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Effect of Cold Rolling on the Annealing Texture of a Near-α Titanium

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Abstract

A near-alpha titanium-based polycrystalline alloy was chosen to investigate the effect of 3 different degrees of cold rolling reduction on the final annealing texture. Coupon specimens with a weak initial texture were sampled from the plate and cold worked at room temperature up to 60%, 80% and 95% nominal reduction in thickness without intermediate annealing. After the cold rolling the samples were annealed at 900°C for up to 30 minutes followed by air-cooling and 785°C for 15 minutes followed by air cooling. The through thickness texture evolution has been investigated by means of Orientation Distribution Function and Pole Figure measurements using X-Ray diffraction method.

Introduction

Titanium and other metals with hexagonal crystal structure develop sharp deformation textures that lead to a pronounced plastic anisotropy of the polycrystalline sample [1,2]. Various factors can cause anisotropy in metals, among them are: grain morphology [3], second phase precipitates [4,5] and substitutional alloying elements [6]. As a consequence, the deformation texture may vary with slight changes of the material composition [2]. Researchers [5,7] agree that crystallographic textures resulting from thermomecanical processing such as hot or cold rolling are most directly responsible for anisotropy in metal alloys. Anisotropy of mechanical properties is a concern in the forming of metals into shapes and parts and the control of texture throughout the process can provide beneficial use of the variety of available textures in near-α titanium and other titanium alloys [8].

Experimental procedure

The near-α titanium alloy investigated was a Ti-1100 (Ti-6%Al-2.7%Sn-4%Zr-0.4%Mo-0.45%Si). Coupons 3"x 4" x 5/8" taken from the as received material (as rolled) were cold rolled with 60, 80 and 95% reduction in thickness. The final thickness of the samples was 0.250", 0.125", 0.018" respectively. The direction of rolling was reversed after each pass. After cold rolling (CR) the samples were submitted to a duplex annealing (DP). In the first stage of the annealing the temperature and time were 900°C and 30 minutes respectively followed by air cooling. The furnace was then heated up to 735°C for the second stage of the heat treatment. The samples at room temperature were placed inside the furnace, left there for 15 minutes and then removed from the furnace to cool down in air. High purity argon was used during the entire heat treatment process.

Texture Measurements

In order to evaluate the texture gradient through thickness the cold rolled samples and the annealed samples were grinded and polished up to 5%, 15%, 30% and 50% of their thickness. To analyze quantitatively the texture of the samples, five incomplete pole figures; {0002}, $\{10\bar{1}1\}$, $\{10\bar{1}2\}$, $\{11\bar{2}0\}$ and $\{10\bar{1}3\}$; were measured using a Philips Expert X-Ray machine equipped with texture goniometer. The measurements were performed with sample oscillation in order to scan a larger area of the samples' surfaces. The computer software popLa developed at Los Alamos, New Mexico, was used to convert the recorded intensities for the 5 pole figures. These pole figures were finally used for the calculation of the crystallite Orientation Distribution Functions.

Results and Discussion

Texture, or crystallographic preferred orientation of grains, is characterized by {hkl} crystallographic planes oriented parallel to the rolling plane and <uvw> crystallographic directions parallel to the rolling direction [9]. For the case of hexagonal materials, such as Titanium, Zinc and Zirconium, 4 indices are used to represent both the crystallographic planes and directions and the texture is therefore described in the form {hkil}<uvtw>. For hcp metals, most of the important texture components which appear in the discussions of the rolling and annealing textures are located on ϕ= 0° and ϕ = 30° sections of the orientation distribution functions (ODF). For that reason, these two constant ϕ sections of the Eulerian space were chosen to represent the texture results. Fig. 1 shows the ϕ= 0° and ϕ = 30° sections of the ODF describing the textures of the as received α titanium samples.

A very weak texture with maximum intensity of 2.8 times random at $\phi = 30°$ characterizes the as received material. Fig.2 shows the $\phi = 0°$ and $\phi = 30°$ sections of the ODF for the cold rolled and annealed samples.

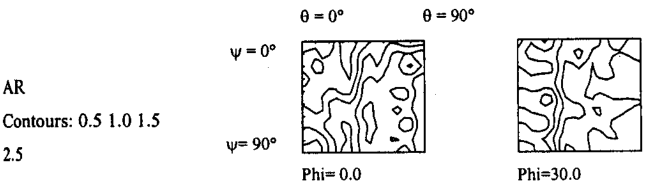

Fig. 1. $\phi = 0°$ and $\phi = 30°$ sections of ODF, Roe notation, for the as received material.

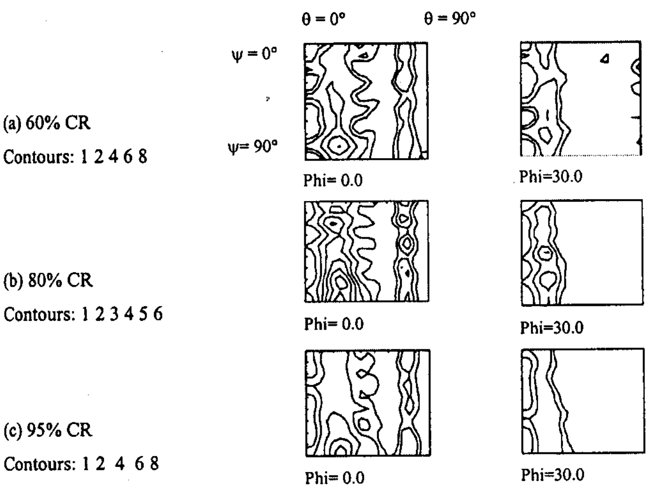

Fig. 2. $\phi = 0°$ and $\phi = 30°$ sections of ODF, Roe notation, for the cold rolled samples: a) 60%, b)80% and c)95%.

The texture results in fig.2 shown that after cold rolling the component of texture $(\bar{1}014)[1\bar{2}10]$, deviated 5° from the recrystallization component, was intensified.

A fiber type texture along $\theta = 75°$ in $\phi = 0°$section was also developed after cold rolling being intensified after annealing in the case of 60% cold reduction, kept constant for the 80% and finally randomized in the case of 95% cold rolled (fig.3).

Fig. 3 shows the orientation distribution function for the annealed samples. From the results it was found that, after the heat treatment, both the recrystalization and the cold rolled components were enhanced leading to a final texture that can be described as a mixture of the recrystallization component, $(\bar{1}013)[1\bar{2}10]$, and the cold rolling component, $(\bar{2}115)[0\bar{1}10]$, with exception for the 60% cold rolled sample in which the texture component $(\bar{1}013)[1\bar{2}10]$ had its intensity decreased from 4.07 times random to 2.9 times random after annealing. It is known that the recrystallization texture component, $(\bar{1}013)[1\bar{2}10]$, develops at the expenses of the cold rolling texture, such as the component $(\bar{2}115)[0\bar{1}10]$ [8]. However, from the figs. 2 and 3 it can be seen that both $(\bar{1}013)[1\bar{2}10]$ and $(\bar{2}115)[0\bar{1}10]$ components were intensified after annealing and showed similar densities in the ODF suggesting that the recrystallization component was formed at the expenses of components other than the cold rolling component $(\bar{2}115)[0\bar{1}10]$.

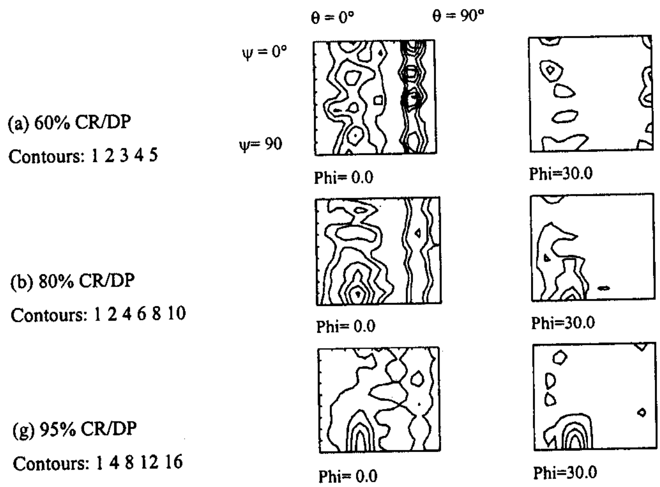

Fig. 3. $\phi = 0°$ and $\phi = 30°$ sections of ODF, Roe notation, for the duplex annealed samples: a) 60% CR, b) 80% CR and c) 90% CR.

The texture gradient was analyzed by means of the maximum intensities of the ODF for each of the four, 5%, 15%, 30% and 50%, positions through thickness direction and the results are being shown in fig.4. The results show that for the 80% CR sample there was a very small gradient varying from 5.5 times random at 5% of the thickness to 6.6 times random at 50% of the thickness. On the other hand, for the samples 60% and 95% CR a higher texture gradient was found. In the case of the 60%CR the maximum intensity occurred at the middle of the sample and its value was twice as much as the value at the near surface (5% of the thickness). The opposite has occurred with the 95%CR sample where the maximum intensity of texture was 15.07 times random at 5% of the thickness and 9.3 times random at the middle thickness. For the case of annealed samples the texture gradient increased with cold reduction and the maximum peaks were found always at the near surface layer. Fig. 5 shows orientation distribution along the $\psi = 90°$ axis on the $\phi = 0°$ section ($[1\bar{2}10]$ // RD fiber texture).

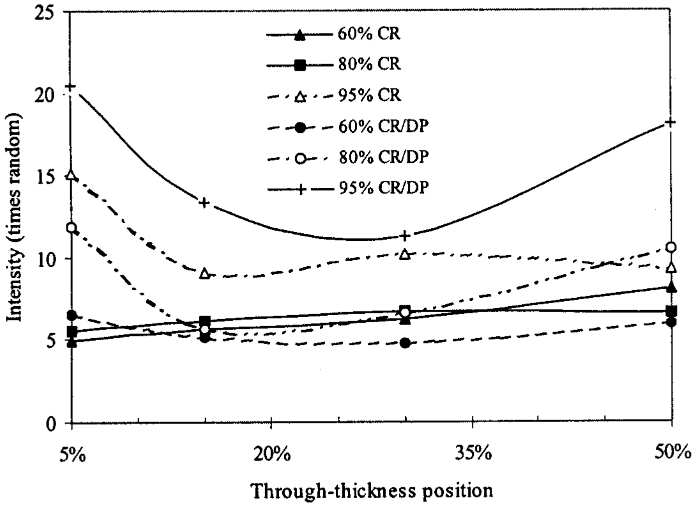

Fig.4.Maximum intensities of the ODF as a function of thickness position.

It can be seen that the orientation spread about $(\bar{1}013)[1\bar{2}10]$ orientation decreased remarkably with increasing rolling reduction. Moreover, it is clear from this result that the orientation density of the $(\bar{1}013)[1\bar{2}10]$ component of texture increased appreciably with increasing rolling reduction. Similar result was found for pure Ti [10]. After duplex annealing this $(\bar{1}013)[1\bar{2}10]$ component was intensified for the 80 and 90% CR samples while it decreased for the 60% CR.

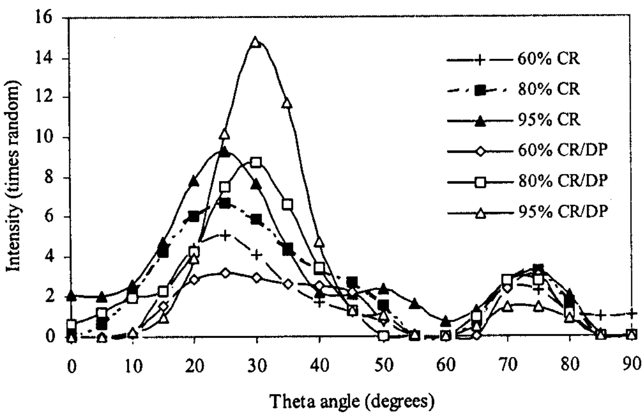

Fig. 5. Orientation distribution along the $\psi = 90°$ axis on the $\phi = 0°$ section observed in the cold rolled and duplex annealed specimens.

Conclusion

The effect of cold rolling reduction on the final annealing texture of α titanium samples have been investigated. Results from orientation distribution function have shown that:

1-After being cold rolled for 3 different degrees of reductions; 60%, 80% and 95%; and duplex annealed, the initially weak texture of the α titanium plate was intensified as the percentage of reduction increased. However the expected high cold rolling texture component was poorly developed.

2-The duplex annealing intensified the $(\bar{1}013)[1\bar{2}10]$ component, in the case of 80% and 95% CR samples, while the 60% CR sample exhibited a drop in the intensity for this component. The cold rolling component of texture increased its density for all the 3 samples leading the final texture to be formed as a combination of both recrystallization and cold rolling texture.

3- Since the cold rolling texture increases the anisotropy of mechanical properties, the processing path investigated here have shown to be non efficient for the purpose of developing products for applications where anisotropy of mechanical properties is not desirable.

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