THE INFLUENCE OF HEAT TREATMENT ON THE MICROSTRUCTURE OF THE CASTED Ti6Al4V TITANIUM ALLOY

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Abstract

This paper deals with the results of influencing the microstructure of a Ti6Al4V model titanium alloy by solution treatment at 1050 ^{o}C, 950 ^{o}C and 800 ^{o}C followed by water or air cooling and by aging treatment at 550 ^{o}C. The solution treatments at temperature 1050 ^{o}C and 950 ^{o}C, respectively, followed by water cooling lead-to formation of α′ martensite. In other cases of treatments a lamellar structure of α+β phases was formed. The effect of the heat treatment parameters is documented by optical and scanning electron microscopy and by hardness measurements.

Introduction

Titanium and titanium alloys have a wide range of applications in aerospace, energetic, chemical and automobile industry. Some titanium alloys are excellent materials for biomedical use, especially as orthopaedic alloys. The most important characteristic features of these biomedical titanium alloys are high strength, low density, excellent corrosion resistance and the best biocompatibility among the metallic biomaterials. The Ti6Al4V alloy, originally having been developed as a construction alloy for aircraft industry, belongs to the most significant alloys within the implant alloys for hard tissue replacement [1].

The conventional technology of implant production is thermo-mechanical treatment of semi-finished products and subsequent machining to final shape and dimensions. Vacuum and plasma metallurgy together with precision casting technology represent a high potential to reduction of costs for final implant. At the Department of Materials Engineering SUT, lead by prof. Žitňanský, series of ingots fromTi6Al4V alloys have been prepared by precision casting [2,3]. Different heat treatments were carried out on the cast specimens in order to influence the microstructure as well as the properties of the model Ti6Al4V alloy. This work is connected to our previous experimental heat treatment processes [4,5] and represents a certain summary of the realised research.

Materials and experimental procedures

Ti6Al4V model alloy prepared by plasma metallurgy in protective argon gas was tested in this work. The nominal chemical composition (in weight %) of the alloy: 6 % Al, 4 % V and the balance of Ti.

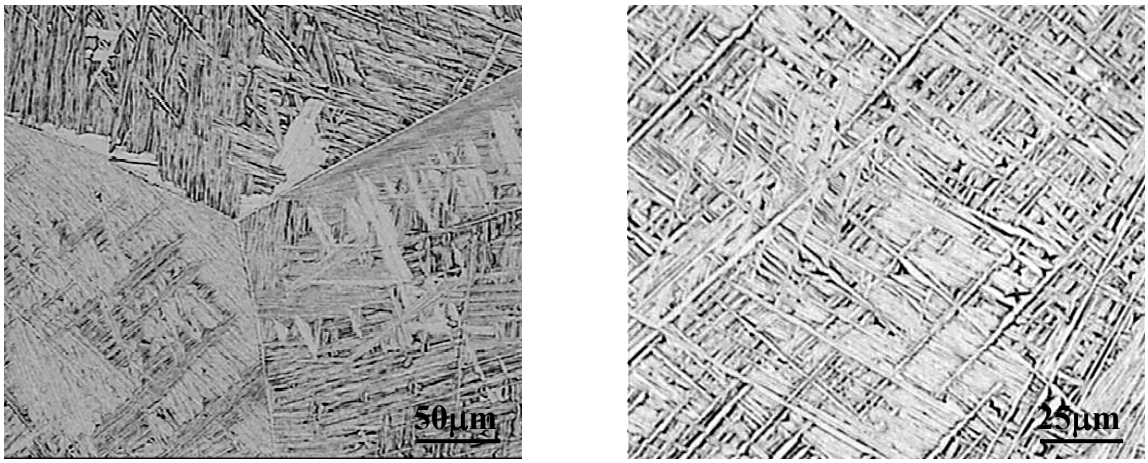
Solution treatment at 1050 ^{o}C/1h, 950 ^{o}C/1h and 800 ^{o}C/1h, respectively, with water and air cooling were applied. After the solution treatment an aging treatment at 550 ^{o}C/4h was used by air cooling. The heat treatment was realised in an LM 212.11 induction furnace.

The specimens for the metallographic analysis were ground, polished and etched in reagents having the following compositions: 1,5 ml HF + 2 ml HNO_3 + 10 ml H_2O. The

investigation of the microstructure was carried out by a NEOPHOT 30 optical and a JEOL JSM 5310 scanning electron microscope. Thin foils of the Ti6Al4V alloy were investigated by a JEOL 200 CX transmision electron microscope. HV10 hardness test were carried out by a Briviskop BVR 187.5H device.

Results and discussion

The microstructure of the precision cast Ti6Al4V model alloy is shown in Fig. 1a and b, showing the two-phase, microstructure consisting of α and β solid solutions. The α phase (shown light) has a lamellar structure which is relatively regular and between these lamellae are thin areas of the β phas (shown dark). Within prior β grains α + β colonies are formed, containing α lamellae with similar crystallographic orientation. Growing from the boundaries of the prior β grains α phase is formed which ″delimits″ these grains (grain boundary α).



a) b)

Fig. 1 The initial microstructure of the Ti6Al4V model alloy
a) Character of microstructure, b) Detail of lamellar structure (α + β)

The types of microstructures having been produced by the different applied solution treatments are shown in Fig. 2. Water cooling from 1050 ^{o}C leads to acicular α′ martensite structure. Between martensitic laths remaining β phases can be seen, no precipitation of grain boundary α was recognized. Solution treatment at 1050 ^{o}C followed by air cooling leads to the typical lamellar α + β structure with grain boundary α in the prior β grains.

Water cooling from 950 ^{o}C produces a microstructure which consists of acicular α′ martensite and primary α phase, which was not dissolved in β phase at 950 ^{o}C. The temperature β transus, i.e. the temperature of α + β → β transformation is ~ 1000 ^{o}C [6]. After the solution treatment at 950 ^{o}C/air the structure consisits of a lamellar mixture of α + β phases, primary α and grain boundary α.

The metallographic investigation showed that no α′ martensite phase was formed after the treatment at 800 ^{o}C/water. As a result of fast cooling a metastable β phase with a certain level of supersaturation could occur. Following the air cooling from 800 ^{o}C a lamellar structure of α + β phases was observed. The grain boundary α phase was present in the structure after solution treatment at 800 ^{o}C both after water and air cooling.

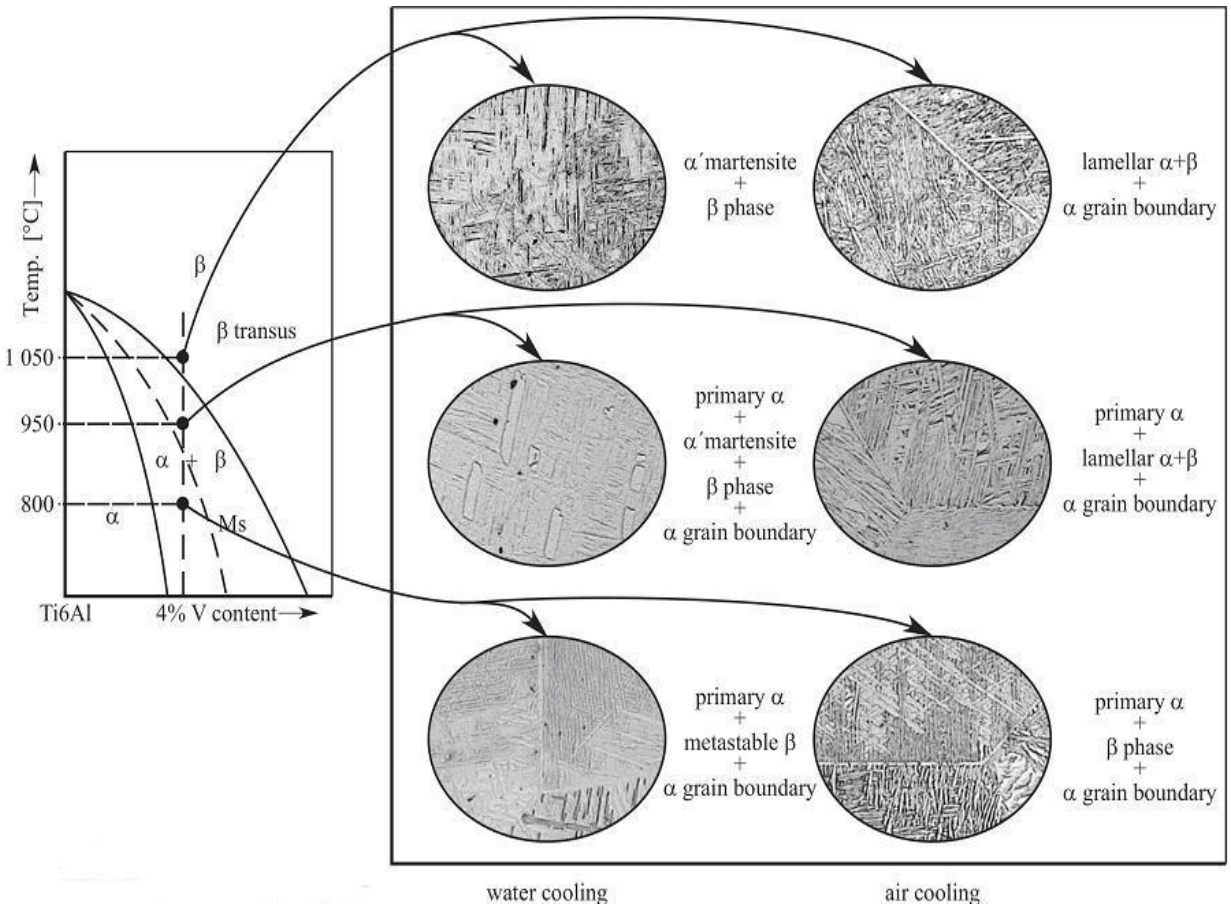


Fig. 2 The microstructures developed after solution treatment of the Ti6Al4V model titanium alloy

After each solution treatment process a 4 h aging treatment at 550 ^{o}C followed by air cooling was carried out. The characteristic features of the microstructure formed after the solution treatment remained basically unchanged even after this ageing treatment. In Fig. 3 and Fig. 4 typical microstructures are shown after the 950 ^{o}C/ water + 550 ^{o}C and 950 ^{o}C/ air + 550 ^{o}C heat treatment processes.

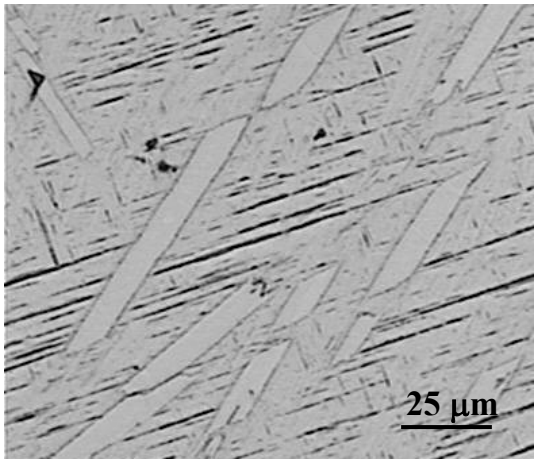


Fig. 3 Ti6Al4V, 950 ^{o}C/1h/water + 550^{o}C/4h

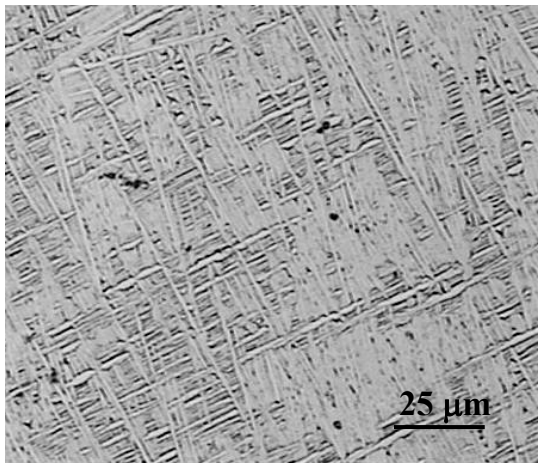


Fig. 4 Ti6Al4V, 950 ^{o}C/1h/air + 550^{o}C/4h

The microstructures after the applied heat treatment processes were observed also by scanning electron microscopy (SEM). The SEM analyses verified the results obtained by optical microscopy. Fig.5 displays the still typically acicular martensite structure after the1050 ^{o}C /water + 550 ^{o}C treatment. A detailed view to the lamellar areas of α phase with narrow areas of β phase (α + β colony) after the 1050 ^{o}C/air + 550 ^{o}C treatment is shown in Fig. 6.

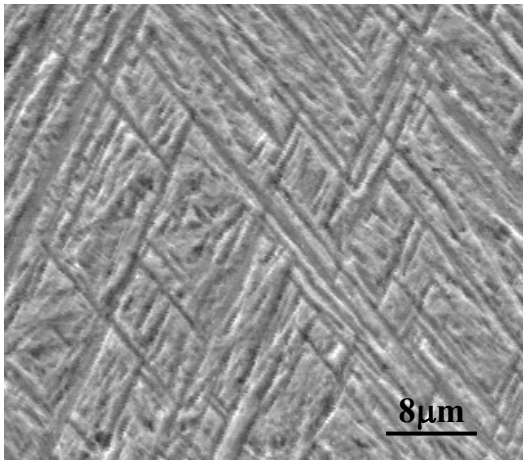


Fig. 5 Ti6Al4V, 1050 ^{o}C/1h/water + 550^{o}C/4h, SEM

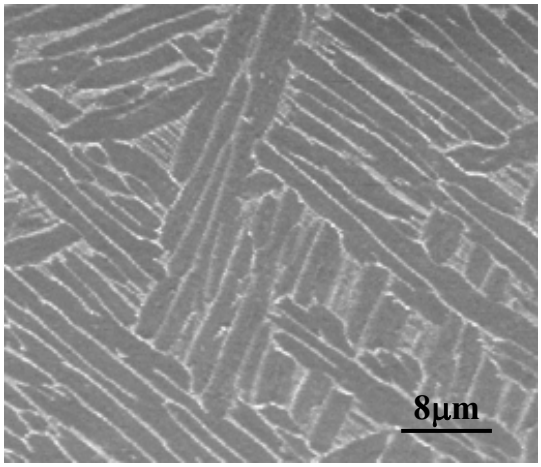


Fig. 6 Ti6Al4V, 1050 ^{o}C/1h/air + 550^{o}C/4h, SEM

Hardness measurements were carried out to investigate the effects of the applied heat treatment processes on the mechanical properties of the specimens. The initial hardness of the as cast alloy was 312 HV. The results of hardness tests after different heat treatments are shown in Table 2. The highest hardness values were measured after the 1050 ^{o}C/ water and 950 ^{o}C/ water treatments. Air cooling basically did not have any influence on the initial hardness of the alloy. The subsequent aging treatment at 550 ^{o}C leads to the increase of hardness in comparison with previous solution treatment. The growth of hardness can be explained by the decomposition of martensite structure, i.e. $\alpha' \rightarrow \alpha + \beta$. If the martensite structure is not formed after the solution treatment, the hardness during the aging treatment will rise probably as a result of precipitation of the fine α phase from β phase, i.e. *metastable* β → *fine* α + β.

Table 2 The influence of applied heat treatment on the hardness of the Ti6Al4V model alloy

Casted Ti6Al4V titanium alloy **Hardness in as-cast condition 312 HV 10**	**Solution treatment**	1050 ^{o}C/ 1h/water	1050 ^{o}C/ 1h/air	950 ^{o}C/ 1h/water	950 ^{o}C/ 1h/air	800 ^{o}C/ 1h/water	800 ^{o}C/ 1h/air
	Hardness HV 10	405	320	395	311	344	319
	Solution treatment + aging	1050 ^{o}C/ 1h/water + 550 ^{o}C/4h	1050 ^{o}C/ 1h/air + 550 ^{o}C/4h	950 ^{o}C/ 1h/water + 550 ^{o}C/4h	950 ^{o}C/ 1h/air + 550 ^{o}C/4h	800 ^{o}C/ 1h/water + 550 ^{o}C/4h	800 ^{o}C/ 1h/air + 550 ^{o}C/4h
	Hardness HV 10	428	338	414	352	368	346

To characterize the mechanisms of phase transformation during aging treatment an investigation by transmission electron microscopy (TEM) is planned. As a first result of the TEM investigation the as-cast state of the alloy can be seen in Fig. 7. Fig. 7 TEM micrograph showing the substructure of the as cast alloy.

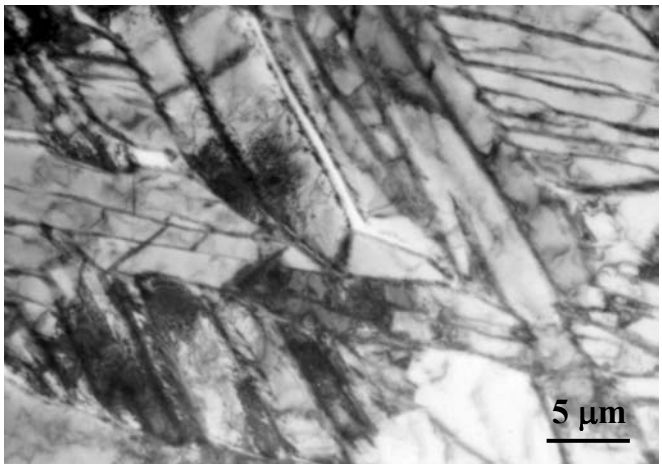


Fig. 7 The substructure of the Ti6Al4V model titanium alloy, TEM

Conclusions

The results obtained from experimental heat treatment of a cast Ti6Al4V model alloy show that an α′ martensite structure is formed after water cooling form the solutiontreatment at 1050 ^{o}C and 950 ^{o}C. After water cooling from 800 ^{o}C only lamellar α phase structure was observed in untransformed β phase, α′ martensite structure did not appear. Air cooling from each solution temperature leads to formation of lamellar structure of α + β phases. The character of the formed microstructures has not changed basically after the aging treatment at 550 ^{o}C. After aging treatment an increase of hardness was registered in comparison with the solution treated state. The highest increase of hardness (above 100 HV) relative to the initial hardness was detected after the heat treatment at 1050 ^{o}C/1h/water + 550 ^{o}C.

Acknowledgement

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