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PHASE AND STRUCTURAL TRANSFORMATIONS IN Ti-Ta ALLOYS IN WIDE REGION OF COMPOSITIONS

PRZEMIANY FAZOWE I STRUKTURALNE W STOPACH Ti-Ta W SZEROKIM ZAKRESIE SKŁADÓW

Optical microscopy, X-ray diffraction, transmission electron microscopy, and hardness measurements were used to study the structure of quenched Ti-Ta alloys containing 1-40 at.% tantalum. Two martensitic phases, α' and α'', are formed in quenched Ti-Ta alloys. The type of martensite crystal structure is determined by the composition of the alloy. The α'-phase is formed in the alloys containing up to 10 at.% tantalum. The orthorhombic α''-phase was found in the alloys containing 15-30 at.% Ta. The concentration dependence of the lattice parameters of the α''-phase is given. Omega-phase precipitation were not found in quenched alloys. The alloys of 35-40 at.% Ta consist of metastable β-phase only upon quenching. The electron diffractions patterns of the Ti-Ta alloys containing from 25 to 35 at.% tantalum exhibit diffuse scattering. It was established that stress-induced $\{110\}_\beta$ and $\{332\}_\beta$ twinning appeared in metastable β-phase.

Keywords: Ti-Ta alloys, martensitic transformation, crystal structures

Struktury stopów Ti-Ta zawierających 1-40% at. Ta badano metodami mikroskopii optycznej, dyfrakcji rentgenowskiej i transmisyjnej mikroskopii elektronowej. Dwie fazy martenzytyczne α' i α'', zidentyfikowano w tych stopach. Rodzaj struktury martenzytu zależy w pierwszym rzędzie od składu chemicznego. Faza α' tworzy się w stopach zawierających do 10% at. Ta, a fazę ortorombową α'' zidentyfikowano w stopach zawierających 15-30% at. Ta. Zmierzono zależność parametru fazy α'' od składu chemicznego. Nie zidentyfikowano natomiast fazy ω. Stopy z zakresu 35-40% Ta zawierają po hartowaniu metastabilną fazę β. Dyfrakcje elektronowe wykonane ze stopów zawierających 25-35% Ta wykazują rozmyte refleksy, które jak ustalono wynikają z bliźniakowania na płaszczyznach $\{110\}_\beta$ i $\{332\}_\beta$ wywołanego naprężeniem w metastabilnej fazie β.

1. Introduction

The study of the phase and structural transformation in titanium-tantalum alloys is of great importance in a wide region of compositions for the determination of the general regularities of the formation of metastable and nonequilibrium states in titanium alloys with transition metals. Until now, the binary alloys of titanium with other metals of Group V (vanadium and niobium) have been studied in most detail. The titanium-tantalum alloys were studied much less comprehensively. The most systematic data on the structure and phase composition of the titanium-tantalum alloys were obtained in [1-6]. Therefore the aim of this work was to study the structure and phase composition of quenched Ti-Ta alloys containing 1-40 at.% tantalum.

2. Experimental

The alloys containing 1, 10, 15, 20, 25, 30, 35, and 40 at.% tantalum were investigated. All the alloys were melted from iodide Ti (99,96 wt.%) and Ta (99,5 wt.%) in an arc furnace in a helium atmosphere. The specimens were homogenised in the β-phase region at 1000°C for 3 hours in vacuum of 1×10^{-3} Pa and then were quenched from this temperature in iced water (T = 0°C). The structure of all alloys was analysed by X-ray diffraction using Cu Kα radiation. Microstructure investigations were performed in a METAVAL optical microscope and a JEM-200CX transmission electron microscope. Vickers hardness was measured using a TPP-2 tester at load of 49 N (5 kg).

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3. Experimental results

X-ray diffraction analysis showed, that the phase composition and structure of the quenched alloys depend strongly on the alloying element content. After quenching, the alloys with 1 and 10 at.% Ta consist only of the α'-phase (Fig. 1). In more concentrated β-quenched titanium-tantalum alloys the α''-phase with orthorhombic structure is formed. The transition from α'-phase to α''-phase is revealed through the splitting of some lines of the α'-phase in X-ray diffraction patterns. The Ti-35 at.% Ta and Ti-40 at.% Ta consist of only β-phase. A characteristic feature of the X-ray diffraction patterns of the Ti-10 at.% Ta is the splitting of (1120) line of the α'-phase.

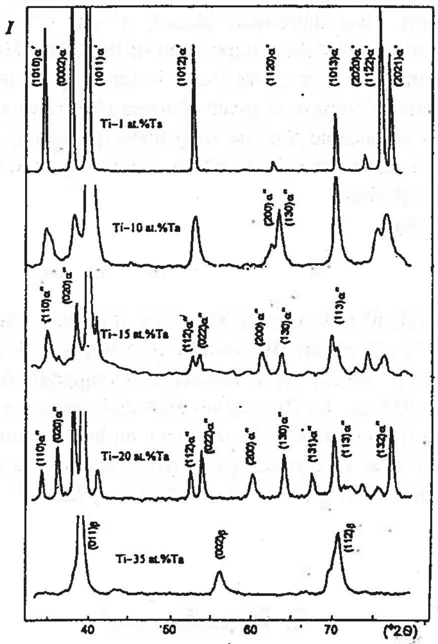

Fig. 1. Experimental diffraction patterns (lines) for five Ti-Ta alloys showing different constituents: Ti-1 at.% Ta (α'-phase); Ti-10 at.% Ta (α'-phase); Ti-15 at.% Ta (α''-phase); Ti-20 at.% Ta (α''-phase); Ti-35 at.% Ta (β-phase)

Figure 2 shows dependencies of the lattice parameters of the α'- and α''-phases from the alloying metal concentration for the titanium-tantalum alloys. It can be seen that the lattice parameters a and c in all alloys regularly decrease with the increase of the alloying metal concentration. After transition to the α''-phase the lattice parameters $b/\sqrt{3}$ and c decrease also, however the lattice parameter a increases. It is interesting to note that the minimum concentration of alloying metal necessary for beginning of the α''-phase formation is observed in Ti-Ta alloy at 15%. The smaller concentration limit of alloying metal is observed in the T-Ru, Ti-Os and Ti-Ir alloys and it is 2 at.% [1]. The graphs in Figure 2 allow to establish the compositional range for the α''-phase formation in titanium-tantalum alloys. It can see that the h.p.c. α'-phase is formed in range 1-10 at.%, and the orthorhombic α''-phase in range 15-30 at.%. The factor limiting the α''-phase formation in region of higher concentration of alloying metal is lowering Ms till room temperature and retaining the metastable β-phase the after quenching. The degree of rhombic distortion of the α''-phase depends on an expansion of the α''-phase range. In all titanium alloys the degree of rhombic distortion of the α''-phase grows with increasing alloying metal concentration in the alloy. The maximum difference between parameters a and $b/\sqrt{3}$ is observed for Ti-Ta alloys and the minimum difference is for Ti-V and Ti-Ir alloys. It is possible to assume, that the initiation of $\alpha'' \rightarrow \beta$ transformation by quenching alloys to lower temperatures as compared to room temperature or intensive plastic deformation will allow to displace boundaries of the α''-phase formation in direction of higher concentration of alloying metal and obtain the orthorhombic α''-phase with higher degree of rhombic distortion.

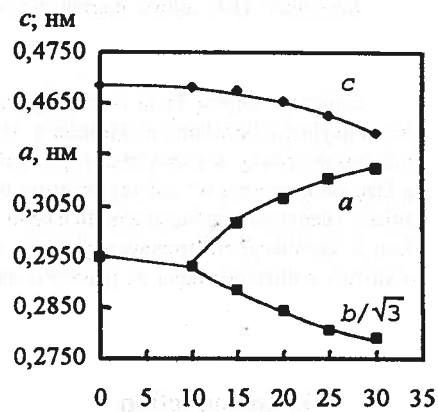

Fig. 2. Dependence of the lattice parameters α'- and α''-phases on concentration of tantalum in the Ti-Ta alloys

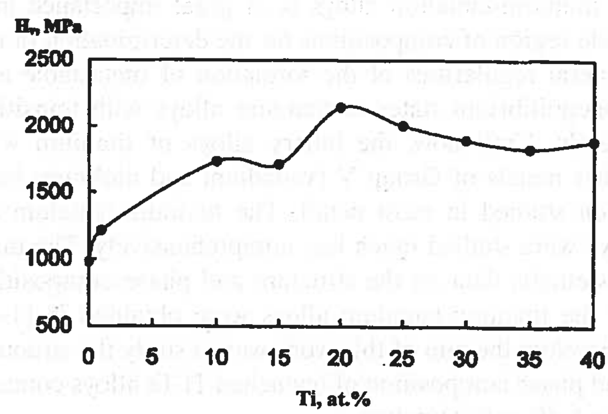

Fig. 3. Vickers hardness of quenched Ti-Ta alloys as a function of tantalum content

The hardness of quenched alloys changes regularly with increasing tantalum content (Fig. 3). The hardness is minimum for the Ti-1 at.% Ta, then increases, and reaches a maximum for the Ti-20 at.% Ta. With further increase in tantalum content, the hardness somewhat decreases. The hardness for the Ti-15 at.% Ta alloy is lower then that for the Ti-10 at.% Ta alloy. Such a decrease of hardness is caused by the appearance of the α''-phase in the alloy.

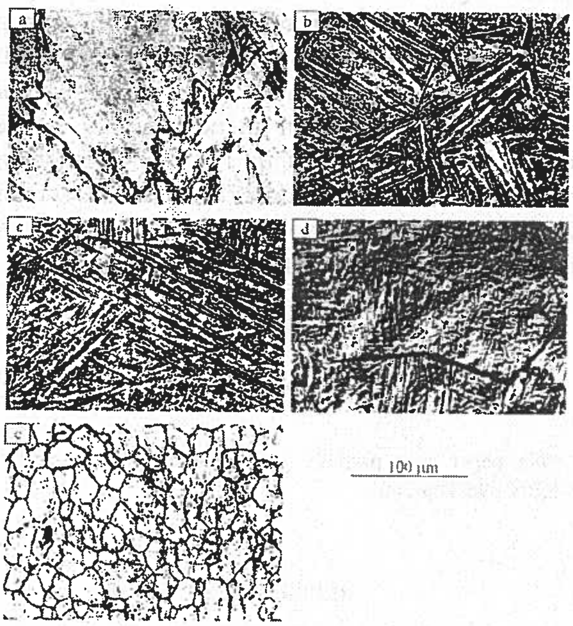

Fig. 4. Optical micrographs of quenched Ti-Ta alloys: (a) Ti-1 at.% Ta; (b) Ti-10 at.% Ta; (c) Ti-15 at.% Ta; (d) Ti-20 at.% Ta; (e) Ti-35 at.% Ta

The metallographic studies reveal that the microstructure of quenched alloy changes, depending on the tantalum content. The Ti-1 at.% Ta alloy has a structure of massive (lath) martensite (Fig. 4a). As a in the case of iron-base alloys, the laths form packets of various dimensions and shape. Within one grain of the initial β-phase, several variants of packets are usually observed. In more concentrated β-quenched titanium-tantalum alloys internally twinned martensite is formed. Figure 4b and 4c show typical martensite structure observed in the quenched Ti-10 at.% Ta and Ti-15 at.% Ta alloys. Large and often twinned primary martensite plates and many smaller martensite platelets are clearly defined. After the transition to the α''-phase the primary martensite plates become much thinner, their length increases strongly (Fig. 4c). The shape and size of the α''-phase martensite is changed strongly in the Ti-20 at.% Ta alloy (Fig. 4d). It is observed an essential decreasing a size of the α''-phase martensite plates in this alloy. It can be supposed that the change of a size and shape of martensite plates at transition to the α''-phase is connected with a change of the mechanism of an accommodation of elastic energy during martensite transformation. Etching of the Ti-35 at.% Ta and Ti-40 at.% Ta alloys reveals only the initial β-grain boundaries (Fig. 4e).

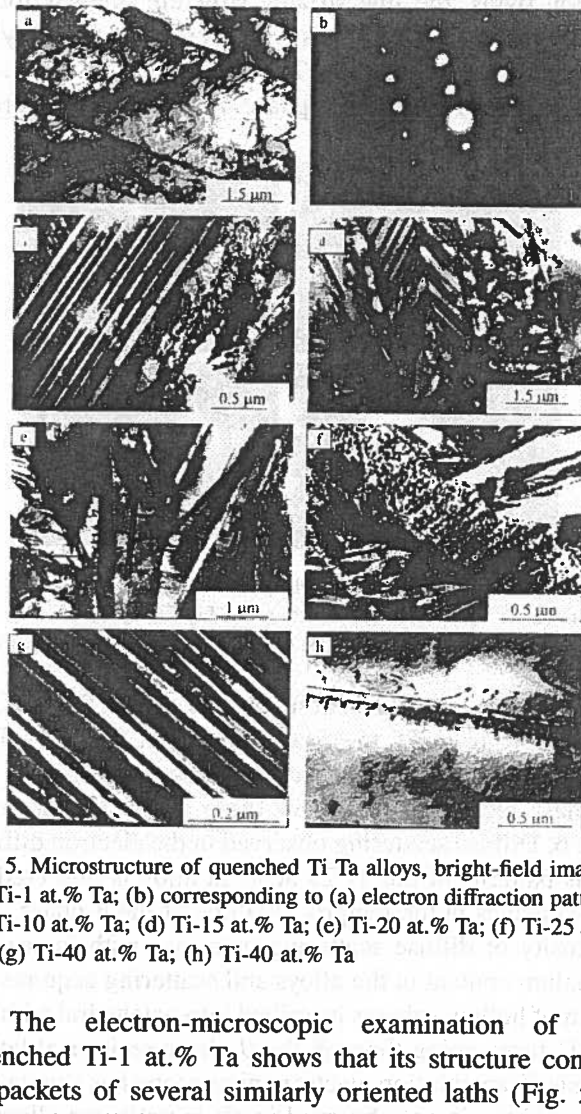

Fig. 5. Microstructure of quenched Ti Ta alloys, bright-field images: (a) Ti-1 at.% Ta; (b) corresponding to (a) electron diffraction pattern; (c) Ti-10 at.% Ta; (d) Ti-15 at.% Ta; (e) Ti-20 at.% Ta; (f) Ti-25 at.% Ta; (g) Ti-40 at.% Ta; (h) Ti-40 at.% Ta

The electron-microscopic examination of the quenched Ti-1 at.% Ta shows that its structure consist of packets of several similarly oriented laths (Fig. 5a). As a rule, all the laths within a packet exhibit one and the same variant of twelve possible variants described by Burgers orientation relationship. In most cases, the adjacent parallel laths within a packet are only slightly disoriented. In some electron-diffraction pattern the α'-phase reflections become separated into rows of closely spaced reflections (Fig. 5b). The angle of disorientation usually does not exceed 2° to 3°. The quenched Ti-10 at.% Ta alloy has internally twinned plate martensite morphology (Figure 5c). The martensite plates form agglomerates of various configurations. The amount and size of the internally twinned martensite plates depend on the contents of tantalum in the alloy. The twinning plane is parallel to the $\{10\bar{1}1\}$ plane of the α'-phase. The Ti-15 at.% Ta alloy with the α''-phase have also the martensite structure, but the configuration of plates, the thickness of the transformation twins, and the average spacing between them are somewhat changed. In some cases, packets of alternate plates with common or close parallel habit planes were observed (Figure 5d). The twinning plane is parallel to the {111} plane of the α''-phase. Instead of the transformation twins, the fine striated structure often is found inside the martensite plates with increasing the alloying metal content (Figure 5e). The Ti-25 at.% Ta and Ti-30 at.% Ta alloys have a two-phase $\alpha + \beta$ microstructure.

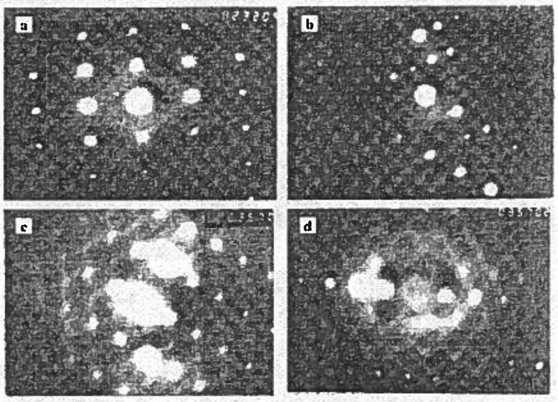

Fig. 6. Diffuse effects in the electron diffraction patterns of the quenched Ti Ta alloys: (a) Ti 25 at.% Ta; (b, c) Ti 30 at.% Ta; (d) Ti 35 at.% Ta. Zone axes are (a), (c), (d) [110] and (b) [133]

The electron diffraction patterns of the Ti Ta alloys containing from 25 to 35 at.% tantalum exhibit diffuse scattering. The diffuse effects in various sections of the β-phase reciprocal lattice for these alloys are shown in Fig. 6. Diffuse scattering observed in the electron diffractions patterns of the Ti 25 at.% Ta alloy is observed on {111} planes in the reciprocal lattice of the β-phase. The intensity of diffuse scattering increases with increasing tantalum content in the alloys and scattering acquires the form of hollow spheres inscribed into octahedral with the {111} faces going through the β-phase reciprocal-lattice points. Transmission electron microscopy has shown that the ω-phase is not observed in all investigated alloys. It means that $\beta \rightarrow \omega$ transformation is completely suppressed by quenching in titanium-tantalum alloys. One of the more important features of the Ti-35 at.% Ta and Ti-40 at.% Ta alloys is the instability of the β-phase. Therefore thin-foil electron-microscopy specimens of these alloys can exhibit thin twins which form during the thinning process, presumably as a result of relaxation of bulk constraint [7]. Typical microstructures observed in these alloys are shown in Fig. 5 g, h. It was established that stress-induced $\{110\}_{\beta}i\{332\}_{\beta}$ twinning appeared in metastable β-phase.

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4. Conclusions

Phase and structural state of the quenched titanium-tantalum alloys containing 1-40 at.% tantalums were studied. The quenched alloys containing less than 10 at.% tantalum have a packet structure consisting of α'-phase laths. The orthorhombic α''-phase was found in the alloys containing 15-30 at. pct Ta. The concentration dependence of the lattice parameters of the α''-phase is given. It was established that, upon quenching, the $\beta \rightarrow \omega$ transformation in the alloys is completely suppressed and the ω-phase is not formed in the quenched alloys. The alloys of 35-40 at. pct Ta consist of metastable β-phase upon quenching only. The electron diffractions patterns of the Ti-Ta alloys containing from 25 to 35 at.% tantalum exhibit diffuse scattering. It was established that stress-induced $\{110\}_{\beta}$ and $\{332\}_{\beta}$ twinning appeared in metastable β-phase.

Acknowledgements

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