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THE INFLUENCE OF HEAT AND SURFACE TREATMENT ON THE WEAR RESISTANCE OF TITANIUM ALLOYS

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Abstract: *Titanium and titanium alloys are on the full rise in their fields of use and, as a consequence, the studies related to them enjoy a growing attention. The wear, one of the common applications in practice can be improved through changes in structure and through the composition and nature of the superficial layers. This paper examines both the opportunities provided by heat treatments on the structural changes of the mass of alloy, respectively the surface treatments on the durability in the abrasive friction. Among the thermal treatments that have been applied there are: hardening and annealing in air atmosphere and in vacuum installations; the surface treatments is consisted by nitriding and laser pulsed process coating. Wear tests have established the hierarchy of the efficiency of these processes.*

Keywords: *titanium, heat treatment, surface treatment, wear, nitriding, resistance*

1. GENERAL CONSIDERATION

Titanium alloys with wide applications in various fields, from manufacturing to aviation, electrotechnics, electronics, medicine, present multiple structural systems, possibilities offered by their polymorphism. Various structural compositions can be obtained through heat and thermo chemical treatment operations. In titanium alloys, there are typically three types of layers, as in the Ti-Al system (figure 1).

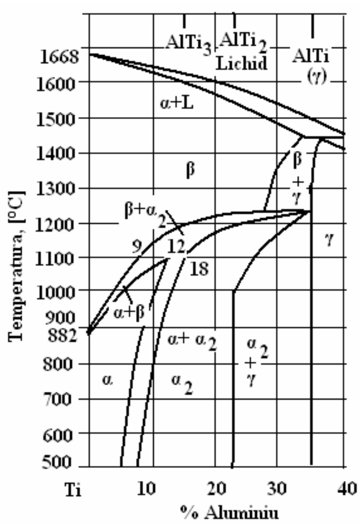
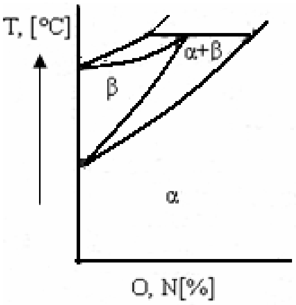


Figure 1. The Ti-Al equilibrium diagram [1]

Also, both in binary alloys of titanium, but especially in the polynary alloys, more complex structures can be found through the presence of intermetallic compounds.

These structures give produce different sets of extremely different properties.

Various structural aspects may be obtained both though chemical composition, but also through heat treatment, treatment that can be efficient due to allotropic transformation of titanium: the α allotropic form under 882°C with hexagonal compact lattice (h.c.), respective the β allotropic form above this temperature, with centered cubic volume lattice (c.c.v.). The alloying elements, extremely numerous in the case of titanium, may cause stabilization for α phase Al, Ge, C, N, O, Ca) or for β phase (V, Mo, Cr, Si, Mn) as in figure 2.



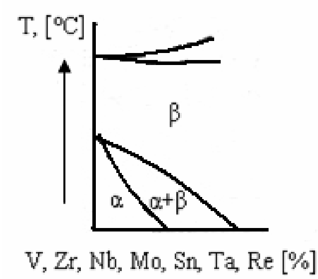


Figure 2. The Ti-X equilibrium diagram for alphagene (a) and betagene (b) alloy elements [2]

In addition, the alloying elements form, as it has been shown, defined Ti_mX_n type compounds and out of balance phases (through thermal treatments) such as:

- the α′ phase: supersaturated in betagene elements solid solution with deformed hexagonal lattice;
- the α″ phase: the martensitic solid solution with rhombic lattice;
- the β_{sem} phase: supersaturated solid solution;
- the ω phase: solid solution with hexagonal lattice.

Each of these phases, with their own properties, imprints features included in a wide range of values to the alloy in equilibrium or heat-treated, according to the quantitative ratio of them.

1. EXPERIMENTAL TESTS

For the experimental tests, it has been chosen the Ti6Al4V titanium alloy, which can be found in applications from many areas. The standardized and the experimentally determined chemical compositions are provided in table 1.

Table 1. The chemical composition for Ti6Al4V titanium alloy

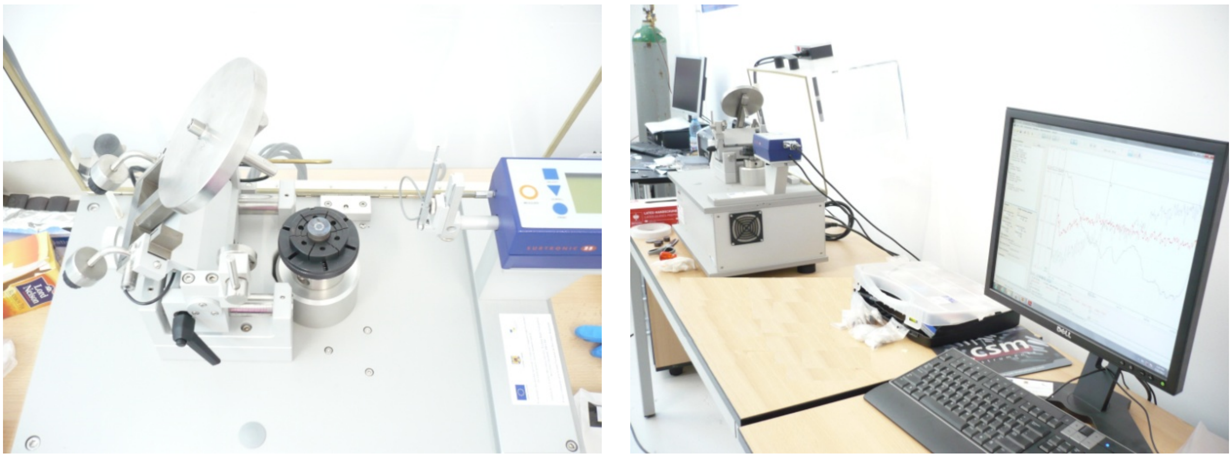
No.	Values	Chemical composition [%]								
		Al	V	Fe	C	N	O	H	Ti	Residual elements
1	after AS9100 ISO 14001	5,5-6,75	3,5-4,5	≤0,4	≤0,08	≤0,05	≤0,2	≤0,015	rest	≤0,4
2	measured	6,23	4,14	0,2	0,02	0,02	0,19	0,003	rest	<0,4

A large number of specimens for the wear tests have been produced from the material with the composition given above, delivered by the supplier in the form of a 20 mm diameter bar. These were distributed in three for each type of treatment. The treatments applied, the technological parameters as well as some mechanical properties obtained are shown in table 2.

Table 2. Treatments applied to the samples for wear tests [3]

No.	Kinds of material	The treatment applied	The technological parameters			Hardness [HRC]	Resilience KCU [J / cm^2]
			Temp. [°C]	Time [min]	Quenching medium		
1	Ti6Al4V	Delivery status	-	-	-	42,56	55,30
2		Hardening in the furnace with controlled atmosphere	850	60	water	53,46	36,58
3		Hardening in vacuum	1020	90	nitrogen ventilated	56,56	37,17
4		Hardening and annealing	500	60	air	54,63	40,42
5		Hardening in vacuum and annealing	500	30	air	58,13	46,33
6		Hardening, annealing and nitriding	520	240	air	844,56 [HV 0,3]	-
7		Hardening, annealing and nitriding	540	240	air	881,06 [HV 0,3]	-

The samples that had been taken were tested for resistance to wear. It was used a TRIBOMETER device with a SUBTRONIC 25 TAYLOR HOBSON PRECISION component, to determine the profile of the wear surface (figure 3).



a) b)

Figure 3. The tribometer device to determinate the wear resistance:
a) the test facility; b) connecting the tribometer to a PC

The tests were carried out by pressing a sphere with a diameter of 6 mm on the surface of the sample, with a force of 10N, a linear speed of 10cm/s and a stop after 5000 laps. The wear rate is provided directly after measuring the surface of the wear trace with the help of the tribometer surface analyser, the specialized software is the one that provides the test results.

In table 3, there are presented the average wear rates of the samples with different structures, coming from the heat treatments previously applied.

Table 3. The wear rate

No.	Kinds of material	The treatment applied	The metallographic structure of samples	The wear rate $[10^{-6}\ cm^3/\ N\cdot m]$
1		Delivery status	$\alpha+\beta$	0,934
2		Hardening in the furnace with controlled atmosphere	$\alpha+\alpha'+\beta$	0,561
3		Hardening in vacuum	$\alpha''+\beta_x+\omega$	0,729
4		Hardening and annealing	$\alpha+Ti_mXn+\beta$	0,472
5	Ti6Al4V	Hardening in vacuum and annealing	$\alpha+\beta_x+\omega$	0,314
6		Hardening, annealing and nitriding	nitrogen	0,522
7		Hardening, annealing and nitriding	nitrogen	0,336

During the series of trials, there have also been done the measurements of the volumes of material lost through wear, at different periods of time. The test conditions were the same as above. The table 4 and figure 4 show this aspect of the wear process.

Table 4. The volume losses during the trials

Time [min]	The lost volume, $[10^{-6}\ mm^3]$			
	Sample in delivery status	Sample hardened from 850°C	Sample hardened from 850°C, annealed to 500°C, 60 min	Sample hardened from 850°C, annealed to 500°C, 120 min
5	0,05553838	0,04801529	0,07312854	0,06000434
10	0,1319666	0,115608	0,1475726	0,1824015
15	0,2070887	0,1999108	0,1818821	0,150185
20	0,3082072	0,2079159	0,2743207	0,1758861
25	0,3866197	0,3643489	0,3383027	0,2352871
30	0,4385598	0,3898323	0,3658791	0,2675284
35	0,4730372	0,3924167	0,4068844	0,3590557

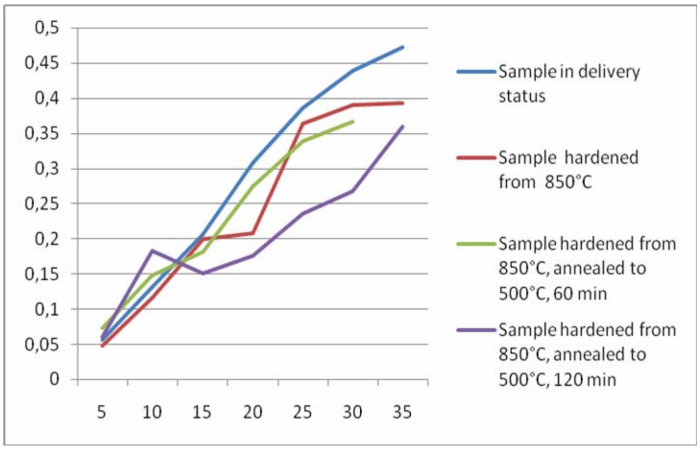


Figure 4. The variation of loss wear volume in the samples analyzed

The above mentioned ideas prove that there are notable differences in wear resistance, depending on the treatment.

Based on the sample values in as-annealed (delivery) status, there can be obtained significant increases of them, determined by the metallographic structure.

An increase of the hardness and the decrease of the wear rate can be achieved through the hardening; the annealing can be achieved through the precipitation of ω phase; the hardness further increases with favorable effects on durability. Good results can also be obtained through thermo chemical treatment (respective nitriding). In all the analyzed variants, the resilience is being kept relatively high, with good effects on shock resistance.

2. CONCLUSION

The experimental tests have demonstrated the capability of the titanium alloys to respond to the heat treatments through structural changes. This layout allows modifications of certain mechanic features depending on the necessities.

It has been proven that there is a significant correlation among the structure, the mechanic properties and the wear resistance.

Also, it has been demonstrated that there are advantages of vacuum heat treatment, especially after annealing, over the one in air atmosphere or atmosphere controlled.

The nitriding thermo chemical treatment proved to be more effective at 540°C, when the diffusing layer proved to be more consistent.

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