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Author(s)	Sato, K.; Matsumoto, H.; Chiba, A. et al.
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Microstructure evolution and age-hardening of hexagonal α’ martensite in Ti-12mass%V-2mass%Al alloys on annealing

K Sato[1], H Matsumoto[1], A Chiba[1] and TJ Konno[1]

1. Institute for Materials Research, Tohoku University, 2-1-1 Katahira, Sendai 980-8577, Japan

ksato@imr.tohoku.ac.jp

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Titanium alloys are widely used in aerospace, automobile and biomedical applications due to their high specific strength and corrosion resistance [1]. Among the Ti-alloy systems, Ti-V alloys composed of hexagonal α’ martensites possess low Young’s moduli (~60GPa) and high strength (~1000MPa), and show a good machinability for cold groove rolling [2]. Recent studies on α’-type Ti-V-Al alloys revealed the increase of Young’s modulus and Vickers hardness by aging at 300-400^{o}C [2]. However, x-ray diffraction patterns of these annealed alloys, as well as those of the as-quenched alloy after solution treatment (STQ), exhibit no reflections of the equilibrium α or β phases, i.e., the α’ martensite phase is maintained. In this study, microstructure composed of α’ martensites in Ti-12mass%V-2mass%Al alloys and its decomposition behaviors upon aging were studied by transmission electron microscopy and electron diffraction.

Ti-12V-2Al alloys were prepared by arc melting in an argon atmosphere using high purity Ti, V, and Al, followed by homogenization at 1150^{o}C for 24h. The homogenized buttons were solution treated at 950^{o}C for 2h, and then quenched into ice water. Aging conditions for the STQ alloys were 300-500^{o}C for 0.5-500h. Microstructures of these alloys were studied using a JEOL JEM-2000FX (200kV) and a JEM-3011 (300kV) TEMs. HRTEM and STEM images were obtained using an FEI Titan 80-300 (S)TEM operating at 300 kV with a field emission gun and a CEOS image corrector.

Figure 1(a) shows a bright-field (BF) TEM image and the corresponding selected area diffraction (SAED) pattern of the STQ alloy viewed along the [-12-10] axis of the hexagonal α’ martensite phase. A broken line indicates the trace of the {10-11} twin, which is typically observed in quenched Ti-V alloys. An acicular martensite structure with martensite plates, a few hundred nanometers in thickness, is seen in Fig. 1(b). These martensite morphologies are composed of large primary martensite plates and many other smaller ones. The SAED pattern shown in Fig.1(b) includes reflections from the β phase in addition to those from the α’ martensite (indicated by arrowheads). The observed β phase can be considered as a retained phase on quenching [3].

Figure 2(a) shows an SAED pattern of the alloy annealed at 400^{o}C for 24h with a beam incidence of $[001]_{\beta}$, which also shows reflections from α’ martensite with $[-12-10]_{\alpha'}$ incidence. The Vickers hardness, as high as 377Hv, was observed for this alloy (the STQ alloy showed 205Hv). Fig. 2(b) is a dark-field (DF) TEM image taken with -110_{β} reflection, showing fine precipitates, 10-100nm in sizes, inside α’ plates. A broken line indicates the trace of the {10-11} twin. Such fine acicular β precipitates were also confirmed by a HAADF-STEM image shown in Fig. 2(c). Thus, the age-hardening can be attributed to the high-density fine β precipitates inside the primary α’ plates.

As the aging temperature increases, partitioning of V becomes prominent. Figure 3(a) shows a BF-TEM image and the corresponding SAED pattern for the alloy annealed at 500^{o}C for 24h. The primary α’ phase decomposed into the α/β two phases with distinct morphology, exhibiting clear habit planes, which resulted in an abrupt decay of hardness (281Hv). The Burgers’ orientation relationship was observed between the α and the β phases. HRTEM observation revealed a relation, $(01\text{-}1\text{-}1)_{\alpha} \parallel (101)_{\beta}$, at the α/β interface as shown in Fig. 3(b) [4]. Therefore, it can be considered that the β precipitate grows parallel to the primary {10-11}-type twin plates. These observations indicate a good lattice correspondence exist between the hexagonal α and the cubic β phases [5].

References

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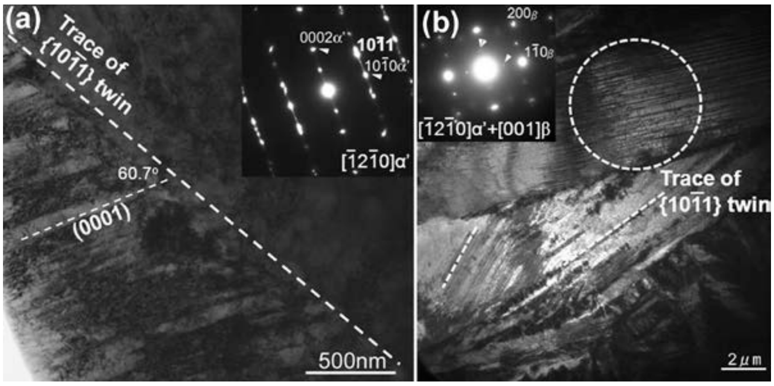

Figure 1. *Microstructures of the as-quenched α'-type Ti-12%V-2%Al alloy. (a)*$[-12-10]_{\alpha'}$*, (b)[-12-10]α' +* $[001]_{\beta}$.

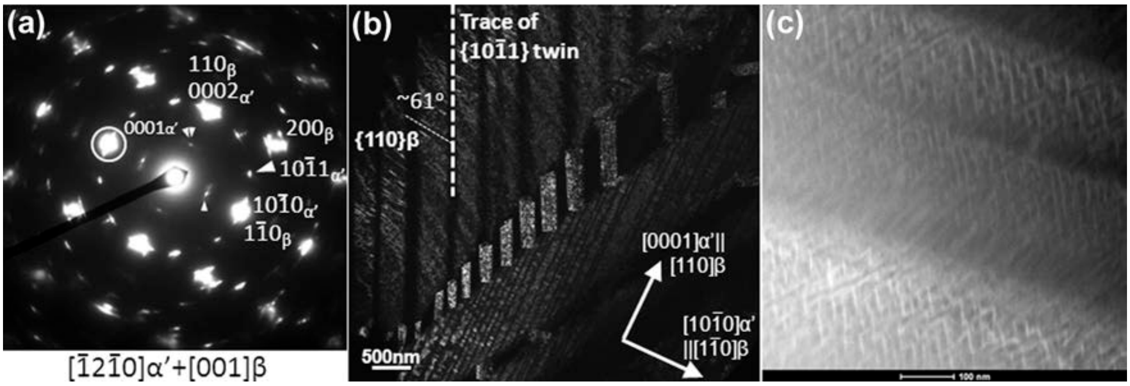

Figure 2. *Microstructure of the Ti-12%V-2%Al alloy after aging at* 400^{o}*C for 24h. (a)SAED pattern with beam incidence of* $[-12-10]_{\alpha'}$ *or* $[001]_{\beta}$*. Single- and double-arrowheads indicate* $0001_{\alpha'}$ *from different variants. (b)DF-TEM image taken using* -110_{β} *reflection. (c)HAADF-STEM image taken with detector angles of 60-210mrad.*

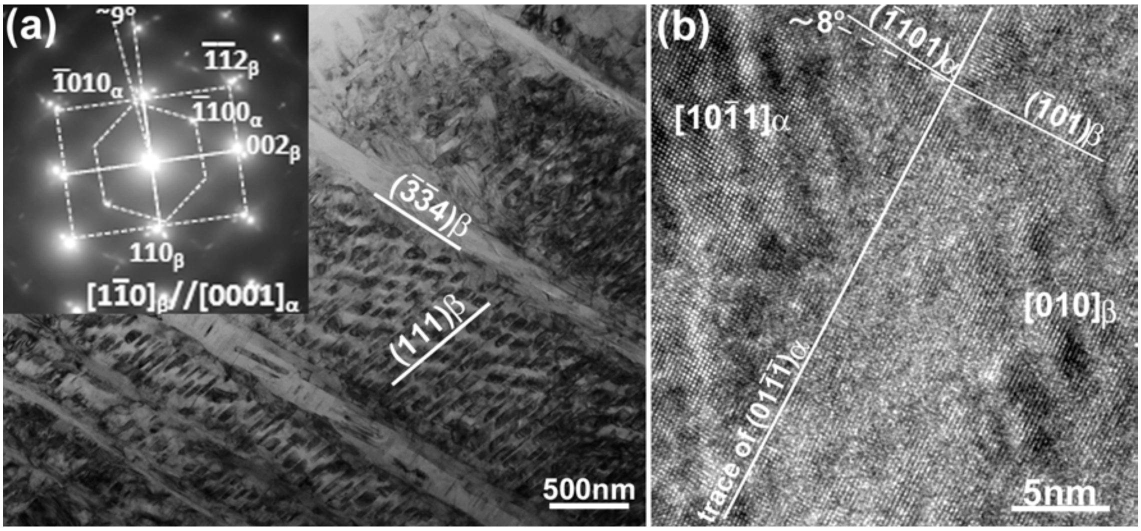

Figure 3. *Microstructure of the Ti-12%V-2%Al alloy after aging at* 500^{o}*C for 24h. (a)BF-TEM image and the corresponding SAED pattern, showing the Burgers' orientation relationship between the α and the β phases. (b)*C_S*-corrected HRTEM image at the α/β interface region.*