Rare Metal Materials and Engineering
Volume 47, Issue 5, May 2018
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com

ScienceDirect

Cite this article as: Rare Metal Materials and Engineering, 2018, 47(5): 1333-1340.

ARTICLE

Effect of Hot-rolling Temperature on Microstructure and Dynamic Mechanical Properties of Ti-6Al-4V Alloy

Luo Yumeng[1], Liu Jinxu[1], Li Shukui[1,2], Cheng Xingwang[1]

[1] *School of Material Science and Engineering, Beijing Institute of Technology, Beijing 100081, China;* [2] *State Key Laboratory of Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, China*

Abstract: The equiaxed Ti-6Al-4V alloys were rolled with an overall reduction ratio of 0.78 at 840, 870, 900 and 930 °C. The microstructure, texture and anisotropy of dynamic mechanical properties of the rolled alloy were investigated. Results show that the recrystallization and phase transformation do not occur until the rolling is performed at a temperature higher than 900 °C, and then the microstructure of the rolled alloy turns into bimodal, while the amount of lamellar $\alpha_s+\beta$ structure and recrystallized α grains shows an increasing tendency with the increased rolling temperature. Moreover, it is interesting to find that although the texture varies with the rolling temperature, the <0001> direction of α phase keeps parallel to the normal direction (ND) during the hot-rolling process at various temperatures. Based on the analyses of dynamic mechanical properties, Ti-6Al-4V alloy exhibits anisotropy of dynamic mechanical properties after hot-rolling at different temperatures. However, resulting from the rolling-temperature-depended texture and distribution of dislocation, the anisotropic tendency of dynamic mechanical properties varies with the rolling temperature. Moreover, with the increased rolling temperature, the dynamic flow stress loaded along ND decreases, while the adiabatic shearing failure strain slightly increases. The dynamic flow stress loaded along RD remains constant, while the adiabatic shearing failure strain exhibits an obviously decreasing tendency with the increased rolling temperature. The dynamic mechanical properties loaded along Transverse Direction (TD) remain constant when the rolling temperature is in the range of 840 °C to 900 °C, while the dynamic flow stress loaded along TD increases evidently when the rolling temperature reaches 930 °C, but the adiabatic shearing failure strain decreases greatly.

Key words: titanium alloy; hot-rolling; dynamic mechanical properties; anisotropy

Ti-6Al-4V alloy, owing to its excellent combination of high strength, low density and good corrosion properties, is known as the most important structural used alpha/beta titanium alloy [1-3]. Due to its high specific strength, Ti-6Al-4V alloy also has good application prospect in high-speed-impact protection field.

Since most of the industrial application of Ti-6Al-4V alloy rely on plate via hot-rolling, the microstructure and texture evolution of Ti-6Al-4V alloy during hot-rolling has been well documented [4-8]. However, due to the complex influence factors such as rolling temperature, reduction ratio, cooling rate and initial microstructures, it is a huge workload to reveal the whole changes in texture, microstructure and the mechanical properties of the hot-rolling Ti-6Al-4V alloy. Salem et al.[4] particularly investigated the effects of preheat temperature and inter-pass reheating on texture evolution during unidirectional hot-rolling of Ti-6Al-4V with an equiaxed microstructure. Results revealed that, with the decreased rolling temperature, the intensity of basal poles decreased on the rolling direction, while that increased on the normal and transverse direction. Ari-Gur et al. [5] investigated the microstructure evolution and texture of two kinds of Ti-6Al-4V alloys with different transformed β initial microstructures, and the effect of reduction ratio, and rolling temperature on macrotexture and microtexture was revealed particularly, but the microstructure evolution was not

Received date: May 14, 2017
Foundation item: National Natural Science Foundation of China (51571033, 11521062)
Corresponding author: Liu Jinxu, Ph. D., Associate Professor, School of Materials Science and Engineering, Beijing Institute of Technology, Beijing 100081, P. R. China, Tel: 0086-10-68913937, E-mail: liujinxu@bit.edu.cn

described in detail. Soon afterwards, to fully distinguish the globular primary α microtexture and the secondary α microtexture, Dye et al. [8] made an in situ observation of the texture and microstructure evolution of β-annealed Ti-6Al-4V during rolling and globularization. In their research, in situ synchrotron X-ray diffraction was employed to examine how the texture develops during dynamic recrystallization, and results showed that during globularization, the texture strength was increased at highly strained areas. In conclusion, the investigations on the texture of Ti-6Al-4V alloy during the rolling process are relatively detailed, but the evolution of microstructure is not well documented. So far, how the rolling temperature influences the microstructure including the phase proportion, phase morphology, phase dimension, grain distribution tendency and dislocation structures is not clear. Moreover, since the industrial rolling process is partially conducted to ingot or forged Ti-6Al-4V alloy with a lamellar or martensitic structure, studies about the microstructure and texture evolution of the Ti-6Al-4V alloy with an equiaxed or bimodal structure are relatively less.

Apart from the texture and microstructure, the mechanical properties and anisotropy of the rolled Ti-6Al-4V alloy also draw attention. Amateau, Dull and Raymond [9] investigated the effect of rolling process on plastic anisotropy of Ti-6Al-4V alloy. In their study, the anisotropy of quasi-static tensile mechanical properties was described in detail. Similarly, the yield strength under quasi-static condition of hot-rolled Ti-6Al-4V alloy along the rolling direction was reported to be a little lower than that along TD [10]. Song et al. investigated the effect of hot rolling condition on the anisotropy of quasi-static mechanical properties in Ti-6Al-4V alloy [11]. Results show that, the anisotropy of quasi-static mechanical properties was greatly influenced by the rolling temperature and cross rolling ratio. However, among these studies, there is little work focusing on dynamic mechanical properties of the hot-rolling Ti-6Al-4V alloy. It is well known that under dynamic loading condition, the failure mechanism of Ti-6Al-4V alloy is adiabatic shear failure as a result of relatively higher adiabatic shear sensitivity. Due to different failure mechanisms between dynamic and quasi-static conditions, the dynamic mechanical properties and anisotropy of mechanical properties may have great differences with that under quasi-static condition. Thus, it is necessary to investigate the dynamic mechanical properties and their anisotropy of the rolled Ti-6Al-4V alloy. Furthermore, the study on dynamic mechanical properties has merit for the application of rolled material in the fields of protection.

In the present work, Ti-6Al-4V alloy with an equiaxed structure was rolled with the same reduction ratio at four different rolling temperatures. The purpose of the present paper is to investigate the effect of the hot-rolling temperature on microstructure and texture of Ti-6Al-4V alloy with an initial equiaxed microstructure. Moreover, the effect of hot-rolling temperature on dynamic mechanical properties and anisotropy of mechanical properties is also studied.

1 Experiment

The material used in this study was forged Ti-6Al-4V alloy with a typical equiaxed structure which is shown in Fig.1, and the chemical compositions are 6.22 wt% Al, 3.98 wt% V, 0.024 wt% C and balance Ti. The β transus temperature of the alloy is about 982 °C. The texture of the original material used in this investigation is almost random. Then four bulks of forged Ti-6Al-4V alloy were unidirectional rolled with an overall reduction ratio of 0.78 at four different temperatures: 840, 870, 900 and 930 °C. Before rolling, the bulk was kept at rolling temperature for 45 min. Then, rolling was performed in 5 passes with thickness reduction process of 45 mm→33 mm→24 mm→18 mm→13 mm→10 mm, and all the rolling plates were air cooled after the final pass.

Microstructural features of the plates were examined on the Normal Surface (NS), Rolling Surface (RS) and Transverse Surface (TS) by Scanning Electron Microscope (SEM), soon after metallographic polishing and etching. The texture measurements were carried out by X-ray diffraction using Cu Kα radiation. Moreover, samples for TEM observations were prepared from the rolled plates with the surface parallel to NS, RS and TS, and dislocation structures were investigated.

In order to investigate the dynamic mechanical properties of the Ti-6Al-4V rolled at different temperatures, uniaxial dynamic compression tests were carried out at the strain rate of about 3.5×10^3 s^{-1} using Split Hopkinson Pressure Bar (SHPB), as shown in Fig.2. The cylindrical specimens with a dimension of Φ5 mm×5 mm were machined from the rolling plates. Fig.3 shows the schematic of cutting specimens. In this figure, RD is the rolling direction of the

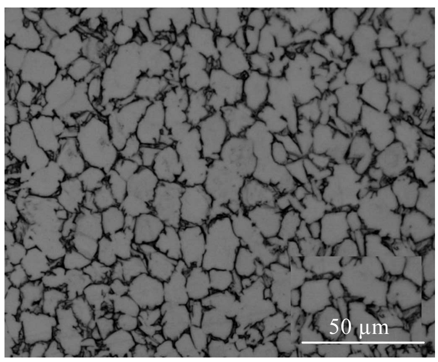

Fig.1 Microstructure of Ti-6Al-4V alloy before rolling

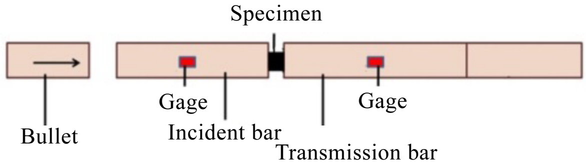

Fig.2 Schematic of the Split Hopkinson Pressure Bar (SHPB) equipment

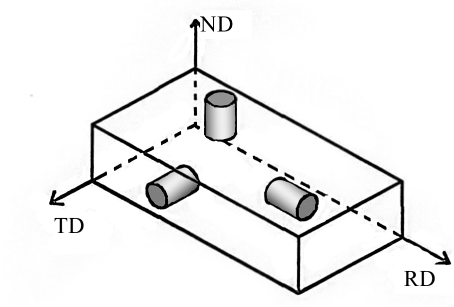

Fig.3 Diagrammatic sketch of cutting specimen

plate, ND is the normal direction, and TD is the transverse direction. To study the anisotropy of mechanical properties, specimens were sectioned with their axial directions parallel to the three orthogonal directions listed above.

2 Results and Discussion

2.1 Microstructure and texture

The microstructure of rolled Ti-6Al-4V demonstrates a marked dependence on rolling temperature. Figs.4b~4d show the SEM microstructures observed on different surfaces (NS, RS and TS) of Ti-6Al-4V rolled at 840 °C, and results show that the rolled Ti-6Al-4V has an elongated microstructure. The initial equiaxed α grains are greatly elongated along the RD and slightly compressed along ND. Since no equiaxed grain or lamellar α grain is observed by SEM, it can be sure that dynamic recrystallization and phase transformation do not occur during the rolling process at 840 °C. Compared with the SEM results of Ti-6Al-4V rolled at 840 °C, the microstructure of the Ti-6Al-4V rolled at 870 °C (Figs.4e~4g) shows the same microstructure feature, indicating that dynamic recrystallization and phase transformation do not occur while the rolling temperature is 870 °C.

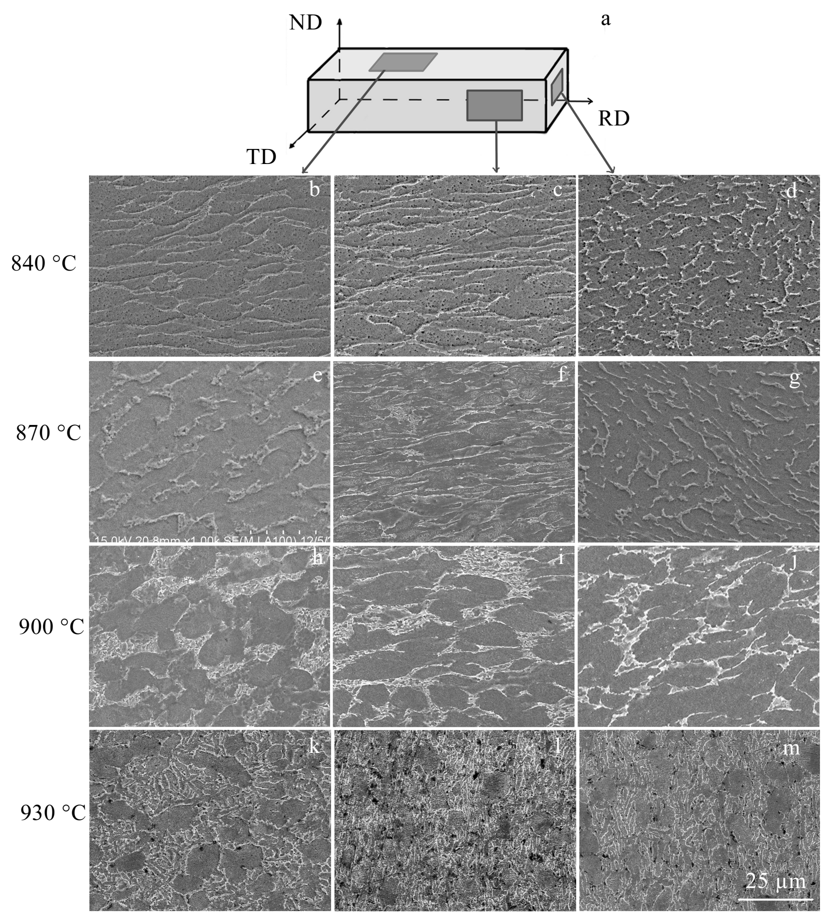

Fig.4 SEM microstructures observed on different surfaces of Ti-6Al-4V alloy at different temperatures

Significant variation of microstructure appears at a rolling temperature of 900 °C. Figs.4h~4j show the microstructures of Ti-6Al-4V rolled at 900 °C observed along ND, RD and TD, respectively. Compared with the microstructure of 840 and 870 °C, there are also some elongated initial α grains in Ti-6Al-4V rolled at 900 °C. However, it should be pointed out that, there are some equiaxed grains observed by SEM. Observed by TEM, it is clear that these low-dislocation-density equiaxed grains are recrystallized (Fig.5). Thus, dynamic recrystallization occurs during the hot-rolling process at 900 °C. Moreover, another difference between the microstructure rolled at 900 and 870 °C is the proportion of the combination of lamellar $\alpha_s+\beta$ structure which is transformed from high-temperature β phase. The proportion of the combination of lamellar $\alpha_s+\beta$ structure in Ti-6Al-4V rolled at 900 °C is about 20%, which is higher than the microstructure of Ti-6Al-4V rolled at 870 °C, indicating the occurrence of phase transformation during the hot-rolling process at 900 °C.

When the rolling temperature is 930 °C, the phase transformation and dynamic recrystallization are more obvious. Figs.4k~4m show the microstructure of Ti-6Al-4V rolled at 930 °C observed along ND, RD and TD, respectively. After hot-rolled at 930 °C, Ti-6Al-4V exhibits a typical bimodal feature, instead of elongated initial α grains. There are a large amount of approximately equiaxed α grains and the combination of lamellar $\alpha_s+\beta$ structures, and the proportion of lamellar structure in Ti-6Al-4V rolled at 930 °C increases to about 50%, which is transformed from the larger β grains formed at a relatively higher rolling temperature. Moreover, owing to the severe phase transformation and dynamic recrystallization process, the microstructure is greatly refined.

Based on the analyses of microstructure mentioned above, the three-dimensional microstructure evolution sketches of Ti-6Al-4V varied with the rolling temperature are shown in Fig.6. In conclusion, the effect of rolling temperature on microstructure can be described as follows: when the rolling temperature is lower than 900 °C, the α grains are elongated along the rolling direction; when rolling is performed at a temperature larger than 900 °C, recrystallization and phase transformation occurs, and the proportion of elongated initial α grains decreases with the increased rolling temperature, while that of the recrystallized equiaxed α grains and the combination of lamellar $\alpha_s+\beta$ structures increase. When the rolling temperature reaches 930 °C, the microstructure turns into typical bimodal.

To investigate the texture of rolled materials, the pole figures and orientation distribution function (ODF) figures were obtained by XRD. Fig.7 shows the texture analyzing results of Ti-6Al-4V rolled at 840, 870, 900 and 930 °C, and the results of the high-function-point are marked out

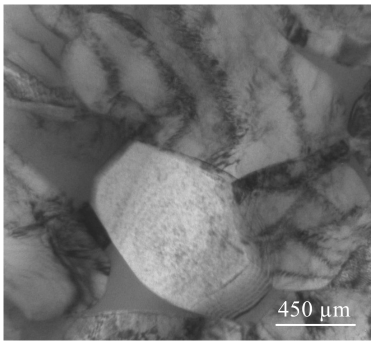

Fig.5 Low-dislocation-density grain in Ti-6Al-4V alloy rolled at 900 °C

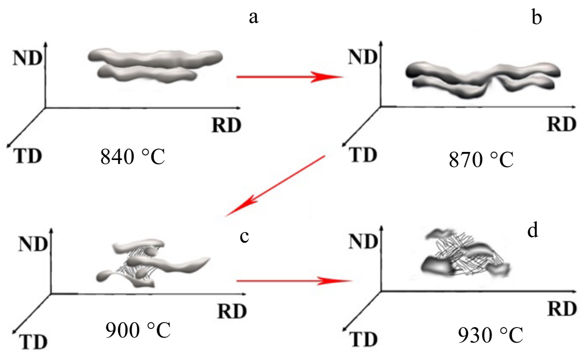

Fig. 6 Three-dimension sketch of microstructures formed at different rolling temperatures: (a) 840 °C, (b) 870 °C, (c) 900 °C, (d) 930 °C

on the ODF figures. Based on the analysis of pole figures and ODF figure, the main texture in the alloy rolled at 840 °C is {0001} <3$\bar{4}$10>, and {0001} <3$\bar{4}$10> and {0001} <$\bar{7}$430> are the main textures of the Ti-6Al-4V rolled at 870 °C. The textures formed in the material rolled at 900 °C are analyzed to be {0001} <$\bar{2}$110> and {0001} <$\bar{4}$310>, while the main texture in Ti-6Al-4V alloy rolled at 930 °C is analyzed to be {0001} <1$\bar{1}$00>. Thus, it is obvious that the texture varies with the rolling temperature. However, based on the results listed above, it should be noted that though the texture varies with the rolling temperature, the <0001> direction of α phase in the rolled Ti-6Al-4V alloy is always parallel to ND.

To further analyze the rolled alloy, TEM results of Ti-6Al-4V alloy rolled at different temperatures were compared. The dislocation of the Ti-6Al-4V alloy rolled at 840 °C is shown in Fig.8a and 8b. As mentioned before, dynamic recrystallization does not happen when the rolling temperature is lower than 900 °C. Thus, owing to the severe deformation, the dislocation density is greatly high.

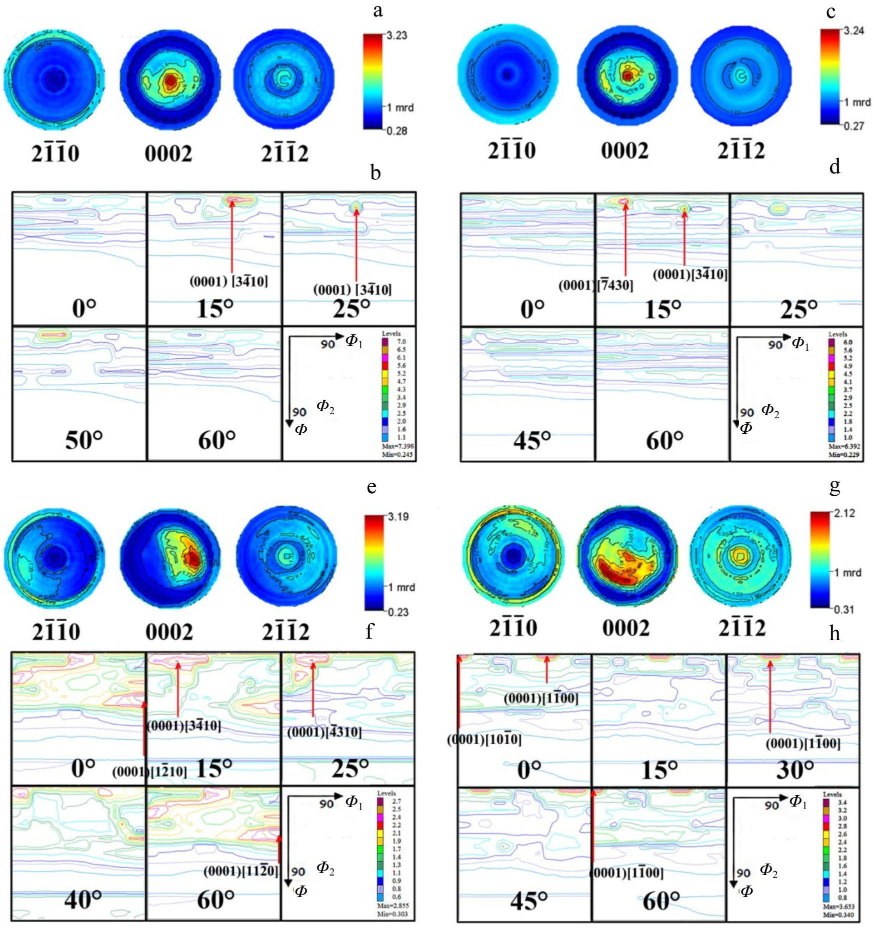

Fig.7 Select pole figures (a, c, e, g) and ODF results (b, d, f, h) of the Ti-6Al-4V alloy rolled at 840 °C (a, b), 870 °C (c, d), 900 °C (e, f) and 930 °C (g, h)

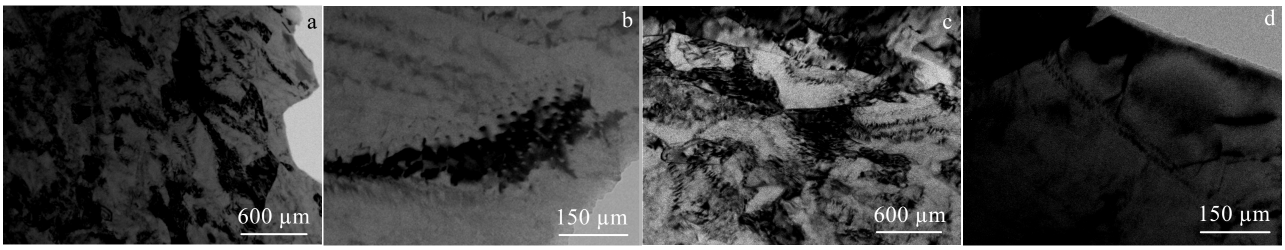

Fig.8 Dislocation structures of the Ti-6Al-4V alloy rolled at 840 °C (a, b) and 870 °C (c, d), observed along ND: (a, c) high density dislocations; (b, d) dislocations parallel to ND

Moreover, when the microstructure is enlarged, as shown in Fig.8b, a large number of cross sections of dislocations are observed distributed along ND. Thus, after the hot-rolling at 840 °C, numerous dislocations are apt to distributed parallel to ND. The dislocation structure of Ti-6Al-4V rolled at 870 °C has the similar feature with that rolled at 840 °C, as shown in Figs.8c~8d. The dislocation density is also very high, and there are also some dislocations parallel to ND. However, the amount of the dislocations distributed parallel to ND exhibits a decreasing tendency. Fig.9 shows the dislocation structure of Ti-6Al-4V rolled at 900 °C. In the alloy rolled at 900 °C, the dislocations parallel to ND are not observed. As mentioned before, several low-dislocation-density grains are formed after rolling at 900 °C, indicating a decrease of dislocation density, which results from the recrystallization

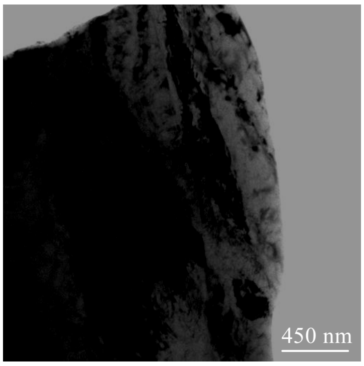

Fig. 9 Dislocation structures observed along ND of the Ti-6Al-4V alloy rolled at 900 °C

process. In the Ti-6Al-4V alloy rolled at 930 °C, as shown in Fig.10a, there is a large number of approximately equiaxed *α* grains with low dislocation density, due to the dynamic recrystallization process. Compared with the Ti-6Al-4V alloy rolled at 840, 870 and 900 °C, the dislocation density of the alloy rolled at 930 °C is evidently decreased. Moreover, it should be noted that, after rolled at 930 °C, lots of dislocations being parallel to TD are formed in Ti-6Al-4V alloy, as shown in Fig. 10b.

2.2 Dynamic mechanical properties

In order to investigate the effect of rolling temperature on the dynamic mechanical properties of Ti-6Al-4V alloy, SHPB tests were conducted, and the true strain-stress curves of the Ti-6Al-4V rolled at different temperatures (840, 870, 900 and 930 °C) were compared. Figs.11a~11c show the dynamic compressive true strain-stress curves loaded along ND, RD and TD, respectively. When loaded along ND, with the increased rolling temperature, as shown in Fig.11a, the flow stress exhibits a decreasing tendency, while the adiabatic shearing failure strain slightly increases. However, with the increased rolling temperature, the adiabatic shearing failure strain loaded along RD greatly decreases though the flow stress keeps constant, as shown in Fig.11b. When the material is loaded along TD, the stress-strain curves of the Ti-6Al-4V alloy plates rolled at 840, 870 and 900 °C are nearly the same, while the material rolled at 930 °C exhibits a relatively higher flow stress and a greatly decreased adiabatic shearing failure strain, as shown in Fig.11c. Based on the strain-stress curves of Ti-6Al-4V alloy rolled at different temperatures, it can be concluded that the effects of rolling temperature on dynamic mechanical properties vary with the loading direction.

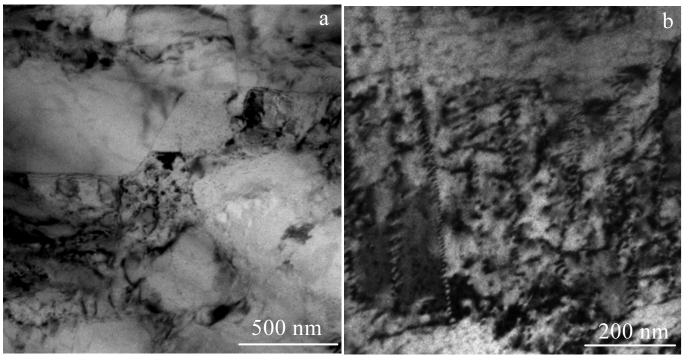

Fig.10 Dislocation structures of the Ti-6Al-4V alloy rolled at 930 °C: (a) observed along ND; (b) dislocations parallel to TD, observed along TD

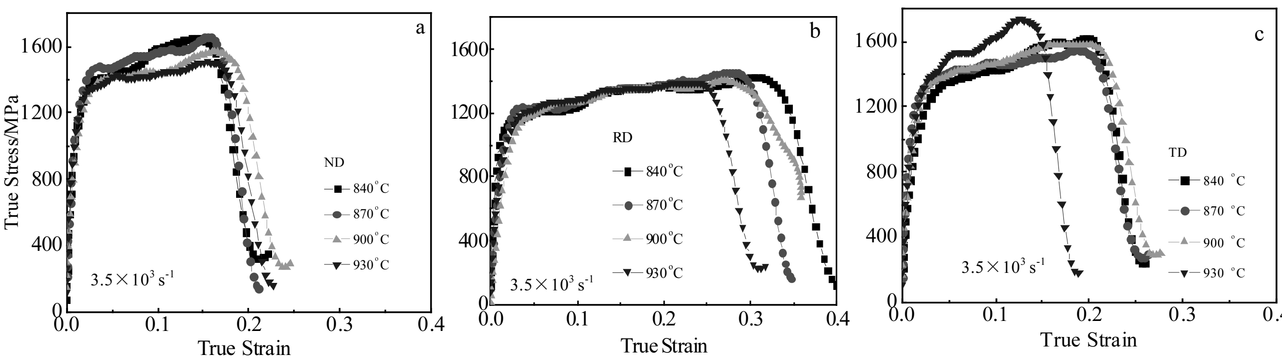

Fig.11 Dynamic strain-stress curves of the Ti-6Al-4V alloy at different rolling temperatures: (a) compressing along ND; (b) compressing along RD; (c) compressing along TD

Another point that should be noted is that the rolling temperature also has obvious effect on anisotropy of dynamic mechanical properties. It is well known that, Ti alloys always exhibit the anisotropy of mechanical properties after rolling [4-8]. Fig.12 shows the dynamic strain-stress curves of T Ti-6Al-4V rolled at different temperatures (840, 870, 900 and 930 °C). It is evident that though the rolling temperature changes, all the dynamic mechanical properties of Ti-6Al-4V exhibit an obvious anisotropy. When Ti-6Al-4V rolled at 840 °C is dynamic loaded along RD, as shown in Fig.12a, the material exhibits the best ductility and lowest flow stress, but the rolled alloy shows the highest strength and lowest adiabatic shearing failure strain when loaded along ND. Moreover, both the flow stress and adiabatic shearing failure strain loaded along TD are between that of RD and ND. In Fig.12b, Ti-6Al-4V rolled at 870 °C also exhibits the same tendency of dynamic mechanical properties anisotropy due to the same microstructure. Fig.12c shows the dynamic mechanical properties anisotropy of Ti-6Al-4V rolled at 900 °C. It is evident that when the rolling temperature is 900 °C, the ductility along TD is still better than that along ND, but the flow stress loaded along ND is similar to that along TD. Moreover, material still exhibits the best ductility and the lowest strength when loaded along RD. Fig.12d shows the dynamic mechanical properties curves of the material rolled at 930 °C. The alloy also exhibits the best ductility and the lowest strength when loaded along RD, but the alloy exhibits the best strength and the lowest ductility when loaded along TD instead of ND, which can be attributed to the evidently increased flow stress and greatly decreased adiabatic shearing failure strain loaded along TD. In sum, with the increased rolling temperature, the anisotropy of dynamic mechanical properties varies: the flow stress loaded along RD is always the lowest, while the adiabatic shearing failure strain is always the highest, but both the flow stress and ductility between TD and ND show an inverse tendency with the increased rolling temperature.

As mentioned before, while the rolling temperature increases from 840 °C to 930 °C, the main texture is changed from {0001} $<3\bar{4}10>$ to {0001} $<1\bar{1}00>$. The variation of texture is a reason of the difference in the mechanical properties anisotropy. Moreover, research [12] shows that, dislocation distribution also exhibits obvious effect on anisotropy of mechanical properties. In this work, while the rolling temperature of Ti-6Al-4V alloy is increased from 840 °C to 900 °C, the dislocations parallel to ND disappear gradually. Moreover, while the rolling temperature is 930 °C, several dislocations are apt to parallel to TD. Since the dislocations parallel to loading direction do not have an effective displacement as the dislocations which are perpendicular to loading direction, deformation parallel to a large amount of dislocations will be more difficult. Thus, Ti-6Al-4V alloy rolled at 840 °C exhibits the highest flow stress loaded along ND resulting from the large amount of dislocations parallel to ND. Similarly,

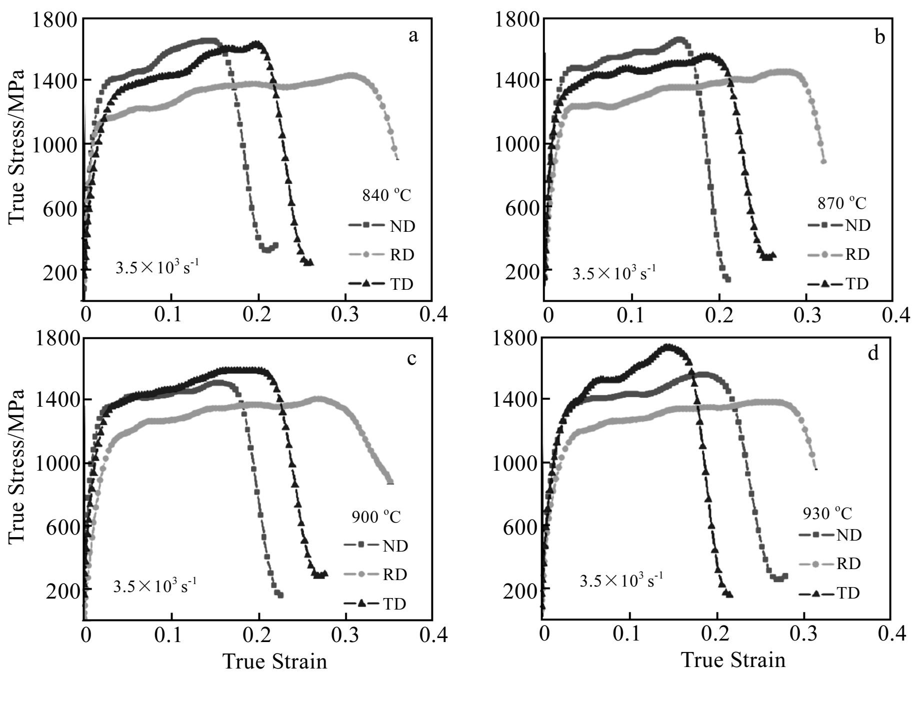

Fig.12 Anisotropy of the dynamic mechanical properties of the Ti-6Al-4V alloy rolled at 840 °C (a), 870 °C (b), 900 °C (c), and 930 °C (d)

the alloy rolled 930 °C exhibiting the best strength and lowest ductility along TD can also be explained. Thus, the distribution variation of dislocation is another reason of the difference in the mechanical properties anisotropy.

3 Conclusions

1) For the Ti-6Al-4V alloy with an equiaxed structure, when the rolling temperature is lower than 900 °C, the initial α grains are elongated along RD without dynamic recrystallization and phase transformation. When the rolling temperature is higher than 900 °C, the amount of lamellar $\alpha_s+\beta$ structure and globularized α grain increases with the increased rolling temperature, and the material exhibits a bimodal feature owing to the severe dynamic recrystallization and phase transformation process.

2) Texture also varies with the rolling temperature, but the <0001> direction of α grain is always parallel to ND of the plate. Moreover, a large number of dislocation parallel to ND observed in the alloy rolled at 840 °C disappear with the increased rolling temperature.

3) Dynamic mechanical properties of Ti-6Al-4V alloy are also greatly influenced by the rolling temperature, but the effect of rolling temperature varies with the loading direction. Furthermore, the tendency of dynamic mechanical properties anisotropy also varies with the rolling temperature. When the rolling temperature is lower than 900 °C, the material loaded along ND exhibits the largest flow stress and the lowest adiabatic shearing failure strain, while the alloy loaded along RD exhibits the best ductility and the lowest strength. However, when the rolling temperature is higher than 900 °C, both the flow stress and ductility between TD and ND show an inverse tendency with the increased rolling temperature, but material loaded along RD still exhibits the best ductility and the lowest strength.

References

1 Salem A A, Semiatin S L. *Materials Science and Engineering A*[J], 2009, 508(1-2): 114
2 Srinivasan R, Miracle D, Tamirisakandala S. *Materials Science and Engineering A*[J], 2008, 487(1-2): 541
3 Roy S, Suwas S. *Metallurgical and Materials Transactions A* [J], 2013, 44A(7): 3303
4 Salem A A, Glavicic M G, Semiatin S L. *Materials Science and Engineering A*[J], 2008, 496(1-2): 169
5 Ari-Gur P, Semiatin S L. *Materials Science and Engineering A* [J], 1998, 257(1): 118-127
6 Li Y, Sun K, Liu P, Chui P. *Vacuum*[J], 2014, 101(SI): 102
7 Lopatin N V. *International Journal of Material Forming*[J], 2013, 6(4): 459
8 Warwick J L, Jones N G, Bantounas I. *Acta Materialia*[J], 2013, 61(5): 1603
9 Amateau M F, Dull D L, Raymond L. *Metallurgical Transactions*[J], 1974, 5(3): 561
10 Srinicasan R, Bennett Mats D, Tamiriskandala S. *Journal of Materials Engineering and Performance*[J], 2009, 18(4): 390
11 Song J H, Hong K J, Ha T K. *Materials Science and Engineering A*[J], 2007, 449-451: 144
12 Luo Yumeng, Liu Jinxu, Li Shukui. *Rare Metal Materials and Engineering*[J], 2014, 43(11): 2692

热轧温度对 Ti-6AL-4V 合金组织及动态力学性能的影响

骆雨萌[1]，刘金旭[1]，李树奎[1,2]，程兴旺[1]

(1. 北京理工大学 材料学院，北京 100081)

(2. 北京理工大学 爆炸科学与技术国家重点实验室，北京 100081)

摘　要：在 840，870, 900 和 930 ℃条件下分别对等轴 Ti-6AL-4V 合金进行总变形量为 78%的热轧，随后对热轧 Ti-6AL-4V 合金的显微组织形貌、织构及动态力学性能进行研究。结果表明，当热轧温度达到 900 ℃以上时，TI-6AL-4V 合金中才发生再结晶及相变，显微组织类型由等轴组织变为双态组织，$\alpha_s+\beta$ 组织及再结晶等轴 α 晶粒的含量随热轧温度升高而增加。热轧 Ti-6AL-4V 合金中的织构随热轧温度变化而改变，但 α 晶粒的<0001>方向始终平行于轧板的法向。热轧 Ti-6AL-4V 合金的动态力学性能具有明显的各向异性，且各向异性规律随热轧温度的变化而改变。随着热轧温度的升高，沿法向加载时，合金的动态流变应力不断减小，绝热剪切临界失效应变不断增大；沿轧向加载时，合金的动态流变应力基本保持不变，但临界失效应变明显降低；沿横向加载时，合金的动态力学性能在 840 ℃到 900 ℃的热轧温度范围内基本保持不变，但当热轧温度为 930 ℃时，合金的动态流变应力明显升高，临界失效应变明显降低。

关键词：钛合金；热轧；动态力学性；各向异性

作者简介：骆雨萌，女，1988 年生，博士生，北京理工大学材料学院，北京 100081，电话：010-68913937，E-mail: luoyumoe@qq.com