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Microstructure and texture evolution in titanium subjected to friction roll surface processing and subsequent annealing

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Abstract: Commercial purity and high purity titanium sheets were initially strained by a new technique, named as friction roll surface processing (FRSP). Severe strain was imposed into the surface layer and strain gradient was formed through the thickness of the sheet. The microstructure and texture in as-strained state were investigated by optical microscopy and X-ray diffraction technique. On the surface of the sheets, ultra-fine grains were found to have a sharp texture with a preferred orientation strongly related to the FRSP direction. The evolution of microstructure and crystallographic texture of FRSPed samples during recrystallization were also studied by electron back-scattered diffraction (EBSD) technique after being annealed at selected temperatures and time. The results indicated that the preferred orientations resulting from FRSP and annealing in the surface layer were formed during rolling and its recrystallization textures were reduced by FRSP. In addition, the texture evolved stably without change in main components during the annealing.

Key words: titanium; friction roll surface processing; severe plastic deformation; preferred orientation; recrystallization; texture evolution; ultra-fine grains

1 Introduction

Properties of metals and alloys depend on both their microstructure and texture developed during producing process. In order to optimize the final properties, it is necessary to understand the whole metallurgical phenomena which occur during the producing process. Many earlier studies presented the development of microstructure and texture for FCC and BCC metals and alloys during deformation and subsequent recrystallization [1−5]. In contrast, far fewer works on hexagonal metals and alloys have been reported.

Titanium and titanium-based alloys have been widely used in various engineering and medical fields. Especially, pure titanium gives an outstanding advantage in biomedical applications owing to its corrosion resistance, high inertness and biocompatibility. There have been some efforts to elucidate the mechanism and enhance its mechanical properties through a variety of techniques. Microstructure and texture evolution in titanium after cold-rolling and subsequent annealing have been investigated to know the deformation mechanism [6−8]. The characteristics of titanium at the different recrystallization stages were also studied [9,10]. On the other hand, severe plastic deformation (SPD) is used to improve strength of pure titanium by producing the ultrafine-grained microstructure. SPD is a recent approach to fabrication of bulk nanostructured metals and alloys. By using SPD, the resulted nanocrystalline materials exhibited some unique structural characteristics and novel properties which were fundamentally different from those of the conventional ones with general grain structure [11]. Several attempts have been successfully applied to titanium [12−14]. High ultimate tensile strength and ductility were obtained in titanium billets which were processed using equal channel angular extrusion followed by conventional cold rolling [14]. These studies on recrystallization during and after SPD have been performed to understand the formation of

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ultrafine grained microstructure in titanium. Besides forming the ultrafine grained microstructure, another possibility of SPD is to make a preferred orientation [15−18]. It has been reported that basal α slip was dominant in CP-Ti when deformation proceeds during ECAP via route A (in which there is no rotation of the sample between passes) at 350 °C [19]. However, DHEDA et al [20] found that ECAP resulted in more random textures within commercially pure titanium after the sample was subjected to one pass of ECAP at room temperature. Effect of SPD on texture evolution of material after deformation and annealing is still under the investigation. Furthermore, some properties such as corrosion resistance, fatigue and formability strongly depend on the microstructure in the surface layer. Therefore, more attention should be paid to the importance of the microstructure control on the surface layer sufficiently.

We recently proposed a new severe straining technique, named friction roll surface processing (FRSP), to control the microstructure and texture on the surface layer in commercial purity titanium [21,22]. As a result, the formation of a unique preferred orientation that is strongly related to the FRSP direction was found. In the present study, FRSP and annealing were applied to surface modification in commercial purity and high purity titanium sheets. The work focuses on the development of FRSP recrystallization texture and its relationship to the original texture during annealing. The differences in microstructure and texture formed between the commercial purity and high purity titanium sheets are also discussed.

2 Experimental

FRSP [21] is a straining technique which enables to make ultrafine grains with a strong preferred orientation in surface layer. The schematic illustration of FRSP is displayed in Fig. 1. Fixed rolls with dimensions of d70 mm×10 mm and d70 mm×5 mm, which were made of tool steel SK3, rotated at 48 r/min. The indentation of roll plunged into samples was selected as 0.2 mm. The feeding speed of sample was set at 14 mm/min. The directions of roll rotation and sample feeding were defined as shown in Fig. 1. FRSP was carried out as follows: First, the interface where the roll and the sample just touched was located, and was regarded as the reference plane at which the indentation was zero. Then, the roll was placed in the given indentation without contacting with the sample. After rotating the roll, the sample was moved forward until the entire surface was treated. This procedure resulted in making the working plane lower than the reference plane and led to a great amount of friction.

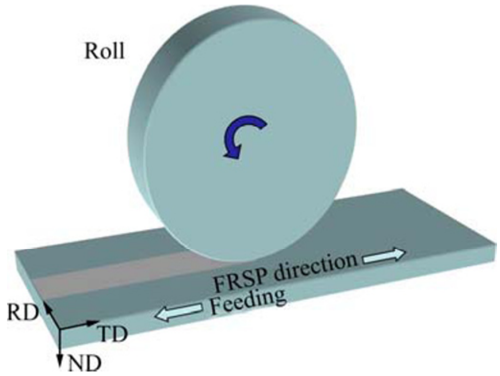

Fig. 1 Schematic illustration of friction roll surface processing (FRSP) (Rotating roll is fed in feeding direction, which is parallel to TD, the width direction of rolled sheet sample in the present study)

Commercial purity titanium (CP-Ti) sheet (grade 1) with an average grain size of 30 μm was used in the present study. In order to investigate the effect of purity, high purity titanium (HP-Ti) with an average grain size of 100 μm was processed by FRSP also. The chemical compositions of the two kinds of titanium sheets are listed in Table 1. The as-received CP-Ti sheet was initially cold rolled to a thickness of 1 mm and subsequently annealed at 800 °C for 1 h. HP-Ti sheet was initially cold rolled to a thickness of 1 mm and subsequently annealed at 700°C for 0.5 h. Samples with dimensions of 60 mm×20 mm×1 mm were machined from the titanium sheets. In our previous study [20], three types of samples, marked as RD, TD and RD+45° treated samples were studied. FRSP was conducted with the FRSP direction parallel to the rolling direction (RD), transverse direction (TD) and the direction rotated by 45° from RD to TD, respectively. In the present study, FRSP was conducted with the processing direction parallel to the transverse direction (TD) of sample, namely, TD sample was chosen to be studied in more detail. This is because in TD sample the textures formed by FRSP and annealing can be identified easily from the textures

Table 1 Chemical compositions of titanium samples used

Sample		w/%							
		O	N	H	C	Fe	Ni	Al	Ti
CP-Ti	Top	0.041	0.002	0.0024	0.009	0.031	−	−	Bal.
	Bottom	0.043	0.002	0.0022	0.007	0.018	−	−	Bal.
HP-Ti		0.0243	0.002	0.0014	0.0015	0.0017	0.0002	0.0001	Bal.