doi: 10.56761/EFRE2024.C3-P-054901

# Oxidation resistance research of TC-25 alloy

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**Abstract.** In the work the change in the composition, structure and properties of the surface of a titanium alloy during high-temperature oxidation was investigated. Oxidation was carried out in air at a temperature of 700 °C for 1, 3 and 5 hours. As a result of oxidation, a layer of oxides is formed on the surface, identified by X-ray diffraction analysis. The formation of oxides on the surface is also evidenced by an increase in the mass of the sample. The oxide layer affects the mechanical properties of the surface. The hardness of the alloy was measured using the Vickers method; as a result of oxidation, the hardness of the alloy surface increases. In this case, a large fluctuation in surface hardness values is observed during long-term oxidation (5 hours), associated with the heterogeneity of the oxide layer. Oxidation causes an increase in abrasive resistance during dry friction. During long-term annealing (5 hours), fluctuations in the friction coefficient are observed due to oxidation processes.
**Keywords:** annealing, rutile, titanium solid solution, hardness, friction, phase composition.

## 1. Major sections

The working environment of titanium alloys and, in particular, of the studied TC-25 alloy is high-temperature, due to its widespread use in the aviation industry. Titanium alloys have high indicators of important applied properties: low density, high hardness, corrosion resistance. During the work, studies were carried out on the effect of high-temperature oxidation in air on mechanical properties and phase composition. The sample was subjected to isothermal annealing at a temperature of 700 °C for 1 hour, 3 hours and 5 hours. The elemental and phase composition of the TC-25 alloy sample was studied; the values of hardness, mass and friction coefficient were obtained for each annealing time.

### *1.1. Elemental composition of the TC-25 alloy*

The elemental composition was obtained using X-ray microanalysis. Several sections of the sample were studied at different annealing times. Based on the data obtained, the values were averaged over the entire surface; the result is presented in Table 1.

**Table 1**. Elemental composition of the alloy at different annealing times (*t*).

| *t*, h | Elemental composition, at. % | | | | | | |
|---|---|---|---|---|---|---|---|
| | Al | Ti | V | Zr | Mo | Sn | O |
| 0 | 10.9 | 84.9 | 2.2 | 1.3 | 0.7 | 0.7 | – |
| 1 | 6.1 | 49.9 | 1.7 | 0.7 | 0.6 | 0.6 | 42.1 |
| 3 | 5.7 | 40.6 | 1.3 | 0.5 | 0.1 | 0.4 | 52.6 |
| 5 | 4.1 | 35. 2 | 0.6 | 0.5 | 0.4 | 0.4 | 59. 3 |

Intense diffusion of oxygen into the sample is observed within an hour of heat treatment. Its content was 42 at. % on the surface of the sample. With further high-temperature oxidation, the increase in oxygen content in the sample slowed down, which indicates the formation of a barrier layer of oxides on the surface of the titanium alloy, preventing further penetration of oxygen.

### *1.2. Phase composition of the TC-25 alloy at different annealing times*

After an hour's annealing, the oxygen content in the surface layers was 42 at. %, which led to the appearance of additional peaks in the X-ray diffraction pattern related to oxide phases.

The main phase of the initial sample is a solid solution of alloying elements in the HCP titanium lattice. The main alloying element is aluminum (Table 1). Diffraction peaks related to the β-Ti(V, Mo, Zr, Sn) solid solution, which has a BCC lattice structure, were also detected.

After annealing, a displacment of the diffraction peaks towards smaller angles was observed. This indicates a decrease in interplanar distances. Diffraction peaks appear that are related to the oxide phase of rutile, which has a tetragonal crystal lattice. A decrease in the intensity of diffraction peaks related to the solid solution of alloying elements in the HCP titanium lattice indicates the diffusion of oxygen into the studied alloy and its introduction into the titanium lattice.

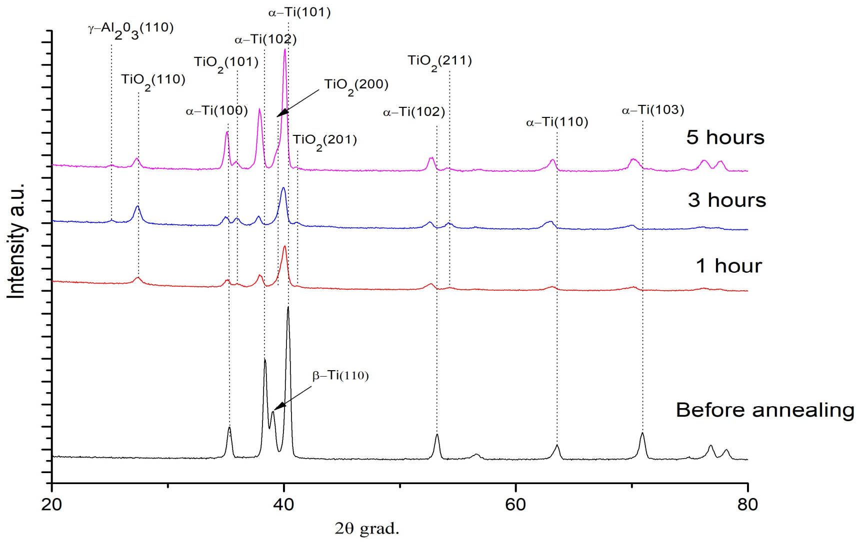


Fig. 1. X-ray diffraction patterns of TC-25 before annealing and after 1, 3 and 5 hours of annealing.

When annealing for 3 hours, the intensity peaks decrease and shift towards smaller diffraction angles. The appearance of diffraction peaks related to the $\gamma$-$Al_2O_3$ phase is also observed [2].

However, when the oxidation time is increased to 5 hours, a sharp jump in intensity and a decrease in the half-width of the main peak (α-Ti(100)) is observed, which may be caused by the process of primary recrystallization of grains in the titanium solid solution.

According to the known relationship between the parameters of the hexagonal lattice and the Wulff-Bragg formula: $2d\sin(\theta) = m\lambda$ , The values of the titanium lattice parameters were calculated:

$$\frac{1}{d^2} = \frac{4}{3} \cdot \frac{\left(H^2 + KH + K^2\right)}{a^2} + \frac{L^2}{c^2}, \tag{1}$$

where $a$ and $c$ are the parameters of the elementary lattice.

The calculation results are listed in Table 2.

As the annealing time increases to 3 hours, both parameters increase their value, but with a subsequent increase in time they decrease.

**Table 2.** Unit lattice parameters ($a$, $c$) for different annealing times ($t$) at a temperature of 700 °C.

| $t$, h | $a$, nm | $c$, nm |
|---|---|---|
| 0 | 0.2 935 ± 0.0079 | 0.4693 ± 0.0072 |
| 1 | 0.2948 ±0.0079 | 0.4748 ± 0.0073 |
| 3 | 0.2964 ± 0.0 080 | 0.4754 ± 0.0073 |
| 5 | 0.2952 ± 0.0079 | 0.4 750 ± 0.0064 |

*1.3. Mechanical and tribological properties of TC-25 alloy*

Due to the increase in oxygen content and the formation of oxides on the surface, the mass of the sample was measured.

The biggest increase in mass is observed with increasing annealing time from 3 hours to 5 hours, which corresponds to 52.6 at.% oxygen (Table 1).

To gain insight into the effect of oxidation processes on the surface layers, the hardness and friction coefficient of the sample were measured.

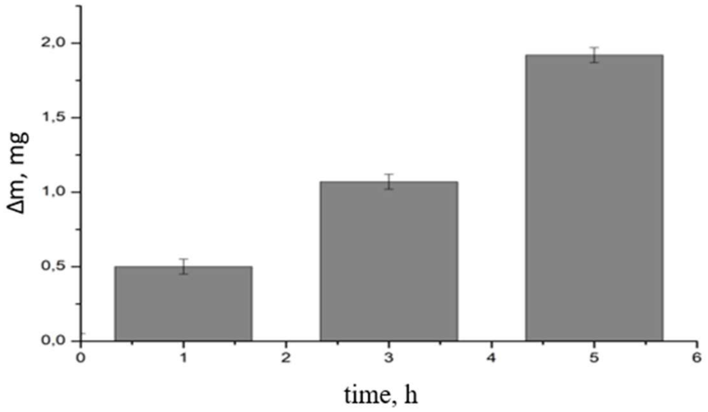


Fig. 2. Dependence of mass change ($\Delta m$) on annealing time ($t$).

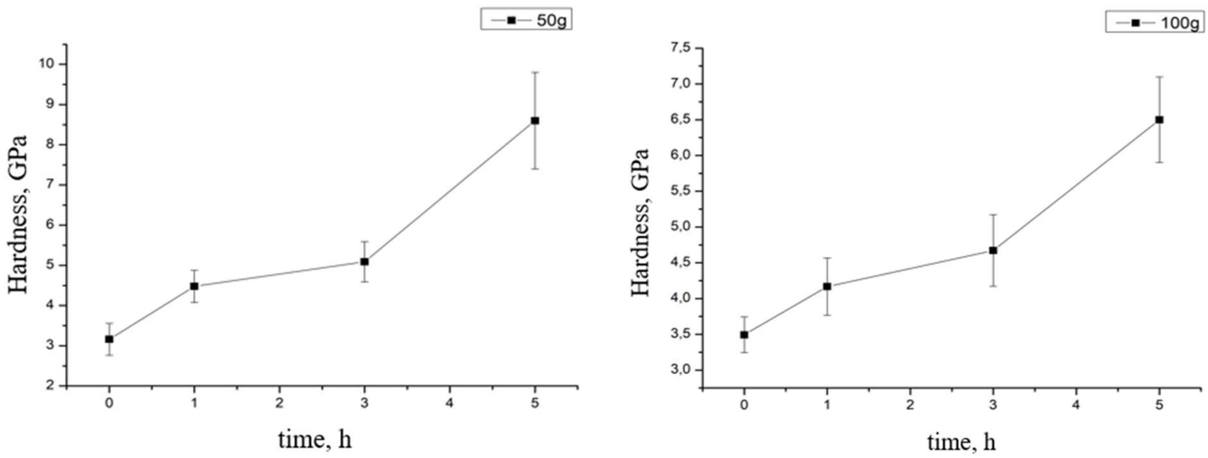


Fig. 3. Dependence of sample hardness on annealing time ($t$), measured at loads of 50 and 100 grams.

An increase in sample hardness was revealed with increasing oxidation time, which indicates the formation of oxides on the surface, the hardness of which is greater than the hardness of the alloy under study [1]. There is a twofold jump in hardness after 5 hours of annealing compared to 3 hours, as well as a significant discrepancy in this value over the entire surface of the sample, which can be seen in Fig. 3. in the form of an increased error for 5 hours. This indicates an increased degree of sample heterogeneity after 5 hours of annealing compared to previous times of heat treatment.

When measuring the friction coefficient, there is a significant change in the average value of the friction coefficient during annealing for 1 hour (from 0.50 to 0.15), as well as a strong smoothing of the dependence, where for the original sample it is fair to note that it was rough, and for the heat-treated sample time hour – smoother and its surface is uniform. This indicates the formation of an oxide layer on the surface.

When studying the dependence obtained for 3 hours, an increase in the average friction coefficient by 0.07 was noticed. The uniformity of the surface is also maintained. The initial portion of the dependence can be explained by the fact that the indenter reached a steady state. Although it can be argued that the surface becomes more uniform due to the parallel orientation of the curve relative to the axis of the friction path.

After 5 hours, a significant change in the dependence is observed: a strong fluctuation in the values of the friction coefficient occurs and the range of values of the friction coefficient increases greatly relative to the previous measured values. This can be explained by the formation of local areas saturated with oxides, which indicates a high degree of heterogeneity.

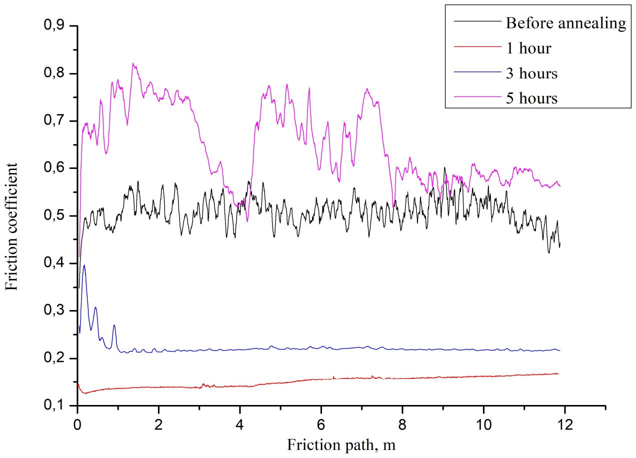

Fig. 4. Dependence of the friction coefficient on the friction path of the sample before annealing and after annealing for 1, 3 and 5 hours.

Optical images of wear tracks were obtained corresponding to different heat treatment times (for 3 hours of annealing there is no image due to the fact that the track depth was comparable to surface irregularities). As mentioned above, there is an increase in the degree of surface heterogeneity with increasing annealing time from an hour to 5 hours, and the surface of the sample after an hour's heat treatment became smoother in comparison with the original one.

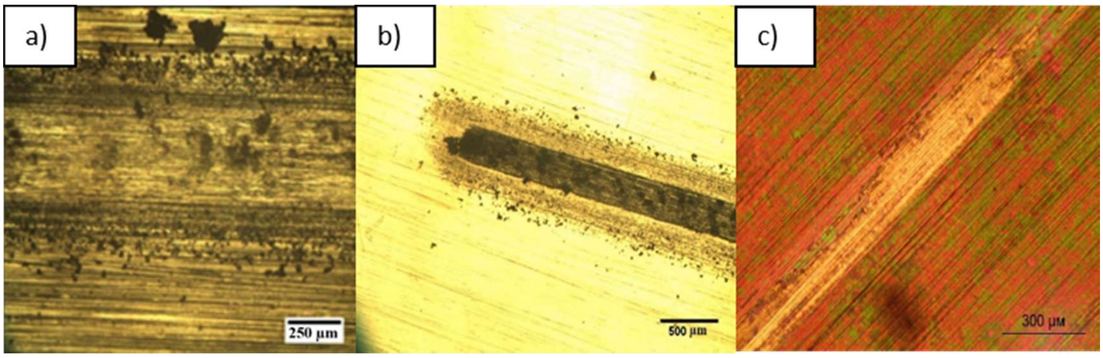

Fig. 5. Optical image of the track a) of the original sample, b) after 1 hour of annealing, c) after 5 hours of annealing.

To assess abrasive resistance, the transverse dimensions of the tracks were measured in several places and average values were obtained. For the initial sample, the transverse width of the track was 510 µm, after 3 hours of annealing – 370 µm, after 5 – 160 µm. A decrease in this value indicates an increase in the abrasive resistance of the sample with increasing heat treatment time.

## 2. Conclusion

In this work, a study was made of the effect of heat treatment on the composition and functional properties of titanium alloy TC-25. It can be concluded that the oxidation process is expressed in the appearance of oxide phases in the structure of the sample: rutile for one-hour annealing and $\gamma$-$Al_2O_3$

after three hours. In connection with their formation, an increase in the hardness of the sample was recorded, since the hardness of the oxide film on the surface exceeds the hardness of the TC-25 alloy.

The oxidation process is also expressed in an increase in the unit cell parameters of the titanium solid solution with an increase in annealing time to 3 hours. After 5 hours, a sharp jump in the intensity values of the peaks of the solid solution of alloying elements in the lattice of the α-Ti solid solution is observed in the X-ray diffraction pattern.

The mass of the sample, as well as its hardness, increased with increasing hardness. However, after 5 hours there was a strong fluctuation in the hardness values along the surface of the sample, which is also characteristic of the friction coefficient.

## 3. References

[1] M.D. Kiran, H.K.Govindaraju, T. Jayaraju, Evaluation of Mechanical Properties of Glass Fiber Reinforced Epoxy Polymer Composites with Alumina, Titanium dioxide and Silicon Carbide Fillers, *Elsevier*, vol. **5**, 22355, 2018; doi: 10.1016/j.matpr.2018.06.602

[2] H. Guleryuz, H. Cimenoglu, Oxidation of Ti–6Al–4V alloy, *Journal of Alloys and Compounds*, vol. **472**(1–2), 241, 2009; doi: 10.1016/j.jallcom.2008.04.024