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Effects of thickness and texture on mechanical properties anisotropy of commercially pure titanium thin sheets

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ABSTRACT

Simultaneous effects of thickness and texture on the anisotropy of mechanical properties and fracture behaviors of commercially pure titanium thin sheets were studied. The activation of different deformation systems, due to the split distribution of basal texture, led to mechanical properties anisotropy. The crack initiation and propagation energies, when the loading direction was parallel to the initial rolling direction, decreased with increasing thickness ranges from 0.25 to 1 mm. The changes of size, shape and distribution of dimples with increasing thickness confirmed the restriction of deformation systems and the development of triaxial stress state and plane-strain condition at the notch tip. However, in transverse-directed specimens, the energy release rate increased with increasing specimen thickness up to 0.75 mm and then decreased. The fractography of these specimens explained the simultaneous effects of thickness and texture on structural stability and high accommodated plastic deformation at the notch tip.

1. Introduction

More than 1000 tons of titanium devices of every description and function are implanted in patients worldwide every year. In this field, thin sheet devices as internal and external bone fixators are one of the major applications of titanium and its alloys. Because of different fracture behaviors of thin sheet materials from bulk ones [1] and also inherent anisotropy and the limited quantity of slip systems in hexagonal close-packed (HCP) materials [2], an in-depth understanding on the effects of metallurgical and geometrical parameters on the mechanical properties anisotropy plays a crucial role in the design of surgical and orthopedic implants.

Laboratory experiments indicate that energy release rate varies with the thickness of specimens and three distinct regions, corresponding to “very thin” (region I), “very thick” (region III) and “intermediate range thickness” (region II) specimens can be distinguished. In thin specimens, due to the absence of geometrical constraints in the thickness direction, the materials can easily plastically deform, i.e., the pure plane-stress condition and the energy release rate increases almost linearly with specimen thickness up to a maximum value at a critical thickness. For very thick specimens, the state of stress is predominantly plane-strain, except for a thin layer at the free surfaces where plane-stress dominates, and the development of triaxial stress state at the notch tip constrains the activation of deformation systems and the accommodation of plastic deformation. Consequently, the fracture process takes place at the lowest value of the critical energy release rate [3]. For intermediate values of specimen thickness, the fracture behavior is neither predominantly plane-stress nor predominantly plane-strain and the increase in specimen thickness increases the plane-strain dominant region and decreases the energy release rate. Although many investigations have focused on fracture behavior of thick sheets, few authors have studied the fracture behavior of thin and intermediate ones. Asserin-Lebert et al. [4] reported that the energy release rate of 6056 aluminum alloy increases with increasing specimen thickness up to 3.2 mm and then decreases at high thicknesses. Shaji et al. [5] showed that fracture toughness of MP35N alloy increases with thickness changes from 0.5 to 16 mm. Kang et al. [6] showed that the fracture toughness of copper foils with thicknesses ranging from 0.02 to 1 mm has higher value at a thickness of 0.3 mm. Although, they showed that the fracture toughness of copper foils depends on loading direction, because of the face center cubic structure of copper crystals, the critical thicknesses and the extension of regions in the toughness–thickness curve revealed no texture dependency. Besides of geometrical constraints, different metallurgical factors such as microstructure and crystallographic texture can strongly affect the activation of deformation systems and the anisotropy of mechanical properties. In our previous works [7,8] the role of rolling and phase transformation microstructures and textures on mechanical properties anisotropy and fracture behaviors of commercially pure (CP) titanium were investigated.

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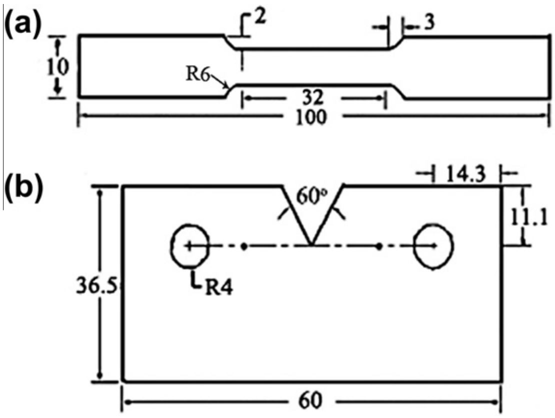

Fig. 1. The geometry of the test specimens (scale in mm): (a) smooth tensile and (b) Kahn specimen. The thicknesses of specimens were 0.25, 0.5, 0.75 and 1 mm.

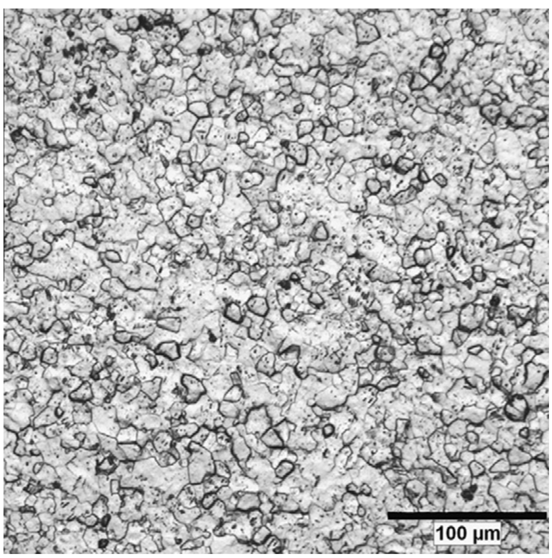

Fig. 2. The microstructure of studied CP-titanium.

Table 1
Tensile tests results of examined materials.

Specimen direction	RD				TD			
Thickness (mm)	0.25	0.5	0.75	1	0.25	0.5	0.75	1
Yield strength (MPa)	375	371	370	381	474	479	476	465
Tensile strength (MPa)	465	454	478	471	530	537	527	516
Elongation (%)	8.8	16	22.25	27	15.81	18.46	25.18	31.5

Although many studies have been focused on the separate effects of thickness and texture [9–11] on energy release rate of different materials, the simultaneous effects of these factors on mechanical properties, especially in thin sheet metals with HCP structure, have been not studied yet. In present research, the simultaneous effects of thickness and notch as geometrical constraints and crystallographic texture as a metallurgical constraint on tensile and tear fracture behaviors of CP-titanium were investigated.

2. Experimental procedure

The material used in present study was CP-titanium grade 2, in the form of a hot-rolled and annealed 1 mm-thick plate. The chemical composition of the alloy is (in wt.%): 99.375 Ti, 0.015 H, 0.030

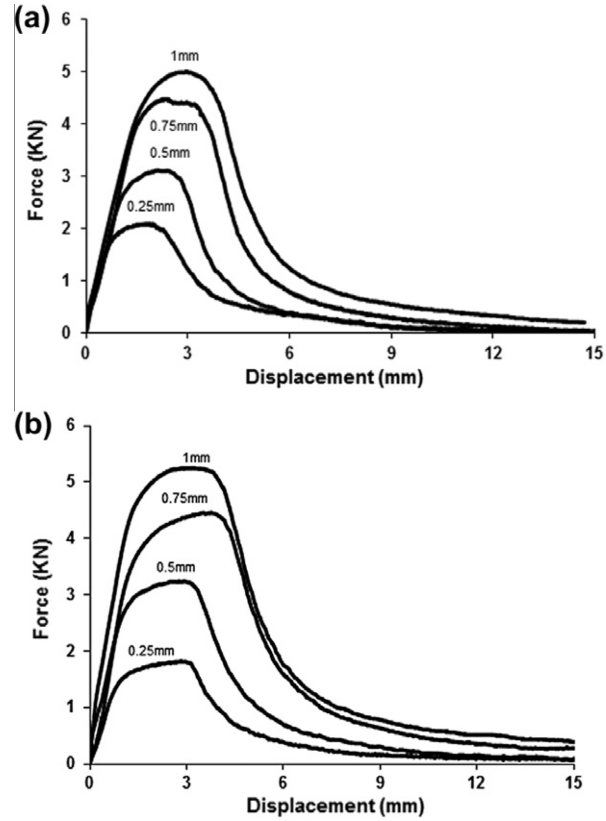

Fig. 3. The load–displacement curves of tear tests: (a) RD and (b) TD specimens.

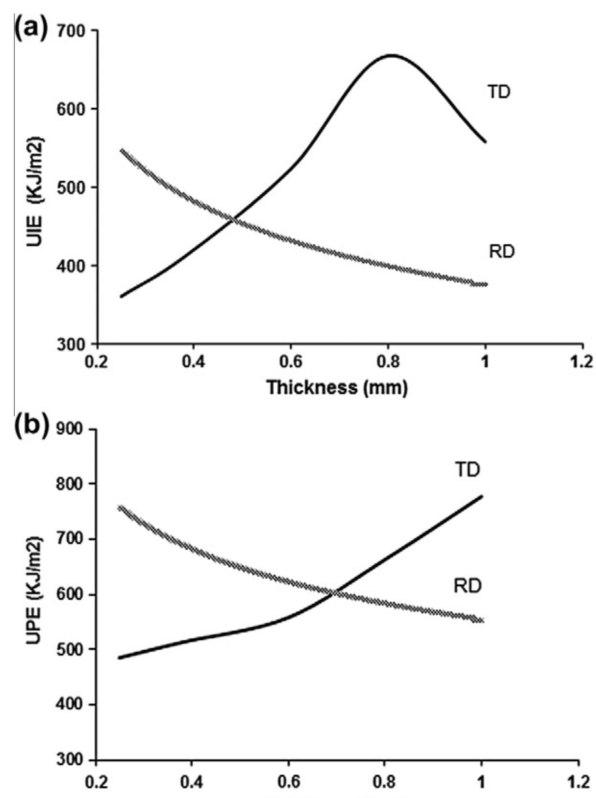

Fig. 4. The effect of thickness on: (a) UIE and (b) UPE values of RD and TD specimens.