PHASE STRUCTURE AND PHASE TRANSFORMATION OF Ti—25Al—10Nb—3V—1Mo ALLOY

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Abstract

Phase structure and phase transformation of Ti—25Al—10Nb—3V—1Mo alloy are studied through the examination of the microstructure of different heat—treatment system (different in solution temperature, cooling rate in solution treatment and treating times. It has been shown that the alloy was mainly composed of α_2 and β phase. The volume of primary α_2 would be decreased as the solution temperature got higher. Primary α_2 and secondary α_2 showed difference in their lattice parameters. After the solution treatment between 900 — 1080℃, the β phase will be ordered B2 structure, but the β phase in 900℃ air—cooling and 1000℃ water—quenching specimens will be disordered after being treated at a intermediate temperature (800—850℃) for 1 hour and aged at 700℃.

Introduction

In recent years, considerable effort has been made to develop advanced titanium aluminide alloys based on $Ti_3Al(\alpha_2)$ for aircraft turbine engine components and other high—temperature applications. But the application for adequate high — temperature properties and attractive low density is mainly limited by their lack of plasticity at room—temperature. The last decade, however, some ductility has been gained for titanium aluminides, especially for α_2 alloy, by adding β phase stabilizer elements. These developments of α_2 were achieved through stabilizing the high — temperature ductile phase of Ti into the structure and increasing the non-basal activity in Ti_3Al. The most typical alloy is Ti—25Al—10Nb—3V—1Mo (at%) (referred to below as TD2).

Since 1985, BIAM (Beijing Institute of Aeronautical Materials) has been undertaking the Research on Titanium Aluminides——a project which belongs to the National Advanced Technology Program (863 Plan). As melting, forging and heat—treating techniques were adapted with the characteristics of our nation, the main properties of Ti_3Al alloys have reached about the same level of U. S. A.. Typically, the room—temperature tensile properties are σ_b 1050MPa, $\sigma_{0.2}$ 850MPa, δ_5 3—6%. The largest Ti_3Al alloy ingot and forgings in our country have been produced under the industrial condition. The first component (turbine baffle) of Ti_3Al alloy in our country withstanded successfully the trial running of a turbo—jet engine for the first time (28 hours and 45 min.), which was also the first Ti_3Al alloy rotor component trial running in aero—engine in the world[1,2].

Heat—treatments have been playing a significant role in the combination of the room — temperature ductility and the strength at elevated temperature. In the present paper, rolling bars heat—treated in different modes (different in solution temperature, cooling rate in solution treatment and treating times) have been used for the research of variation of the microstrcture in detail (including the analysis of phase struc-

ture, the equilibrium of α_2 and β phase and the ordering behavior of β phase).

Experimental

The experimental specimens were taken from the 16mm diameter bars rolled in α_2 +β region. The analyzed chemical composition of the alloy is Ti—14. 36Al—19. 30Nb —3. 48V—2. 15Mo (wt%). the α_2 +β/β transus temperature was determined as 1115℃. The specimens were first solution treated below the transus point at five different temperature (900℃, 950℃, 1000℃, 1050℃, 1080℃) for 1 hour and then cooled in 4 rates: water—quenching, salt—quenching to 815℃, air—cooling and furnace cooling to 815℃. Some of the specimens are subsequently treated in intermediate temperature (800—850℃) for 1 hour, and some are also aged aged at 700℃ for 8 hours.

Microstructures of the specimens heat —treated in different systems were analyzed by optical observation, X—Ray diffraction analysis and scanning electron microscopy observation. Meanwhile, thin films were also prepared and the microstructure of these alloys was examined through the use of transmission electron microscopy and selected area electron diffraction using a H—800 electron microscope.

Results and Discussion

Microstructure

The structures obtained after solution treatment, intermediate temperature treatment and aging are shown in Fig. 1. TD2 alloy is known to be combined of α_2 and β phase through metallography, X — ray diffraction and TEM analysis. α_2 is of D019 structure and its lattice parameters are determined as a = 0. 576nm, c = 0. 464nm through X—Ray diffraction analysis. β is of

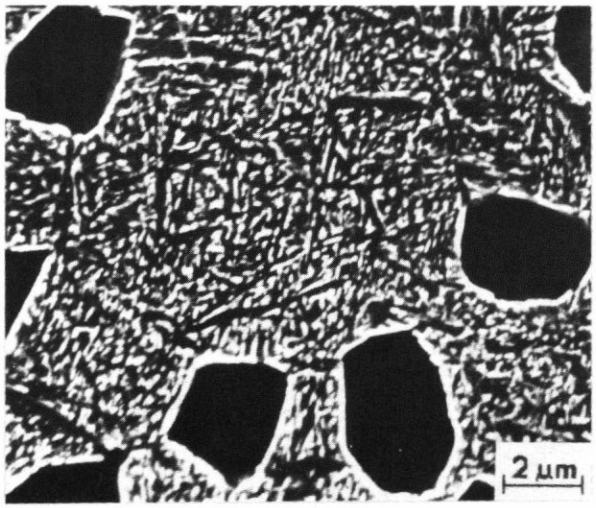

Fig. 1 Microstructure of Ti—25Al—10Nb—3V—1Mo Alloy (1000℃×1h. AC+(800—850)℃×1h. AC+700℃×8h. AC)

b. c. c. structure with the lattice parameter as a = 0. 322nm. The morphology of TD2 alloy can be divided into primary α_2 and transformed β which can still be divided into secondary α_2 and remained β. The primary α_2 is referred to the equiaxed α_2 formed during solution treatment, and the secondary α_2 is precipitated from β phase during intermediate treatment and aging at 700℃.

An notable phenomenon in X — Ray diffraction analysis is the separation of the (201) peaks of primary α_2 and secondary α_2 (Fig. 2). The specimens only solution treated at 1000℃ contain no secondary α_2, and the specimens of 900℃ three—times treatment (been solution treated at 900℃, intermediate treated and aged) contain only a little amount of secondary α_2. The interplanar spacing of α_2(201) face is determined as 0. 219nm by the specimens of two systems above. However, a d=0. 221nm diffraction peak would appear beside the 0. 219nm peak while the specimens contain considerable amount of secondary α_2, which are of 1000℃ three — times treatments. Meanwhile, α_2(201) peak would be d=0. 221nm when only a little amount of or no primary

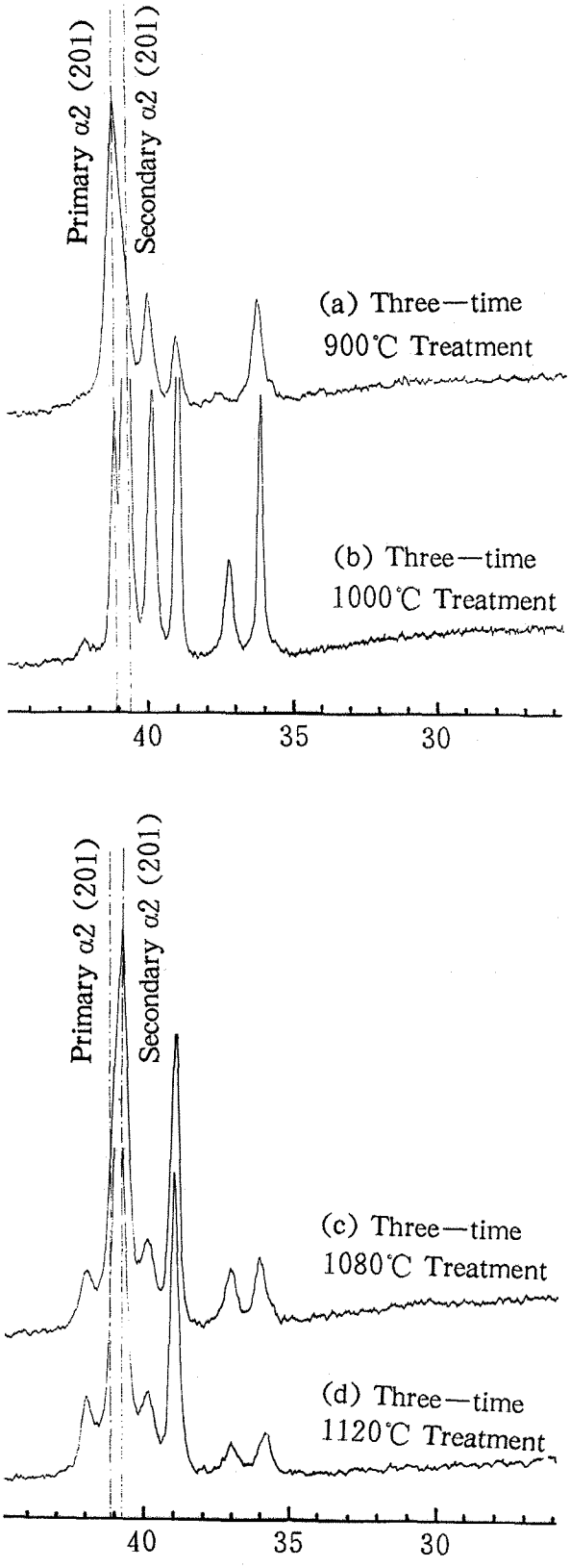

Fig. 2 Separation of the (201) peaks of primary α_2 and secondary α_2

α_2 is contained in the specimens of 1080℃ and 1120℃ three—times treatment. Thus, determines can be made from above that the interplanar spacing of primary α_2's (201) face is 0. 219nm and secondary α_2's of 0. 221nm.

The difference between the interplanar spacing of these two kind of α_2 is on account of their different precipitate temperature. As secondary α_2 is precipitated from β during intermediate treatment or aging at 700℃, the content of β stabilizer elements (e. g. Nb, Mo, V) in it would be higher than that of primary α_2 formed at high temperature when being solution treated. Thus, the lattice parameter of secondary α_2 would be larger, and the interplanar spacing is increased.

The equilibrium of α_2 and β phase

α_2 and β phase will get equilibrated while being solution treated at different temperature. As it has been shown by quantitative analysis of optical metallography[3], the volume fraction of primary α_2 increases with decreasing solution temperature(Fig. 3).

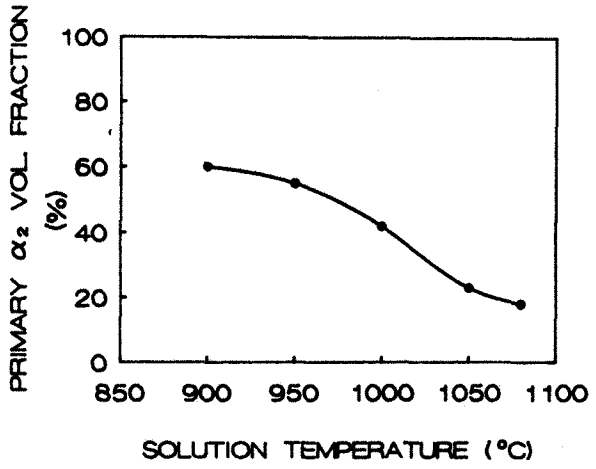

Fig. 3 The influence of solution temperature on the volume fraction of primary α_2

Tab. 1 Semi—quantitative Analysis of X—Ray Diffraction

	Heat-treatment System	Diffraction Indensity		Normalized Result	
		α_2(002)	β(110)	α_2	β
1#	1000℃×1hAC*	232	1715	0.120	0.880
2#	1#+800-850℃×1hAC	62.5	420	0.598	0.402
3#	1#+700℃×8hAC	274	154	0.640	0.360
4#	2#+700℃×8hAC	436	242	0.643	0.357
5#	4#+700℃×100hAC	330	191	0.633	0.367
6#	4#+700×500hAC	404	228	0.640	0.360

* AC: Air-cooling

After solution treatments, supersaturated β phase is retained. α_2 and β will get equlibrated at corresponding temperature as the specimens are being intermediate treated and/or aged at 700℃ for 8 hours. Beside of the observation of their metallography, semi—quantitative analysis of X—ray diffraction is applicated to determine the variation of the volume fraction of α_2 and β phase. Diffraction intensity of (002) face of α_2 (d = 0.232 peak) and (110) face of β is choosed. But as the specimens are of rolled bars, the texture is so intensive that the intensity of the peaks is influenced directly by the orientation of diffraction faces. Thus, diffraction specimens are taken as pentagonal prism shape. Six diffraction patterns, including a base surface and five cylindrical surfaces, are get, and the average intensity of the peaks is calculated to determine the variation of the volume fraction of α_2 and β phase exactly.

As it's shown in Tab. 1, the diffraction intensity of α_2 phase is stronger (and of β phase is weaker) in the alloys only solution treated, comparing with the alloys been intermediate treated afterwards. This indicated the precipitation of α_2 from β in intermediate treatment. Just in the same case, parts of βphase will transformed into α_2 during the aging at 700℃. As their diffraction intensity shows quilt the same, the content of α_2 and β become stable after being aged at 700℃ for 8 hours, and no changes of the content will be made if the alloys are treated at 700℃ for more than 8 hours.

The ordering behavior of β phase in TD2 alloy

If 5—17% Nb is added to a Ti_3Al based alloy, in some cases, β phase will be transformed into an ordered phase, whose chemical composition is Ti_2AlNb. Generally, the ordered β phase is considered of B2 super—lattice structure in which it has already been shown that Ti occupies one sublattice and Al and Nb the other.

In our experiment, the nature of the ordering behavior of β phase is confirmed through the judgment of the existence of the super—lattice β(100) peak in X—ray diffraction and of the super—lattice spot (100) in the SAED with (100)β zone.

The retained β in all the specimens which have been only solution treated can be observed characteristic of ordered B2 structure. However, after the same aging at 700℃, significant difference in the ordering

behavior of retained β phase were observed in the samples of different solution treatment.

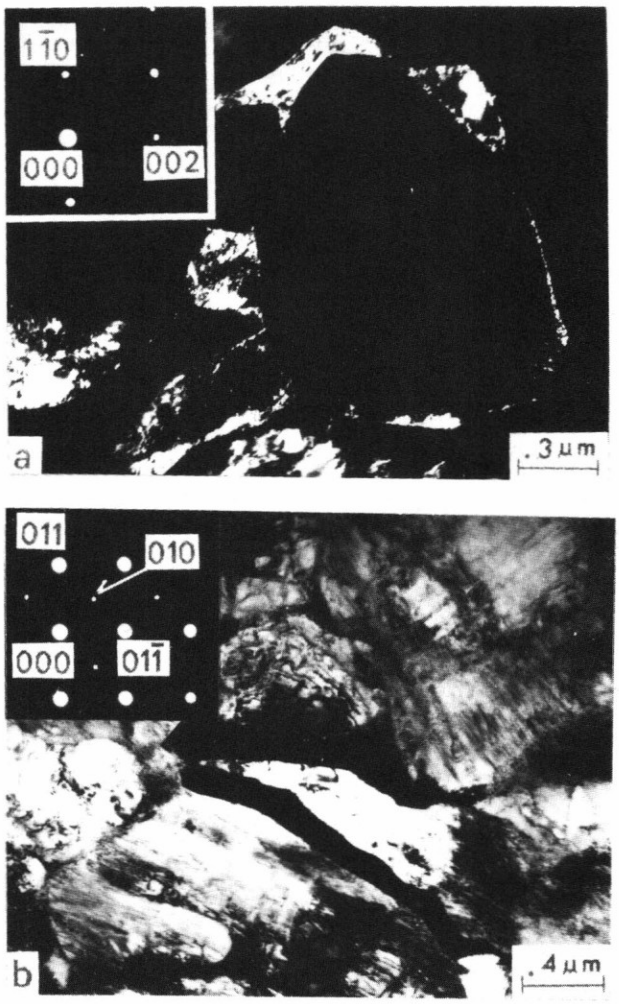

Fig. 4 Ordering behavior of β phase. (a) TEM DF showing the disordered β phase in 900℃ three—time treated specimen ([100] zone axis of β phase). (b) TEM BF of ordered β phase in 950℃ three—time treated specimen ([100] zone axis of β phase with (010) superlattice spots).

The Influence of Solution Temperature on the Ordering Behavior of β Phase Diffraction patterns indicate the absence of super—lattice spots in SAED of the β phase in the 900℃ air—cooled (Fig. 4 a) specimens after being aged. But when the solution temperature is 950℃ or above it, β phase will maintain ordering state after aging.

The results gained above indicate that during the cooling of the solution treatment, the β phase of TD2 alloy will produce a B2 (CsCl) type structure over a wide range of composition deviated from the stoichiometrical composition. This is on account of the existence of conservative anti — phase boundary that can be in analogy to the drawing out of a T—thick layer of atoms. And if the number of atoms in this layer is not of the stoichiometrical composition, the existence of APB will cause the changes of composition. Nevertheless if the local density of a composition gets too high, the energy of conservative anti—phase boundary will be increased precipitously, as a large quantity of like atoms are obliged to be produced. The ordering structure of β phase will become unstable if the APB is too wide and too much while the ordering region is too small. As the results show above, the content of Nb in β phase is already rich at 900℃. Although it's ordered after being solution treated, too much APB and too small ordering region is gained because of the deviation from the stoichiometrical composition. After being aged at a lower temperature, the unstable ordered β phase will be disordered. The specimens solution treated at or above 950℃ will remain ordering during aging process.

The Influence of Cooling Rate on the Ordering Behavior of β Phase As the experiments show, ordered β phase in the 1000℃ water—quenching specimens will be disordered after aging. But if the cooling rate is slow than water—quenching after 1000℃ treatment β maintain ordering state after aging.

To understand the phenomenon, a low degree of undercooling $\triangle T$ is expected to cause a large average size of ordered regions because the nucleating is of a low rate. On

the other hand, the original size of the regions decreases with the increasing of $\triangle T$. During the decreasing of temperature, the long range ordering (LRO) degree is increasing and the atoms in the region are arranged in a new order through homogeneous diffusion. The only way to establish LRO in an entire crystal is the coarsing of APB, the rate of which is corresponding to the type of superlattice. Multiple types of ordering region and complicated APB are in the Ti_2AlNb.

Thus, although the β phase of the water — quenching specimens are of ordering structure after solution treatment, small size of it's ordering region is caused by the high $\triangle T$ and short diffusion time. And this will lead to the disordering after intermediate treatment and aging.

Conclusions

1. The TD2 alloy has been shown to contain α_2 phase (D019 structure, a = 0. 576nm, b = 0. 464nm) and β phase (ordered or disordered, b. c. c. , a = 0. 322nm). The morphology of the alloy can be divided into primary α_2 and transformed β which can still be divided into secondary α_2, retained β.
2. The volume fraction of primary α_2 decreases with increasing solution temperature. The content of α_2 and β phase remains stable after being aged more than 8 hours.
3. The β phase solution treated at 900 — 1080℃ will be ordered B2 structure. But the β phase of 900℃ air — cooled and 1000℃ water — quenched specimens will change to be disordered, but the others will maintain ordering state, after being intermediate treated and aged.

Reference

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