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DETERMINATION OF PARAMETERS OF THE SURFACE LAYER ACCORDING TO INDENTATION DIAGRAM FOR TITANIUM ALLOY TI-6AL-2.5MO-1.5CR-0.2SI-0.5FE

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ABSTRACT

The present article is a study of titanium alloy according to the diagram of indentation of a spherical indenter. The typical diagram of indentation is considered. The diagram shows typical areas characterizing the process, including loading, pause, and unloading. Mathematical dependence used to calculate the indentation diagram are considered. A schematic diagram of the setup for recording a spherical indenter is shown. The results of indentation and calculation of various indicators characterizing surface layer for a titanium alloy are given. The effectiveness of this method is also shown. After heat treatment in air, the best results are demonstrated by a coating of silver, niobium, aluminum, and also pure titanium. After heat treatment in vacuum, the Young's modulus of the coatings is aligned. After heat treatment in air also improves the Young's modulus of some coatings.

1. INTRODUCTION

Current trends in development of materials science and technologies for modification of surface layers are aimed at obtaining the specified physical and mechanical parameters, taking into account the operating conditions of parts. This is of particular importance, specifically, in modern aircraft engine building, where the tasks of ensuring wear resistance, fatigue strength, fretting resistance, corrosion resistance, and etc., are relevant. Their correct decision is based not only on a reasonable choice of modes and methods of technological impact (coating, chemical heat treatment, etc.) but also on possibilities of reliable assessment and prediction of such impact [1-4].

2. PURPOSE OF THE STUDY

Purpose of the study is to determine characteristics of the surface layer for a titanium alloy with different coatings according to the pattern of indentation of a spherical indenter.

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3. RESEARCH METHODS

Traditional methods for determining the mechanical properties of materials are tensile testing, compression, evaluation of hardness and micro-hardness, etc. Of particular interest is the method based on continuous recording of load and depth of penetration of the indenter into the test sample.

As samples for determining the Young's modulus, the samples of titanium alloy Ti-6Al-2.5Mo-1.5Cr-0.2Si-0.5Fe were used. A total of 20 samples were obtained, on which various coatings were applied.

The coatings were applied to the samples by the method of electro-spark doping on an ELFA-731 instrument. The process parameters are as follows:

I= 7 A, C= 5 mF. Coatings were applied.

A typical indentation diagram is shown in Figure 1

In this case, the 0-1-2 area is described by the following formulas [5]

$$P_i = a(h_{\sum i} - h_{\sum yi})^n + P_{y0} \quad (1),$$

where

$h_{\sum i}$ is the current depth of the indenter at loading;

P_i is current indentation force;

n is indicator

a is coefficient depending on the physical and mechanical properties of the material and size of the indenter.

Figure 1, the curve 3-4 is the discharge section. During unloading process, energy is relaxed. This site is described by the following dependencies:

$$P_i = b_j(h_{ui} - h_{0j})^m \quad (2),$$

where b_j is coefficient depending on the physical and mechanical properties of the material and size of the indenter;

h_{ui} is the current value of the depth of introduction at unloading;

h_{0j} is residual penetration depth corresponding to the final (j-th) point under loading;

m is score.

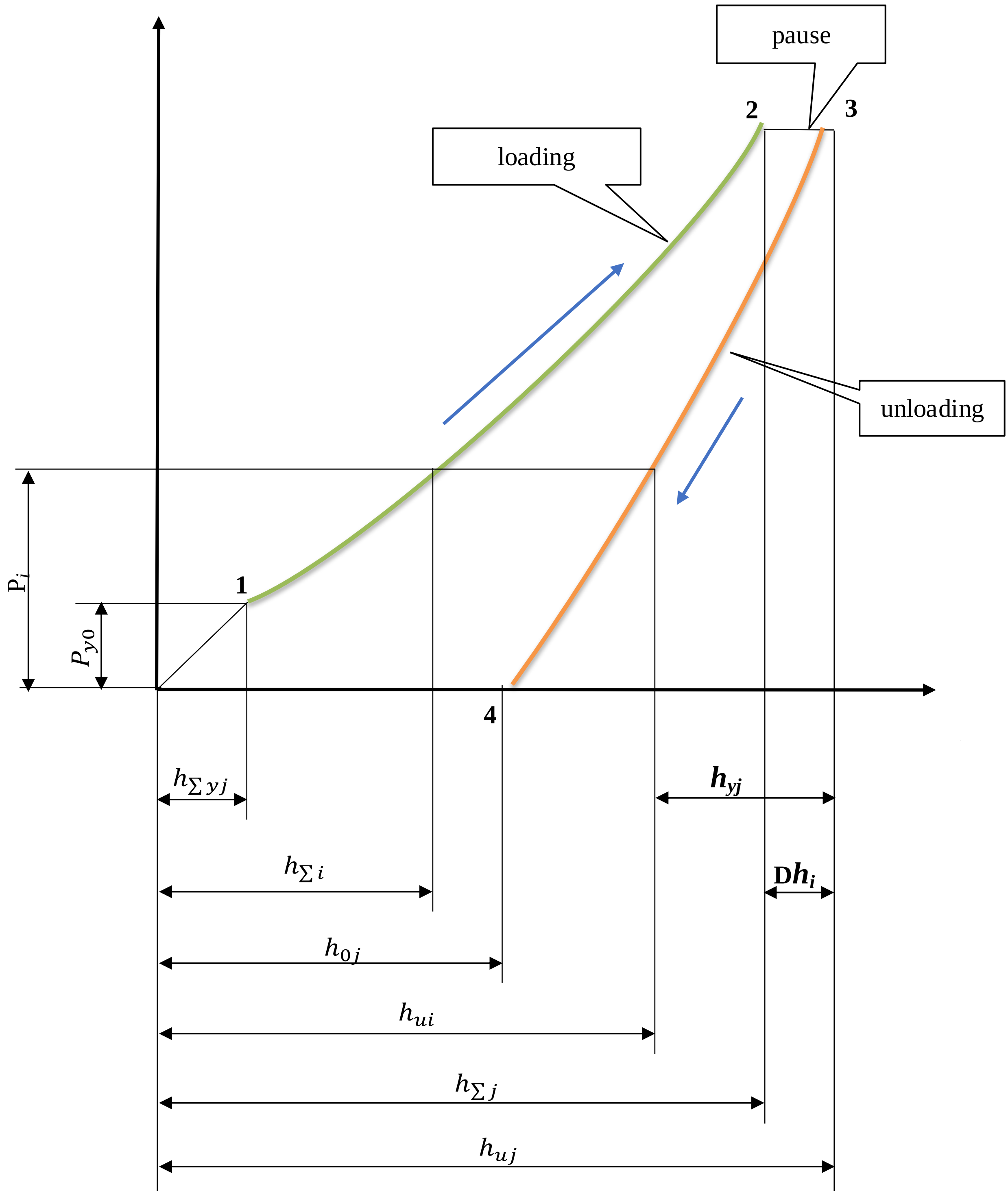

Figure 1: A typical diagram of the indentation of a spherical indenter [5].

The constants a, b, c, n, m, and r, are determined, which are calculated by following dependencies [5]

$$n = \frac{1}{N-1}\sum_{i=1}^{N-1}\frac{lgP_{i+1} - lgP_i}{lgh_{\sum(i+1)} + lgh_{\sum(i)}},$$

$$a = \frac{1}{N}\sum_{i=1}^{N-1}\frac{P_i}{h_{\sum i}^{n}},$$

where N is the number of points on the corresponding curves taken for calculation; (for b, c,

m, and r - the formulas are similar).

Young's modulus of the studied material is

$$E = \frac{(1-\mu^2)mP_j}{2\sqrt{2Rh_{\Sigma j}(h_{\Sigma j}-h_{\Sigma oj})-e_1 mP_j}} \quad (3),$$

where, e_1, is elastic constant indenter.

The average contact pressure during loading and unloading is determined by the following formulas:

$$q_{li} = \frac{P_i}{A_{кн}} = \frac{a}{2\pi R} h_{\Sigma i}^{n-1} \quad (4),$$

and

$$q_{ui} = \frac{P_i}{A_{кр}} = \frac{b_j h_{\Sigma j}}{2\pi R(h_{\Sigma j}-h_{\Sigma oj})} \left(h_{pi} - h_{oj}\right)^{m-1} \quad (5).$$

Magnitude of the contact pressure is advisable to consider depending on the degree of deformation in the imprint, which, unlike the cone and pyramid, is variable when the spherical indenter is pressed in due to a violation of the geometric similarity of the well. In addition, the degree of deformation for comparative evaluation is convenient because it is dimensionless. The degree of deformation is determined during loading and disarmament as follows [5].

$$\varepsilon_{liI} \approx \frac{1}{2}\sqrt{\frac{h_{\Sigma i}}{2R}} \quad (6),$$

$$\varepsilon_{uiI} = \frac{h_{pi}}{2\sqrt{2Rh_{\Sigma j}-h_{\Sigma j}^2}} \quad (7).$$

Table 1. Without heat treatment [5].

Material	Ag	Cu	W	Ni	Cr	Ta	Al	VK6M	Nb	Zr	Ti
B	0.02	0.03	0.04	0.02	0.02	0.02	0.02	0.01	0.04	0.03	0.01
D	0.12	0.13	0.14	0.13	0.13	0.13	0.12	0.13	0.13	0.12	0.12
E, x10^6 MPa	0.12	0.11	0.10	0.11	0.11	0.11	0.11	0.10	0.12	0.11	0.12
a	8.74	6.37	5.78	7.29	7.29	8.37	8.63	9.14	5.26	6.98	10.35
b	16.91	14.99	15.84	17.19	16.05	13.86	16.02	19.16	13.67	16.46	15.69
c	32.57	24.03	22.03	27.83	28.30	32.93	33.30	35.26	17.39	26.10	37.42
n	1.23	1.30	1.34	1.27	1.27	1.23	1.23	1.21	1.36	1.29	1.18
m	1.29	1.32	1.30	1.27	1.29	1.36	1.30	1.20	1.40	1.30	1.31
r	0.99	1.09	1.14	1.04	1.04	0.98	0.99	0.96	1.20	1.07	0.94
q, MPa	2260	2090	2069	2155	2155	2189	2260	2248	2059	2166	2260

Table 2: After heat treatment in air

Material	Ag	Cu	W	Ni	Cr	Ta	Al	VK6M	Nb	Zr	Ti
B	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.01	0.01
D	0.12	0.11	0.12	0.13	0.11	0.12	0.11	0.13	0.14	0.15	0.11
E, x10^6 MPa	0.12	0.12	0.11	0.10	0.13	0.12	0.12	0.10	0.10	0.11	0.15
a	9.80	9.12	8.67	8.89	12.22	9.26	9.99	9.44	5.54	9.76	11.29
b	15.54	18.80	19.01	17.73	17.05	15.52	17.76	16.70	15.82	7.26	12.52
c	32.19	28.86	27.69	33.14	32.92	30.17	31.78	32.70	20.91	30.19	35.07
n	1.17	1.20	1.20	1.21	1.10	1.19	1.18	1.18	1.34	1.14	1.15
m	1.31	1.21	1.18	1.25	1.26	1.28	1.25	1.27	1.28	1.55	1.50
r	0.95	0.98	0.98	0.96	0.91	0.97	0.96	0.94	1.15	0.93	0.93
q, MPa	2115	2115	2056	2166	2166	2115	2205	2111	2048	1946	2270

4. RESULTS

A special installation was used to record indentation diagram of the spherical indenter.

It allows you to push the indenter and move the sample in the tangential direction with continuous recording of the indentation force *P* from 0 to 800 N, penetration depth *h*, friction force *F*тр, displacement value in the tangential direction *z*.

The forces were evaluated by the deformation of elastic elements with strain gages pasted on them. To eliminate the effect of force *P* on the readings *Fm*, a strainer is additionally installed, which has a flexible connection with the table and, for this reason, does not perceive tensile stresses in contrast to elastic elements. The tangential displacement of the sample *z* was recorded on a potentiometer by changing the voltage across a resistor connected to an electrical circuit using a voltage divider circuit. In this case, the resistor slider was rigidly connected to the table. The operation of the installation in semi-automatic mode was provided by the electrical circuit.

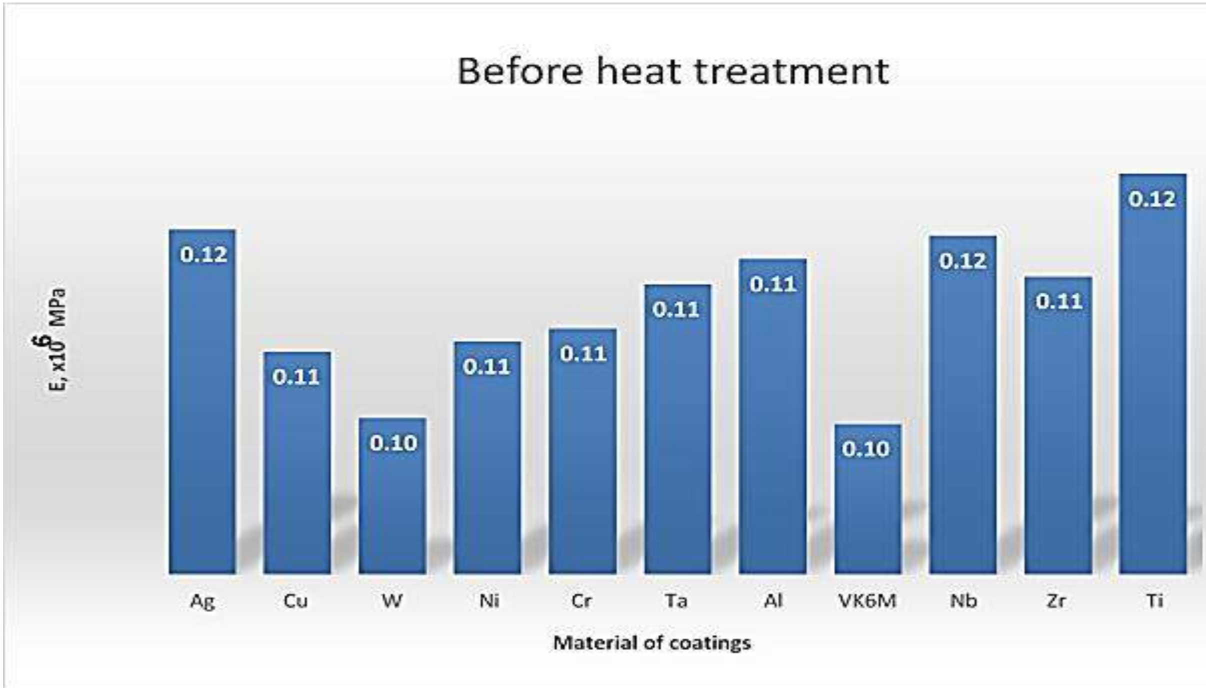

Figure 2: Results of calculation of Young's Modulus.

The samples were made in form of plates with a thickness of at least 8 mm, which gave reason to consider them as an elastoplastic half-space. After loading, the shutter speed was carried out for 10 ... 15 seconds, set using a time relay, then unloading was performed. In each case, at least three experiments were performed, followed by averaging the results. To eliminate the mutual influence of neighboring prints, they were located at a distance exceeding their diameter by five times. The calibration results were processed by the method of least squares.

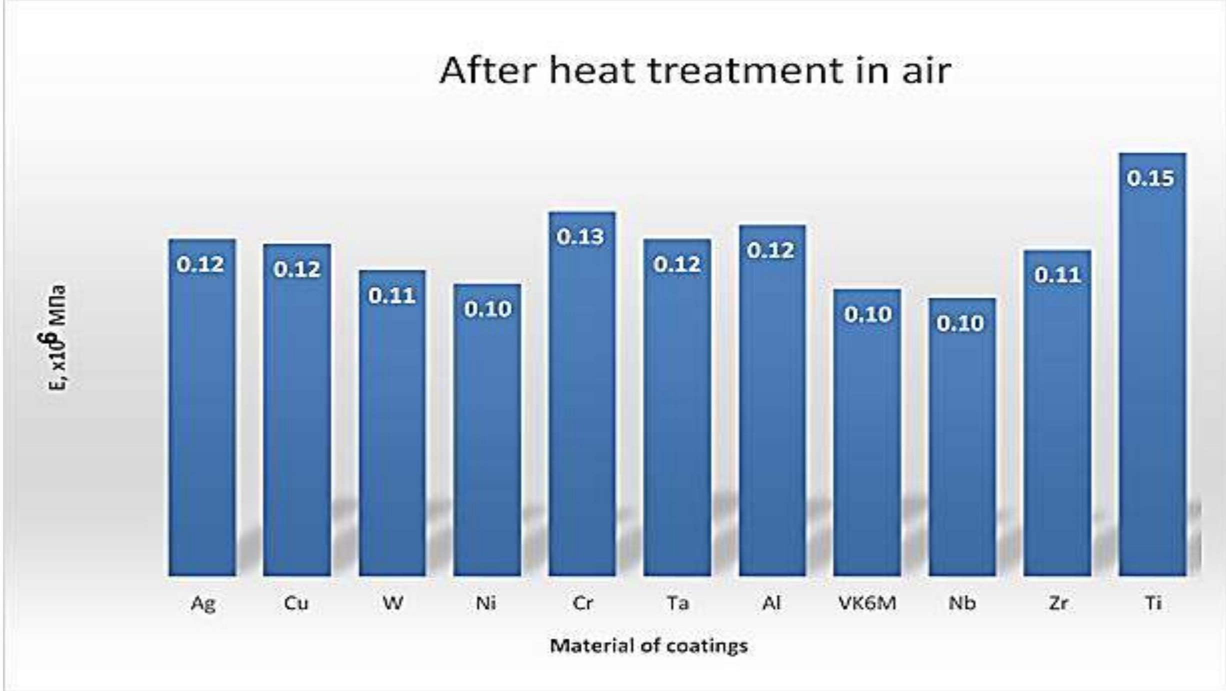

Figure 3: Results of calculation of the Young's Modulus after the heat treatment in air.

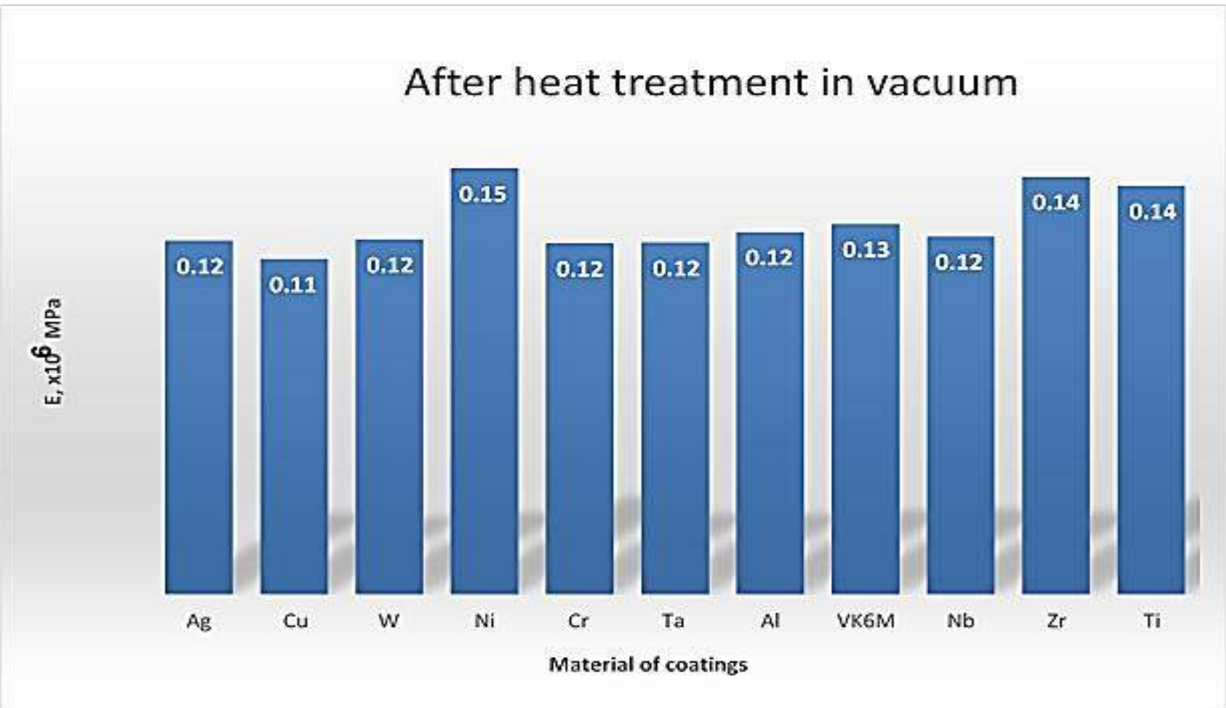

Figure 4: Results of Calculation of the Young's Modulus after heat treatment in vacuum.

To check accuracy of the instrument readings, a hardness measure HV5-424 (reference) was used, the working surface of which was processed within Ra = 0.12 ... 0.02 µm.

The loading rate was 10-40 N/s, and its change in the specified range had practically no effect on the results obtained. The results of calculations according to the diagram of indentation of a spherical indenter are presented in Tables 1 and 2 and also presented in Figures 2, 3, and 4.

5. FINDING

It can be stated that assessment of the physic-mechanical properties of the surface layer according to the diagram of indentation of a spherical indenter, is an effective way to study the surface layer of materials. As you can see, in air, the best results are demonstrated by a coating of silver, niobium, aluminum, and also pure titanium. After heat treatment in vacuum, the Young's modulus of the coatings is aligned. Heat treatment in air also improves the Young's modulus of some coatings.

6. AVAILABILITY OF DATA AND MATERIAL

Data used or generated from this study can be requested to the corresponding author.

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