Size Effect of Ultra Pure Ti Thin Strip under Asymmetrical Rolling

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Abstract. In order to study the size effect on properties of ultra pure Ti tensile tests were performed with ultra pure Ti foil (thickness range from 30μm to 280μm) by asymmetrical rolling. A pronounced size effect was observed at thickness of 34μm. The results were shown that the ultimate strength were increased as sample thickness down from 280μm to 34μm, however, were decreased as the thickness from 34μm to 30μm with ultrahigh strain. These features seemed to be link to the increasing of fraction of surface grain to volume, which led to the less districting on dislocation slip.

1. Introduction

In recent years, many researchers interested in the mechanical properties of materials in micro scale, as significantly increasing demand of miniaturization production and multi-functional integration. To fabricate micro scaled parts efficiently and accurately, the mechanical behavior in micro scaled deformation is one of the most significant issues to be explored and in-depth understanding of those behaviors is of great necessity to be established [1].

When the components are in the micrometer or below, the plastics deformation behaviors and the properties are no longer the same as those of bulk materials, which known as the “size effect”. Many studies have focused on the effect of different size parameters, such as specimen size, grain size and surface topography, on the mechanical properties including ultimate strength and yield strength [2-4]. It has been found that, when the ratio of the thickness to grain size is below 5, the yield strength of Ti increases with the decrease in thickness due to the large volume fraction of oxides layer on the surface [5].

Although the size dependent mechanical behavior has been reported in many materials, the size effect on the deformation of ultra pure Ti foils, which in asymmetrical rolling process, have been paid little attention. Therefore, the present work studies the size effects on the deformation behaviors of ultra pure Ti with thickness ranging from 30 μm to 280 μm via tensile testing at room temperature.
2. Materials and methods
The study was carried out on ultra pure Titanium in the form of plate with dimensions of 11.2×40×60 mm (thickness×width×length), which cut from round cakes with diameter of 385 mm, that was shown in Fig.1. The chemical composition (wt%) of ultra pure Titanium utilized is 99.999% Ti.

![Figure 1. The industrial pure copper specimens (a) before and (b) after rolling](image1)

The material in the initial state was subjected to a main cold rolling to a final thickness 30μm obtained in the two stages without intermediate annealing at room temperature. At first, it was rolled to 1500μm on a laboratory two high mill with the work roll diameter of 180 mm, then, rolled to final thickness 30μm by Micro Metal forming Mill (3M mill).

The 3M mill was a new kind of rolling mill with ultra-thin rolling capacity developed by our research group. It was shown in Fig.2. The mainly parameters and characters were as follows: backup roll diameter 120 mm, work roll diameter 50 mm, roll barrel length 130 mm, maximum roll force 200kN. The speed ratio between up and down rolls can be changed from 1 to 1.3 continuously.

![Figure 2. Illustration of (a) 3M-Iasymmetric mill and (b) the control system.](image2)

3. Results and discussions
True stress-strain curves of samples with thickness from 30μm to 280μm were depicted in Fig.3. When the ultra pure Ti sample was deformed by micro rolling, dislocations were generated, move and stored; the storage cause the materials to work harden.

The stress strain curves almost covered each other. However, a pronounced size effect was found when thinner than 34μm: the ultimate strength decreased as thickness decrease from 34μm to 30μm with further deformation, that is, the thinner foils had lower ultimate tensile strength. As the same time, the elongation decreased in the asymmetrical rolling process.
Figure 3. (a) Tensile true stress-strain curves; and (b) ultimate strength vs. thickness for ultra pure Ti of thickness from 30μm to 280μm.

The elastic deformation was affected by the size effect, that is, a surface grain ratio change in deformed metal was found when thickness of ultra pure Ti samples down from 280μm to 30μm by asymmetrical rolling. Due to the micro rolling, the geometry scale of ultra pure Ti was spanned from macro to micro, in which it was rolled from 280μm to 30μm without intermediate annealing at room temperature. The notable character of micro rolling was the negative roll gap, that is, the elastic contact deformation between work roll, which outside the loaded roll gap, was remained. Fig.4 was shown the difference of normal gap rolling and negative gap rolling. The different rolling process, the friction was increased as the thickness varying from macro to micro, which in agreement with literature [6], that could lead to the effective grain refinement.

Figure 4. Difference of (a) normal gap rolling and (b) negative gap rolling.

As asymmetrical rolling process, the surface grains significantly increased with thickness decreasing. The constraints along the grain boundaries of ultra pure Ti on the surface grains are relaxed. As result, the size effect was found. A remarkable work softening from 34μm to 30μm was displayed clearly in Fig.5, which are rarely observed in other heavily cold worked materials [1].
4. Conclusion
The size effect on mechanical properties in ultra pure Ti foil during compound deformation, was systematically investigated in the present work. The following conclusions can be drawn. The uniaxial tensile tests were carried out with different thickness of 280μm, 140μm, 100μm, 65μm, 34μm and 30μm. The ultimate strength of ultra pure Ti foil at first increased from 280μm to 34μm, however, decreased from 34μm to 30μm. Decreasing thickness increased the surface ratio, which an important factor in constitutive model considered size dependent. High surface ration means more surface grain in sample, which less strict in dislocation slip, led to ultimate strength decrease.

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