Deformation and phase transformation of disorder α phase at (α+γ) two phase region in high Nb containing TiAl alloy

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Abstract

In this paper, the deformation and phase transformation of disorder α phase at (α + γ) two phase region in as-forged Ti-44Al-8Nb-(W, B, Y) alloy are investigated by hot compression and hot packed rolling. Detailed microstructural evolution demonstrates that the as-deformed microstructure is significantly affected by deformation conditions. The mircrostructure differences are mainly due to temperature drop and strain rate. The evolution of α lamellae into α grains is in detailed description. Moreover, the disorder α lamellae can also be decomposed into some new α grains by the assisted decomposition mechanism of γ grains. Microstructure evolution model of current TiAl alloy at 1250 °C during hot rolling is built.

Keywords: TiAl alloy; disorder α phase; deformation behavior; phase transformation; continuous dynamic recrystallization; rolling doi:10.20944/preprints202106.0033.v1

1. Introduction

TiAl alloys, especially high Nb containing TiAl alloys, have attracted significant attentions due to excellent oxidation resistance, creep properties and good elevated temperature strength [1-4]. Due to their attractive properties, the sheets of TiAl alloy are potential to be used in aerospace applications such as inlet flaps, nozzle tiles for gas turbine engines, back structures for scramjets and thermal protection shields [5, 6]. Nevertheless, they are not yet fully commercialized due to the low room temperature ductility and poor hot deformability [4, 7]. Some studies have shown that thermal processing is considered to be attractive and high-efficiency way to enhance the ductility and workability through microstructure refinement and homogenization[8].

In terms of manufacturing of TiAl alloy sheets, the ingot metallurgical has been developed and applied to a variety of alloy systems [4, 9]. The cast ingot with fully lamellar or nearly lamellar colonies must undergo a series of thermal deformation to achieve the breakdown of coarse lamellar colonies. To date, the deformation behavior and deformation mechanism of the lamellar colonies are studied in detail by researchers in lots of literatures. For example, the interruption, rotation, bending, kinking, and breaking down of lamellar colonies are responsible for microstructure evolution of Ti-45Al-8.5Nb-(W,B,Y) alloy [9]. Dynamic recrystallization, superplastic deformation, the mechanical twinning plays a critical role in hot rolling process for PM Ti-45Al-7Nb-0.3W alloy [10]. The bending and fracturing of the lamellar structures and dynamic recrystallization is the main mechanism for the flow softening in the later stage of the hot pack-rolling of a Ti-47Al-2Cr-0.2Mo alloy [11]. Dynamic recrystallization of γ grains is the main softening mechanism during hot forging for Ti-43Al-2Cr-2Mn-0.2Y [12]. Based on above analysis, we can see that almost all literatures paid more attention on the transformation of γ phase or studied the lamellar colony as a whole and neglected the role of disorder α phase.

In fact, prior to hot deformation, the TiAl alloys are often annealed within (α + γ) phase region for hours [9, 13] and these γ phase will be transformed into disorder α phase, so the TiAl alloy contains a large amount of disorder α phase at deformation temperature, which plays an important role in deformation process. Yet, So far, it has been rarely documented about the deformation behavior of disorder α phase. In this paper, the deformation behavior of disorder α phase in high Nb containing TiAl alloy as an example was investigated by hot compression and hot packed rolling. The aim of this work is to clarify the deformation and phase transformation of α lamellae and α grains at (α + γ) two phase region.

2. Experimental

The cylindrical samples for isothermal compression with dimensions of Φ8 × 12 mm^3 and plate samples with dimensions of 40 × 40 × 12 mm^3 for hot packed rolling were cut from the as-forged Ti-44Al-8Nb-(W, B, Y) alloy. Both the samples were heat treated at 1250 °C for 2 h prior to hot deformation and then compressed to 58% of original height of the samples through three times deformations, namely the reduction of 25% for per pass. The nominal strain rate is 0.1 s^{-1} for isothermal compression and 0.5 s^{-1} for hot packed rolling, respectively. And the reheating time between two deformations is 15 s and 15 min for isothermal compression and hot packed rolling, respectively. The heat treated and deformed samples were immediately quenched into ice water to preserve the deformed microstructure and then sectioned through their longitudinal axis for microstructure analysis.

Specimens for electron backscatter diffraction (EBSD) and transmission electron microscope (TEM) were mechanically polished, followed by electrolytic polishing. In the following, α_2 is expressed as ordered α phase and α represents the disorder α phase at high temperature, unless otherwise specified. All orientation maps use the inverse pole figure coloring scheme relative to X direction.

3. Results and discussion

The EBSD analysis results of as-forged microstructure are shown in Fig. 1. It can be seen from Fig. 1a) that the microstructure of as-forged alloy is mainly composed of coarse lamellar colonies (average size of 120 μm) and a number of equiaxed γ grains distributed around lamellar colonies. These equiaxed γ grains with high angle grain boundary (blue line) around lamellar colonies are recrystallized grains produced during the forging. The partition fraction of the γ phase in as-forged alloy is about 82 vol. %, and the α_2 phase is only about 18 vol. %. And the majority of α_2 lamellae and γ lamellae in lamellar colony still remain lamellar structure. As can be seen from Fig. 1b), the orientation of α_2 lamellae inside lamellar colony is substantially the same. By observing the pole figure of specific α_2 lamella, γ1 lamella and γ2 lamella phase in Fig. 1b), it can be found that α_2 lamella and γ1 lamella still obey the Blackburn orientation relationship. While, the γ2 lamella does not follow such a relationship with α_2 lamella. Moreover, the γ2 lamella contains more low angle grain boundaries (red line) than γ1 lamella.

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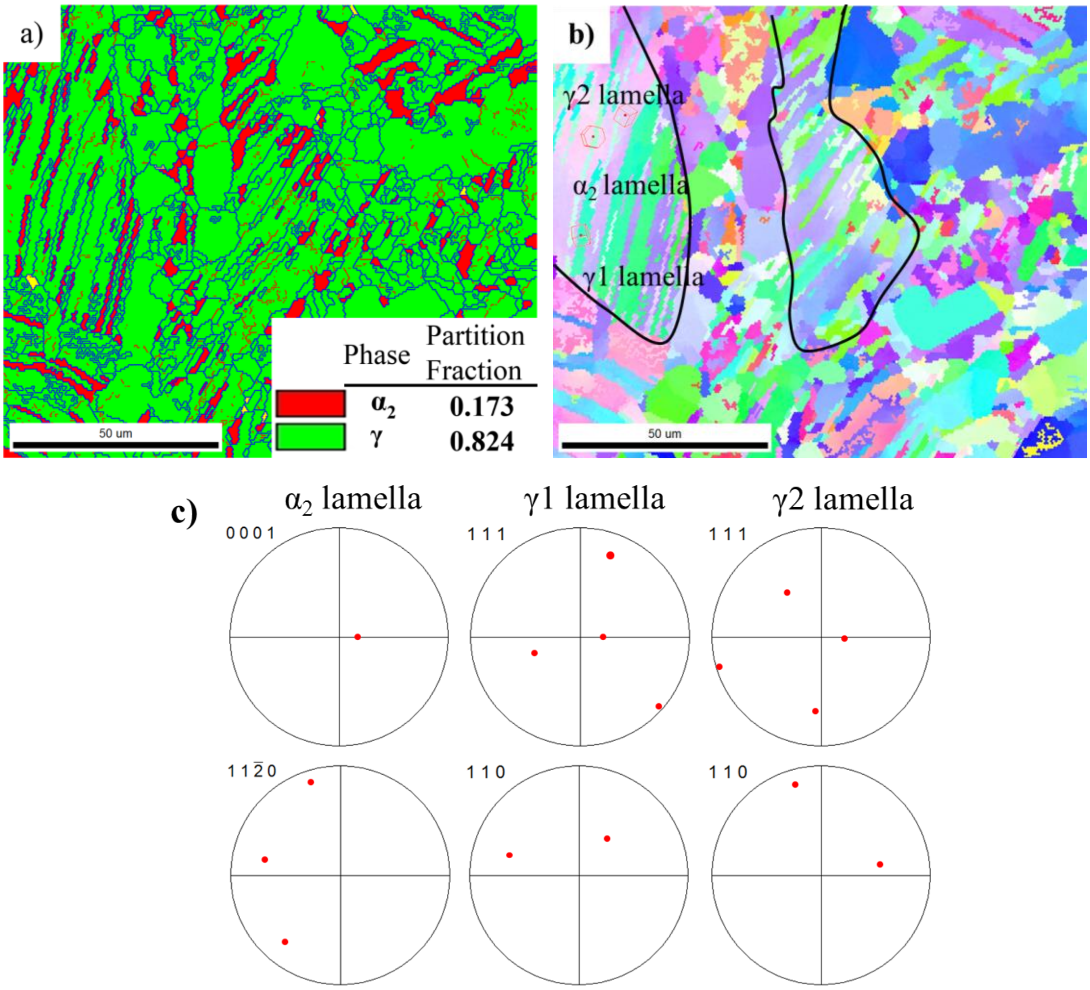

Fig. 1 EBSD analysis of as-forged Ti-44Al-8Nb-(W, B, Y) alloy: a) phase map, b) orientation map and c) pole figures of α_2 lamella, γ1 lamella, and γ2 lamella.

The microstructure of as-quenched alloy by EBSD analysis after annealing at 1250 °C for 2 h is shown in Fig. 2. The microstructure is still mainly composed of lamellar colonies and equiaxed α grains and γ grains around lamellar colonies. The phase transition of γ phase into α phase and disorder transformation of ordered α_2 phase into disorder α phase take place during annealing at (α+γ) two phase region, leading to the increase of α phase content. It can be included from Fig. 2a) that after annealing, the partition fraction of disorder α phase with equiaxed and lamellae morphology in as-heat-treated alloy is more than 70 vol. %. So, the preformed sample contains more than 70 vol. % disorder α phases prior to hot packed rolling, which are softer than ordered α_2 and γ phases and easier to be deformed, confirmed by thermal deformation[4, 14]. According to phase diagram, there is higher disorder α phase content for current TiAl alloy at 1250 °C by decreasing Al content moderately than other high Nb containing

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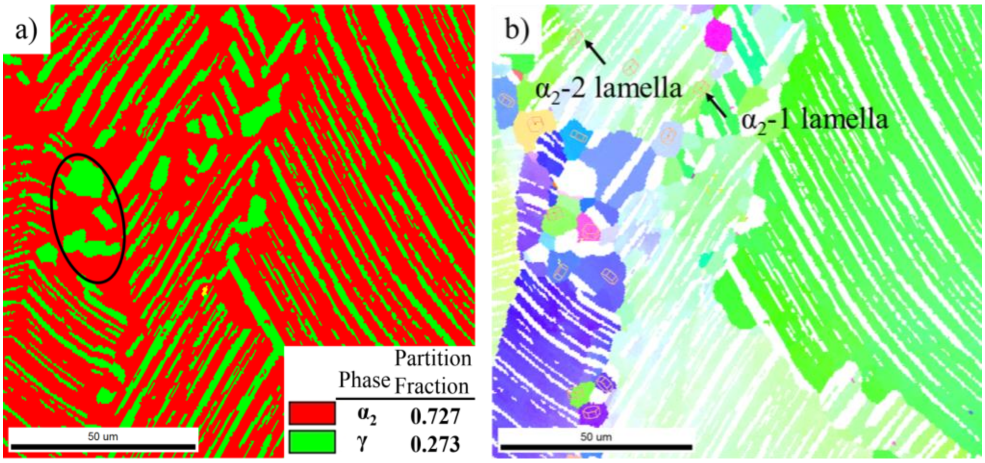
TiAl alloy with relative higher Al content such as Ti-45Al-8.5Nb-(W, B, Y) alloy, Ti-46Al-9Nb alloy and Ti-45Al-7Nb-0.3W alloy. Therefore, the deformability at 1250 °C is superior to other high Nb containing TiAl alloys. While, the current alloy still has relatively higher peak flow stress due to high Nb contents and nearly lamellar structure, confirmed by hot compression experiments[15]. The higher content α-grains and α-lamellae at (α+γ) two phase region play an important role in the transformation of the lamellar colonies.

Fig. 2b) and 2c) are the orientation maps of α phase and γ phase, respectively. It can be found that some α lamellae and γ lamellae in lamellar colonies have not followed the strict orientation relationship by observing the orientation of α lamellae and γ lamellae in Fig. 2b) and Fig. 2c). There is a certain degree of deviation from standard orientation between γ lamellae and α lamellae, especially for γ lamellae. The analysis of orientation difference measurement shows that the orientation difference between α_2-1 lamella and α_2-2 lamella in Fig. 2b) is 2.9 ° and the orientation difference between γ1 lamella and γ2 lamella in Fig. 2c) is as high as 13 °. This indicates that the orientation relationship of α lamellae and γ lamellae cannot be changed due to the phase transformation during isothermal holding at 1250 °C, and still maintains the orientation relationship formed during hot forging. It is easier for these lamellae who don't follow Blackburn orientation relationship or containing much low angle grain boundaries to take place recover and recrystallization.



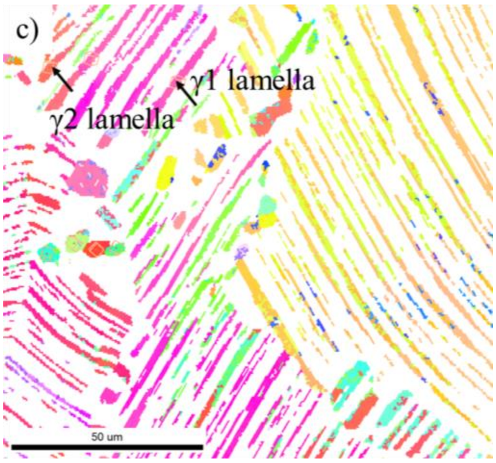


Fig. 2 EBSD analysis of water quenched Ti-44Al-8Nb-(W, B, Y) alloy after annealing at 1250 °C for 2 h: a) phase map, orientation maps of b) α_2 phase and c) γ phase

Fig. 3 shows the microstructure of as-quenched alloy after isothermal compression. After isothermal compression lamellar colonies have undergone significant and thorough decomposition and are completely transformed into slightly elongated γ and α grains perpendicular to compression direction. It can be apparently seen from the orientation of each α grain marked with 3D grain orientation in Fig. 3b) that these newly formed α grains have significant orientation differences with other α grains, indicating that dynamic recrystallization is more likely for disorder α phase to take place in such deformation condition. Moreover, the total partition fraction of α phase in as-deformed alloy is not significantly changed compared with that in as-heat-treated alloy and still remains about 73 %, as seen in Fig. 3a). Fig. 3c) and d) show the orientation and pole figures of α grains and their surrounding γ grains. It can be seen that these finer α grains and surrounding γ grains do not follow Blackburn orientation relathionship, implying that no phase transformation from α phase to γ phase occurs during isothermal compression.

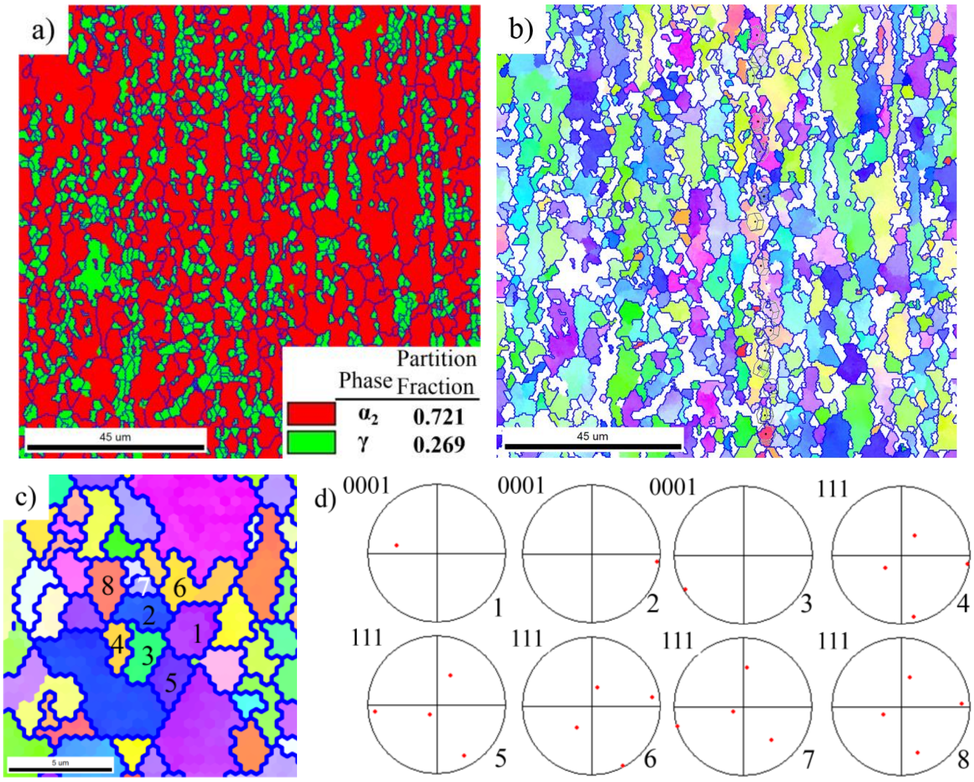


Fig. 3 EBSD analysis of quenched microstructure after three times' isothermal compression under the condition of 1250 °C/0.1 s^{-1}/25%: a) phase fraction, orientation map of b) α phase, c) orientation map in a) and d) pole figure of each grain in c)

The microstructure of water quenched alloy after hot packed rolling is shown in Fig. 4. It contains a large amount of recrystallized grains and a certain amount of remnant lamellar colonies marked with black line. And the orientation difference of α lamellae in remnant lamellar colony is obviously increased compared with that in as-heated-quenched alloy. It is measured that the misorientation between αL1 lamella and αL2 lamella is as high as 16.5 °, as shown in Fig. 4b).

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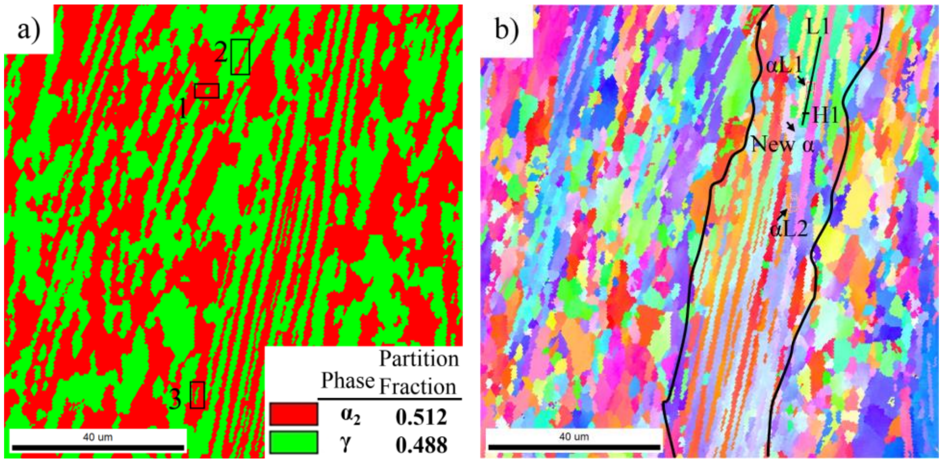

Fig. 4 EBSD analysis of quenched as-rolled Ti-44Al-8Nb-(W, B, Y) alloy: a) phase map and b) orientation map

Fig. 5 shows the misorientation measured along L1 line parallel to αL1 lamella and along H1 line perpendicular to αL1 lamella in Fig. 4b), respectively. The accumulative (point to origin) misorientations in the direction of L1 is gradually increased to 7.4 °, while the largest acuumlative angle along H1 direction is no more than 1 °. This indicates that the rotation degree along the length of αL1 lamella is greater than that along the width. These α lamellae with higher misorientation will absorb deformation engery during the next pass rolling, further promoting the rotation and increasing the misorientation along the length of α lamellae. Some α sub-grains will form along the length of α lamellae during the rotation of α lamellae, and then these α sub-grains are contining to rotate to increase the orientation difference. Eventually, some new α grains will be formed along the length of α lamellae, such as the new α grain arrowed in Fig. 4 b). The above process is the evolution of α lamelae into α grains, namely the continuous dynamic recrystallization (CDRX) of α phase.

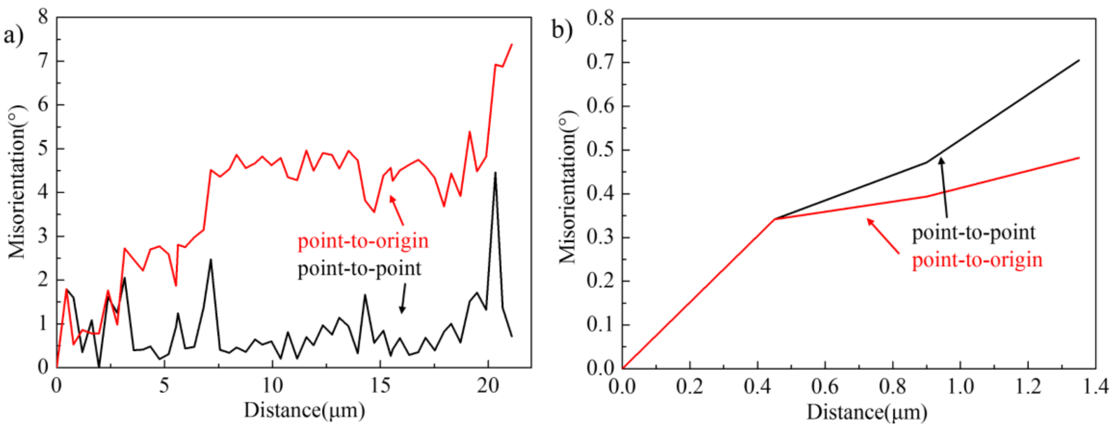

Fig. 5 Misorientation measured along (a) L1 line and (b) H1 line in Fig. 4 b)

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In addition to parts of α grains are formed by the CDRX of α lamellae, more α grains are formed by the CDRX of α grains distributed around lamellar colonies during deformation. The CDRX of parent α grains takes place around lamellar colonies and the orginal coarse α grains are transformed into finer α grains after three passes of hot packed rolling, as shown in Fig. 6 a), such as the region 1 in Fig. 4 a). These newly formed α grains have certain orientations between each other, for instance the misorientations among α-1 grain and α-2, α-3, α-4 and α-5 grains are 14.5 °, 16.9 °, 5.8 ° and 28 °.

It also can be seen from Fig. 4a) that after hot packed rolling, the partition fraction of α phase decreases to about 50% with redcution of about 20%. As is well-known, the fabrication of TiAl alloy sheet is not an isothermal process, accompaning by temperature drop. Therefore, the temperature drop during rolling is the main reason for the decrease of α phase content. Fig. 6b) shows the pole figures of α1 grain and γ6 and γ7 grains around α1 in Fig. 6a). Comparing (111)γ with (0001)α pole figures, and $<1\bar{1}0]\gamma$ with $<11\bar{2}0>\alpha$ pole figures between γ6 and α1, (111)γ planes were substantially parallel to (0001)α plane and $<1\bar{1}0]\gamma$ direction is substantially parallel to $<11\bar{2}0>\alpha$ direction, following perfect orientation relationship of (111)γ // (0001)α and $<1\bar{1}0]\gamma$ // $<11\bar{2}0>\alpha$. This indicates that the phase tranformation from α grain to γ grain is promoted by temperature drop during hot packed rolling, resulting in the decrease of α phase content. Moreover, the curvature of γ6 grain in Fig. 6a) also proves the occurrence of phase transformation. Yet, there are some differences in comparsion with the perfect orientation relathionship between γ7 and α1. Such differences are mainly attributed to grain rotation during hot packed rolling.

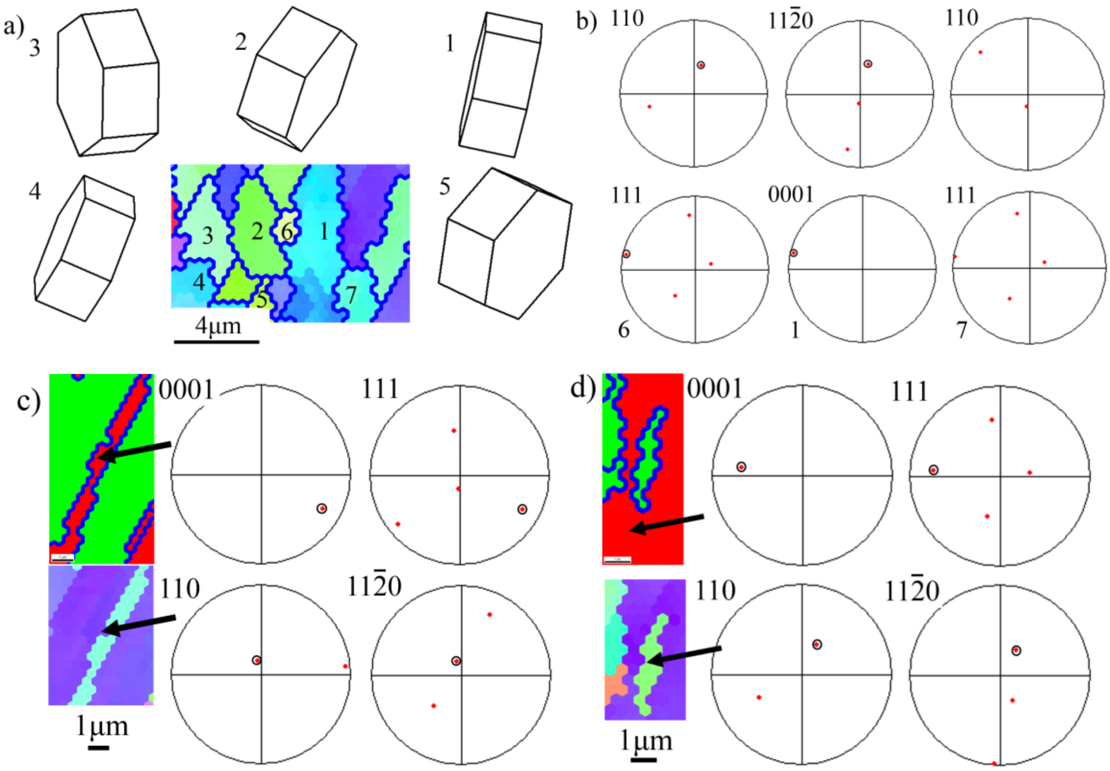

Fig. 6 Local orientation maps and pole figures of corresponding α_2 and γ grains in black rectangle in Fig. 4b): magnification of a), b) region 1, c) region 2 and d) region 3

In addition to phase transformation of α phase to γ phase can take place in α grains, parts of phase transformation can occur on α lamellae. Furthermore, the newly formed γ grains and α lamella also follow Blackburn orientation relationship, as shown in Fig. 6c). It has been reported that the precipitation and growth of γ grains in α lamellae was found in remnant lamellar colonies of Ti-45Al-10Nb alloys[16]. Besides, eutectoid transformation also can occur in recrystallized α grains, confirmed by the orientation relationship in Fig. 6d). So it can be concluded from above analysis that complex deformation and phase transformation take place in disorder α phase during hot packed rolling. Disorder α grains and α lamellae will first be deformed into recrystallized α grains and then newly γ grains or γ lamellae will be formed in these recrystallized α grains. Meanwhile, the discontinuous dynamic recrystallization (DDRX) of γ phase occurs at tri-boundaries, phase boundaries, and twin boundaries, confirmed by previous research [8].

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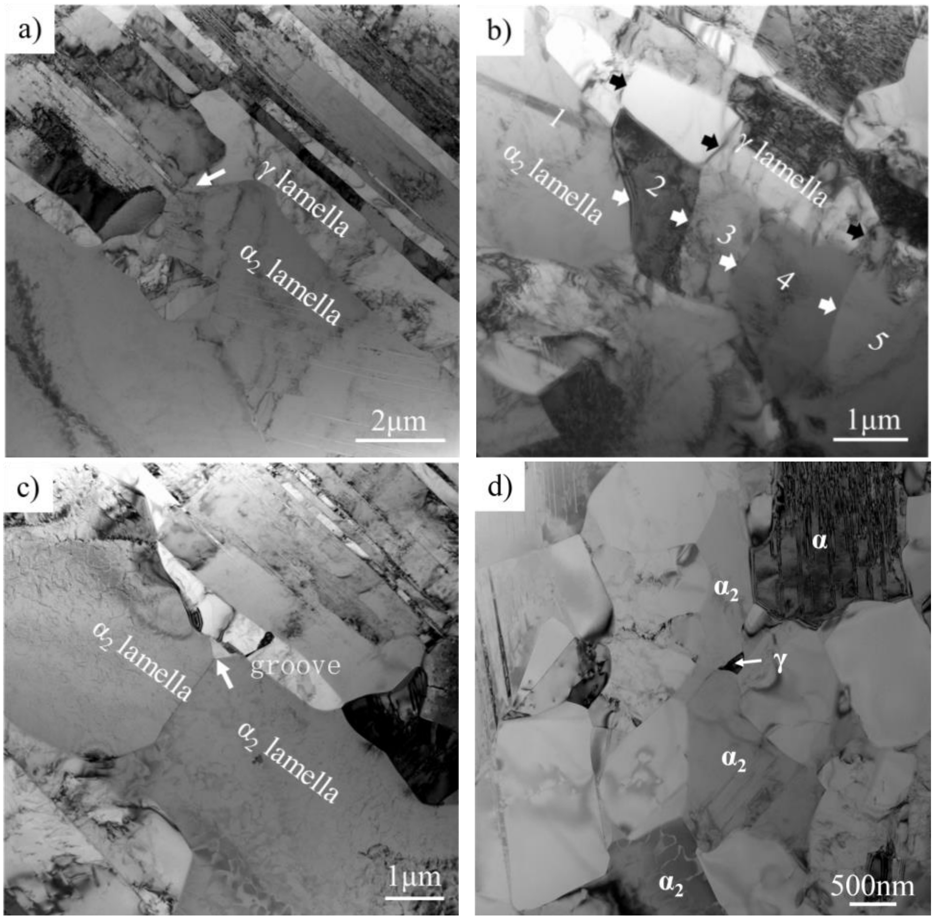
The TEM analysis of water quenched as-rolled Ti-44Al-8Nb-(W, B, Y) alloy is shown in Fig. 7. From the analysis of the lamellar structure in Fig. 7a), it is found that the lamellar structure are mainly consisted of α lamellae with unbalanced interface. During plastic deformation at high temperature, α phase is softer than γ phase and can coordinate the deformation of γ phase though it is still a high stacking fault energy phase. In order to coordinate the deformation of "hard" γ phase, bending, kinking or continuous dynamic recrystallization will take place in α lamella. This is demonstrated by the phenomena of "cut off" of α lamella by γ phase indicted by arrow, as seen in Fig. 7a).



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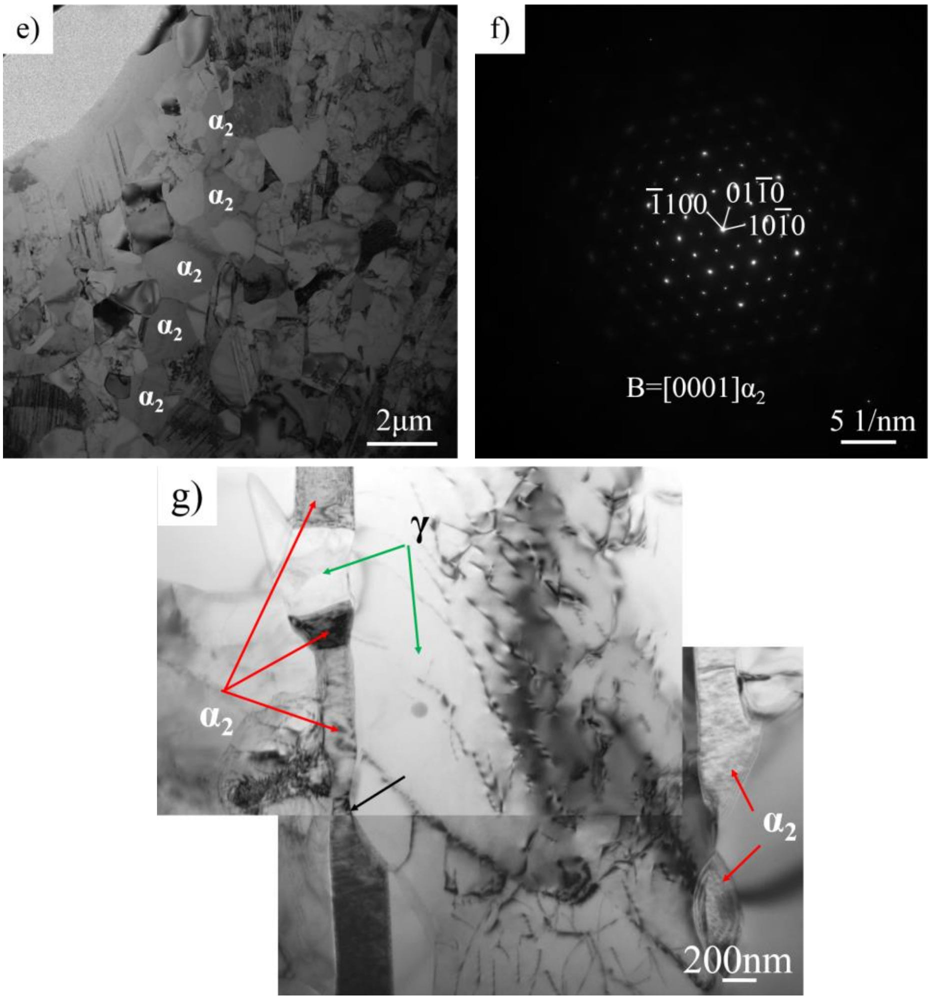

Fig. 7 TEM analysis of α_2 lamellae in water quenched Ti-44Al-8Nb-(W, B, Y) alloy after three passes rolling. a) α_2 lamellae in lamellar colony, b) α_2 sub-grains in α_2 lamella, c) the grooving on the boundary of α_2 lamella, d) γ grain on the boundary of α_2 lamellae, e) equiaxed α_2 grains, f) the diffraction pattern of α_2 grain and g) the final microstructure of as-rolled alloy

During deformation, γ lamellae are easily broken down into some new γ grains, as shown in Fig.7b). Yet, it is difficult for α lamellae to form new α grains as same as γ grains by nucleation and growth. The above analysis shows that there is an increased misorientation in longitudinal direction of α lamella, resulting in the rotation along longitudinal direction is higher than that in the thickness direction. Therefore, some sub-grains are gradually formed along longitudinal direction of α lamella with the increase of rotation. These α sub-grains are pointed out with white arrow, as shown in Fig.7b) whose sub-grain boundaries are mostly perpendicular to the interface of the α/γ lamellae. Then some new α grains will be formed along the length of α lamella. Disorder α lamella can not only be decomposed into some new α grains by itself, but also can be decomposed by "external factor". The schematic diagram of lamellar decomposition can be represented in Fig. 8. Normally, the decomposition mechanism includes boundary splitting mechanism producing lamellar fragmentation and termination migration leading to spheroidization [17].

The groove grain appeared on the boundaries of α/γ lamellae during deformation, can accelerate the decomposition of disorder α lamella and thus form new α grains, as shown in Fig. 7c).

The α lamellae and γ lamellae are indicated by A and B, respectively due to only α lamellae and γ lamellae above Te for current Ti-44Al-8Nb-(W, B, Y) alloy. Thus, in Fig. 8b), S_{AA} and S_{AB} are the surface energies for α/α lamellae interface and α/γ lamellae interface and 2θ is the angle between S_{AA} and S_{AB} from Fig. 8b), the equilibrium equation between S_{AA} and S_{AB} is

$$S_{AA}=2S_{AB}cos\theta \tag{1}$$

It will promote atoms to migrate away from groove due to the high chemical potential at groove. So the curvature radius will continue to increase, resulting in $S_{AA}>2S_{AB}cos\theta$. In order to rebalance the interface energy, the groove in α lamella is deepened to increase the angle θ. The above process takes place repeatedly until these α lamella fragments. The principle of spheroidization mechanism is similar to that of termination migration mechanism, realized by atoms diffusion from small curvature radius to large curvature radius to form equiaxed α grains.

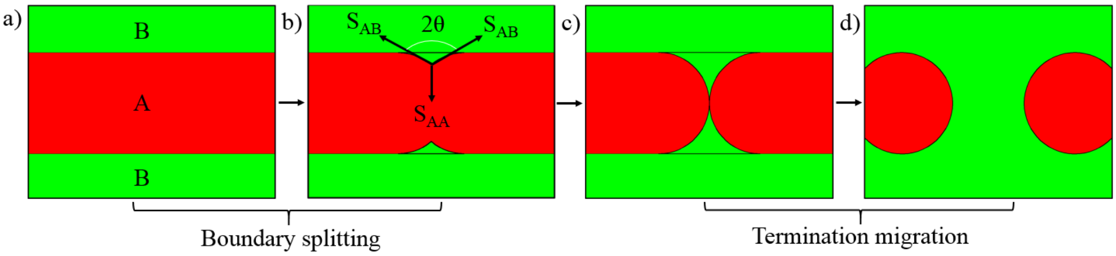

Fig. 8 Schematic diagram of α lamellae decomposition: a), b) boundary splitting mechanism and c), d) termination migration mechanism

It is the external factor that γ grain accelerates the spheroidization of α lamella, as shown in Fig. 7d). As shown in Fig. 6c), the "groove" γ grain is generated by phase transition from α lamella during hot rolling. Since disorder α lamella is soft above Te, γ grains will easily grow up into α lamella and accelerate the decomposition of α lamella.

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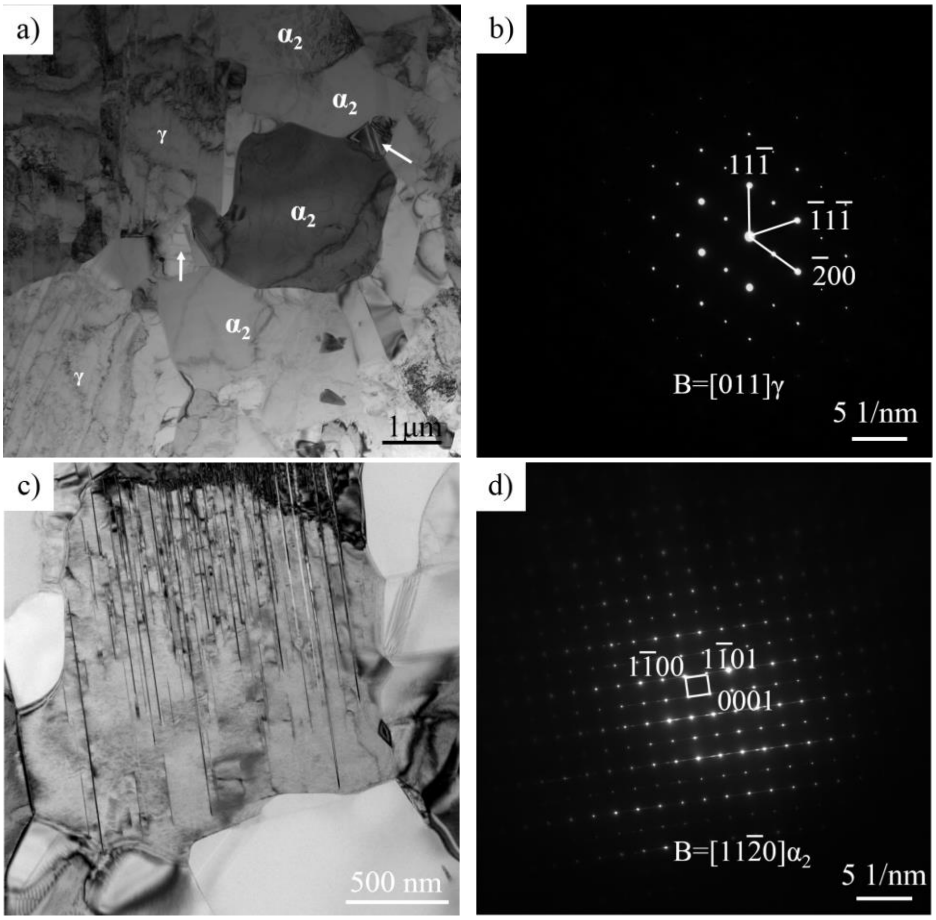
Fig. 7e) is the equiaxed α grains formed by CDRX of α lamella and assisted decomposition mechanism of γ grains. When γ grain goes through α lamella, the parent α lamella will be completely separated, and the α lamella is ultimately transformed into non-continuous equiaxed α grains, as shown in Fig. 7g).

Fig. 9 shows the TEM analysis of microstructure around lamellar colonies in water quenched as-rolled Ti-44Al-8Nb-(W, B, Y) alloy after three-passes rolling. On one hand, α lamellae and γ lamellae inside lamellar colonies are converted into α grains and γ grains. On the other hand, α grains and γ grains around lamellar colonies are changed into finer α grains and γ grains during rolling. Fig.9a) depicts the recrystallized α grains around lamellar colonies and its surrounding γ grains. It has been mentioned that there is a temperature drop of TiAl alloy sheet fabricated by hot packed rolling, CDRX and phase transformation will occur in these equaixed α grains. The white arrow in Fig. 9a) indicates the newly formed γ grains, which are formed by phase transformation of recrystallized α grains, confirmed by the diffraction pattern in Fig. 9b) and the orientation relationship in Fig. 6a) and b).



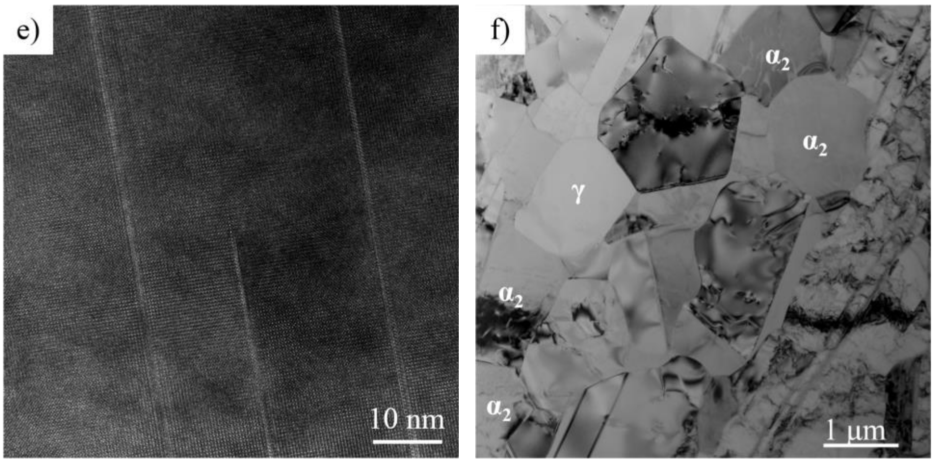


Fig. 9 TEM analysis of microstructure around lamellar colony in as-quenched Ti-44Al-8Nb-(W, B, Y) alloy after three passes rolling. a) the γ grains distributed at recrystallized α grains; b) the diffraction pattern of γ grain; c) the γ lamellae precipitated from α grains; d) the diffraction pattern of α grain; e) HRTEM images of the γ lamellae in α grain and f) recrystallized α and γ grains around lamellar colony.

In addition, γ lamellae will precipitate from recrystallized α grains, forming finer lamellar colonies as shown in Fig. 9c), yet the precipitation of γ lamellae are not complete due to the water quenched. γ lamellae does not across the entire α grain and the thickness of γ lamellae is only a few atomic layers, as shown in Fig. 9d) and Fig. 9e). Fig. 9f) is γ and α grains presented at the surroundings of lamellar colonies. These γ grains includes recrystallized γ grains and γ grains transformed from α grains.

The EBSD analysis of water quenched microstructure in as-rolled Ti-44Al-8Nb-(W, B, Y) alloy with a total rolling reduction of 58% after annealing at 1250 °C for 15 min, as seen in Fig. 10. The newly formed recrystallized α grains, recrystallized γ grains and γ lamellae in Fig.4 will be converted into disorder α grains and α lamellae during re-heating, leading to the content of disorder α phase increase to more than 70 vol. %. Therefore, we can concluded that the partition fraction of disorder α phase at high temperature is higher than 70 vol. % before each pass rolling. Moreover, the content of disorder α grains increases with the progression of rolling and the size and volume fraction of the lamellar colonies are significantly reduced after three passes rolling and twice reheating.

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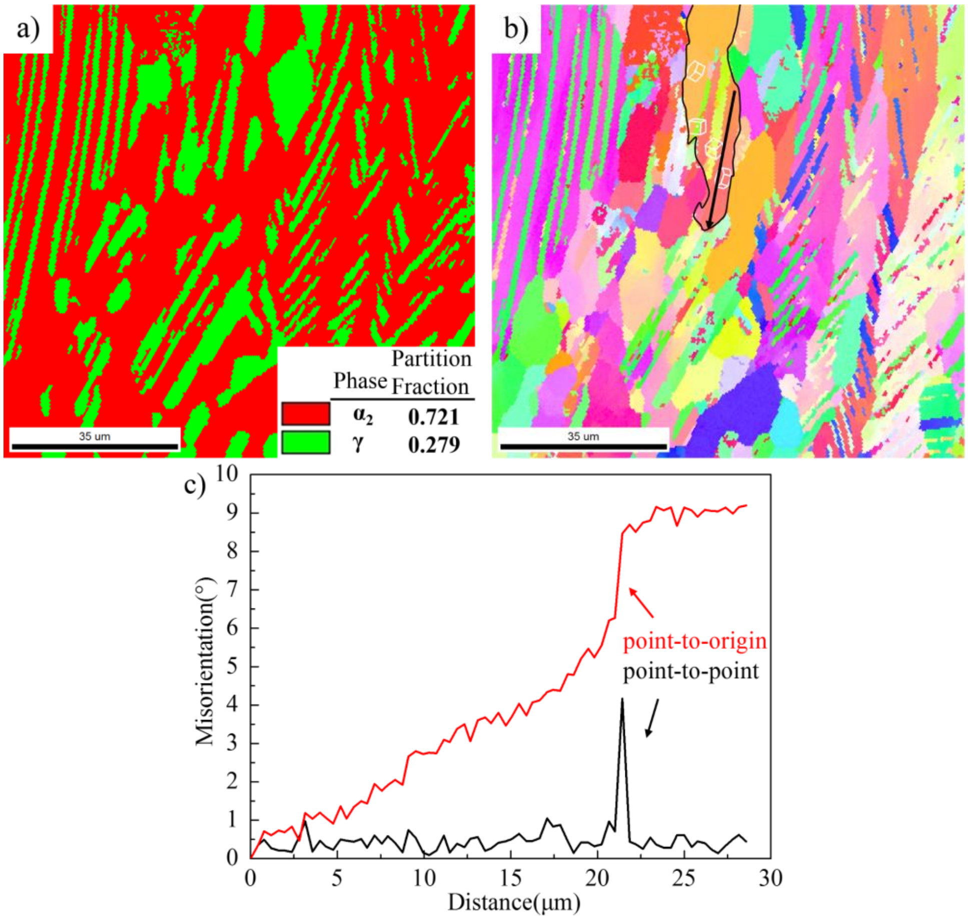

Fig. 10 EBSD analysis of water quenched microstructure in as-rolled Ti-44Al-8Nb-(W, B, Y) alloy with a total rolling reduction of 58% after annealing at 1250 °C for 15 min: a) phase fraction, b) orientation map and c) misorientation measured along the black line in b).

Besides, the orientation relationship between α lamella and γ lamella are not changed and some of them are still absence of the Blackburn orientation relationship, as seen the orientation map of α lamella and γ lamella in black outline in Fig. 10b). Figure 10c) shows the misorientation of α lamella in Fig. 10b) along longitudinal direction, which still has relatively higher accumulative misorientation of 9.2 ° along longitudinal direction. This means that these α lamellae with higher misorientation will preferentially be transformed into new α grains along longitudinal direction during the subsequent rolling process. The above analysis has shown that CDRX is more likely to take place in disorder α grains than in α lamellae. Therefore, the TiAl alloy with microstructure in Fig. 10 has more excellent deformability. Therefore, recrystallization will take place in whether α grains and γ grains or α lamellae and γ lamellae, leading to the reduction of size and content of remnant lamellar colonies.

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Based on above analysis, the microstructure evolution model of Ti-44Al-8Nb-(W, B, Y) alloy at 1250 °C during hot packed rolling can be represented in Fig. 11. 1) First of all, the phase transformation of γ phase to α phase and disorder transformation of ordered α_2 phase to disorder α phase will occur simultaneously during heat preservation process at (α+γ) two phase region. Wherein, the γ grains around lamellar colonies and the γ lamellae within lamellar colonies. Fig. 11 b) describes the microstructure of TiAl alloy before the first pass rolling, consisting of mainly lamellar colonies with coarsened α lamellae and above 70 vol. % disorder α phase. 2) These α lamellae, γ lamellae, α grains and γ grains will be turn into finer α grains and γ grains simultaneously during hot rolling. Yet, the degree of conversion of α grains and γ grains is obviously better than α lamellae and γ lamellae. These α grains and γ grains around lamellar colonies undergo a thorough recrystallization into fine recrystallized α grains and γ grains. By contrast, the misorientation of α lamellae along longitudinal direction are increased and α small amount of α sub-grains or grains have been formed by deformation. Moreover, phase transformation will take place in these recrystallized α grains to γ grains and lamellar colonies during the rolling with temperature drop. In general, the used larger rolling deformation per pass or lower rolling rate is favorable for the decomposition of lamellar colonies.

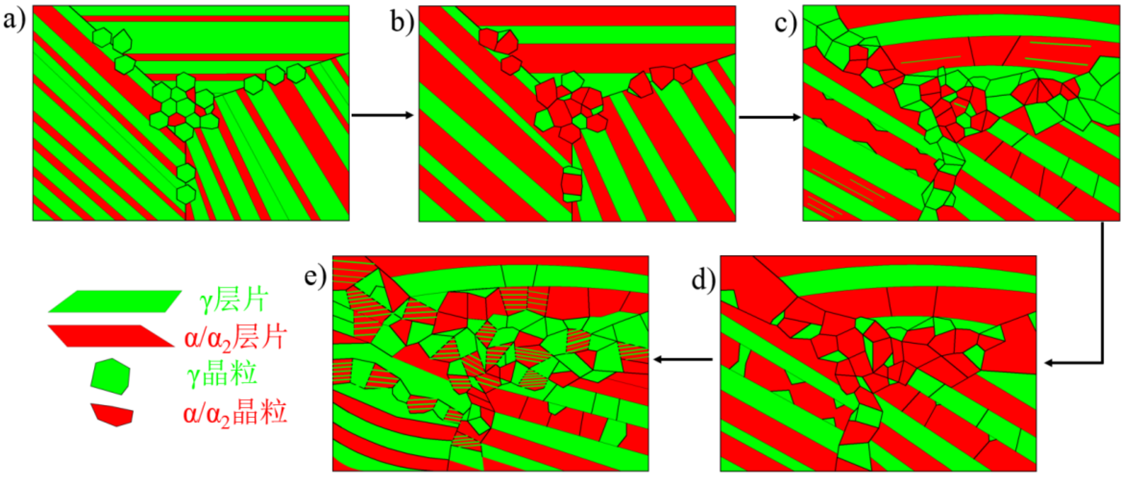

Fig. 11 Microstructure evolution model of Ti-44Al-8Nb-(W, B, Y) alloy at 1250 °C during hot rolling. a) Original microstructure, b) microstructure annealing at rolling temperature for 2h, c) microstructure after first pass rolling, d) microstructure annealing for 15min between two rolling passes and e) microstructure after another one pass rolling.

3) Fig. 11d) is the microstructure of Fig. 11c) after another holding at 1250 °C for 15 min. This process makes the disorder α phase increase to more than 70 vol.% before rolling, with the propotion of α grain increased. Moreover, both the size and content of remnant lamellar colonies are reduced. The workbility of as-rolled alloy is significantly improved due to increased α grains and decreased lamellar colonies after previous hot rolling. 4) Therefore, under the same condition of hot rolling, more finer γ grains and newly formed lamellar colonies are formed, as shown in Fig. 11e). With the progress of deformation, more α lamellae will be converted into α grains due to the increased misorientation and enhanced assissted decomposion of α lamellae by γ grain. Finally, the original coarse lammellar colonies will be converted into fine γ grains and lamellar colonies by repeated rolling deformation and furnace heat preservation process. The proportion of residual lamellar and newly precipitated lamellar colonies in as-rolled microstructure is related to rolling process. The proportion of residual lamellar colonies can be reduced and the volume fraction of newly formed lamellar colonies can be incresased by reducing the rolling strain rate and increasing per-pass and total deformation. In literature, the original coarse nearly lamellar structure with mean grain sizes of 120 mm was converted into a fine duplex microstructure with mean grain sizes of 5.3 mm after hot pack rolling with a large thickness reduction of 85% by 25% reduction per pass[4].

4. Conclusions

From the preliminary data presented above microstructure of as-deformed and as-rolled Ti-44Al-8Nb-(W, B, Y) alloy, the following conclusions are made.

(1) The as-deformed microstructure is significantly affected by deformation conditios. The nearly lamellar microstructure is completely transformed into slightly elongated γ and α grains after three times' isothermal compression under the condition of 1250 °C/0.1 s^{-1}/25%. While, a certain amount of remnant lamellar colonies are contained in as-rolled-quenched microstructure due to temperature drop and higher strain rate after hot packed rolling.

(2) The current TiAl alloy contains more than 70 vol. % disorder α phase before each deformation, which plays an important role in deformation. The rotation degree along the length of lamella is greater than that along the width, so these α lamellae with higher

misorientation will absorb deformation to further promote the rotation and increase the misorientation along the length of α lamellae. Some α sub-grains are formed along the length of α lamellae when the cumulative misorientation value reach to a critical point.

(3) Disorder α lamella can not only be decomposed into some new α grains by itself, but also can be decomposed by "external factor". The "groove" γ grain generated by phase transformation from α lamella during hot rolling can cooperate with α lamellae to be decomposition. When γ grain goes through α lamella, the parent α lamella will be completely separated, and ultimately transformed into non-continuous equiaxed α grains.

(4) Deformation and phase transformation take place during hot rolling. These α grains and γ grains around lamellar colonies undergo a thorough recrystallization into fine recrystallized α grains and γ grains. Phase transformation will take place in these recrystallized α grains to γ grains and lamellar colonies during the rolling with temperature drop.

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