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Characterization of the deformation texture after tensile test and cold rolling of a Ti-6Al-4V sheet alloy

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Abstract. The deformation texture after cold rolling and tensile test of an industrial Ti-6Al-4V sheet alloy was studied using X-ray diffraction. The alloy was subjected to a cold rolling to different thickness reductions (from 20% to 60%) and then tensile tests have been carried out along three directions relatively to the rolling direction (0°, 45° and 90°). The experimental results were compared to the existing literature and discussed in terms of active plastic deformation mechanisms.

1. Introduction

Titanium alloys containing both aluminium and vanadium (Ti-6Al-4V alloy) are widely used in aerospace applications due to their high strength and good corrosion resistance. It is well known that titanium alloys exhibit different types of texture depending on the deformation conditions (deformation mode, temperature and strain rate) and the alloy composition [1, 2]. Tailoring the properties of the industrial alloys has as prerequisite the knowledge of the simultaneous evolution of their texture and microstructure. In this framework, several works were devoted to titanium alloys in general and Ti-6Al-4V alloy in particular [2–6]. Francillette et al. [5, 6] have presented results of a detailed analysis of anisotropic behaviour of a Ti–6Al–4V sheet during cold rolling in correlation with crystalline texture evolution with a specific initial texture. The present work was undertaken in order to clarify details of the plastic deformation texture evolution for Ti-6Al-4V alloy sample with a slight different initial texture.

2. Experimental

The material used in the present study was a commercial titanium based Ti-6Al-4V alloy provided by Air Algérie. The rolling experiments were conducted at room temperature. The total reductions in thickness were of 20, 40, 50 and 60% with a 20% reduction per pass.
The tensile tests were performed using Zwick Roell test machine. Samples were taken from sheets having three orientations: rolling direction (0°RD), 45°RD and transverse direction (90°RD). The samples were strained to failure. The anisotropy parameter (R-value) was determined by tensile test measurements as the ratio between the transverse to longitudinal strain change. The average Lankford factor $\overline{R}$ and its variation ΔR were calculated using following equations [7] :

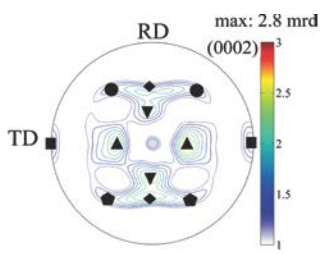
$$\overline{R} = \frac{(R(0) + 2R(45) + R(90))}{4} \tag{1}$$

$$\Delta R = \frac{(R(0) - 2R(45) + R(90))}{2} \tag{2}$$

The texture was determined in the mid-plane of the specimen by measuring incomplete pole figures (0°≤ α ≤ 70°) in back reflection mode using Cu-Kα radiation. A set of three pole figures ($\{10\bar{1}0\}$, (0002) and $\{11\bar{2}0\}$ was used to calculate the orientation distribution function (ODF) using Bunge series-expansion method, with an expansion degree of l_{max} =22, using MTex software [8].

3. Results and discussion

Figure 1 presents the initial texture of Ti-6Al-4V sheet alloy represented by means of a (0002) recalculated pole figure. As mentioned by Francillette et al. [5], the pole figures associated with initial samples after 45° and 90° rotation around ND can be easily deduced. The as-received alloy sheets present a texture somewhat different from conventionally presented ones and consists of a (0002) pole figure of two components the c axes of which are almost in TD and one central component with two peaks at 20° to ND in the ND-RD plane (all these components result from prior hot and cold rolling) [3, 5, 6]. Here, in Fig. 1, besides the two components with c axis in TD (here referre to as A component), five other texture components can be identified:
$\{01\bar{1}3\}<2\bar{1}\bar{1}0>$, $\{01\bar{1}3\}<0\bar{3}32>$, $\{11\bar{2}3\}<\bar{1}\bar{1}22>$, $\{11\bar{2}2\}<1\bar{2}12>$, $\{11\bar{2}2\}<\bar{1}3\bar{2}\bar{3}>$.
The main ideal texture component positions are also presented in Fig. 1 as well as their characteristics. Such a texture may be due to the variation and heterogeneity induced by the combination of plastic deformation, recrystallization and phase transformation during elaboration [3, 6].



Component		{hkil}<uvtw>	Euler Angle		
			φ_1	ϕ	φ_2
●	N	$\{11\bar{2}2\}<1\bar{2}12>$	55/125°	60°	30°
⬟	K	$\{11\bar{2}2\}<\bar{1}3\bar{2}\bar{3}>$	240/300°	60°	30°
◆	M	$\{11\bar{2}3\}<\bar{1}\bar{1}22>$	90/270°	45°	30°
▲	N_1	$\{01\bar{1}3\}<2\bar{1}\bar{1}0>$	0/180/360°	30°	0°
▼	N_2	$\{01\bar{1}3\}<0\bar{3}32>$	90/270°	30°	0°
■	*A*	$\{11\bar{2}0\}<10\bar{1}0>$	0°	90°	0/60°

Figure 1. Recalculated (0002) pole figure of the as-received Ti-6Al-4V sheet alloy (left) and texture characteristics (right).

The textures after cold rolling of Ti-6Al-4V sheets are shown in Fig. 2. After 20% thickness reduction, the A ($\{11\bar{2}0\}<10\bar{1}0>$) component disappeared reflecting the early stage of basal texture formation. The intensity of the $\{11\bar{2}3\}<\bar{1}\bar{1}22>$ component decreased after 40% of thickness reduction. The basal poles were shifted from ND towards TD direction (i.e. T-type texture) during cold rolling. Such a texture is also termed as split rolling direction texture (STD) observed for strains above 40% of thickness reduction while below this strain level, a split rolling direction texture (SRD) is often observed [3– 6].

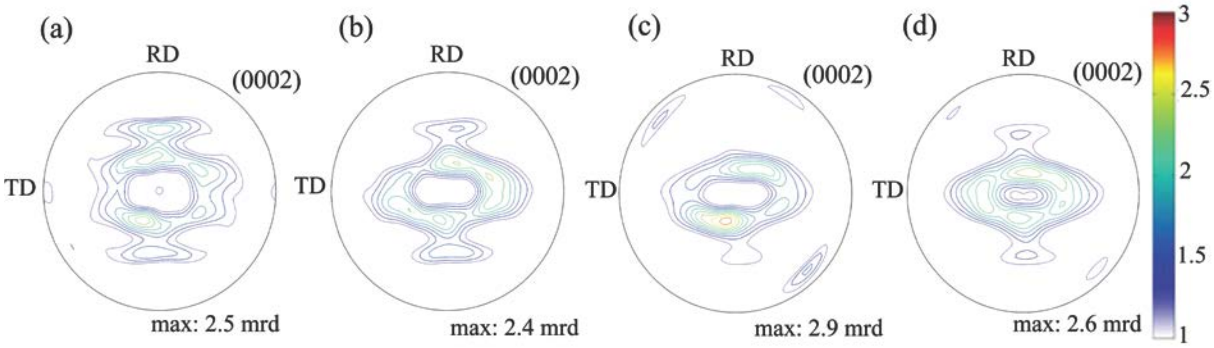


Figure 2. Recalculated (0002) pole figures of Ti-6Al-4V sheets after cold rolling at: a) 20%, b) 40%, c) 50% and d) 60% of thickness reduction.

Rolling up to 50% of thickness reduction caused the development of a T-type texture and the M ($\{11\bar{2}3\}<\bar{1}\bar{1}22>$) component disappeared. The ($\{11\bar{2}3\}<\bar{1}\bar{1}22>$) component was formed also again after rolling to 60% of thickness reduction. The texture simulation made by Philippe et al. [9] predicted that the T-type texture was caused by the activation of $\{1010\}<11\bar{2}0>$ and $\{1011\}<11\bar{2}0>$ glide systems, $\{1012\}<10\bar{1}1>$ tension and $\{1122\}<11\bar{2}3>$ compression twinning.

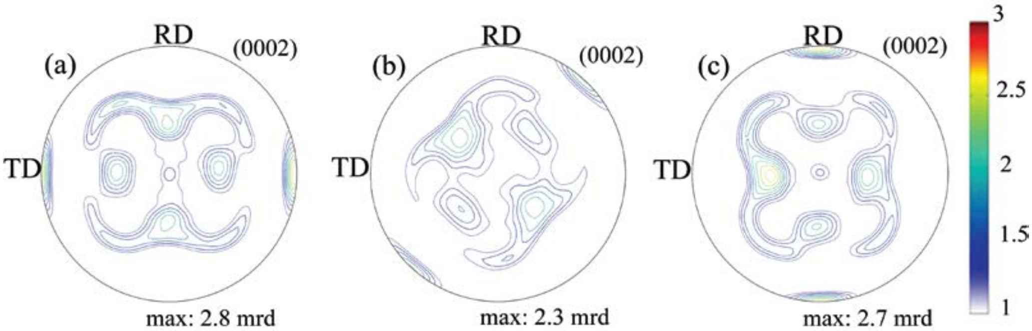


Figure 3. Recalculated {0002} pole figures of the Ti-6Al-4V sheet after cold rolling and after tensile tests for a) 0°RD, b) 45°RD and c) 90°RD.

The textures of tensile tested samples of the Ti-6Al-4V sheet are shown in Fig. 2. Tensile tests in the three different directions do not cause strong changes in the texture characteristics evolution except some intensity sharpening around the $\{11\bar{2}0\}<10\bar{1}0>$, $\{11\bar{1}0\}<2\bar{1}\bar{1}0>$ and $\{01\bar{1}3\}<0\bar{3}32>$ components. Typical stress–strain curves from tensile tests for cold rolled samples are shown in Fig. 4a for 0°RD, 45°RD and 90°RD samples. The deduced mechanical properties are summarized in Fig. 4a. The Young's modulus varied very slightly. The highest yield strength was obtained along 90°RD and the lowest along 45°RD. Our results are in rather good agreement with those of [5, 6]. The elongation-to-failure was slightly higher in 90°RD than in other orientations. 0°RD alloy sample showed the lower value. Additionally, the yield point was much more pronounced in the 90°RD than in any other orientation. The planar anisotropy, or R value, shown in Fig. 4b was lowest along RD (3.14) and increased towards TD (4.75). These values seem to be higher than those presented by Kuwabara et al. [10] (1.8-5.2) or Revil-Baudard et al. [11] (2.3-5.1).

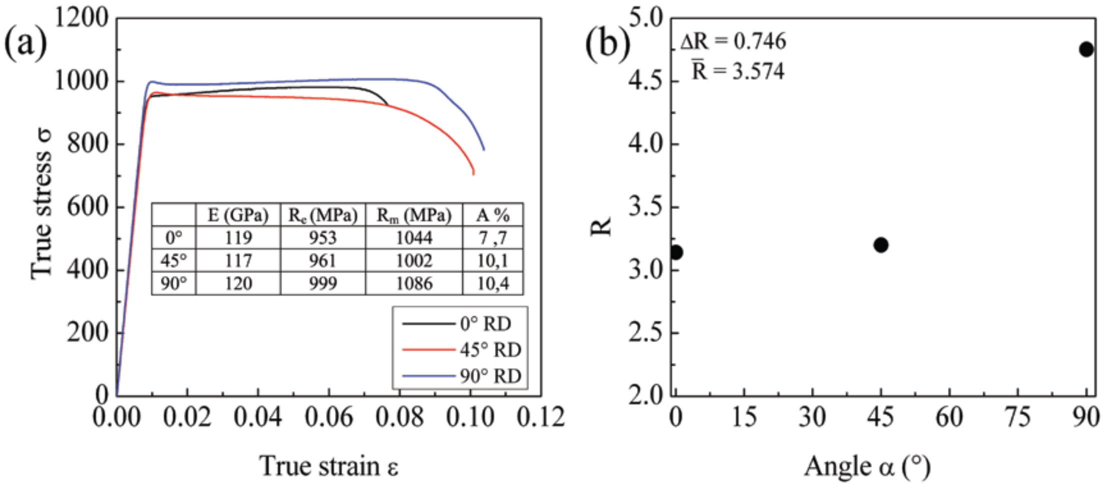


Figure 4. Stress-strain curves of Ti-6Al-4V sheet alloy and b) evolution of R value versus angle to rolling direction.

4. Conclusion

The crystalline texture evolution formed after cold rolling and tensile tests along three different directions (0°, 45° and 90° to the rolling direction) of Ti-6Al-4V sheets was investigated by X-ray diffraction. It was found that cold rolling of the Ti-6Al-4V sheet with a complex initial texture (with six components: $\{11\bar{1}3\}<2\bar{1}\bar{1}0>$, $\{01\bar{1}3\}<0\bar{3}32>$, $\{11\bar{2}3\}<\bar{1}\bar{1}22>$, $\{11\bar{2}2\}<1\bar{2}12>$, $\{11\bar{2}2\}<\bar{1}3\bar{2}\bar{3}>$, $\{11\bar{2}0\}<10\bar{1}0>$) resulted in a split transverse direction (STD) texture. The texture after tensile tests was not considerably modified and was quite similar to the initial texture in the 3 studied directions.

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