Bull. Mater. Sci., Vol. 22, No. 3, May 1999, pp. 581–584.

Evolution and stability of texture during thermomechanical processing of Ti–24Al–11Nb alloy

SATYAM SUWAS and R K RAY*

Department of Materials and Metallurgical Engineering, Indian Institute of Technology, Kanpur 208 016, India

Abstract. The evolution of basal texture during thermomechanical processing of Ti–24Al–11Nb alloy has been studied as a function of different processing variables like hot rolling temperature, amount of deformation, cooling conditions etc. The stability of the deformation texture during post-rolling annealing and during the $\alpha_2 \rightarrow \beta \rightarrow \alpha_2$ phase transformation cycle was also investigated. Unrestricted rolling of primary α_2 to maximum thickness reduction at the lowest rolling temperature has been found to be most favourable for obtaining a good basal texture. Texture of transformed (secondary) α_2 is generally non basal when the transformation takes place from deformed β. Rolling texture does not seem to change during annealing leading to recrystallization. The $\alpha_2 \rightarrow \beta \rightarrow \alpha_2$ phase transformation cycle does not change the starting basal texture and a starting non basal texture also does not give rise to basal texture due to this treatment.

Keywords. Rolling texture; recrystallization texture; textural stability; Ti–24Al–11Nb

1. Introduction

The need for developing materials with enhanced engine performance through lighter weights and higher operating temperatures spurred research interest on Ti_3Al and its derivatives. However, this material suffers from a severe limitation due to complete absence of room temperature plasticity. Niobium addition has emerged as the most successful means for overcoming this drawback. Addition of Nb to Ti_3Al (α_2) stabilizes the b.c.c. (β) phase of titanium even at room temperature and thereby strength, toughness and ductility all increase. The first Ti_3Al based composition which demonstrated satisfactory room temperature ductility has been reported to be Ti–24Al–11Nb (in at%). Since then a number of studies have been carried out with a view to exploiting the full potential of this material. As the application of Ti–24Al–11Nb or any other Nb modified Ti_3Al base alloy requires the material mostly in sheet form, several attempts have been made to study the deformation processing of this material. Since it is not suitable for room temperature rolling, elevated temperature working with or without a post annealing treatment is usually recommended. Although quite a few papers have been published on the processing of Ti_3Al–Nb alloys and Ti–24Al–11Nb alloy in particular, the issue of textures which is likely to be of extreme importance for such h.c.p. structured materials with regard to mechanical properties, has not at all been paid serious attention (Banerjee 1994). It has also been established that h.c.p. Ti alloys, composed mainly of basal-textured α grains, exhibit significant improvement in ductility which ultimately decides the sheet formability characteristics of the material. An attempt has therefore been made to explore various possibilities for the production of basal texture in thermomechanically processed Ti–24Al–11Nb alloy sheets. In addition, the stability of basal texture, as evolved during processing, has been examined as functions of both annealing effects and $\alpha_2 \rightarrow \beta \rightarrow \alpha_2$ phase transformation cycle.

2. Experimental

The alloy with the nominal composition Ti–24Al–11Nb (at%) was cast in the form of a pan cake. This material was suitably cut into small pieces and these were then subjected to hot rolling at three different temperatures, namely, 1173 K, 1293 K and 1373 K, for rolling reductions ranging from 50% to 80%. All the samples were quenched in water from the rolling temperature. The samples with the highest reduction were also furnace cooled from the respective rolling temperatures. Some pieces of the as-cast material were given a prior heat treatment for the equilibration of phases and then subjected to rolling at 1173 K by different amounts of reduction followed by water quenching.

The above as-rolled materials were subsequently annealed isochronally (for 1 h) within the temperature range 1123 K–1293 K (at ~ 50 K intervals) and also isothermally at 1173 K for time intervals ranging from 1 h–12 h. In an alternative route of heat treatment, the differently processed as-rolled materials were heat treated at three different temperatures, corresponding to different phase fields, and then finally furnace cooled to room temperature.

*Author for correspondence

Texture study of the as-processed samples was undertaken using both the X-ray pole figure as well as the orientation distribution function (ODF) methods. Each ODF was calculated from the data of 6 pole figures, viz., (20$\bar{2}$0), (0002), (20$\bar{2}$1), (20$\bar{2}$2), (22$\bar{4}$0) and (20$\bar{2}$3), using the series expansion method of Bunge (1982) with $l_{max} = 32$.

3. Results and discussion

3.1 *Rolling texture*

The results of the present investigation indicate that the starting material, i.e. the as-cast alloy, possesses a strong basal texture and that this texture does not change significantly due to prolonged annealing at 1173 K. Strong basal texture is also obtained when the starting material is rolled at 1173 K, both in the water quenched and in furnace cooled conditions (figures 1a and b). Among these two, the former gives rise to the sharpest basal texture.

The material, which was prior heat treated at 1173 K for a long time before rolling at 1173 K upto 80% reduction, exhibits an even sharper basal texture as compared to the samples mentioned above. In this case most of the orientations are concentrated along [0001] ‖ ND fibre. The degree of deformation during rolling also has a profound effect on the nature and extent of texturing. For example, the material rolled at 80% reduction at 1173 K shows a sharper basal texture than the one rolled to 50% reduction (figure 2).

Rolling at temperatures above 1173 K but below the β-transus (1373 K ± 10 K) is not favourable for obtaining good basal texture. Figure 1c shows the (0002) pole figure of a 1293 K rolled material to a reduction of 80%. As it can be seen, the intensity of basal (0001)⟨uvtw⟩ orientations are only moderately strong. Furnace cooling of the same material gives rise to a relatively weak basal texture (figure 1d).

Hot rolling at temperatures above the β-transus followed by furnace cooling was carried out in order to have an idea about the transformation texture of secondary α_2 resulting from the hot rolled β phase. The temperature which was chosen for this purpose, namely 1373 K, is just near the $\alpha_2 + \beta/\beta$ phase boundary, where there is only a feeble chance of β recrystallization during furnace

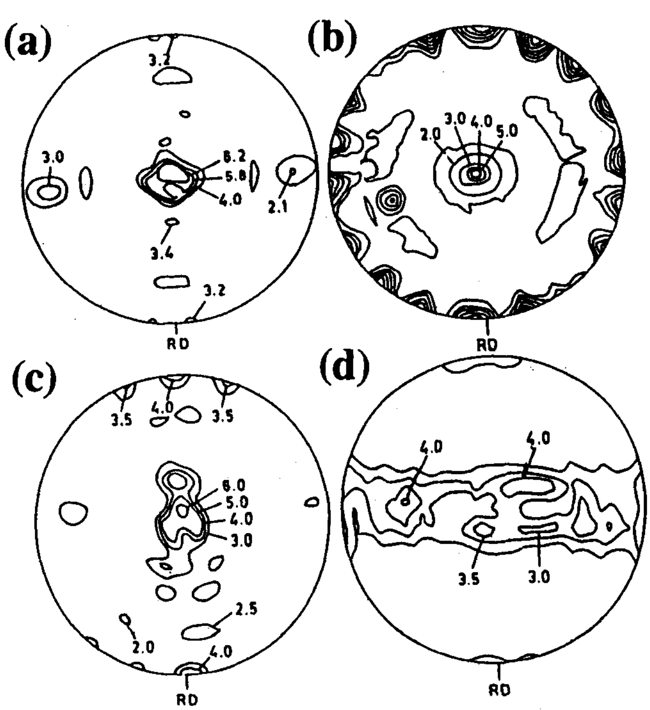

Figure 1. (0002) pole figures for the as-cast materials rolled at (**a**) 1173 K and water quenched, (**b**) 1173 K and furnace cooled, (**c**) 1293 K and water quenched and (**d**) 1293 K and furnace cooled.

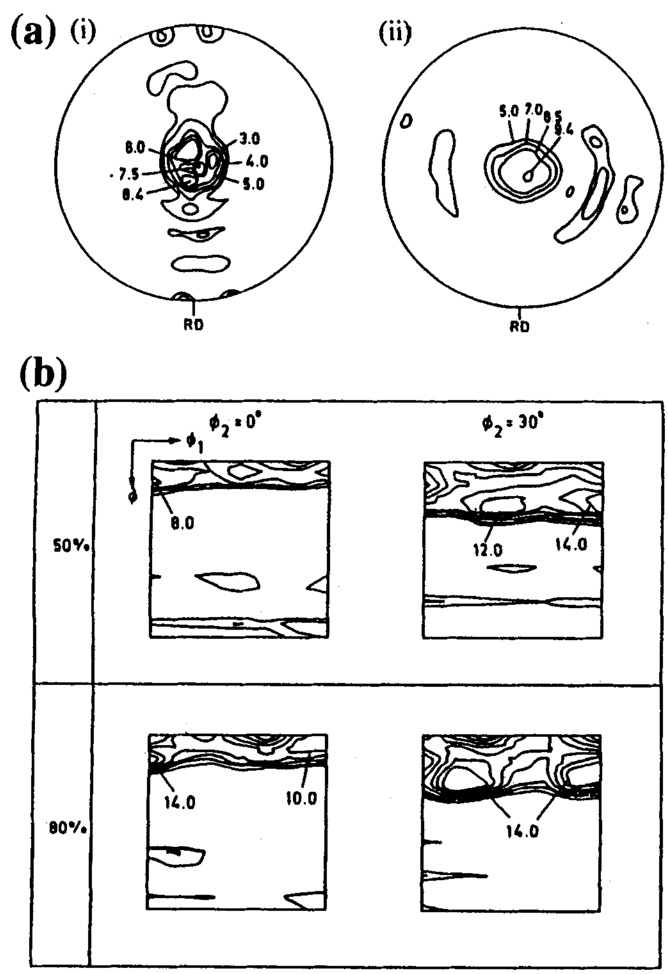

Figure 2. (**a**) (0002) pole figures for the material prior heat treated and rolled at 1173 K to the thickness reductions (i) 50% and (ii) 80% and (**b**) $\phi_2 = 0°$ and 30° sections of the ODFs for the same (50% and 80% rolled) materials.

cooling. The β rolling texture consists of {011}⟨uvw⟩, {112}⟨uvw⟩, {113}⟨uvw⟩ and {223}⟨uvw⟩ as the main components along with several other weaker ones. The resulting transformation textures are expected to be in accordance with the Burger's (1934) orientation relationship. Figures 3a and b represent the textures of the as-rolled and the rolled and furnace cooled materials. As it can be seen, the nature of texture evolved in transformed α_2 is completely non basal. This has been attributed to variant selection during $\beta \rightarrow \alpha_2$ transformation. According to Fredericks (1973), in titanium or its alloys, when the transformation β (b.c.c.) $\rightarrow \alpha$ (h.c.p.) takes place from deformed β, only one of the six variants of transformation is allowed. Therefore, only a few of the β rolling components of texture will be favouring the transformation into α_2 with basal orientation. Correspondingly, the resulting transformation texture is found to be away from basal and weak.

3.2 *Stability of rolling texture on annealing*

The stability of the rolling texture on post rolling heat treatment was studied by subjecting the rolled material to isochronal annealing for 1 h at temperatures 1123 K, 1173 K, 1233 K and 1293 K, followed by water quenching. These temperatures were chosen such that α_2 remained the major phase, thus allowing the effect of heat treatment on the basal texture of α_2 phase to be examined. It was observed that on annealing at the lowest temperature, 1123 K, where recrystallization of the α_2 just begins, the basal texture weakens perceptibly and a number of other non basal orientations develop. However, it more or less regains its strength on annealing at 1173 K and 1233 K. The basal texture again starts degrading at 1293 K. On the basis of the above results, further isothermal annealing was performed at 1173 K over intervals of time ranging between 15 min–12 h. The isothermally annealed samples also have shown initially a tendency for degradation of basal texture and evolution of non basal components for shorter annealing times and re-intensification of the basal texture after longer annealing times (figures 4a to d). However, a relatively prolonged annealing for 12 h was found to be deleterious for the basal texture. The above observations on textural changes on isochronal as well as isothermal annealing are compatible with the common behaviour of annealing textures of h.c.p. metals and alloys where the rolling textures are retained after recrystallization (Dillamore and Roberts 1965).

3.3 *Stability of textures during $\alpha_2 \rightarrow \beta \rightarrow \alpha_2$ transformation*

Finally, an attempt was also made in this investigation to examine the effect of $\alpha_2 \rightarrow \beta \rightarrow \alpha_2$ transformation cycle on the stability of the basal as well as the non-basal

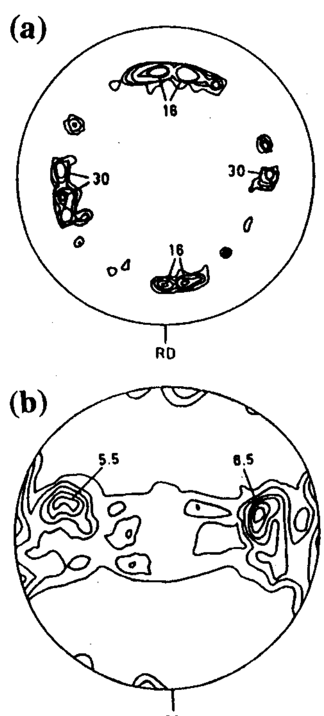

Figure 3. (**a**) (200) pole figure for the 1373 K rolled and water quenched material and (**b**) (0002) pole figure for the 1373 K rolled and furnace cooled material.

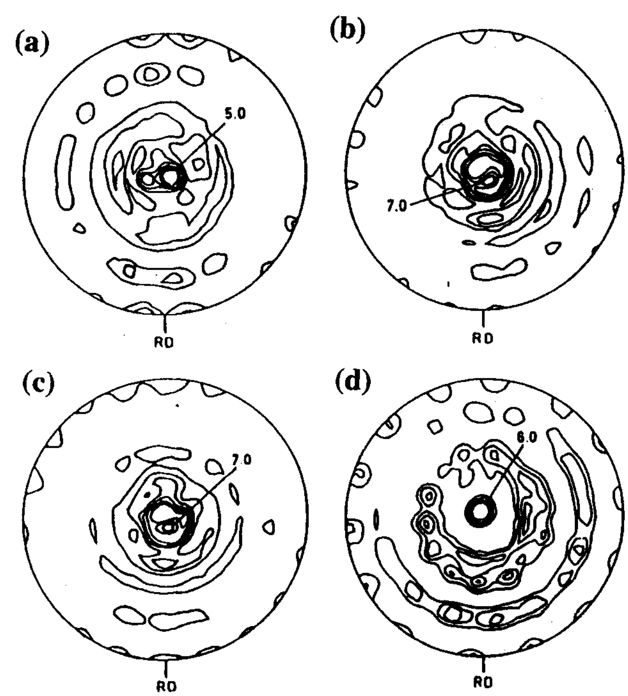

Figure 4. (0002) pole figures for the materials isothermally annealed at 1173 K for (**a**) 15 min, (**b**) 30 min, (**c**) 2 h and (**d**) 12 h.

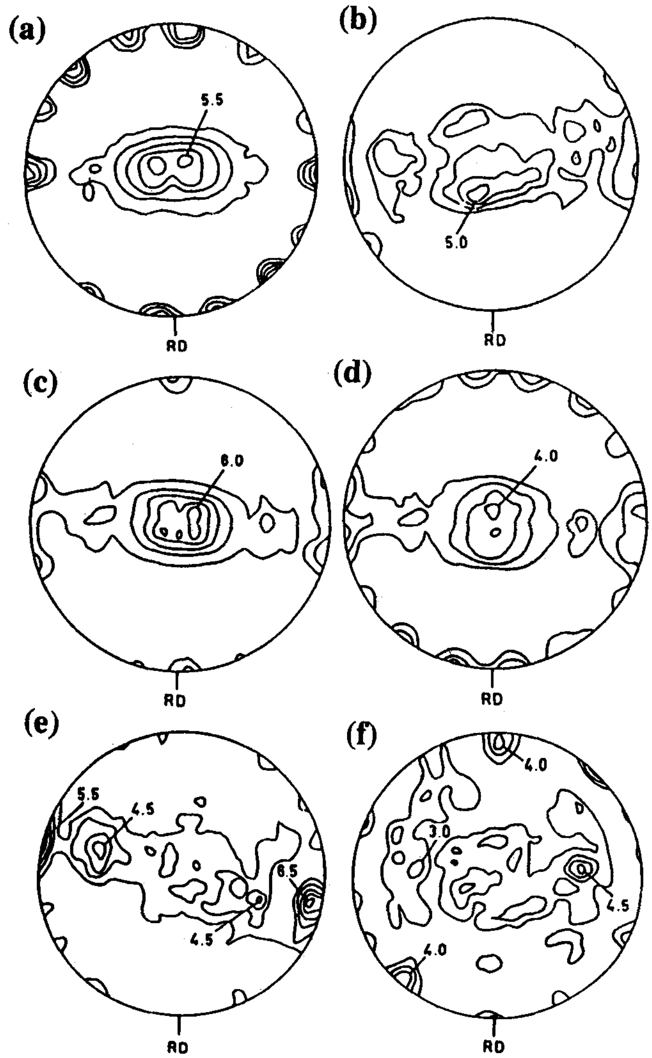

Figure 5. (0002) pole figures for the materials rolled at 1173 K (80%, furnace cooled), subjected to heat treatments at (**a**) 1173 K, (**b**) 1373 K; rolled at 1293 K (80%, furnace cooled), subjected to heat treatments at (**c**) 1173 K, (**d**) 1373 K; and rolled at 1373 K (80%, furnace cooled) subjected to heat treatments at (**e**) 1173 K, (**f**) 1373 K.

components of texture. For this purpose samples showing three different types of textures—basal, weakly basal with non-basal components, and perfectly non-basal texture—were subjected to heat treatments in mostly the α_2 phase field, equiproportional $\alpha_2+\beta$ phase field and the β phase field followed by furnace cooling.

The texture results indicate that the material which already has a reasonably strong basal texture undergoes degradation on heat treatment in the α_2 phase field for a long time (figure 5a). Heat treatment at the higher temperature of 1293 K degrades it further. After heat treatment above the β-transus, the material undergoes a phase transformation to β followed by a second $\beta \rightarrow \alpha_2$ phase transformation during furnace cooling (figure 5b). This treatment has also been found to be detrimental to the preservation of the basal texture.

Similar heat treatments carried out on the material having a weak near basal texture and other non-basal components have shown results different from that of the material with starting basal texture. Heat treatment of this material at 1173 K seems to enhance the intensity of near basal texture (figure 5c). However, heat treating the same material at 1293 K causes a deterioration of the basal texture. Surprisingly, heat treatment at 1373 K caused significant improvement in the basal texture (figure 5d).

Heat treatment of the material with completely non-basal starting texture, followed by furnace cooling does not seem to favour the formation of basal texture irrespective of the heat treatment temperature used (figures 5e and f). These differences have been attributed to the differences in the nature of stress state of the starting α_2 phase from which β forms, to be re-transformed into secondary α_2 during furnace cooling.

4. Conclusions

It is essential to have at least some intensity of the basal texture component in the starting material in order that a strong basal texture can be produced upon processing. Rolling at lower temperatures with high amounts of reduction usually favours the development of basal texture which remains reasonably stable even after complete recrystallization on heat treatment.

Acknowledgements

The authors are grateful to Dr D Banerjee, Director, DMRL, Hyderabad for his constant encouragement as well as for providing the texture measurement facility. We also thank Dr A K Singh for his cooperation and Dr A K Gogia and Mr T K Nandy for several useful discussions. The grant-in-aid from AR & DB, Ministry of Defence, Government of India, is duly acknowledged.

References

Banerjee D 1994 *Intermetallic compounds, principles and practice* (eds) J H Westbrook and R L Fleischer (New York: John Wiley & Sons), Vol. 2, p. 91

Bunge H J 1982 *Texture analysis in materials science* (London: Butterworths)

Burger W G 1934 *Physica* **1** 561

Dillamore I L and Roberts W T 1965 *Metall. Rev.* **10** 271

Fredericks S F 1973 AFML-TR-73-265