Rev. Adv. Mater. Sci. 31 (2012) 85-89

TEXTURE ANALYSIS OF ω - PHASE Ti SUBJECTED TO HIGH PRESSURE TORSION

Vil Sitdikov and Igor Alexandrov

Ufa State Aviation Technical University, 12, K. Marx, Ufa, 450000Russia

Received: April 20, 2012

Abstract. This paper presents the research results of crystallographic texture and deformation mechanisms, which are characteristic of the ω-phase of Ti, subjected to high pressure torsion under pressure of 6 GPa at temperature 298K. The research has been carried out on the disk-shaped samples with radius 20 mm and thickness 1.5 mm in an initial state (the as-received condition) and in states after 0.1, 0.5, 1, and 5 rotations under the high pressure torsion. The methods of X-ray analysis and computer modeling have been used here. As a result, the evolution mechanisms of preferable orientations, the activity of slip and twinning systems in ω-phase according to the degree of severe plastic deformation have been determined.

1. INTRODUCTION

At present it has been found out that it is possible to form bulk nanostructured states with the grain size of tens and hundreds nanometers and non-equilibrium high-angle grain boundaries in different materials with the help of severe plastic deformation (SPD) [1-5]. Specific deformation behavior consisting in almost absolute absence of deformation strengthening [2], the SPD paradox [5], the low temperature and/or high rate superplasticity [6] can be characteristic of the formed states. In general, it should be noted that the mechanisms of deformation behavior of metals in nanostructured states are crucially different from those, which exist in an annealed coarse-grained state.

Nanostructured Ti, obtained by the SPD methods is one of the most investigated metals due to wide perspectives of its industrial application. The X-ray diffraction method plays an important role during the research of its microstructure and crystallographic texture properties. In particular, with the help of this method in nanostructured Ti obtained by the SPD method, the authors [7-9] have revealed the development of a ω-phase, which affects its strength and ductility. At the same time, the detailed X-ray analysis of the deformation mechanisms in the ω-phase of Ti in the process of development of a nanostructured state by the high pressure torsion, as well as the texture development mechanisms in this phase, has not been carried out.

The goal of this paper is the analysis of crystallographic texture evolution to reveal the dynamic slip and twinning systems in the ω-phase, affecting the strength and ductility of Ti, subjected to the HPT.

2. THE EXPERIMENTAL METHODOLOGY

Ti (0.12wt.% O, 0.01wt.% H, 0.04wt.% N, 0.07wt.% C, and 0.18wt.% Fe) with the average grain size 10 μm has been chosen as the material under examination. The initial ingots of the annealed Ti (α - phase) with the diameter 20 mm and thickness 1.5 mm have been subjected to HPT under pressure of 6 GPa in closed dies at temperature 298K. The different level of the accumulated deformation degree has been achieved due to the variation of number of

Corresponding author: Vil Sitdikov, e-mail: svil@mail.rb.ru

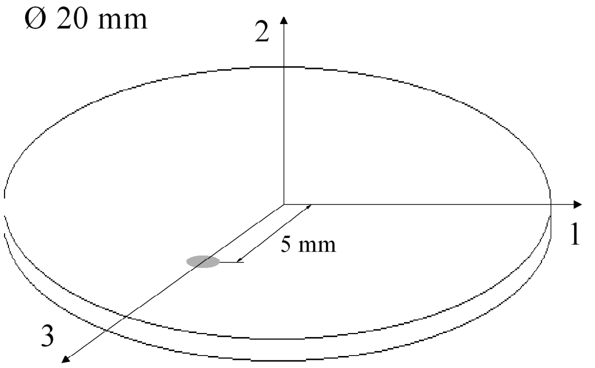

Fig. 1. Scheme illustrating the position of the chosen investigated area in the ingots.

rotations during torsion (N = 0.1, 0.5, 1, and 5 rotations).

The exposure of pole figures (PF) has been carried out by the X-ray analysis with the help of diffractometer DRON-3m, equipped with automatic texture attachment. The diameter of the illuminated region was equal to ~ 0.6 mm.

The results of experimental research have been presented as full PFs, calculated with the help of the software LaboTEX [10]. Thus, a zone located at the distance of 5 mm from the center of the sample, i.e. at the distance of 1/2 of the radius of a disk-shaped sample, has been studied, considering the inhomogeneity of the material flow in all the investigated ingots. The exposure has been carried out in the shear plane (Fig. 1). The deformation has been realized at room temperature.

To make it more evident the PFs obtained in the plane 1-3 were rotated about the axis 1 (Fig. 1) counterwise through 90°, so that the shear direction was horizontal in the PF plane, and the PF axes were in plane 1-2.

3. THE MODELING METHODOLOGY

Computer modeling of the texture development processes has been realized within the context of visco-plastic self-consistent (VPSC) model [11], allowing to predict the character of textures, which are developed during large deformations, more precisely than in any other existing models [12]. The VPSC model is the most advanced one, and presently being used more often for the analysis of texture development in metallic materials. Application of this model for the case of plastic deformation of materials allows estimating the activity of potential slip systems (SS) and twinning systems (TS).

To reveal the active slip systems, which are responsible for appearing some or other maxima on the PFs, on the basis of literature analysis, 7 slip and twinning systems have been chosen. These systems include: the basal $\{0001\}\langle\bar{1}\bar{1}20\rangle$, the prismatic $\{10\bar{1}0\}\langle\bar{1}2\bar{1}0\rangle$, the pyramidal of the 1st order $\{10\bar{1}1\}\langle\bar{1}2\bar{1}0\rangle$ with the Burgers vector a = $1/3\langle11\bar{2}0\rangle$, the pyramidal of the 1st order $\{10\bar{1}1\}$ $\langle\bar{1}\bar{1}23\rangle$ and of the 2nd order $\{112\}\langle\bar{1}\bar{1}23\rangle$ with the Burgers vector $c + a = 1/3\langle11\bar{2}3\rangle$ slip systems, as well as the tensile twinning systems $\{10\bar{1}2\}\langle\bar{1}011\rangle$ and compression $\{2\bar{1}\bar{1}2\}$ $\langle2\bar{1}\bar{1}\bar{3}\rangle$.

Taking into consideration the opportunity to activation all the possible families of the slip and twinning systems in the VPSC software, each of the slip or twinning system had been assumed a value of a relative critical resolved shear stress (CRSS). The choice of active slip and twinning systems has been made on the basis of calculating the minimum work expended on deformation. In the result of variation of value of relative CRSS the action of some slip/twinning system lightened, while the other one became more difficult.

The conclusion about activity of some or other slip and twinning systems has been made on the basis of comparison of simulated PFs with the experimental ones. The temperature of deformation while modeling crystallographic textures of Ti had been assigned equal to 298K and corresponding to the temperature of experimental investigations. The lattice parameter for ω-Ti is c/a =0.608. While modeling the texture development processes, 7 variations of the active slip and twinning systems mentioned above have been viewed here.

To find out activation mechanisms of some or other slip and twinning systems, one type of slip/twinning systems has been assigned the least relative CRSS τ_0, equal to 1, and 10 times more to the other systems, according to the methodology [13]. As a result the other systems took part in deformation, but their contribution into the texture development processes was minor.

4. THE RESULTS AND THEIR DISCUSSION

As it has been demonstrated in the recent investigations of the authors of the paper, that during the HPT in α-Ti, beginning with N = 0.1, the change of phase transformation takes place into ω-Ti, the volume fraction of which increases along with the adding of number of rotations at HPT [14]. The quantitative phase analysis by the method of intensity ratio of X-ray peaks has shown that, if the part of ω-phase is ~1% after 0.1 rotation, it increases up to ~33%

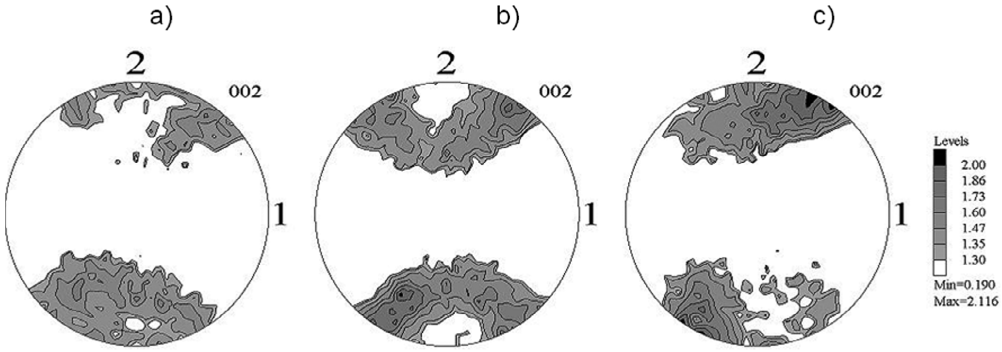

Fig. 2. The experimental (0001) PFs of ω-Ti in plane 1-2: a) the state after the HPT, N = 0.5, b) the state after the HPT, N = 1, c) the state after the HPT, N = 5.

after N = 0.5, and up to ~58% after N = 5. After N = 5 rotations the w-phase becomes the main phase in the SPD Ti.

The investigation of the crystallographic texture evolution in α-Ti during the HPT has been carried out by the authors of this paper in work [14]. It has been demonstrated that the type of the developing textures can be explained by activation of the basal, prismatic and pyramidal (of the 1st type) slip systems and by the tensile twinning. During the increase of the SPD degree the basal slip and deformation by the tensile twinning are the active ones.

Fig. 2 presents (0001) PFs of ω-Ti for different number of rotations during the HPT. As it can be seen (Fig. 2a), at N = 0.5 at the periphery of (0001) PFs the diffused peaks are being developed. The most intensive maxima start appearing during the increase of number of HPT rotations amid the pointed out diffusion of the pole density. In particular, it is possible to point out four maxima at N = 1 on PFs, which are located on periphery.

At N = 5 the maxima are located irregularly in relation to the axes of PFs (Fig. 2), while the intensity of the texture maxima is relatively high. This fact points out the activity of the slip and twinning systems in the ω-phase of Ti, which is being deformed plastically during the SPD, the same way as α-Ti.

The results of modeling of the crystallographic texture of ω-Ti for seven various cases of activation,

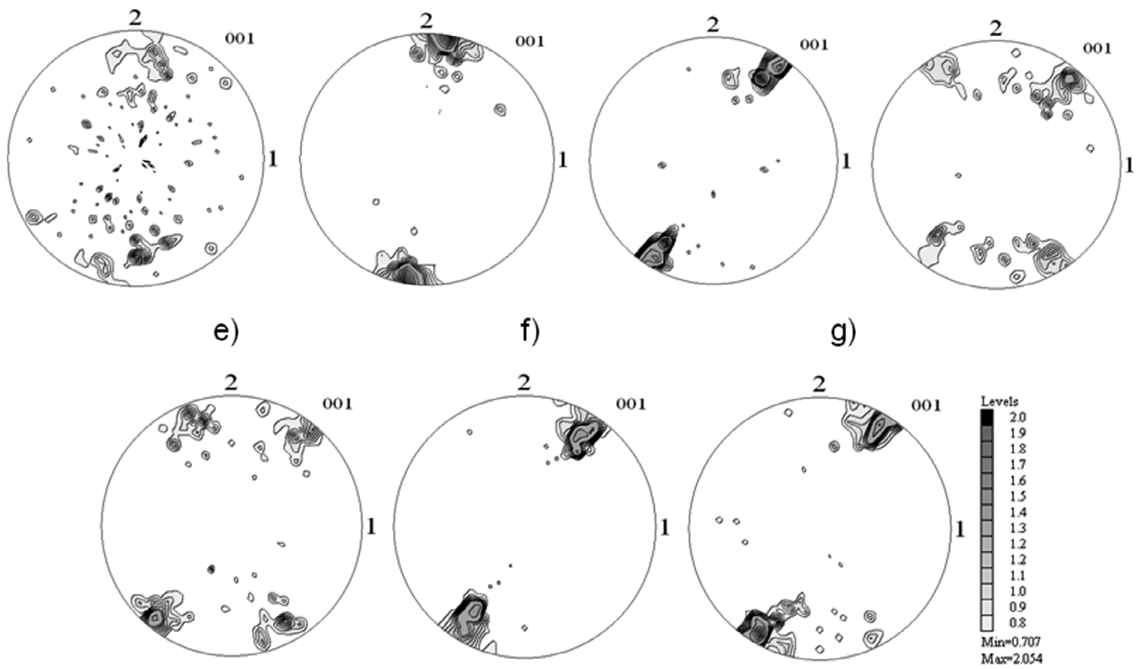

Fig. 3. The simulated (0001) PFs of ω-Ti in the plane 1-2 for 7 cases, when only one type of slip or twinning systems are active: a) basal SS, b) prismatic SS, c) pyramidal <*a*> SS, d) pyramidal <*c*+*a*> SS of the 1st order, e) pyramidal <*c*+*a*> SS of the 2nd order, f) TS by tension, g) TS by compression.

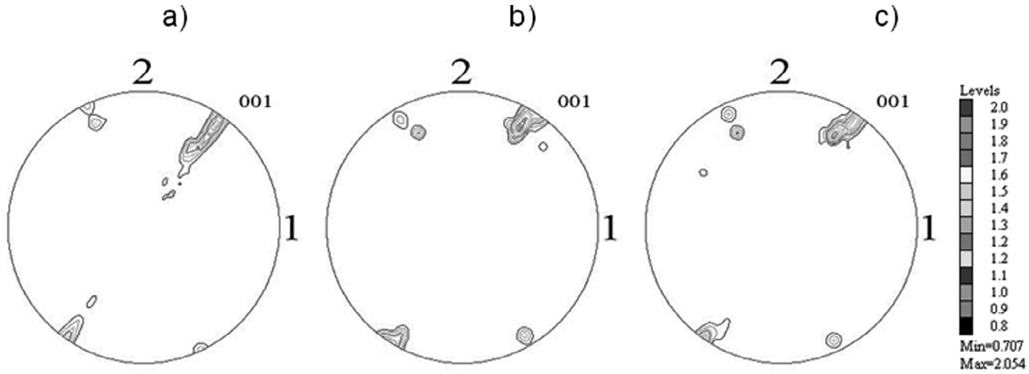

Fig. 4. The simulated (0001) PFs of ω-Ti in plane 1-2: a) the state after the HPT, N = 0.5, b) the state after the HPT, N = 1, c) state after the HPT, N = 5.

mentioned above in the section "Modeling methodology", of some slip and twinning systems separately, during the realization of the simple shear scheme, are presented in Fig. 3. The analysis of the modeling results shows that during the realization of the cases 1 and 2, while the prismatic and basal slip systems are operating (Figs. 3a and 3b), the simulated PFs are different from the experimental ones at every considered stage of SPD (Fig. 2). This means, that the dislocation slip along the above mentioned planes in ω-Ti at HPT is limited.

During the realization of cases 3, 6, and 7 simulated (0001) PFs (Figs. 3c, 3f, 3g) are similar to the experimental ones at N = 1 and 5 HPT rotations, shown in Figs. 2b, 2c. This means that activity of pyramidal <*a*> slip systems, twinning systems of tension and compression can bring to the development of crystallographic texture, similar to the experimental ones at the HPT (Figs. 2 and 3). In cases 4 and 5, when the pyramidal <*a*+*c*> systems of the 1st and the 2nd order are acting, the simulated PFs (0001) are similar to the experimental ones at N = 0.5 and 1 (Figs. 3a and 3b). This points out the activity of the pyramidal <*a*+*c*> systems of the 1st and the 2nd order at all the SPD stages.

Thus, in the result of crystallographic texture modeling within the VPSC model under condition of operating only one certain slip or twinning system separately it has been determined that the dislocation slip along the pyramidal <*a*>, pyramidal <*a*+*c*> systems of the 1st and 2nd order of the slip systems, as well as the twinning deformation by tension and compression can provide the development of SPD process in w-phase of Ti at all the SPD stages.

Fig. 4 presents the modeling results of the texture development processes in ω-phase of Ti at simultaneous activation of pyramidal <*a*>, pyramidal <*a*+*c*> of the 1st and 2nd order of the slip systems, as well as the twinning deformations by tension.

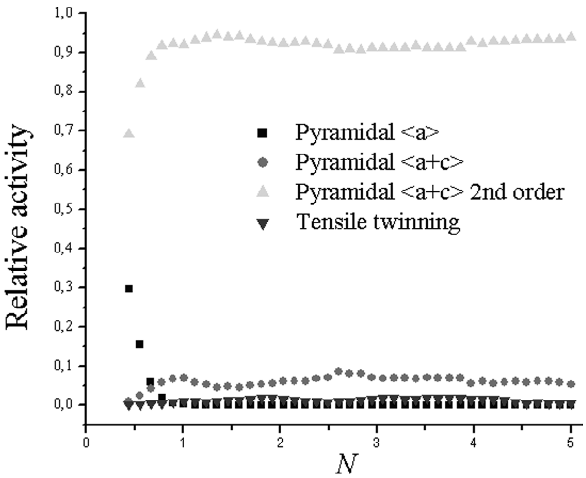

Fig. 5. The relative activity of the slip and twinning systems in ω-Ti depending on the number of rotations at HPT.

The comparison of the simulated (0001) PFs (Fig. 4) with the experimental ones (Fig. 2) shows, that there is quite a good correspondence between them. So, the conclusion can be made that the dislocation slip along the pyramidal slip systems and processes of twinning by tension are able to provide the SPD process of the ω-phase Ti.

The relative activity of the mentioned slip and twinning systems is presented in Fig. 5. The modeling results have shown that the most active slip systems are the pyramidal <*a*+*c*> ones of the 1st and 2nd order. The dislocation slip along the pyramidal <*a*> slip systems is active only at an initial stage of SPD. Besides, one can see that the activity of the processes of twinning by tension is quite low at the HPT.

Thus, it is evident that the mechanisms of the texture development processes in α-Ti and ω-Ti during the HPT, realized at room temperature, are different. At small number of rotations the most active in α-Ti are the basal, the prismatic and the pyramidal (of the 1st type) slip systems and the tensile twinning systems, while in ω-Ti the most active are the pyramidal <*a*> and <*a*+*c*> of the 1st and the 2nd order slip systems. During the increase of the number of rotations in α-Ti the most active are the basic slip systems and the tensile twinning systems, while in ω-Ti the pyramidal <*a*+*c*> of the 1st and 2nd order slip systems. The found out differences in the processes of texture development in the pointed out phases, are evidently connected with the difference in the lattice parameters α (*c*/*a* =1.587) and in ω (*c*/*a* =0.608) phases of Ti.

5. CONCLUSIONS

In the result of analyzing the texture development processes in ω-phase of Ti it has been determined that the most active slip systems are the pyramidal <*a*+*c*> ones of the 1st and the 2nd order. Therefore, the activity of the pyramidal <*a*> slip systems is noticeable only at an initial stage of SPD. Besides, the HPT is followed by activation of the twinning processes by tension, though their contribution into deformation is inconsiderable.

ACKNOWLEDGEMENTS

The authors are grateful for financial support within the state contract N 16.523.12.3002.

REFERENCES

[1] R.Z. Valiev and I.V. Alexandrov, *Nanostructured Materials, Obtained by the Sever Plastic Deformation* (Logos, Moscow, 2000).

[2] R.Z. Valiev, R.K Islamgaliev and I.V. Alexandrov // *Prog. in Mater. Sci*. **45** (2000) 103.

[3] R.Z. Valiev and I.V. Alexandrov, *The Bulk Nanostructured Metallic Materials* (Academkniga, Moscow, 2007).

[4] M.J. Zehetbauer, H.P. Stüwe, A. Vorhauer, E. Schafler and J. Kohout // *Adv. Eng. Mater.* **5** (2003) 330.

[5] R.Z. Valiev and I.V. Alexandrov // *Doclady Academii Nauk RF*, **380** (2001) 34.

[6] R.Z. Valiev // *Mater. Sci. Forum* **243-245** (1997) 207.

[7] Y. Ivanisenko, A. Kilmametov, H. Rosner and R. Valiev // *Int. J. Mat. Res*. **99** (2008) 1.

[8] Y.Todaka, H. Azuma, Y. Ohnishi, H. Suzuki and M. Umemoto **//** *Journal of Physics* **240** (2010) 112.

[9] K. Edalati and E. Matsubara // *Metall. and Mat. Trans*. **40A** (2009) 2079.

[10] Information on http://www.labosoft.com.pl.

[11] R.A. Lebensohn and C.N. Tome // *Acta Mater*. **41** (1993) 26.

[12] U.F. Kocks, C.N. Tome and H.R. Wenk, *Texture and anisotropy: preferred orientations in polycrystals and their effect* (Cambridge University Press, Cambridge, 1998).

[13] S. Li // *Acta Mater*. **56** (2008) 1031.

[14] V.D. Sitdikov, I.V. Alexandrov and J.T. Bonarski // *Mater. Sci. Forum* **667-669** (2011) 187.