Shear band evolution and nanostructure formation in cold-rolled titanium

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Introduction Highly localized deformation in the form of shear band is an unstable deformation mode that develops in majority of metallic materials subjected to high strain-rate deformationThe potential mechanisms controlling the fine microstructures in shear band may include dynamic and/or static recovery, dynamic and/or static recrystallization, and phase transformation.

A large number of results obtained from cold working deformation in titanium indicated that twinning occurs at small strain level, and then slip dominates the deformation at high strain levels. Thus, it is expected that twining plays an important role in plastic deformation, microstructure formation and grain refinement of titanium in shear bands under cold rolling condition. The study of the grain refining process in shear band by rolling deformation may help us to understand the grain refinement mechanism occurred in severe plastic deformation (SPD).

This paper aims to study the detailed evolution and the microstructures of shear band in a commercial titanium subjected to cold rolling, particularly via the investigation of the microstructure variations inside shear bands by TEM to reveal the grain refining mechanism within shear bands.

Materials and experimental methods

- Material: commercially pure titanium (Grade 2), 100mm x100mmx 12mm
- Deformation mode: cold rolling at strain rate about $3S^{-1}$
- Microstructure observation: OP, SEM, TEM

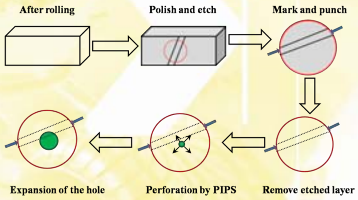

Fig. 1. Schamatic illustration of the preparing process for TEM samples

Results and discussions

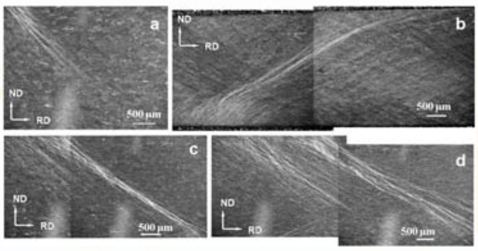

Fig. 2. SEM micrographs showing the evolution of the localized deformation at different rolling deformations: (a) 33.3 %, (b) 50.0 %, (c) 66.7 % and (d) 83.3 %.

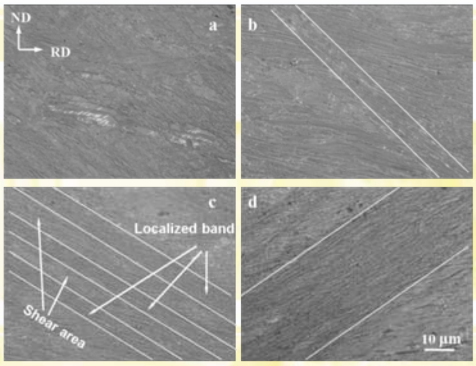

Fig. 3. SEM micrographs at high magnifications showing the shear bands developed at different rolling deformations: (a) 33.3 %, (b) 50.0 %, (c) 66.7 % and (d) 83.3 %.

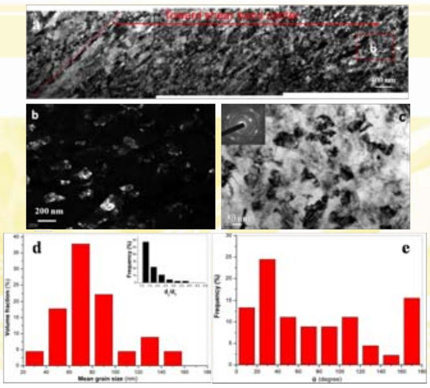

Fig. 4. TEM micrographs of microstructure inside shear band after 83.3% cold-rolling:

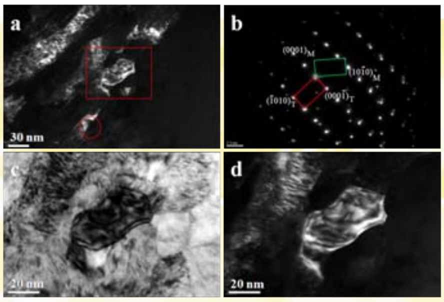

Fig. 5. (a) BF showing the parallel or segmented lamellar band with several tenths nanometer in width; (b) Corresponding SADP; (c) BF showing the linkage between a nanograin and a twin lamella; (d) DF of (c).

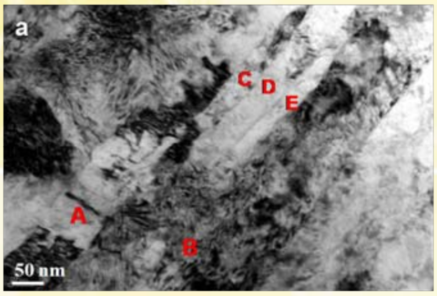

Fig. 6. A dislocation wall lamella split up to form long laths;

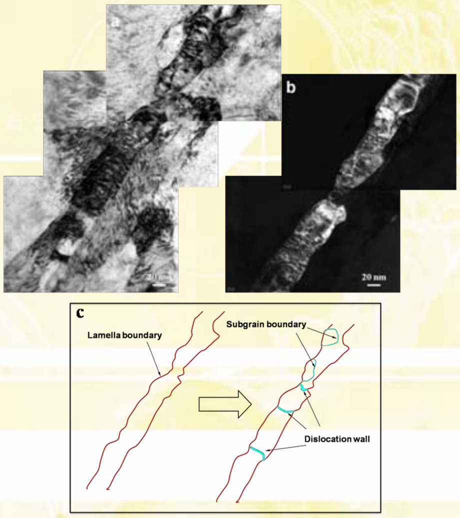

Fig. 7. (a) BF of a long laths breaking-down into subgrains; (b) Corresponding DF of the long laths breaking-down into subgrains; (c) A schematic illustration of the process of the breaking-down

Rolling deformation (%)	Corresponding strain	Temperature increase (K)
16.7	0.21	34.1
33.3	0.47	75.6
50.0	0.80	129.3
66.7	1.27	205.1
83.3	2.07	334.4

Table 1. The calculated temperature increases within shear bands developed at different rolling deformation.

Summary A heavy deformed region was firstly initiated from the edge of the cold-rolled titanium plate at early rolling deformation stage, and then localized bands were developed in the heavy deformed region. With the increase of the rolling deformation, these localized bands extended and connected by consuming the shear areas between them. A shear band with about 25 µm in width was formed when the shear areas between the localized bands were consumed out. The TEM observation revealed the presence of fine grains in the heavy deformed area. It was believed that these fine grains firstly fragmented from the twin lamella as small twin segments, then rotated and developed into fine nanograins with high angle boundaries through dynamic/static recovery. The fine grains were most likely to generate the localized bands, comprised the trigger of localized band. The heavy deformed area, in which the Fine grains were fragmented from the twin lamella as small twin segments, can be considered as the precursor in the subsequently formation of localized band. This study indicates that the grain refinement inside shear band was completely via a shear deformation-induced splitting and breaking-down process instead of a thermally controlled phase transformation or nucleation and growth of new grains.