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CHANGE IN MICROSTRUCTURE AND HARDNESS OF TI-6%AL-4%V ELI ALLOY ON TEMPERING PROCESS

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ABSTRACT

A Ti-6Al-4V alloy is one of important titanium alloys used for aerospace, power generation, chemical and biomedical applications. The alloy is available in two grades; commercial grade (0.16mass% (%)-0.2% oxygen) and extra-low interstitial (ELI) grade (0.10%-0.13% oxygen). In this study, effect of tempering on microstructure and hardness of the Ti-6Al-4V ELI alloy was investigated. The alloy was heat-treated at temperature of 1323K for 3.6ks for solution treatment at a bcc (β) phase region. The alloy is subsequently quenching into the water to promote a martensitic transformation, and then tempered at temperatures from 923K-1123K for various times from 0.6ks to 7.2ks. Microstructure of quenched specimen is a martensitic structure, which exhibits a needle-like structure. On the other hand, the microstructure of the tempered specimens are hcp+bcc (α+β) dual-phase. It is observed that the β phase increases as the tempering temperature increases or time prolongs. Hardness measurement shows that the hardness of the tempered specimen gradually increased as the time and the temperature increase. It is thought that the increase in hardness of the tempered specimen is due to precipitation hardening of the β phase.

KEY WORDS

Titanium, microstructure, tempering, precipitation hardening, martensite, dual-phase, β phase

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INTRODUCTION

Titanium and its alloys have been considered as one of the most applied engineering metallic materials for industrial application. Among various titanium alloys, Ti-6Al-4V alloy, which has excellent specific tensile and fatigue strengths and corrosion resistance is mainly applied for aircraft structural and engine parts, materials for petrochemical plants and surgical implants. It is due to its excellent combination of the properties such as elevated strength-to weight ratio, toughness and corrosion resistance [1].

Ti-6Al-4V alloy is (α+β) dual-phase type alloy, which microstructure is strongly sensitive to heat treatment parameters. At ambient temperature, the microstructure is composed of α phase as matrix and β phase as second-phase. Above 873K, the α phase transforms to the β phase, while above 1268K, the whole microstructure is equiaxed β grain.

On the other hand, the Ti-6Al-4V alloy is available in two grades; commercial grade (0.16mass% (%)-0.2% oxygen) and extra-low interstitial (ELI) grade (0.10%-0.13% oxygen) [2]. The microstructure and mechanical properties of the Ti-6Al-4V alloy depends on chemical composition such as oxygen and interstitial alloying elements instead of the heat-treatment parameters. However, the microstructural change of as-quenched Ti-6Al-4V ELI alloy during tempering is still unclear. Moreover, the effect of microstructures on the hardness of the alloy is also important to be understood in order to improve mechanical properties of the alloy.

In this study, effect of tempering on microstructure and hardness is investigated in order to clarify relationship between microstructure and hardness in the Ti-6Al-4V ELI alloy.

EXPERIMENTAL PROCEDURES

A Ti-6Al-4V ELI alloy, which has oxygen content around 0.11%, was used in this study. Chemical composition of the alloy is shown as below. As received Ti-6Al-4V ELI alloy was cut into cubic shape of dimension 10mmx10mmx10mm. Before the specimens were heat-treated, each of the specimens was folded with stainless steel foil to reduce oxidation during heat treatment. Then, the specimens were subjected to solution treatment at 1323K for 3.6ks and then water-quenching. Microstructures were observed by optical microscopy. Hardness of as-quenched and tempered specimens was measured by Vickers hardness tester with load of 2kg. Volume fraction of the β phase was estimated using an image analysis software.

RESULTS AND DISCUSSION

Microstructure and Hardness of the As-Quenched Ti-6Al-4V ELI Alloy

Figure 1 shows microstructure of the as-quenched Ti-6Al-4V alloy. The as-quenched Ti-6Al-4V ELI alloy exhibits a needle-like structure. The needle-like structure is formed due to martensitic transformation on water-quenching. Thus, the microstructure of the as-quenched Ti-6Al-4V ELI is a martensitic (α') structure. Hardness measurement shows that the α' structure has hardness of around Hv328. It is found that the hardness of the as-quenched Ti-6Al-4V alloy is almost the same with other researchers' result. [3].

Microstructural Change of the Tempered Ti-6Al-4V ELI Alloy

Figure 2 shows microstructures of specimens of the Ti-6Al-4V ELI alloys, which were tempered at 1023K for 0.6ks (a), 3.6ks (b) and 7.2ks (c). Moreover, microstructures of the specimens, which are tempered at 923K (a), 973K (b) and 1023K (c) are shown in Figure 3. It is found that β phase precipitates in needle-like shape within α' structure on tempering. The β phase increases as the tempering temperature increases or the time prolongs as shown in Figure 4.

Change in Hardness of the Tempered Ti-6Al-4V Alloy

Figure 5 shows the hardness of the Ti-6Al-4V ELI alloys. It is obviously found that the hardness of the tempered specimens increases when the tempering time prolongs (a) or the tempering temperature increases (b). It is known that the hardness of martensitic steel will be decreased when the steel is subjected to tempering. The change in hardness of the tempered steel has strong relationship with and can be plotted against tempering parameters [4].

$$P = T\,(k + \log t) \qquad \text{……………………….(1)}$$

where, P is the tempering parameters, k is a constant; 20 [4], T is temperature (^{o}C) and t is time (hour). Figure 6 shows change in hardness of the tempered Ti-6Al-4V ELI alloy as a function of the tempering parameter. It should be noted that the hardness is increased as the tempering parameter increased. This result differs from the tempering behavior of the martensitic steel, which the hardness decreases as the tempering parameter increases. It is thought that the hardening mechanism of the α' structure in the as-quenched Ti-6Al-4V ELI alloy is not mainly due to dislocation hardening by which the hardness of the martensitic steel is obviously increased. Moreover, it is thought that recovery of dislocation, which will occur on tempering, has very small effect on the change in the hardness of the tempered Ti-6Al-4V alloy. On the other hand, it can be thought that the precipitation of β phase give a significant influence on the hardness of the tempered Ti-6Al-4V ELI alloy. Figure 7 shows relation between volume fraction of b phase and hardness in the tempered Ti-6Al-4V ELI alloy. It is clearly observed that the hardness increases when volume fraction of the β phase increases. Therefore, it is thought that the hardening mechanism of the Ti-6Al-4V alloy on tempering is due to the precipitation hardening by the β phase.

CONCLUSION

The effect of tempering on microstructure and hardness was investigated in order to clarify relationship between microstructure and hardness in the Ti-6Al-4V ELI alloy, and the following findings were obtained:

(1) The Ti-6Al-4V ELI alloy exhibits martensitic structure after solution heat-treatment and water-quenching. The microstructure has a typical martensitic structure, which is a needle-like form. During tempering, the β phase precipitates in needle-like form within the α' phase.

(2) Hardness of the Ti-6Al-4V ELI alloy increases as the tempering temperature increases or the tempering time prolongs. The increase in the hardness almost corresponds to the increase in the β phase. Hence, it is thought that the hardening mechanism in the tempered Ti-6Al-4V alloy is due to the precipitation of the b phase.

REFERENCES

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Table and figures

Table 1 Chemical compositions of the Ti-6Al-4V ELI alloy

Al	V	O	H	N	C	Si	Ti
6.1	4.0	0.11	0.003	0.007	0.011	0.03	bal.

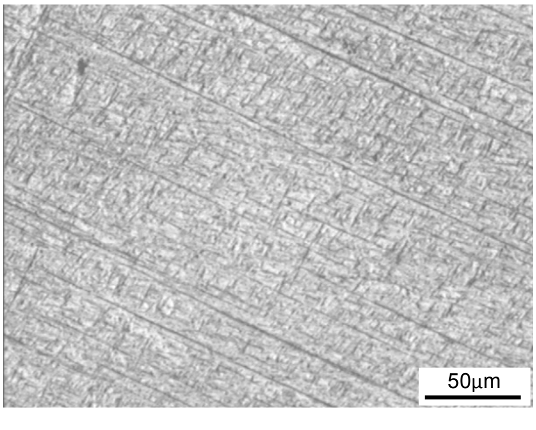

Figure 1. Microstructure of as-quenched Ti-6Al-4V ELI alloy

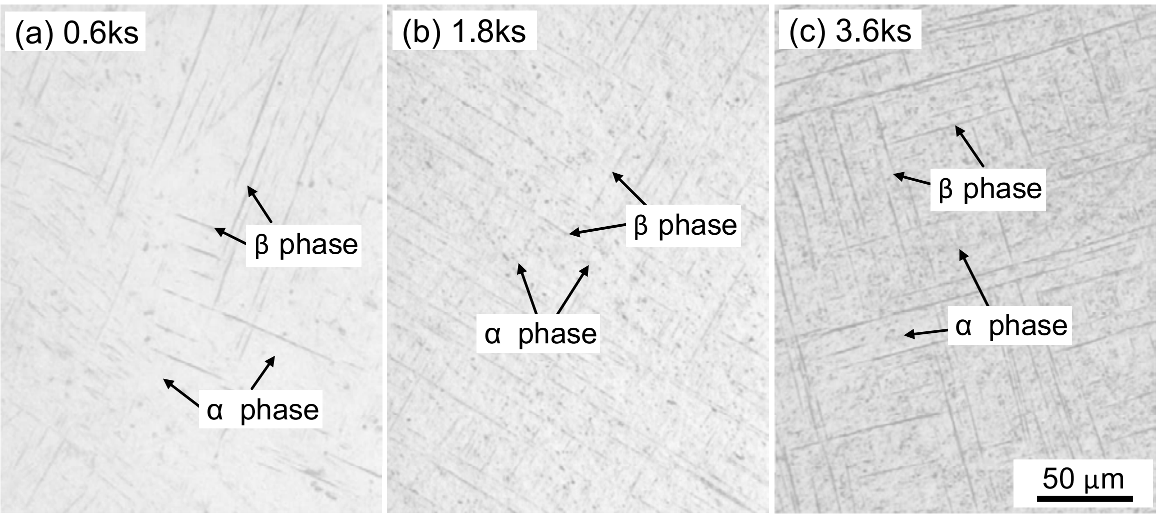

Figure 2. Microstructures of specimens of the Ti-6Al-4VELI alloy. The specimens were tempered at 1023K for 0.6ks (a), 1.8ks (b) and 3.6ks (c) after solution treatment.

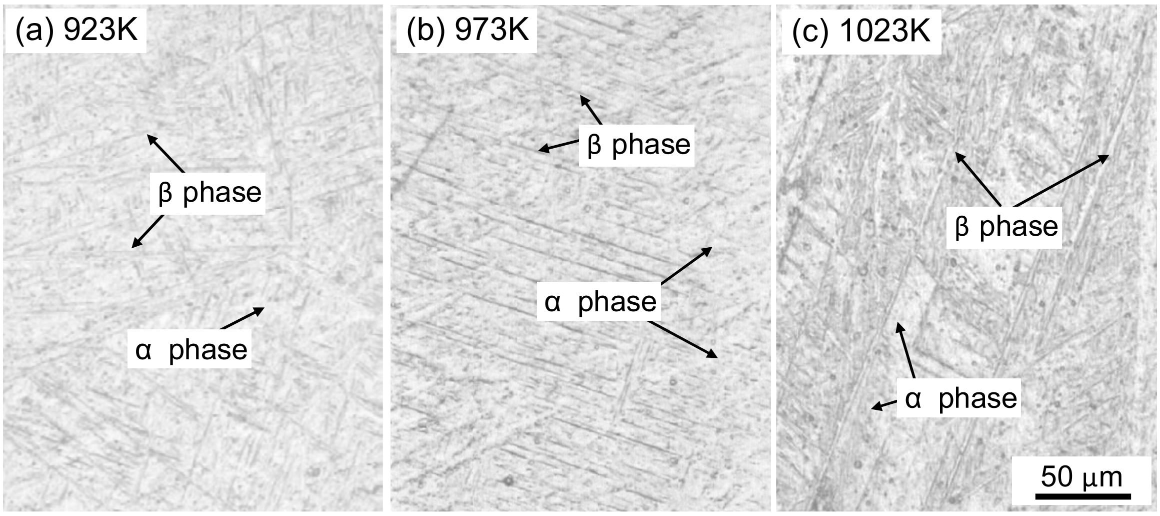

Figure 3. Microstructures of specimens of the Ti-6Al-4VELI alloy. The specimens were tempered at 923K (a), 973K (b) and 1023K (c) for 3.6ks after solution treatment.

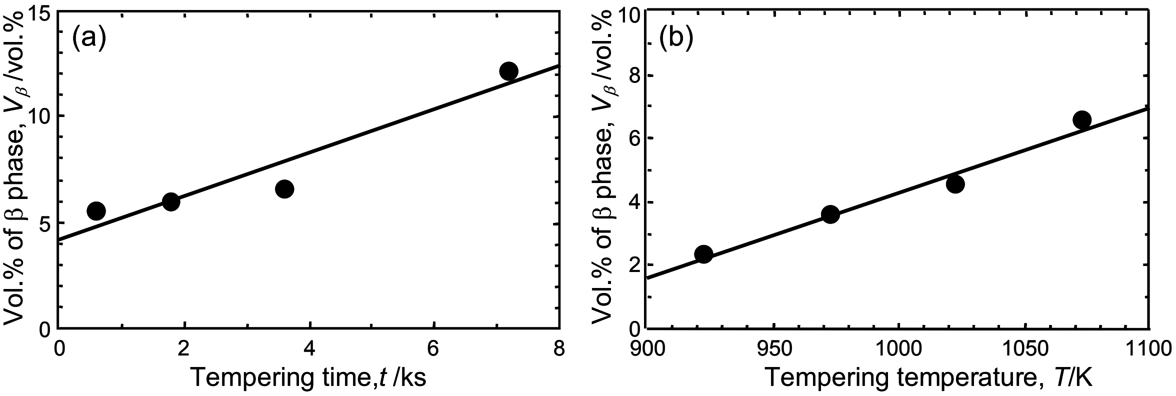

Figure 4. Relation between volume fraction of the β phase and the tempering time (a) or the tempering temperature (b).

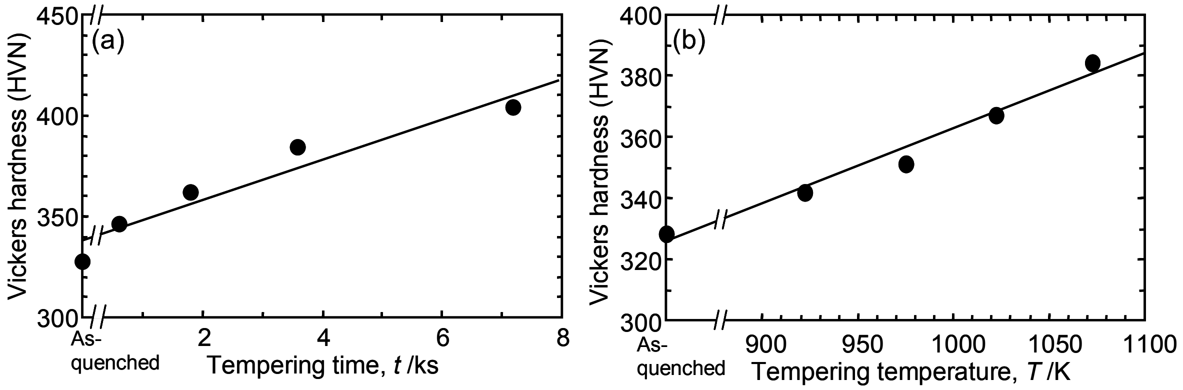

Figure 5. Relation between Vickers hardness and tempering time (a) or tempering temperature (b).

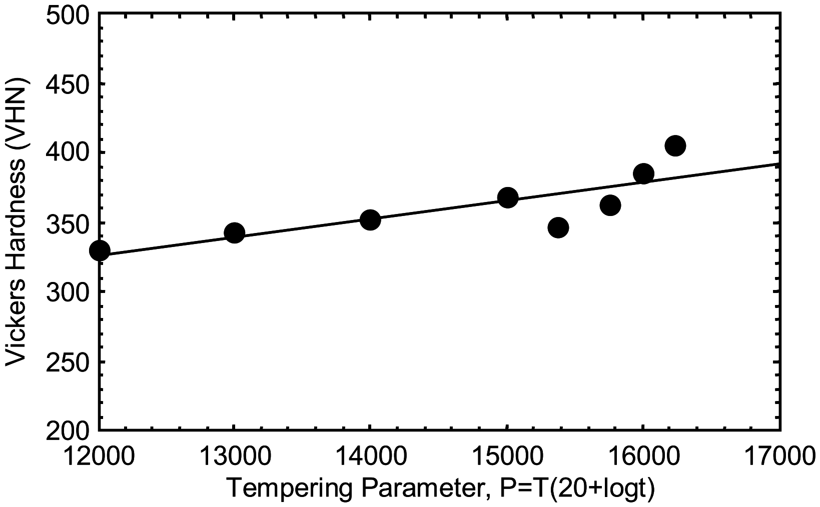

Figure 6. Change in hardness of the tempered Ti-6Al-4V ELI alloy as a function of the tempering parameter.

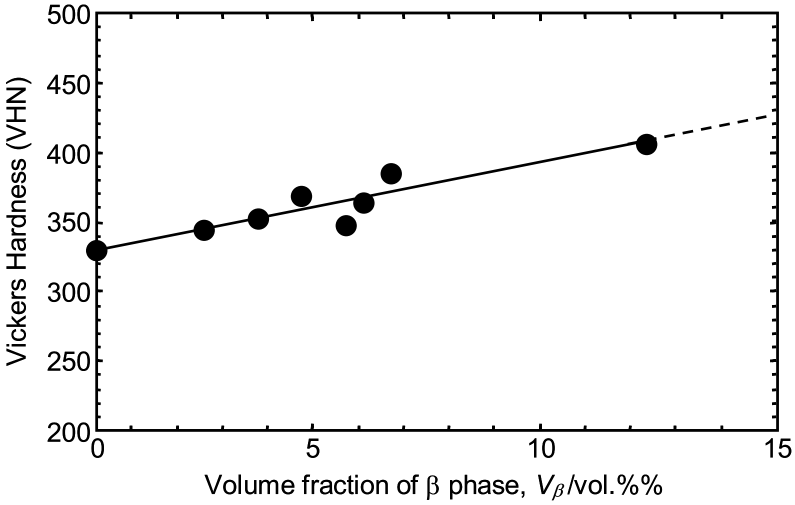

Figure 7. Relation between volume fraction of b phase and hardness in the tempered Ti-6Al-4V ELI alloy.