

FEATURES OF ANNEALING MICROSTRUCTURE AND TEXTURE IN Ti-25Al-10Nb-3V-1Mo SHEET^①

Mao Weimin, Yu Yongning, Yang Hong, Song Bo

*Department of Materials Science and Engineering,
University of Science and Technology Beijing, Beijing 100083*

Zou Dunxu, Wang Bin

*Department of Superalloy, Central Iron and Steel Research Institute,
Ministry of Metallurgy Industry, Beijing 100081*

ABSTRACT Some features of microstructure and texture development during annealing in Ti-25Al-10Nb-3V-1Mo sheet, in which the microstructure was composed of hexagonal α_2 phase and β phase were investigated. The result shows that texture of α_2 phase is mainly $\{1124\} \langle 1121 \rangle$, and β phase is $\{111\} \langle uvw \rangle$ before and after annealing. The structures transformed into stable state by annealing, i. e. β phase transformed into α_2 phase at temperature 850 °C or 950 °C, or α_2 phase transformed into β phase at temperature 1 050 °C. Meanwhile, α_2 phase took shape of equal-axial structure. During annealing, recrystallization was almost not found and so recovery was the principal procedure. α_2 phase was tendentially distributed around grain boundary of β phase in which a higher boundary energy should exist.

Key words Ti-25Al-10Nb-3V-1Mo texture rolling deformation annealing

1 INTRODUCTION

Ti₃Al-based intermetallic compound is a new kind of material which has potentiality of various applications because of its low density, high ratio of strength to density, good high-temperature strength and oxidation resistance. Some of the alloying elements such as Nb, V and Mo were added into Ti₃Al-based intermetallic compounds, by which the β phase existing at high temperature could be maintained to room temperature and combined with hexagonal α_2 phase into two-phase microstructure. This microstructure improved the plasticity at room temperature. So a Ti-25Al-10Nb-3V-1Mo alloy system which has good synthetical properties was invented^[1, 2].

The properties, volume fraction, distribution state and texture of second phase have significant effect on synthetical properties of parent phase based alloy, i. e. the synthetical properties

of alloy could be finally modified by means of heat-treatment or thermo-mechanical treatment with which the distribution state, volume fraction, even properties and texture of the second phase were changed. It is the two-phase feature of Ti-25Al-10Nb-3V-1Mo alloy that makes it possible to adjust the microstructure and texture to satisfy the requirements of working and application of the alloy. As shown above, it is necessary to study the regularity of microstructure and texture changes in two-phase Ti-25Al-10Nb-3V-1Mo alloy. In this paper, the features of microstructure and texture during annealing of rolled Ti-25Al-10Nb-3V-1Mo sheet were discussed.

2 EXPERIMENTAL

Ti-25Al-10Nb-3V-1Mo sheets were about 0.425 mm thick after about 10% cold-rolling reduction. The sheets were heated at 850, 950

① Supported by the National Natural Science Foundation of China(No. 59271006);

Received Jul. 21, 1995, accepted Oct. 24, 1995

and 1050 °C for 2 h respectively in vacuous fuse furnace, and then the samples involved in vacuous fuse were cooled to room temperature. Microstructure of samples before and after annealing were examined by scanning electron microscopy. The $\{2000\}$, $\{0002\}$, $\{2021\}$, $\{2022\}$, $\{2240\}$ and $\{2242\}$ pole figures of α_2 phase and $\{110\}$, $\{200\}$ and $\{112\}$ of β phase were determined using X-ray reflection technique, and the ODFs (Orientation Distribution Function) were calculated by Bunge method^[3].

3 RESULTS

Fig. 1 illustrates the microstructure of samples before and after annealing. It is exhibited

that the microstructure is composed of two phases, i. e. hexagonal α_2 phase and β phase^[1,2] (Fig. 1). The roughly continuous matrix with light color is β phase, and the structure with dark color is α_2 phase distributed homogeneously and slightly elongated in rolling direction, expressing the characteristic of rolling deformation. Each dark color area is always a small area composed of α_2 phase, which is named here as "phase bulk" temporarily. Both the volume and size of the α_2 phase "phase bulk" would vary after annealing at different temperatures. The shape of the phase bulk would tend to be changed into equiaxial structure (Fig. 1b-d).

The size of α_2 "phase bulk" was slightly increased after annealing at 850 °C (Fig. 1a, b).

Fig. 1 Two phase structure of Ti-25Al-10Nb-3V-1Mo sheet before and after annealing

(a) —cold rolled; (b) —850 °C annealing; (c) —950 °C annealing; (d) —1050 °C annealing;
N. D —normal direction of plane; R. D —rolling direction

As annealing temperature was further increased to 950 °C, amount of newly-precipitated α_2 phase appeared between the particles of α_2 phase. Not only were the volume fraction and dimension of α_2 phase bulk increased but also α_2 phase was gradually transformed into equiaxial structure (Fig. 1c). At 1050 °C, the α_2 phase was transformed into equiaxial structure, but fine dispersed α_2 phase did not exist. The volume fraction of α_2 phase was decreased (Fig. 1d). As shown in Fig. 1d, α_2 phase was tendentially distributed at boundary of β phase.

Textures before and after annealing expressed by ODFs are shown in Fig. 2 and Fig 3. The figures are φ_2 (from 0° to 60°) sections for α_2 phase and φ_1 (from 0° to 90°) sections for β phase with 5° interval. The values of φ , as well as φ_1 for α_2 phase and φ_2 for β phase were located in range of 0° to 90°. The density demonstrated the amount of orientated grain accumulated.

In rolled sheets, the textures in α_2 phase

were dominantly ($\varphi_1 = 90^\circ$, $\varphi = 25^\circ$, $\varphi_2 = 0^\circ$) i. e. about $\{1124\} \langle 1121 \rangle$, but the texture in which $\{0001\}$ was parallel to rolling plane is observed in small amount ($\varphi_2 = 0^\circ$ section with low φ value). Fig. 2b to Fig. 2d show no significant texture change in α_2 phase after annealing, and the dominant texture $\{1124\} \langle 1121 \rangle$ was still maintained. The orientation density near $\{1124\} \langle 1121 \rangle$ after annealing at 950 °C was higher than that at other temperatures (Fig. 2c).

The texture in β phase was mainly a fibre texture in which $\{111\}$ was parallel to rolling plane, i. e. ($\varphi_1 = 0^\circ \sim 90^\circ$, $\varphi = 55^\circ$, $\varphi_2 = 45^\circ$) $\{111\} \langle uvw \rangle$ texture (Fig. 3a). This texture could be discovered in cold-rolled IF steel sheet^[4] or warm-rolled Fe₃Al based sheet^[5]. A significant texture change in β phase was not found and the texture was still $\{111\}$ fibre texture after annealing. But the density of $\{111\}$ texture was strengthened slightly (Fig. 3b) after

Fig. 2 ODFs of α_2 phase (levels: 2, 4, 6)

Fig. 3 ODFs of β phase

(a) —cold rolled (max= 8.3, levels: 3, 6); (b) —950 °C, 2 h (max= 9.1, levels: 3, 5, 7, 9)

Fig. 4 Phase diagram of Ti₃Al- β phase stabilizing element

annealing at 950 °C.

4 DISCUSSION

It was shown that with increasing elements stabilizing β phase, such as Nb, the equilibrium

percentage of β phase increases and can even reach 100%. Phase diagram as shown in Fig. 4 roughly exhibits the relationship between the volume fraction of β phase and the elements which make β phase stable^[6]. If the samples are heated at higher temperature and then cooled rapidly, the transformation of high temperature β phase to α_2 phase is so incomplete that a metastable microstructure will be achieved, in which the volume fraction of α_2 phase is less than equilibrium value. The sheets used in this study were just in this metastable state. Because of the nonequilibrium state, α_2 phase will precipitate from β phase during annealing at 950 °C and grow up (Fig. 1c). In addition, a great amount of dispersed α_2 phase precipitate so that the volume fraction of α_2 phase is obviously increased (Fig. 1c). All of these indicate that the volume fraction of two phases has a significant deviation from that at equilibrium. The primary precipitations of α_2 "phase bulk" are most brought to equal-axial microstructure, which indicates that the energy in α_2/β phase boundary promotes the microstructure change. A higher temperature is necessary to complete the transformations, since both of the equal-axial process and precipitation behavior are controlled by diffusion. Clearly,

850 °C is not high enough to complete these transformation in the alloy (Fig. 1b). According to Fig. 4, there is a significant change in equilibrium volume fraction between α_2 phase and β phase when the temperature reaches 1 050 °C. The equilibrium volume fraction of α_2 phase has been decreased to less than that present in the sheet, which results in decreasing of α_2 phase after annealing. It can be estimated that the α_2 phase precipitates along the grain boundary of β phase at 1 050 °C, near solvus curve of β phase and it becomes coarser (Fig. 1d). Then α_2 phase can not completely precipitate from supersaturated β phase in following air cooling, so the decreasing of α_2 phase is observed at room temperature (Fig. 1d).

The stored energy induced by cold deformation will become the driving force of recrystallization. No significant recrystallization was observed in various annealing microstructures. The elongation of α_2 phase grains in primary structure is not intensive, which shows that cold deformation is not high enough to induce recrystallization. Examination on two phases textures also shows no significant change in the orientation distribution (Fig. 2, 3), i. e. the evidence for significant migration of high angle boundaries is not discovered so that a typical recrystallization during annealing did not occur in the alloy. The increase of orientation density near $\{1124\} \langle 1121 \rangle$ may be related to newly-precipitated α_2 phases which precipitate tendentially on the primary α_2 phase oriented around $\{1124\} \langle 1121 \rangle$. Generally, the β phase has good plasticity so that it increases the alloy ductility significantly. It can be therefore deduced that β phase has experienced more cold-deformation and possesses higher defect density. During annealing, a recovery process at least occurs in β phase. By recovery, the defect density in cold-rolled grains stably oriented around $\{111\} \langle uvw \rangle$ is reduced, the lattice distortion is released, so orientation density in $\{111\} \langle uvw \rangle$ is increased (Fig. 3).

5 CONCLUSION

The cold roll texture in Ti-25Al-10Nb-3V-1Mo alloy sheet is mainly $\{1124\} \langle 1121 \rangle$ for α_2 phase and $\{111\} \langle uvw \rangle$ for β phase. There are no significant texture changes in both phases after annealing. During annealing, all of the chemical energy for phase transformation, the phase boundary energy, the grain boundary energy and the stored energy could drive the microstructure changes. The chemical energy induces phase transformation between α_2 phase and β phase. The phase boundary energy brings α_2 phase into equiaxial structure. The grain boundary energy of β phase makes α_2 phase distribute along the β phase grain boundary. The stored energy was not high enough to induce recrystallization. But there should be a relatively higher defect density in β phase which experienced more deformation and then texture $\{111\} \langle uvw \rangle$ became sharper after recovery.

It is the various driving forces for microstructure changes that makes it possible to adjust the microstructures by means of working or heat-treatment procedures to obtain different mechanical properties required in Ti-25Al-10Nb-3V-1Mo alloy.

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(Editd by Peng Chaoqun)