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Texture and microstructure evolution of commercially pure titanium during hot rolling: Role of strain-paths

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ABSTRACT

Commercially pure (CP) titanium plates were subjected to hot rolling down to 50%, 70%, 80% and 90% reduction in thickness through unidirectional rolling (UDR), multistep cross-rolling (MSCR) and reverse-rolling (RR). It was observed that the samples had dominant basal texture (basal fiber) irrespective of the reduction percentages and the modes of rolling. Two types of twins, $\{1\bar{1}02\}\langle11\bar{2}0\rangle$ type tensile twins and $\{1\bar{2}12\}\langle1\bar{1}00\rangle$ type compressive twins, were observed in the microstructures. These twins were present in more abundance in the samples processed under MSCR and RR conditions, particularly for 50% reduction in thickness. A decreasing trend of average grain size, average grain orientation spread and fractions of twin boundaries as well as low angle grain boundaries was observed as a function of deformation for the UDR and RR strain paths. The MSCR samples have shown a deviation from the trend, which has been attributed to dominance of twinning in the deformation mechanism.

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1. Introduction

Titanium, as a hexagonal metal, has pronounced mechanical anisotropy which is always a concern, while forming titanium into different shapes/parts [1,2]. One of the reasons of this anisotropy is believed to be the deformation texture that develops during thermo-mechanical processing of the material [3,4]. In other words, by tailoring the deformation texture, it is possible to render the material isotropic. One of the commonly used processes to alter the deformation texture in the material is cross-rolling [5–7], where the material is rotated by 90° between the intermittent rolling passes. This has been reported in both cubic materials such as copper and nickel [8–10], and also in hexagonal materials such as magnesium and titanium alloys [5,11–14]. However, the role of strain path on texture development has been investigated during cold deformation only [5,11–16]. This was the prime motivation for the present work on textural and microstructural developments during '*hot rolling*' of commercially pure (CP) titanium at different strains and strain paths.

CP-titanium exhibits an hcp (hexagonal close packed) α-phase at room temperature and with increase of temperature beyond 882.5 °C, it undergoes to an allotropic transformation to a bcc (body centered cubic) β-phase [17]. Hot rolling of CP-titanium is usually referred to rolling in α-phase region. The most common slip systems in α-titanium/CP-titanium are basal $(0001)\langle11\bar{2}0\rangle$, prismatic $(10\bar{1}0)\langle11\bar{2}0\rangle$, and pyramidal $(10\bar{1}1)\langle11\bar{2}0\rangle$ slip [18]. However, at room temperature the prismatic slip has lower critical resolve shear stress (CRSS) value to initiate slip. The other slip systems are found to be the first order pyramidal $(10\bar{1}1)\langle11\bar{2}3\rangle$ and the second order pyramidal $(11\bar{2}2)\langle11\bar{2}3\rangle$ slip systems [1,19,20]. Main types of deformation twinning in titanium are $\{1\bar{1}02\}\langle11\bar{2}0\rangle$ & $\{11\bar{2}1\}\langle1\bar{1}00\rangle$ type tensile twinning and$\{1\bar{2}12\}\langle1\bar{1}00\rangle$ type compressive twinning [21–23]. Twinning plays an important role during plastic deformation of CP-titanium in the temperature range when limited numbers of slip systems are operative. It has been well understood that the final property of the material is decided by the choice of deformation mechanism, as this can significantly affect the textural and microstructural developments [2,24–30].

Therefore it is evident that the textural and microstructural development during hot rolling of CP-titanium is an important aspect to be understood. In the present study, CP-titanium (of grade-2) plates were subjected to hot rolling through unidirectional rolling (UDR), multistep cross rolling (MSCR) and reverse rolling (RR). UDR refers to rolling the plates in one direction during each passes of rolling whereas during MSCR the direction of rolling is changed by 90° in each steps of rolling, and during RR the direction of rolling is changed to 180° in each steps of rolling [31]. The consequent development of texture and microstructure has been the subject of present investigation.

2. Experimental details

2.1. Material and sample preparation

CP-titanium (of grade-2) plates with 5 mm thickness were used as the starting material for the present investigation. The plates were received in the form of hot rolled and annealed condition. The

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composition (in wt.%) of these plates is as follows: Fe = 0.034, C = 0.004, N = 0.004, H = 0.004, O = 0.134 and Ti = 99.82. These plates were subjected to hot rolling at 600 °C with 50, 70, 80 and 90% reduction in thickness in a laboratory rolling mill. The hot rolling was performed in three different modes: UDR, MSCR and RR. Different reduction percentages were achieved at a true strain of 30% in each passes of rolling. The rolled samples were then metallographic polished, and electro-polished before subsequent textural and microstructural characterization. Standard procedure was followed for metallographic polishing, whereas electro-polishing was carried out in a Struers polisher, LectroPol-5, at 38 V for 10 s. The electrolyte used was a mixture of perchloric acid, butoxy-ethanol and methanol (1:6:10) at a temperature of 0 °C.

2.2. X-Ray Diffraction (XRD)

XRD was carried out in a Bruker D8-Discover system using CuK$_\alpha$ radiation. Six pole figures, (0002), $(10\overline{1}0)$, $(10\overline{1}1)$, $(10\overline{1}2)$, $(10\overline{1}3)$ and (11

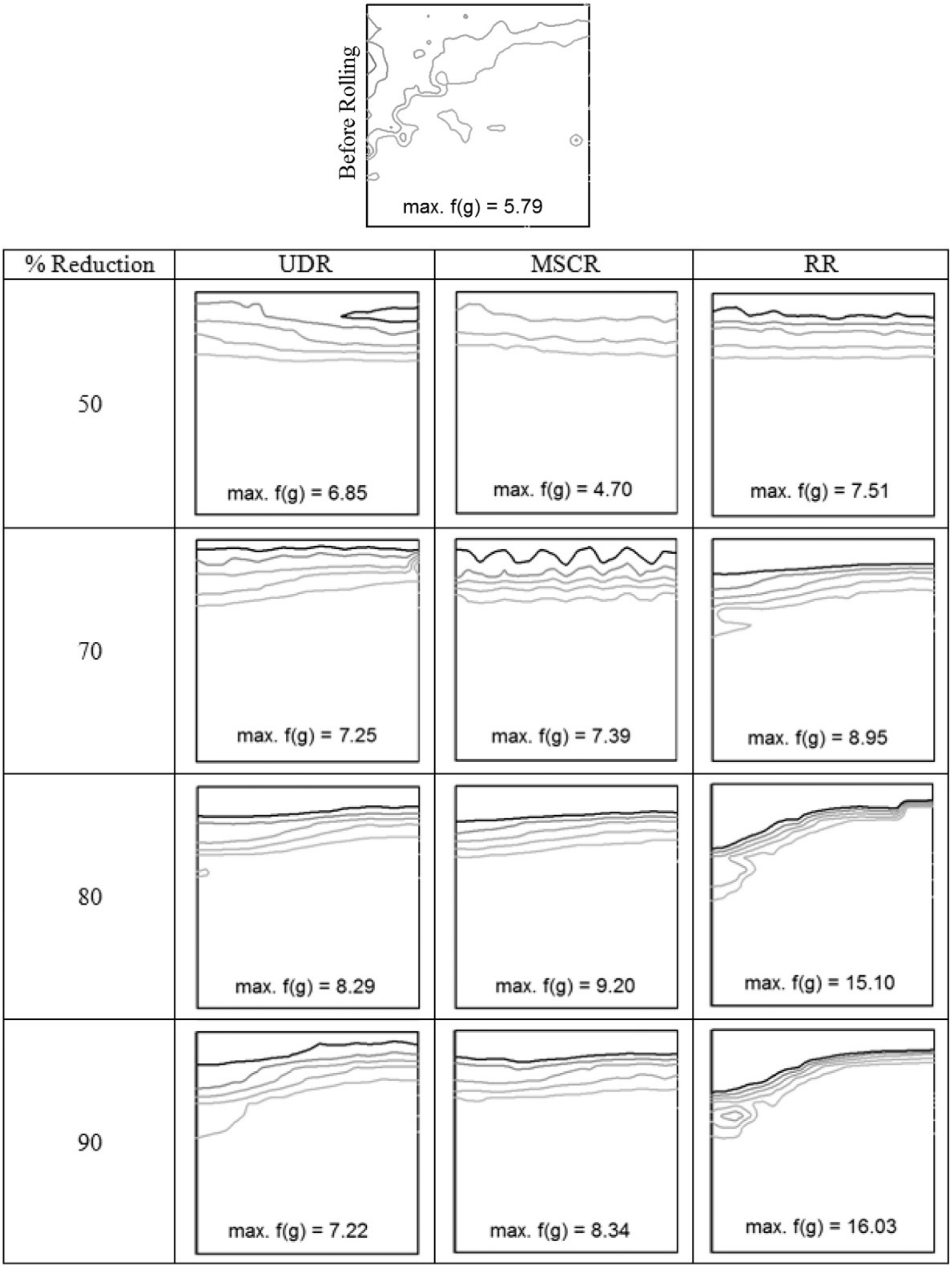

Fig. 1. ODF (at constant $\varphi_2 = 0°$) of CP-titanium samples before and after rolling. The contour levels are at 2, 3, 4, 5 and 6 times random.

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