# Influence of thermomechanical treatment on structure and properties of VT20 titanium alloy workpieces

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At present, VT20 titanium alloy is widely used in many industries as a structural material. However, the service life of products made of this material is relatively low. Among the most effective methods of increasing the service properties of titanium alloy is its combined treatment, including sequential thermocyclic and static-pulse treatments. However, in modern scientific and technical literature there is no complete information on the combined effect of these types of treatments on the structure and properties of VT20 alloy, which complicates its practical application. Therefore, this work is aimed at studying the effect of thermocyclic and static-pulse treatments on the structure, hardness, wear resistance and roughness of VT20 alloy samples. The studies were carried out using modern equipment and complementary methods of physical materials science. On the basis of the conducted research aimed at studying the effect of both thermocyclic and static-pulse treatments on the structure, hardness, wear resistance and roughness of VT20 alloy samples it was found that the grain size and roughness of samples decreased by almost an order of magnitude, hardness increased by an average of 1.27 times, and volumetric wear of the sample decreased by 1.88 times.

***Key words:*** titanium alloy, thermocyclic treatment, static-pulse treatment, hardness, wear resistance.

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## Introduction

Nowadays VT20 titanium alloy is widely used in many industries as a structural material for manufacturing almost all kinds of parts and structures operating at temperatures from –70 to 500 °C. This alloy has a relatively low density (much lighter than iron), high strength, heat resistance (twice as strong as iron) and anti-corrosion properties, which allow to reduce the weight of products compared to steels and aluminum alloys [1–3].

Despite the presence of a significant number of positive properties, titanium alloys are less technologically advanced than steels and aluminum alloys due to a number of specific technological properties, including relatively low surface hardness and low wear resistance, as well as the limited possibility of cold deformation and hardening in this state, which significantly reduces the areas of their practical application [4–6].

At present, the main way to harden the surface of titanium alloys is chemical heat treatment (CHT), which along with surface hardening leads to deterioration of other equally important operational properties such as toughness and ductility.

In this connection, there is a scientific and practical interest related to the development of new technologies allowing to form surface structures with high performance properties on titanium alloys at minimum energy and time consumption [8–10].

Currently, one of the most promising ways to improve the strength of VT20 wrought alloy is thermocyclic treatment (TCT), in which the improvement of the structure and increase in mechanical properties of the alloy occurs as a result of multiple repeated cycles of heating and cooling accompanied by phase and structural transformations [11–14]. At the same time, the analysis of modern methods of hardening the surface of machine parts shows that one of the most promising, but not industrially used meцhods of hardening alloys, including VT20 alloy, in the cold state is static-pulse treatment (SPT), in which the hardened structure of the alloy is formed by shock waves of deformation [15–19].

Earlier studies on hardening of steel workpieces by SPT have shown high efficiency and productivity of such treatment. At static-pulse treatment favorable compressive residual stresses are formed in the surface layer of the hardened parts, increasing the performance characteristics. However, the influence of static-pulse processing on the structure and properties of VT20 alloy has not been studied, which complicates its practical application.

TCT and SPT of titanium alloys are new technologies that allow to form a hardened surface layer with high performance properties on titanium alloys at minimum energy and time consumption.

However, in modern scientific and technical literature there is no full-fledged information on the joint influence of TCT and SPT on the structure and properties of VT20 alloy, which complicates their practical application.

Table 1
**Chemical composition of VT20 material, wt %.**

| Ti | C | Si | Mo | V | N | Fe | Al | Zr | O | H | Impurities |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 85.15–91.4 | up to 0.1 | up to 0.15 | 0.5–2 | 0.8–2.5 | up to 0.05 | up to 0.25 | 5.5–7 | 1.5–2.5 | up to 0.15 | up to 0.015 | oth. 0.3 |

Table 2
**VT20 alloy grain size**

| Test sample | Grain size, µm |
|---|---|
| non-hardened | 172.134 |
| hardened by TCT | 122.906 |
| hardened by TCT + SPT | 43.3 |

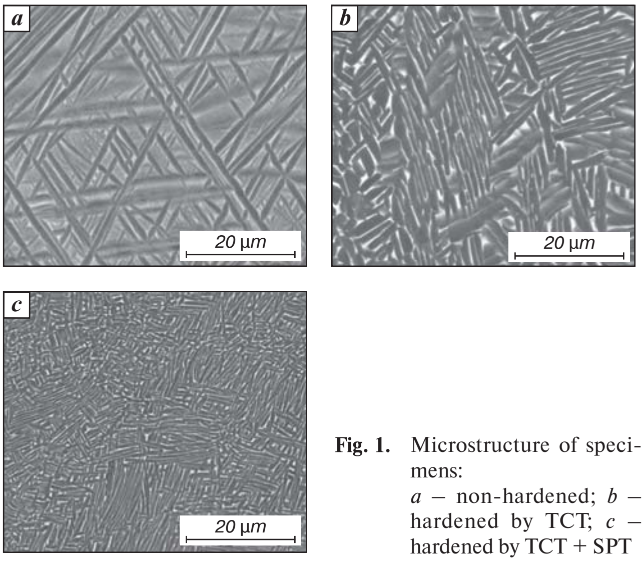

**Fig. 1.** Microstructure of specimens:
*a* – non-hardened; *b* – hardened by TCT; *c* – hardened by TCT + SPT

***The purpose of this work*** is to study the effect of thermocyclic and static-pulse treatments on the structure, hardness, wear resistance and roughness of VT20 alloy samples.

## Materials and methods

To perform the intended research, workpieces in the form of a bar with a diameter of 10 mm, made of VT20 wrought titanium alloy were selected. The chemical composition of the alloy in accordance with GOST 19807–91 is presented in **Table 1**.

TCT of the bar was carried out on the IMASh 20-78 machine with heating from temperature 800 °C to 1100 °C, at heating rate 12 °C per second, in vacuum at $1 \cdot 10^{-4}$ Pa. The cooling rate from 1100 °C to 800 °C was 6 °C per second. The number of cycles was equal to 10.

SPT of the bar was carried out on a screw-cutting lathe of 16K20 model. Machining modes: rotational speed of the workpiece – $V_w$ = 80 ... 100 m/min, longitudinal tool feed – $S_l$ = 1.5 ... 2.0 mm/rev. The value of the force of static tool compression to the machined surface was $P_{st} \geq 2.5 \ldots 4.0$ kN, and the impulse force was $P_{im}$ = = 25.5 ... 40.0 kN [20].

The microstructure of the alloy samples was investigated by scanning electron microscopy using a QUANTA 600 FEG electron microscope. The surface of the sample was ground, polished and etched. Abrasing was performed with metallographic paper with coarse (Nos. 60–70) and fine grain (Nos. 220–240). During abrasing, the sample was periodically rotated by 90°. Abrasive particles were washed off with water and polished on the wheel with metal oxide suspensions ($Fe_3O_4$, $Cr_2O_3$, $Al_2O_3$). After achieving a mirror shine, the surface of the polish was washed with water, alcohol and dried with filter paper.

Samples of VT20 wrought titanium alloy hardened by TCT and SPT treatment and untreated samples were investigated on modern research equipment.

Rockwell hardness of the samples was determined using an Instron 600 MRD (UK) in accordance with GOST 23677–79.

The surface wear resistance of the samples was measured on a computer-controlled automated friction machine (Tribometer, CSM Instruments, Switzerland).

The roughness of the samples surface layer was determined on an automated precision contact profilometer “SURTRONIC 25” (UK). The linear profile of the surface was determined by measuring the vertical deflection of a diamond tip (stylus) moving under a minimum load at a constant speed under conditions of mechanical contact with the specimen. The obtained data were transferred to a computer for further analysis using Talyprofile software. The program calculated the parameters.

## Results and discussion

The results of microstructure study of VT20 wrought titanium alloy samples on electron scanning microscope “QUANTA 600 FEG” in the mode of backscattered electrons are shown in **Fig. 1**.

**Table 2** shows the results of grain size study of VT20 alloy before and after treatment.

From **Fig. 1** and **Table 2**, it can be seen that TCT of the sample contributes to the grain size change in the hardened VT20 alloy. At TCT, the plates of the original structure of VT20 alloy α-phase (dark) become rounded and surrounded by β-phase (light) and its content increases.

**Table 3** shows the results of VT20 alloy phase composition before and after treatment.

It can be seen from Table 3 that TCT of VT20 sample contributes to the significant reduction of β-Ti unstable phase from 7.55% to 0.37%.

Experimental studies of hardness of VT20 sample by Rockwell on 600 MRD Instron device showed the following results: non-hardened sample - HRC 30 ± 2; sample hardened by TCT + HRC 34 ± 2; sample hardened by TCT + SPT – HRC 38 ± 2.

The data obtained show that the hardness of VT20 wrought titanium alloy treated by the TCT method

Table 3
**Phase composition of VT20 alloy**

| Sample | Phase | | | |
|---|---|---|---|---|
| | α-Ti | | β-Ti | |
| | Lattice constant, Å | Content, % | Lattice constant, Å | Content, % |
| non-hardened | $a = b = 2.933712$;<br>$c = 4.679314$ | 92.45 | $a = b = c = 3.253461$ | 7.55 |
| hardened by TCT | $a = b = 2.924906$;<br>$c = 4.668977$ | 99.63 | $a = b = c = 3.239141$ | 0.37 |
| hardened by TCT + SPT | $a = b = 2.927594$;<br>$c = 4.677625$ | 99.68 | $a = b = c = 3.244137$ | 0.32 |

increased on average by 4 units, and in the case of application of the TCT + HRC method the hardness of the samples increased by another 4 units. In general, thermomechanical treatment of VT20 alloy samples resulted in hardness increase by 1.3 times. This result was promoted by grain refinement of the alloy and reduction of the amount of β-Ti phase.

Average values of friction coefficient and volumetric wear obtained during tests of 5 samples of VT20 alloy on a high-temperature tribometer manufactured by CSM Instruments are shown in **Table 4** and **Fig. 2**.

On the basis of tribological studies, the VT20 alloy samples hardened with TCT have better wear resistance indicators in comparison with non-hardened ones, namely, the friction coefficient is 1.1 times less, and the volumetric wear of the sample is 1.3 times less. This result was promoted by grain refinement of the alloy and reduction of the amount of β-Ti phase.

It can also be seen from **Table 1** that SPT of VT20 titanium alloy sample additionally contributes to 1.4 times reduction of friction coefficient and 1.5 times reduction of volumetric wear of the sample, respectively.

In general, thermomechanical treatment of VT20 alloy samples resulted in a decrease in the coefficient of friction by 1.57 times and volumetric wear of the sample by 1.88 times.

This result was achieved by a more fine-grained and high-hardness surface structure of the hardened material, as well as low roughness.

The results of surface roughness studies of VT20 alloy samples on an automated precision contact profilometer Surtronic 25 are presented in **Fig. 3**.

On the basis of roughness studies it was determined that VT20 alloy samples hardened by the TCT + SPT method have better indicators in comparison with non-hardened ones, namely Rmax 0.75 microns and Rmax 7.4 microns, respectively. This result was achieved by the technology of surface plastic deformation accomanied by static-pulse processing. After TCT, there was no significant change in the surface roughness of the samples, so the surface profilogram is not present.

It has been experimentally established that thermocyclic treatment of pseudo-α-titanium alloy in the

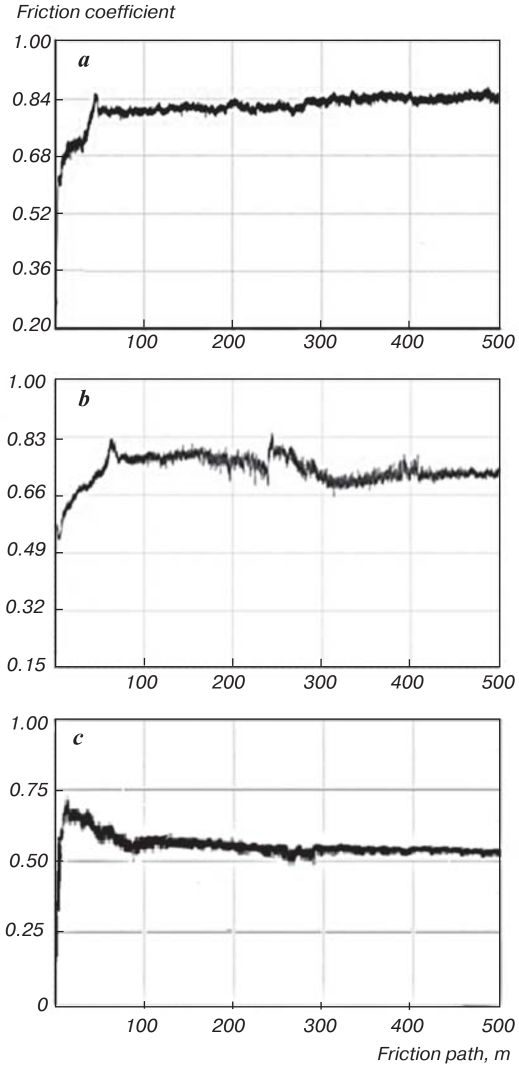

**Fig. 2.** Results of tribological tests of samples:
*a* – non-hardened; *b* – hardened by TCT; *c* – hardened by TCT + + SPT

Table 4
**Tribological characteristics of the tested samples**

| Sample | Friction coefficient (μ) | | | | | Volumetric wear of the counterbody, $mm^3 \cdot H^{-1} \cdot m^{-1} \cdot 10^{-5}$ | Volumetric wear of the sample, $mm^3 \cdot H^{-1} \cdot m^{-1} \cdot 10^{-5}$ |
|---|---|---|---|---|---|---|---|
| | Initial | Minimum | Maximum | Average value | Mean average deviation | | |
| non-hardened | 0.237 | 0.237 | 0.876 | 0.817 | 0.050 | 0.161 | 8.145 |
| hardened by TCT | 0.197 | 0.197 | 0.845 | 0.738 | 0.047 | 0.048 | 6.557 |
| hardened by TCT + SPT | 0.047 | 0.192 | 0.712 | 0.52 | 0.052 | 0.032 | 4.326 |

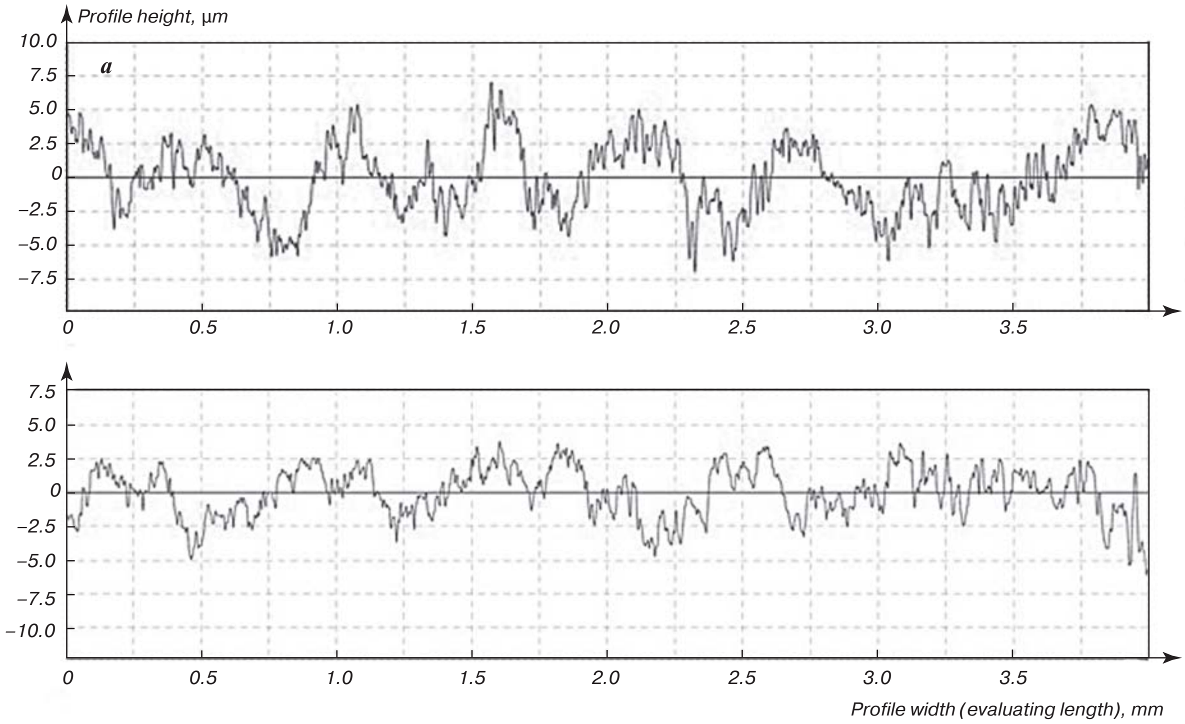

**Fig. 3**. Profilograms of samples surfaces:
*a* – non-hardened; *b* – hardened by TCT; *c* – hardened by TCT + SPT

temperature region of polymorphic transformation causes grain refinement and a decrease in the amount of β-Ti phase, which provides an increase in hardness and wear resistance. Static-pulse processing of pseudo-α-titanium alloy, in turn, leads to grain size reduction, roughness reduction, which also contributes to hardness improvement and roughness reduction.

The obtained results can be used in the development of technologies for hardening of materials manufactured on the basis of resource-saving technologies in order to improve their operational properties [20, 21].

## Conclusion

Thus, thermomechanical treatment of VT20 alloy samples, including sequential TCT and SPT, is a promising direction for improving the operational properties of titanium alloys.

1. On the basis of the conducted research aimed at studying the influence of both thermocyclic and static-pulse treatments on the structure, hardness, wear resistance and roughness of VT20 alloy samples, the following was established:

– grain size and roughness of samples decreased by almost an order of magnitude;

– hardness increased by an average of 1.27 times;

– friction coefficient decreased by 1.57 times and volumetric wear of the sample by 1.88 times.

2. It is noted that TCT and SPT of VT20 titanium alloy are promising technologies allowing to form a hardened surface layer with high operational properties on titanium alloys at minimum energy and time consumption. Repeated heating-cooling cycles during TCT lead to hardening due to coagulation of α-grains. Strengthening of VT20 alloy samples by SPT is achieved as a result of short-term impact of a prolonged energy pulse on the deformation center. At similar degrees of surface layer hardening the value of the static component of the load by the proposed device is much smaller.

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