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Study on Ta-2.5W alloy sheet texture evolution and *r* value anisotropy under different rolling reduction ratio

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ABSTRACT

Two Ta-2.5W alloy sheets were cold-rolled to 1 mm and 0.5 mm thick and their plastic strain ratio (*r* values) were evaluated by tensile tests. The 0.5 mm sheet, comparing with the 1 mm sheet, showed a stronger variation of the *r* value. This is because that the {0 0 1}⟨1 1 0⟩ texture, as revealed by the EBSD, significantly increased in the 0.5 mm sheet, which led to the decrease of *r* value and the increase of anisotropy (Δr) and in turn the deterioration of deep drawing properties. An analytical model was established to correlate the microstructure evolution and the macroscopic *r* value.

1. Introduction

Ta-W alloys were widely used aerospace and military weapons because of their high melting point, excellent forming ability and mechanical properties [1–3]. In forming of different Ta-W structures, rolling is a key step. During rolling, the sheet texture would evolve and affect the *r* value (plastic strain ratio) and thus the deep drawing properties. Kitamura et al. [4] studied the effect of rolling reduction ratio on the texture of titanium-nickel alloys. It was found that the transformation strain anisotropy was the strongest when the rolling reduction ratio was 0, and that the sheet with 10% and 30% rolling strain had similar transformation strain anisotropy. Liu et al. [5] established a predictive model for the *r* of IF steels based on the evolution of textures. Michaluk et al. [6] studied the mechanism of *r* variation with different uniaxial tensile strain of Ta-2.5W alloy. Recently, only Wang et al. [7] studied the grain size and texture evolution of Ta-2.5W sheet during cold rolling. However, the study to correlate the texture evolution and *r* value in Ta-W alloys is still lacking.

Therefore, this study aims to reveal the relation between texture evolution and *r* value variation of Ta-2.5W sheets under different rolling reduction ratio. A predictive model for *r* value on the basis of texture evolution is established, to explain the difference in deep drawing properties.

2. Material and methods

The Ta-2.5W sheets used in this experiment were processed in the following way: a 5 mm thick sheet was cold rolled multiple passes, with each pass of 30% reduction and annealing in between, until it reached the final thickness (1.0 mm and 0.5 mm). Room temperature tensile specimens were cut at 0°, 45° and 90° with respect to the rolling direction (RD). The *r* for both sheets was calculated from the tensile test data. The EBSD was carried out at the center of cross section of the original sheet, the 1 mm and the 0.5 mm sheet, respectively, to obtain the orientation imaging map (OIM) and the crystal orientation distribution function (ODF).

3. Results and discussion

3.1. Tensile mechanical anisotropy at room temperature

r refers to the ratio of the plastic strain in the width direction to the thickness direction. The anisotropy degree of the *r* value, Δr, is a key indicator of the deep drawing properties, which can be expressed as:

$$\Delta r = \frac{1}{2}|r_0 + r_{90} - 2r_{45}| \quad (1)$$

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r_0, r_{45}, r_{90} represent r value at 0°, 45°, 90° with respect to the RD respectively. According to Eq. (1), the results were shown in Table 1, where $\bar{r}$ denotes the average plastic strain ratio, $\bar{n}$ is the average strain hardening index and δ is the elongation. It could be seen that when the sheet was rolled from 1 mm to 0.5 mm, the $\bar{r}$ decreased from 0.634 to 0.335, indicating the sheet is prone to crack. In addition, n decreased significantly along with a large elongation loss, which means the ability to deform uniformly decreased.

3.2. Ta-2.5W sheet microstructure

The OIM is shown in Fig. 1. It can be seen that rolling has changed the grain morphology drastically. For the 5 mm sheet, the grain size is from 50 µm to 150 µm and randomly distributed. When it was rolled to 1 mm, grain refinement was apparent with a uniform stretch in the rolling direction. When the sheet thickness was further reduced to 0.5 mm, the grains showed a typical fibrous tissue parallel to the RD. The width of grains decreased to 5–10 µm. As shown by the white arrows in Fig. 1(c), some relatively thin shear band appeared, indicating that the sheet had experienced a severe plastic deformation. What is more prominent is that the grain orientation aggregates into the {1 1 1} and {1 0 0} plane textures when rolled to 0.5 mm.

3.3. Ta-2.5W rolling texture

For BCC alloy, the texture most influential to deep drawing properties is mainly located at the section of the orientation space (φ_1, Φ, φ_2) (φ_2 = 45°) [8]. Fig. 2 shows the ODF (φ_2 = 45°) of the 0.5, 1 and 5 mm sheet. The texture of 5 mm sheet is slightly concentrated near $(001)[1\bar{1}0]$ and $(001)[\bar{1}\bar{1}0]$ (indicated by arrows 1 and 2). With further rolling, the 1 mm sheet texture became α-fiber texture (φ_1 = 0°, Φ = 0 ~ 90°, φ_2 = 45°) and γ-fiber texture (φ_1 = 0–90°, Φ = 55°, φ_2 = 45°) dominant (Fig. 2b). The majority of texture was $(113)[1\bar{1}0]$ (indicated by arrow 3), and some $(111)[\bar{1}\bar{2}3]$ and $(001)[\bar{1}\bar{1}0]$ textures were present as well (indicated by arrows 4 and 5). As the thickness reduced to 0.5 mm, the texture shifted to the γ orientation line (Fig. 2c). The main texture on the α orientation line was $(001)[1\bar{1}0]$ (as indicated by arrow 6), $(001)[\bar{1}\bar{1}0]$ and $(111)[1\bar{3}2]$ texture also occupies a large proportion (indicated by the arrows 7 and 8, respectively).

As shown in Fig. 2(d) and (e), the α-fiber texture increased only slightly, but the γ-fiber texture increased significantly. The $(113)[1\bar{1}0]$ texture on α orientation line evolved into the $(001)[1\bar{1}0]$ texture, and the $(111)[\bar{1}\bar{2}3]$ texture on the γ orientation line gradually transformed into $(001)[1\bar{3}2]$ texture. For BCC alloy, the presence of γ-fiber texture would improve $\bar{r}$ and effectively suppress the rise of Δr as well, which is conducive to deep drawing [9]. However, the formation of $(001)[1\bar{1}0]$ texture, which is detrimental to deep drawing [10,11], counteracted the favorable effect of the γ-fiber texture, which led to the inferior deep drawing performance of the 0.5 mm sheet.

It is worth noting that the work by Michaluk [6] is similar to ours in materials system and methodology. However, all textures ({0 0 1}⟨1 1 0⟩ texture and γ fiber texture) formed during rolling that can affect deep drawing are evaluated in our study, both positive and negative. This is different from the Michaluk's work which only studied the effect of the {0 0 1}⟨1 1 0⟩ texture.

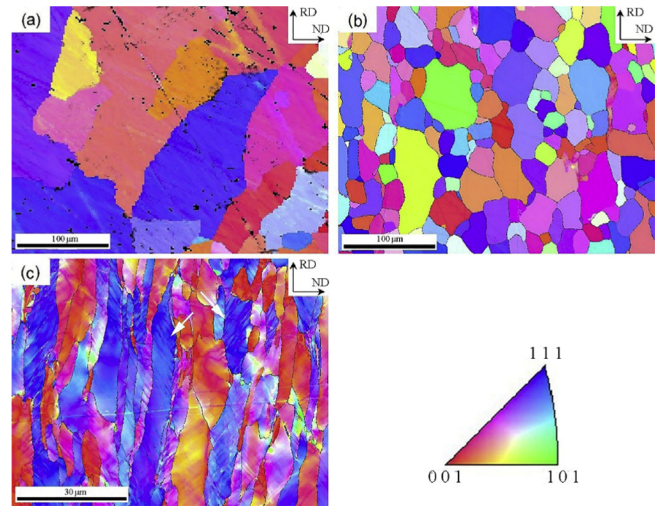

Fig. 1. OIM of section (middle thickness region) of Ta-2.5W sheets with different thickness (a) 5 mm; (b) 1 mm; (c) 0.5 mm.

3.4. r value theory calculation model based on rolling texture

Dong et al. [12] studied the theoretical prediction of the r value based on the sheet texture under the hypothesis that the multi-slip system was simultaneously activated. According to the Schmid law, the r value of a single crystal in the multi-sliding system can be expressed as:

$$r = \frac{\varepsilon_w}{\varepsilon_t} = \frac{\sum[|(b \cdot p)(b \cdot d)|S]}{\sum[|(t \cdot p)(t \cdot d)|S]} \tag{2}$$

where ε_w and ε_t are the total strains of the single crystal along the sheet width and sheet thickness, respectively, and S is the Schmid factor of each slip system, which can be written as:

$$S = (\mathrm{l} \cdot \mathrm{p})(\mathrm{l} \cdot \mathrm{d}) \tag{3}$$

where b, l, t, d and p are the unit vectors of the width direction, tensile direction, thickness direction, slip direction and the normal direction to the slip plane, respectively. Since the Ta-2.5W alloy is BCC structure, {1 1 0}⟨1 1 1⟩, {1 1 2}⟨1 1 1⟩ and {1 2 3}⟨1 1 1⟩ are considered as slip systems. The r value, can be statistically expressed as:

$$r = \frac{\int_V \varepsilon_w(g) f(g) dg}{\int_V \varepsilon_t(g) f(g) dg} \tag{4}$$

g and $f(g)$ are orientation and orientation distribution function, respectively. Fig. 3 shows the result. It can be seen that the theoretical r values calculated from the Eq. (4) is in good agreement with the experimental. It is worth noting the discrepancy in Fig. 3b is a bit large. This may be caused by the measurement error. As the thickness decreased, the strain measurement became inaccurate along the thickness direction. As r is the ratio between the strain in the width direction and the one in the thickness direction, it

Table 1
Ta-2.5W sheet tensile test parameters.

Sheet thickness	r_0	r_{45}	r_{90}	$\bar{r}$	Δr	$\bar{n}$	δ/%
1 mm	0.534	0.635	0.734	0.634	0.0013	0.1515	51.5
0.5 mm	0.126	0.734	0.145	0.335	0.599	0.0645	24.6