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EFFECT OF HEAT TREATMENT ON THE MECHANICAL PROPERTIES OF TWO-PHASE TITANIUM ALLOY Ti6Al7Nb

WPŁYW OBRÓBKI CIEPLNEJ NA WŁASNOŚCI MECHANICZNE DWUFAZOWEGO STOPU TYTANU Ti6Al7Nb

Mechanical properties of the two-phase titanium alloy Ti6Al7Nb, after the heat treatment based on soaking this alloy in the $\alpha + \beta$ range, cooling in water or oil and ageing at two selected temperatures, were determined in the hereby paper. The alloy mechanical properties were determined in tensile and impact tests, supported by the fractographic analysis of fractures. In addition, its hardness was measured and the analysis of changes occurring in the microstructure was performed for all variants of the alloy heat treatment. Regardless of the applied cooling rate of the alloy, from a temperature of 970°C followed by ageing at 450 and 650°C, none essential changes were noticed in its microstructure. It was shown that applying less intensive cooling medium (oil) instead of water (before tempering) decreases strength properties indicators, i.e. tensile strength and yield strength as well as hardness (only slightly). The decrease of the above mentioned indicators is accompanied by an increase of an elongation and impacts strength. Fractures of tensile and impact tests are of a ductile character regardless of the applied heat treatment.

Keywords: heat treatment, microstructure, mechanical properties, two-phase titanium alloy

W artykule określono własności mechaniczne dwufazowego stopu tytanu Ti6Al7Nb po obróbce cieplnej polegającej na wygrzewaniu stopu w zakresie dwufazowym, oziębianiu w wodzie lub oleju oraz starzeniu przy wybranych dwóch temperaturach. Własności mechaniczne stopu wyznaczono w próbie rozciągania i w próbie udarności, które poparto analizą fraktograficzną przełomów. Dodatkowo, dla wszystkich wariantów obróbki cieplnej stopu zmierzono twardość i dokonano analizy zmian zachodzących w mikrostrukturze. Niezależnie od zastosowanej szybkości oziębiania badanego stopu od temperatury 970°C i następnego starzenia przy 450 i 650°C, nie odnotowano istotnych zmian zachodzących w jego mikrostrukturze. Wykazano, że zastosowanie mniej intensywnego ośrodka chłodzącego (oleju) zamiast wody (przed zabiegiem odpuszczania), obniża wskaźniki własności wytrzymałościowych, tj. wytrzymałość na rozciąganie i umowną granicę plastyczności, a także nieznacznie twardość. Obniżeniu ww. wskaźników towarzyszy wzrost wydłużenia oraz udarności. Przełomy próbek rozciąganych i udarnościowych niezależnie od zastosowanej obróbki cieplnej mają charakter ciągliwy.

1. Introduction

A fast development of the contemporary material engineering heads towards looking for new materials of the required – by users – properties as well as towards looking for ways of improvements of already existing materials. Presently, ones of the most attractive materials are two-phase titanium based alloys [1-3]. They are characterised by a favourable combination singling them out from other materials, among others a high relative strength at a room and high temperature, high corrosion resistance and good biocompatibility [4, 5]. Titanium alloys are most widely used in the transportation (mainly aircrafts), shipbuilding, chemical, food, electric/electronic, pulp and paper, medical and sport equipment industries, as well as in geology [2, 4]. Due to good biocompatibility (as compared to other metallic biomaterials), titanium alloys are also applied as prosthetic materials, to produce knee and hip replacement joints, in dentistry and traumatology [6-8]. They are also applied for parts of steam turbines, jet engines, cars, ships, aircraft covers, and for building of modern submarines, where not only their high relative strength and corrosion resistance are utilised but also para magnetism, which renders difficult such submarine detection by magnetic methods [2, 4, 9].

Introduction to these alloys small amounts of alloying elements, application of plastic working or proper heat treatment enables shaping – in a wide range – both their microstructure and mechanical properties [1-4, 10].

Methods of phase transformations, microstructure changes and heat treatments of two-phase titanium alloys and shaping by these operations their mechanical properties are relatively well known from some decades already [1-4, 9-13].

The results of investigations of the influence of the heat treatment on the mechanical properties i.e. ultimate tensile strength, yield strength, hardness, elongation, reduction of area and impact strength of two-phase Ti6Al7Nb alloy, are presented in the hereby paper. The obtained investigation results will supplement the existing data bases concerning phase transformations, microstructure and mechanical properties of

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the Ti6Al7Nb alloy. They will be also useful in designing chemical compositions and heat treatment technology of new, two-phase titanium alloys.

2. Research material

Investigation were performed on the two-phase martensitic Ti6Al7Nb alloy. Chemical composition of the alloy acc. to the ISO 5832-11 as well as the ladle analysis are given in Table 1.

TABLE 1
Chemical composition (wt. %) of the Ti6Al7Nb alloy

Element	Ti	Al	Nb	Fe	C	N	O
ISO 5832-11 specification	bal.	5.5÷6.75	6.5÷7.5	max 0.30	max 0.08	max 0.05	max 0.20
Analysis	bal.	5.80	6.50	0.037	0.017	0.017	0.14

3. Experimental procedure

The Ti6Al7Nb alloy specimens were heated to 970°C, soaked for 1hour, cooled in water or oil at 20°C and ageing at a temperature of 450 and 650°C for 5 hours. Specimens were air cooled after ageing.

Mechanical tests of the Ti6Al7Nb alloy comprised tensile test, impact test and hardness measurements. Static tensile test has been performed using a computer controlled MTS-810 testing machine acc. to PN-EN 10002-1/2005. Proportional test pieces have been used with initial diameter of 8 mm. During this test the following data have been determined: ultimate tensile strength (UTS), yield strength (YS), elongation (EL) and reduction in area (RA).

The impact test were performed acc. to PN-EN 10045-1/1994, using the 150 J Charpy tester.

Fracture surfaces of impact test specimens were also observed.

Hardness has been measured using Vickers apparatus with 294 N indender load.

Microstructure of the specimens was examined using light microscope Axiovert 200 MAT of the Zeiss Company. The samples for microstructural examination were grinded, polished and etched in 6% HF and finally in a solution: 2 ml HF + 2 ml HNO_3+ 96 ml H_2O.

The processes of soaking and ageing of specimens have been performed in RHF 16/19 type Carbolite laboratory furnace.

4. Results and discussion

The bimodal microstructure is consists of large, nearly equiaxial bright α phase grains, which at a temperature of 970°C did not yet transform into the β phase, and of a certain volume fraction of the β phase called - after cooling in water – the transformed β phase. The transformed β phase is fine grained and was obtained from the β phase, which grains did not yet under growth during heating at a temperature of 970°C. The hardness of the sample cooled in water from 970°C equals 315 HV.

The microstructure of the Ti6Al7Nb alloy, obtained after its heating to a temperature of 970°C, soaking for 1 hour, cooling in water and ageing for 5 hours at 450 and 650°C, is presented in Fig. 1.

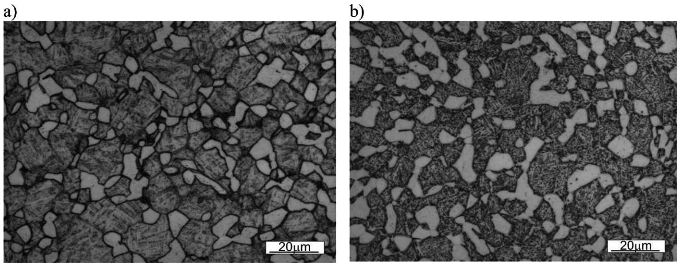

Fig. 1. The microstructure of Ti6Al7Nb alloy, obtained after its heating to a temperature of 970°C, soaking for 1 hour, cooling in water and ageing at 450°C (a) and 650°C (b) for 5 hours

The microstructure of the Ti6Al7Nb alloy, obtained after its heating to a temperature of 970°C, soaking for 1 hour, cooling in oil and ageing for 5 hours at 450 and 650°C, is presented in Fig. 2.

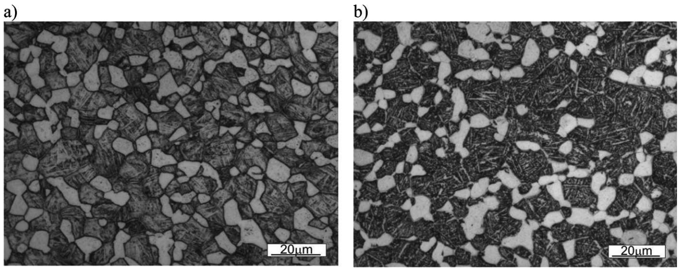

Fig. 2. The microstructure of Ti6Al7Nb alloy, obtained after its heating to a temperature of 970°C, soaking for 1 hour, cooling in oil and ageing at 450°C (a) and 650°C (b) for 5 hours

The analysis of Figs. 1 and 2 indicates a similarity of microstructures obtained after tempering at 450 and 650°C. When the microstructures are observed at large magnifications it is possible to notice the presence of large, bright grains of the α phase, in between which occurs a dark-etching phase called the β-transformed phase. The α phase volume fraction, equals app. 25%. Within the transformed β phase precipitates of the α phase of various plate thickness are seen.

When comparing Figs. 1 and 2 it is seen that the volume fraction of the α phase precipitated from the supersaturated β phase is larger in samples cooled previously in oil (Fig. 2). This is especially visible in case of the sample aged at a temperature of 650°C for 5 hours, after the previous cooling from 970°C (Fig. 2b).

The detailed results of mechanical properties of the Ti6Al7Nb alloy samples after cooling in water and ageing are shown in Table 2.

The detailed results of mechanical properties of the Ti6Al7Nb alloy samples after cooling in oil and ageing are shown in Table 3.

The results of hardness tests of the Ti6Al7Nb alloy confirm small changes occurring in its microstructure.

As can be seen (Table 2 and 3), the average hardness of samples cooled in water and in oil from 970°C and then aged at 450 and 650°C comprises in a very narrow range. Slightly higher values were found after aged at 450°C (334 HV and 324 HV for cooling in water and in oil, respectively). Samples aged at 650°C after the previous cooling from 970°C – regardless of the cooling medium - had similar hardness, i.e. 303 and 305 HV.

TABLE 2
The results of tensile test, impact test and hardness measurements of the Ti6Al7Nb alloy samples after solution treatment at 970°C for 1 hour, water cooling and ageing

Ageing parameters		Solution treatment conditions					
		970°C / 1h / water					
Ageing temp.	Ageing time	UTS (MPa)	YS (MPa)	EL (%)	RA (%)	HV 30	KV (J)
450°C	5h	1147	987	15.5	56.3	334	36.5
650°C	5h	1027	862	14.7	53.4	305	31.4

TABLE 3
The results of tensile test, impact test and hardness measurements of the Ti6Al7Nb alloy samples after solution treatment at 970°C for 1 hour, oil cooling and ageing

Ageing parameters		Solution treatment conditions					
		970°C / 1h / oil					
Ageing temp.	Ageing time	UTS (MPa)	YS (MPa)	EL (%)	RA (%)	HV 30	KV (J)
450°C	5h	1067	918	17.0	56.4	324	40.2
650°C	5h	990	842	17.0	52.0	303	34.3

The analysis of data contained in Table 2 and 3 indicates that the highest impact energy and strength was obtained for the alloy soaked at 970°C, cooled in oil and tempered at 450°C for 5 hours. The alloy impact energy after such heat treatment was 40.2 J. The lowest impact energy (31.4 J) characterises the alloy after cooled in water before the ageing procedure. In case of samples aged for 5 hours at a temperature of 650°C, a higher impact strength was also obtained when oil was used as a cooling medium.

The obtained results of impact energy of the Ti6Al7Nb alloy samples are qualitatively consistent with the fracture toughness results (obtained in K_{IC} test) of the diphase Ti6Al2Mo2Cr alloy, acc. to Ref. [14]. It was shown in this study that the Ti6Al2Mo2Cr alloy tempered at 450 and 550°C, after the previous cooling from the $\alpha + \beta$ range (790°C), was characterised by a higher stress intensity factor (K_{IC}) when it was cooled in oil (not in water).

Acc. to Ref. [14, 15] are of the opinion that the fracture toughness of alloys on the titanium matrix depends also on the kind of the microstructure formed after the aged procedure. The alloy fracture toughness is determined by the thickness of lamellas or aciculars of the α phase. Increasing the cooling rate from temperature in the $\alpha + \beta$ range (e.g. by cooling in water) leads to the α phase refinement and causes the fracture toughness decrease (at the same ageing conditions) [14, 15].

As can be seen, the application of oil instead of water as a cooling medium decreases tensile strength and yield strength, both in case of samples aged at 450 and at 650°C. This decrease of strength properties (UTS and YS) is accompanied with the sample elongation increase (from 15.5% to 17% and from 14.7% to 17%, respectively).

Analysis of data given in Table 2 and 3 indicates that the highest tensile strength (1147 MPa) was obtained after soaking the alloy at 970°C, cooling in water and ageing for 5 hours at 450°C. The lowest tensile strength (990 MPa) was found at the analogous soaking, cooling in oil and ageing for 5 hours at 650°C.

Photographs of fractures of toughness samples, after the heat treatment acc. to the scheme presented in Tables 2 and 3, obtained by the scanning electron microscope, are shown in Figure 3.

The analysis of Fig. 3 indicates that regardless of the applied heat treatment variants (first of all - different cooling conditions), fractures of the Ti6Al7Nb alloy samples are of a similar character. These are ductile fractures with a lot of "voids". Characteristic flat areas which could indicate a brittle fracture occurrence (even in a small amount) are not seen.

It can be noticed that disintegration of the acicular structure of the α phase originated during ageing of the supersaturated β phase positively influences mechanical properties of the tested alloy. A similar effect, but related to the accelerated cooling during quenching, influences favourably strength properties but unfavourably the fracture toughness.

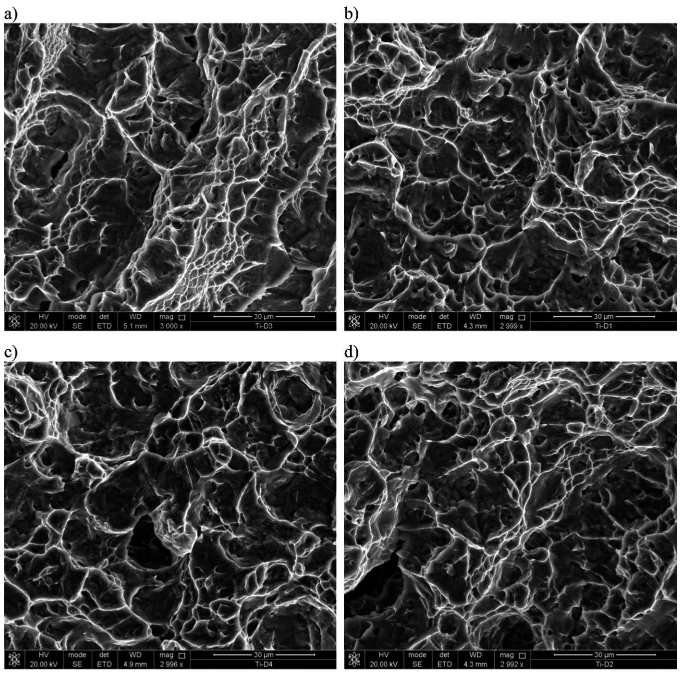

Fig. 3. Fracture surfaces of Ti6Al7Nb alloy after cooling in water from 970°C, ageing at 450°C (a) and 650°C (b); cooling in oil from 970°C, ageing at 450°C (c) and 650°C (d)

5. Conclusions

1. The Ti6Al7Nb alloy microstructure, after the heat treatment based on cooling in water or oil from a temperature of the two-phase range and ageing, does not indicate es-

sential differences and consists of nearly equiaxial grains of the primary α phase and precipitates of the new flake α phase formed from the supersaturated β phase.

2. Applying less intensive cooling medium (oil) instead of water decreases strength properties indicators, i.e. tensile strength and yield strength as well as hardness (only slightly). The decrease of the above mentioned indicators is accompanied by an increase of an elongation and impacts strength.
3. Fractures of tensile and impact tests are of a ductile character regardless of the applied heat treatment.
4. The obtained investigation results will supplement the existing data bases concerning phase transformations, microstructure and mechanical properties of the Ti6Al7Nb alloy. They will be also useful in designing chemical compositions and heat treatment technology of new, two-phase titanium alloys.

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