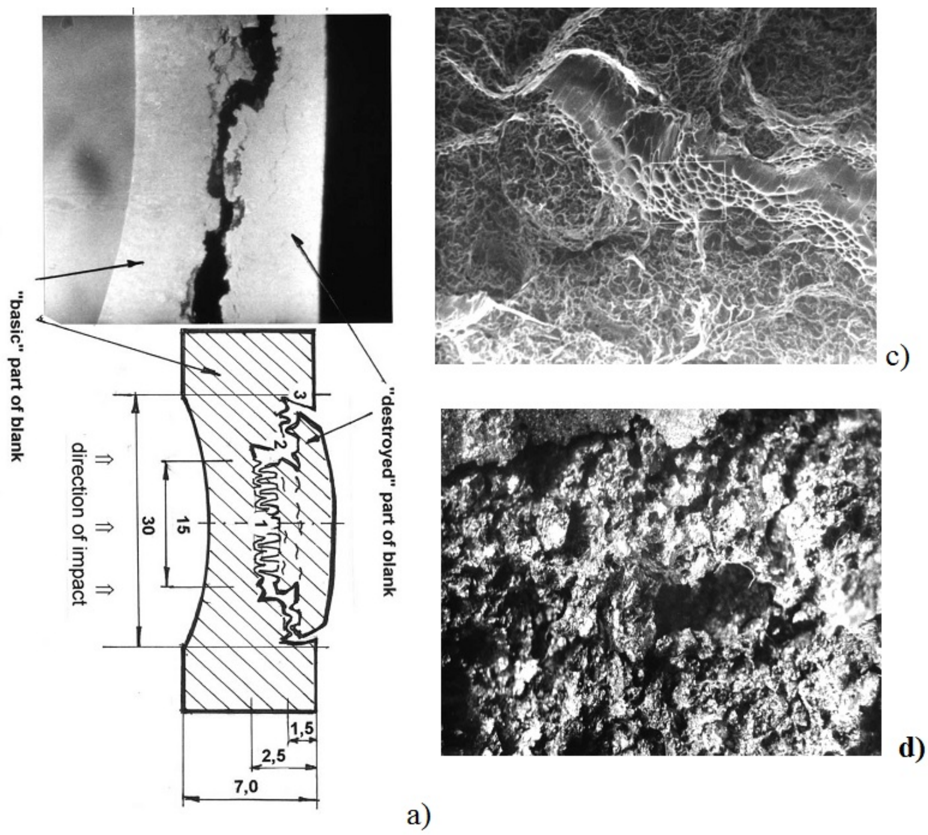

Figure 4: The scheme of destruction of planar target- blank №2, tested over impact velocity of 568 m/s, (b). Sizes are specified in mm. The surface cross-micro-section (a) and free surface of breaking-offs "destroyed" (c) and "basic" (d) parts of target-blank in a zone 1. x 3 (a), x 220 (c), x 14 (d).

It is possible to allocate three stages (3 zones) destructions. Zone 1 - "epicentre" of shock wave in diameter no more than 15 mm, in which characteristic viscous "tunnels" (∅ 100...400 microns) focused along a direction of impact were formed. Zone 2 - "periphery" of shock wave as a ring. Zone 3 - "final destruction". There were, that the surfaces of breaks having at a macro-level antisymmetric character, at micro- level did not coincide. Took place disposal of material, it is especial in a zone 2, Fig. 4(a-b). On Fig. 4(a-d) electron microscope photos of cross-sections and fractures "destroyed" (a, c) and "basic" (a, d) of parts of the target- blank in zone 1 are submitted. It is visible, that fracture of the destroyed blank on mezo- level was formed components of round forms by the size 100...400 microns, Fig. 4(c-d). Such viscous of metal sites could be generated as a result of the rotational mechanism of plastic deformation along narrow micro channels, which direction coincided with a direction of operation of the maximal stress [2]. It is possible to believe, that at the high-speed treatment, the compressing shock wave modulates a structure of target- blank, breaking it on mezo-volumes by the size 100...400 microns, along which boundaries the unloading wave, connecting rotational (rotary) modes, makes located adiabatic shears [2] and destruction.

3.2 Estimation of microhardness of blank metal after shock stressing

On Fig. 5 results of microhardness testing with an interval 20 microns are submitted at loading of 20 grams, in blank metal from alloy VT6 after treatment by a shock wave with speed 568 m/s.

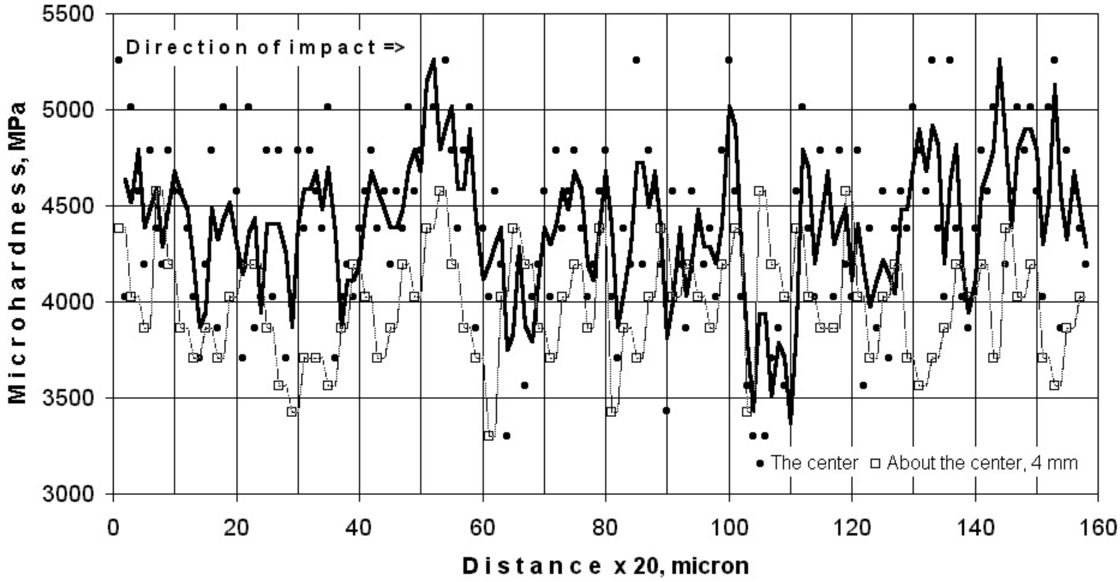

Figure 5: Distribution of microhardness in blank metal from alloy VT6 along a direction of movement of shock wave in a zone 1 with speed 568 m/s

Measurements have been executed starting from edge of "basic" blank part on a trace of movement of wave in the central and peripheral field on distance of 4 mm from the center, in both cases at level of zone 1. Absolute values of microhardness in the center and on periphery reached on the average 4413 and 3996 MPa, accordingly, at average hardness of sample metal in an initial condition 2416 MPa. Apparently from Fig. 5, results of measurement of microhardness after shock stressing had wavy character with the size of a half wave 100...200 microns. In comparison with central, the peripheral wave on distance of 4 mm from the center was in an antiphase and thus, they were self-consistent in mezo-volume 100...200 microns (zone 1). Similar comparative results have been received and at level of zone 2. Peripheral wave on distance of 11 mm from the center, was self-consistent with central less often, but the size of such volumes increased up to 300...600 microns.

3.3 A structure of targets-blanks after shock loading

Structure of blanks metal from alloy VT6, tested anvil block and a blast wave investigated with the help of microhardness measurements, transmission electronic microscopy [5] and X-ray diffraction analysis, Fig. 6.

Results have shown, that with increase of speed of shock wave, took place localization of plastic deformation, to which decomposition of enriched solid solutions

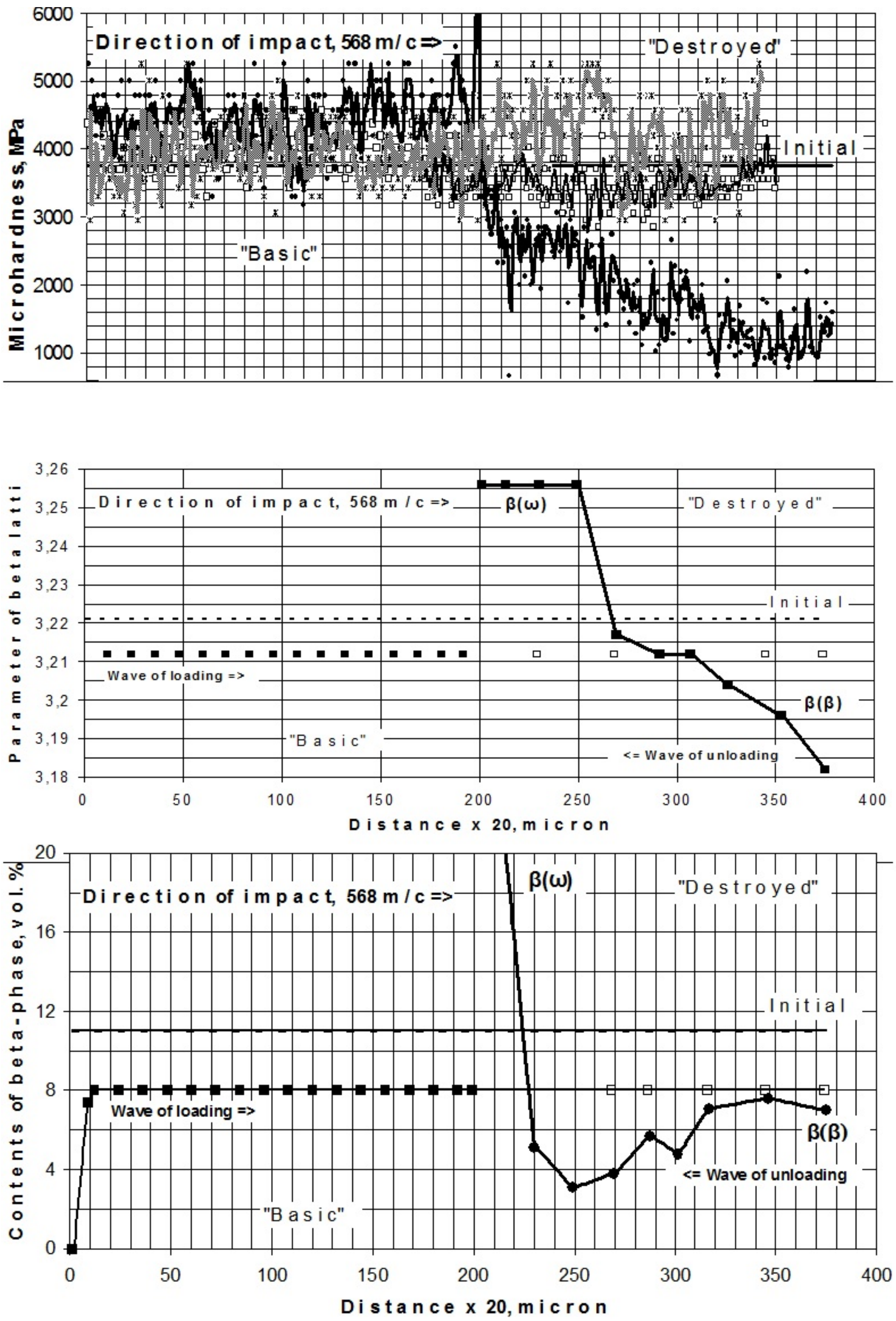

Figure 6: The results of microhardness measurements (a), of analysis parameter lattice (b) and contents (c) of β-phase along the shock wave propagation after shock loading for target-blank №2, tested with impact velocity 568 m/s.

always preceded. In all investigated materials in boundary layers generated mezovolumes, interlayers of β-solid solution under operation of shock wave, were exposed to fractional or decomposition (dissolution) in result $\beta \rightarrow \alpha$-transformation. In such places the structure from fine grains of different orientation which had the heightened microhardness was formed and yielded in condition of microdiffraction "ring" electronogrames,[5], origin of micro-cracks here was observed. Microhardness testing on targets blanks from the VT6 alloy after tested by a shock wave with velocity 568 m/s. On the target №1, remained the whole, results of microhardness measurement changed concerning of an initial level 3760 ± 470 MPa. On the destroyed target №2, along the central zone, microhardness in the "basic" part was above of an initial (4430 MPa), and in "destroyed" parts its sharp decrease up to level 1800 MPa was observed, figure 6 (a). In Fig. 6 (b, c) the results of analysis parameter lattice and contents of β-phase in a target- material №2 before and after shock loading along the shock wave propagation are submitted. As it is seen, in "destroyed" part of target- sample were observed significant changes. Results have shown, that on an input the "loading wave" resulting in decomposition $\beta(\alpha)$ - phases and enrichment by vanadium of α-phase up to formation soft orthorhombic of $\alpha^{//}$-phase, braking a shock wave was formed. As seen in Fig. 6 (c), on an input of target of β-phase was not. The shock wave was reflected in an output from the back party target and the "unloading wave" was formed. Here there was a change of the mechanism of plastic deformation, from shift to rotational [2], and there was an intensive heat-generating, increase of a temperature and opposite $\alpha \rightarrow \beta$ phase transformation. The soft enriched vanadium the $\beta(\beta)$ - phase, was inclined to decomposition up to formation of brittle ω-phase was formed [4]. As seen in Fig. 6 (b), on an output of target, a lattice parameter of β-phase sharply decreased up to level 3,183 A. At movement of the reflected shock wave from the back surface of target- sample, and pauperization of β-phase by vanadium, itвЃЄs a lattice parameter considerably was raised.

4 Conclusion

It is possible to believe, that at the high-speed deformation, compressing the "loading shock wave" modulates material structure, breaking it on mezo-volumes by the size 100...400 microns. Inside formed mezo-volumes the phases of waves are opposite on the sign, that results in a relative relaxation in them of stresses. In titanium alloys of martensite class in which, the "loading wave" resulting in decomposition β-phases with formation $\alpha^{//}$-phases. As a result of self-organizing of system, the "unloading wave" of plastic deformation and destruction, depending on relaxation ability of a material (structural and concentration [3-4], energies of defect of packing, ability of transformation of mechanical energy in thermal, realization of phase transformations) is formed. Here there was a change of the mechanism of plastic deformation, from shift to rotational. Thus there was an intensive heat-generating, increase of a temperature and opposite $\alpha \rightarrow \beta$ phase transformation. By the generated soft enriched vanadium the β-phase, was inclined to decomposition down to formation of brittle ω-phase. In this place the crack was formed.

Acknowledgements

The authors thank Dr. Yu.I. Mescheryakov and S.V. Shtelymakh for help in tests of samples. Work is performed with financial support of the Ministry of Education and Science of the Russian Federation within the grants №933-2014; №1972-2014.

References

[1] Yu.I. Mescheryakov, A.K. Divakov, Institute of Mechanical Engineering Problems, RAS, Russia, Saint-Petersburg, pre-print, 25, 1989.

[2] M.A. Skotnikova, T.I. Strokina, N.A. Krylov, The American Physical Society, Maryland, 2004.

[3] M.A. Skotnikova, M.A. Martynov, S.S. Ushkov, The Germany CCC-Congress Center, Hamburg, 2003.

[4] M.A. Skotnikova, S.S. Ushkov, The Russia Central Research Institute of Structural Materials "Prometey", Saint Petersburg, 1999.

[5] M.A. Skotnikova, N.A. Krylov, J.I. Mescheryakov, The China Beijing conference, Beijing, 2011.

Nikolai A. Krylov, Peter the Great St.Petersburg Polytechnic University, St.Petersburg, Russia

Margarita A. Skotnikova, Pyrotechnics str. 29, St.Petersburg, Russia