Influence of laser processing conditions on the depth and microhardness of layers formed on titanium

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Abstract. In this work, we studied the depth and microhardness of the layers formed on titanium during laser processing in a graphite environment. The energy and duration of the laser pulse varied from 0.76 to 10.17 J and from 0.5 to 3 ms, respectively. As a result of processing, the formation of layers characterized by a depth of 8.3-800 μm and a microhardness of 9.68-28.01 GPa took place. Regression models are constructed that describe the effect of laser processing conditions on the indicated characteristics of the layers. It was found that the pulse energy had the greatest effect on the depth and microhardness of hardened titanium.

1. Introduction

At present, carburizing technologies using gas and solid carbon-containing media are widely used to harden the titanium surface. Cementation in a gas atmosphere at a temperature of 1150 °C allows to reduce the coefficient of friction of the titanium surface. Surface properties depend on the composition of the reaction medium [1].

Cementation is also carried out by pressing titanium bases with graphite powder and subsequent heating. Heating up to 800 °C is carried out by supplying current for 20 minutes. As a result, titanium carbide layers are formed, characterized by a carbon content of up to 36 at.% And a hardness of 6.53 GPa (Knoop, 100 gf). [2]. Heating of titanium products can also be induction. The titanium product is placed in a refractory container filled with graphite. During processing, the samples are heated to temperatures comparable to the temperature of the container. As a result of cementation, TiC layers with a thickness of up to 14 μm and a hardness of up to 20 GPa are formed [3].

It is more rational to carry out local hardening by laser processing of titanium in a graphite environment. Laser treatment of a powder mixture deposited on a titanium sublayer and consisting of titanium with a dispersion of 20-30 μm and CNT, at a radiation power of up to 700 W, allows the formation of carbide layers with a hardness of up to 1125 HV0.5 (11 GPa) [4]. After laser processing in a pulsed mode with a pulse duration of 4 to 12 ms and a power of 250 W, layers with a hardness of up to 934 HV (9.2 GPa) are formed. The formed layers were characterized by a dendritic structure [5].

Despite the existence of works on laser carburizing of titanium, the effect of laser processing conditions on the thickness of the hardened layers and their microhardness has not been sufficiently studied.
2. Methodology
In the experimental work, specimens in the form of VT1 titanium plates with dimensions of $10 \times 10 \times 1$ mm were used. On the surface of the plates, a bulk layer with a thickness of 100-300 µm was formed from graphite powder with a dispersion of 10-35 µm. The surface was processed with a diameter of 8 mm with 50% overlap using the "LRS-50A" installation. Laser radiation was focused on the graphite surface into a spot 0.75 mm in diameter (figure 1). The energy and duration of the laser pulse varied from 0.76 to 10.17 J and from 0.5 to 3 ms, respectively.

The structure of the layers was investigated by optical and scanning electron microscopy (SEM) using the optical system of the "PMT-3" microhardness tester and the "MIRA II LMU" electron microscope. The depth of structural changes was measured from the images of microsections according to the well-known method [6]. Hardness of the coatings was evaluated by microindentation using "PMT-3M" (at the load of 0.98 N). The construction of regression models was carried out in the "Data Fit 9" program.

![Figure 1. Laser treatment of titanium in a graphite environment.](image1)

3. Results
Laser treatment in a graphite medium made it possible to form a layered system on titanium, consisting of a thin, 0.5-6 µm thick coating and diffusion layers with a depth of 8.3-800 µm. These structural areas were characterized by the presence of a fine (from 0.1 µm) dendritic structure (figure 2). The size and shape of the dendritic formations depended on the pulse duration. With an increase in the duration of the laser pulse, the structural elements merged; therefore, the size of individual grains increased. Dendritic structure is visually similar to the structures formed by laser processing in similar works [5].

![Figure 2. Microstructure of titanium (a) after laser treatment at an energy and pulse duration of 1.5 J and 2 ms, respectively, where coating 1 and diffusion layer 2 with a dendritic structure (b) are distinguished.](image2)
In addition to the coating and diffusion layer, the microstructure was distinguished by the presence of a transition layer and, accordingly, boundaries between them, as well as the boundary of thermal effect on the metal (figure 3).

Figure 3. Diffusion layer boundary.

The pulse energy (E, J) had a pronounced effect on the thickness (h, μm) of the diffusion layers. Diffusion layers formed at an energy and pulse duration of 10.17 J and 3 ms, respectively, differed in maximum depth (up to 800 μm) (figure 4a). The pulse duration influenced not only the shape of dendritic formations but also the microhardness of the diffusion layer (H, GPa). The layers obtained with a pulse duration (τ, ms) of 3 ms and average energy values differed in the maximum microhardness, approximately 28 GPa (figure 4b).

Figure 4. Influence of laser processing conditions (energy and duration of a laser pulse) on the depth (a) and microhardness (b) of layers formed on titanium.
4. Conclusions
Laser treatment of titanium in a graphite medium made it possible to obtain a layered structure consisting of coatings, a diffusion layer, and a transition layer. The coatings were characterized by a thickness of up to 6 µm. The diffusion layer had a dendritic structure and high microhardness, up to 28 GPa. The size of structural elements and hardness were most influenced by the pulse duration. The depth of the hardened layer reached 800 µm and depended on the pulse energy. The significant thickness of the structures being formed allows surface finishing.

The established dependences make it possible to choose the modes of laser treatment for the formation of structures with specified properties on titanium.

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References
[1] Ajikumar P K, Vijayakumar M, Kamruddin M, Kalavathi S, Kumar N, Ravindran T R and Tyagi A K 2012 *Int J Refract Met* H 31 62
[2] Boonruang C and Thongtem S 2010 *Chiang mai J Sci* 37 206
[3] Voyko A V, Fomina M A, Koshuro V A, Fomin A A, Rodionov I V, Atkin V S, Galushka V V, Zakharevich A M and Skaptsov A A 2018 *Proc. biomed. opt. imag.* 10716 107161L
[4] Savalani M M, Ng C C, Li Q H and Man H C 2012 *Appl Surf Sci* 258(7) 3173
[5] Hamedi M J, Torkamany M J and Sabbaghzadeh 2011 *Opt Laser Eng* 49(4) 557
[6] Fomina M, Koshuro V, Papshev V, Rodionov I and Fomin A 2018 *Data in Brief* 20 1409