Study of the relationship of induction heating parameters and mechanical properties of commercial purity titanium

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Abstract. In this work, the relationship between the parameters of voltage, inductor current, duration, temperature of induction heat treatment and the hardness of commercial purity titanium was studied. As a result, the temperature ranges at a fixed voltage and current of the inductor were established. At certain technological conditions, with various durations of heat treatment, the hardness of the titanium surface was determined.

1. Introduction
Titanium and its alloys have become widespread in the aerospace and engineering industries due to a combination of mechanical and chemical properties. Low specific weight, high corrosion resistance and biocompatibility ensured their widespread use in medicine [1]. However, titanium can not satisfactorily withstand friction under high loads. Wear resistance mostly depends on the crystal structure, surface treatment quality, friction coefficient and hardness [2]. To increase the wear resistance, titanium and its alloys, as well as zirconium and tantalum, undergo structural and chemical surface modification [3-6].

One of the ways to increase wear resistance is gas thermal spraying. This method allows the control of spraying conditions and the quality of the deposited coating material. The disadvantages of the resulting coatings include high roughness, the presence of inclusions and low adhesion. In addition to various types of spraying, there are methods of vapor deposition using physical and chemical effects (PVD, CVD). These coatings are characterized by high values of adhesion, wear resistance, as well as corrosion resistance [7,8].

There are several methods used to produce a surface layer with the required mechanical properties, one of which is chemical-thermal treatment. When titanium is heated in the air, the oxide film growth and the saturation of the surface layer with oxygen are observed. This effect contributes to the improvement of mechanical properties, e.g. hardness and wear resistance [4].

The purpose of this work is to study the influence of induction heating parameters (voltage, inductor current) and the duration of exposure in the air atmosphere on the treatment temperature and the resulting hardness values.

2. Methodology
For the experiment, titanium (commercially pure titanium VT1-00) samples of a disk shape with a diameter of 13.9–14.1 mm and a thickness of 1.95–2.00 mm were prepared. The sample preparation comprised finishing turning, grinding (Ra 0.32) and cleaning in ethanol. These procedures were followed by a high-temperature induction treatment of the surface, which provided for the exposure time \(t\) at a given temperature 1–3, 60, 120 and 300 s, respectively (Figure 1).
3. Results

In the course of IHT, the maximum temperature reached 1250±50 °C. The control of geometric dimensions showed that all samples retained their shape after heating and they could be further used for hardness testing. With increasing voltage, the samples were characterized by a significant change in thickness and subsequent delamination of the scale.

In the experiment, the effect of the inductor current on the heating temperature of the titanium samples was studied (Figure 2). It can be seen from the graph that at the current values on the inductor equaling 2.3–2.5 kA, there was an average temperature growth to 900–1000 °C. Upon reaching the values of 1000–1100 °C, an increase in current to 3.1–3.3 kA was observed. Then there was a slight increase in the inductor current to 3.5–3.6 kA, which corresponded to the temperature of 1200–1250 °C.
Further, the effect of the inductor current on the hardness of a titanium sample at various voltage values $U$ and IHT duration $t$ was considered. The heating was conducted at the voltage values from 70 to 90 V (Figure 3). The extreme left position of each curve corresponded to the minimum duration of IHT $t = 1–3$ s and the extreme right position $- t = 300$ s. It can be seen that, at minimum voltage, the duration of IHT had a significant effect on hardness.

**Figure 2.** A graph showing the current of the inductor and the temperature of the heated object.

**Figure 3.** A graph showing the inductor current and the obtained hardness.
At the voltage of 70 V, with an increase in the exposure duration, the consumed current fell from 2.4–2.5 to 2.2–2.3 kA. For $t = 1$ s and $t = 60$ s, the temperature interval corresponded to $T = 900–950 ^\circ C$, and as $t$ grew to 120–300 s, the temperature reached 1000–1050 °C. The hardness at the voltage of 70 V and $t = 1$ s equalled 3.3 GPa, at the same time inclusions with high hardness of about 9.3 GPa were observed. In the remaining samples, at the duration $t = 60$–300 s, the hardness increased to 11.7–15.1 GPa, respectively.

At the voltage of 80 V, the inductor current stabilized at 2.9–3.1 kA. The temperature of the sample with an exposure duration $t = 1$ s reached 1000–1050 °C, whereas for the rest it was 1050–1100 °C. The hardness of the samples varied in the range 12.5–15.5 GPa. IHT of titanium at $U = 90$ V showed that the inductor current gradually decreased from 3.5 to 3.1 kA with increasing duration. The temperature range during the exposure was in the range of 1200–1250 °C, while the hardness decreased slightly and amounted to $H = 10.8–14.5$ GPa.

4.Conclusions
Thus, the influence of IHT parameters (voltage, inductor current and exposure duration) on the process temperature in the range of 900–1250 °C and the resulting hardness on the titanium surface in the range of 10.8–15.5 GPa was shown. This value significantly expands the scope of application of commercially pure titanium, in particular in the form of wear-resistant elements (inserts) for the instrument products or cutting elements of intraosseous parts of titanium implants operating in difficultly loaded conditions and harsh environments.

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