Study of the hardness distribution after induction heat treatment of titanium over the surface and the cross-section

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Abstract. In this work, the mechanical properties (microhardness) of a titanium disk after induction heat treatment (IHT) were studied. The influence of the processing parameters (inductor current and temperature) on the distribution of microhardness over the cross-section of the experimental samples was established.

1. Introduction
Currently, there is a growing demand for the use of titanium and its alloys in various industries, as well as in the field of biomedicine [1]. For this reason there is a need in studying the ways to modify its structure. The problem of using commercially pure titanium in medicine is associated with low values of tribological characteristics [2,3]. One of the options for increasing physical and mechanical parameters, in particular hardness, and reducing the friction coefficient is the formation of oxide-ceramic structures by chemical-thermal treatment [4,5]. Such structures can be obtained by methods of physical or chemical vapor deposition (PVD and CVD), ion implantation, nitriding, carburizing or laser surface treatment in various atmospheres. Examples include carbide, nitride, oxide structures and their combinations.

To obtain nanostructured coatings with enhanced physical and mechanical properties, the Aerosol Assisted Chemical Vapor Deposition (AACVD) method is used [6]. This method can be used to obtain nanostructured morphology. Achieving durable, wear-resistant and biocompatible coatings is also possible using the plasma electrolytic oxidation method.

2. Methodology
The samples to be studied were prepared from commercially pure titanium (VT1-00) and had cylindrical shapes (diameter 14 mm, thickness 2 mm). Prior to the induction heat treatment (IHT), the surface of the samples was processed by stepwise grinding by abrasive paper (P400 – P2500) until the surface roughness Ra = 0.16–0.32 μm was obtained. Another stage preceding IHT included the washing of the samples in ethanol.

IHT of titanium disks was performed using "HF-15A" setup. The treatment comprised three stages: intense heating, exposure and free cooling in the open air. The main processing parameters were the inductor current, temperature and processing duration. The temperature range corresponded to T = 900–1500 °C (±50 °C) with a duration t = 1–3, 60, 120, 300 s. The inductor current value ranged from 2.5 to 3.5 kA.
Figure 1. The process of induction heat treatment: 1 – an inductor, 2 – a quartz tube, 3 – a sample.

The microhardness over the surface and the cross-section of the sample was measured using "PMT-3" hardness tester (GOST 9450-76). The load on the indenter was 0.19 N. A microsection was made to measure the microhardness over the cross-section of the sample. The beginning of the measurement (from the surface of active saturation with air oxygen) was performed stepwise (50, 150, 200, 300, 400, 500, 750, 1000 μm). The temperature during IHT was controlled by thermal imaging analysis and colorimetric method (using a heat color scale). The operating current was measured using "UNI-T UT205" current clamp.

3. Results
The samples subjected to IHT were divided into three groups: low temperature (900–1100 °C), medium temperature (1150–1250 °C), and high temperature ones (1300–1500 °C). The surface microhardness in the low-temperature samples varied from 5–8 GPa to 8–11 GPa. The cross-sectional data were lower than those obtained on the surface and equaled from 7.6 to 2.6 GPa.

Figure 2. The results of measuring the hardness of the surface and in the section of titanium samples: 1,2 - low-temperature mode (900–1100 °C)
For the medium temperature mode, the surface microhardness varied from 8–9 GPa to 16 GPa. At high temperature IHT \((T = 1200\pm50 \, ^\circ C \text{ and } t = 300 \, s)\), areas with a hardness of up to 20 GPa were found. In the study of the microhardness over the cross section, the values varied from 10.6 to 2.6 GPa.

![Figure 3](image1.png)

**Figure 3.** The results of measuring the hardness of the surface and in the section of titanium samples: 3,4,5 - medium-temperature mode (1150–1250 \(^\circ C\))

High temperature data were obtained for the surface measurements in the range of 8–14 GPa with the solid inclusions of 15–18 GPa. For the third group of samples, the regularity of reduced microhardness was retained and corresponded to the range of 4.5–13.6 GPa.

![Figure 4](image2.png)

**Figure 4.** The results of measuring the hardness of the surface and in the section of titanium samples: 6,7 - high-temperature mode (1300–1500 \(^\circ C\))

4. **Conclusion**

Thus, the average value of microhardness for the low temperature IHT group of samples (depth within 200–250 \(\mu m\)) was 14–18 % higher relative to deep layers (from 300 to 1000 \(\mu m\)), for the medium temperature group – 13–15 %, and for the high temperature group – 15– 22 %. The presence of a highly hard coating (up to 10–20 GPa) and a hard near-surface layer can increase the tribological characteristics of titanium products, which will expand the area of their effective use in the manufacture of medical products.

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References

[1] Sarma J, Kumar R, Sahoo A K and Panda A 2020 Mater Today Proc 23 561
[2] Senthilvelan J, Monisha K, Gunaseelan M, Yamini S, Kumar S Arun, Kanimuthi K, Manonmani J, Shariffc S M and Padmanabham G 2020 Mater Charact 160 110118
[3] Dolgun E, Zemlyakov E, Shalnova S, Gushchina M and Promahov V 2020 Mater Today 30 688
[4] Maytorena-Sánchez A, Hernández-Torres J, López-Huerta F, Hernández-Campos M A, Zamora-Peredo L, Pacio-Castillo M, Serrano-De la Rosa L E and García-González L 2021 Mater Lett 282 128679
[5] Fomin A, Egorov I, Shchelkunov A, Fomina M, Koshuro V and Rodionov I 2018 Compos Struct 206 467
[6] Taylor M, Pullar R C, Parkin I P and Piccirillo C 2020 J. Photochem. Photobiol., A. 400 112727