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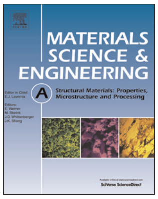

Deformation behavior and mechanical properties of composite twin structures under different loading paths

Yunchang Xin*, Xiaojun Zhou, Yang Wu, Huihui Yu, Qing Liu

School of Materials Science and Engineering, Chongqing University, Chongqing 400030, China

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ABSTRACT

In the present study, several composite twin structures containing different fractions of $\{10\bar{1}2\}$ primary twins (PTs) and $\{10\bar{1}2\}$-$\{10\bar{1}2\}$ secondary twins (STs) were prepared from a rolled sheet by a pre-compression along the transverse direction (TD) and a subsequent recompression along the rolling direction (RD). Mechanical properties under tension and compression along the TD, RD and normal direction (ND) were systematically studied, along with an *in-situ* EBSD experiment, to disclose the exact deformation mechanisms of various composite twin structures under different loading paths. Our results show that the composite twin structures can effectively harden the materials in three dimensions, while the hardening effect is highly dependent on the loading paths and the pre-straining conditions. With a constant TD pre-strain, a higher RD pre-strain can achieve a better hardening, while counterbalance the contribution to mechanical anisotropy. Deformation mechanisms in the composite twin structure vary with the changes in the loading conditions, but are also affected by the grain structure. It is also found that in some cases detwinning of the STs back to the PTs can also take place. However, in grains in which the parent PT is almost invisible or completely transformed into a ST, nucleation of new $\{10\bar{1}2\}$ twins followed by detwinning rather than direct detwinning of this ST takes place under the loading condition that would favor detwinning of STs. Similarly, in grains in which the matrix of PTs is totally consumed, nucleation of $\{10\bar{1}2\}$ twins followed by detwinning will occur under the loading condition that generally starts detwinning of PTs. As nucleation of new twins has a higher activation stress than detwinning of the pre-existing twins, the mechanical properties can be improved.

1. Introduction

Grain refinement is an effective way to harden Mg alloys without obvious compromise in plasticity [1–6]. Various effective methods have been developed to refine grains in Mg alloys, including equal channel angular extrusion (ECAE) [7], friction stir processing [8], multi-directional forging [9] and high pressure torsion [10]. The grain refinement is also effective to reduce the tension–compression yield asymmetry [3,11]. Methods for strengthening Mg alloys rely on strategies that judiciously control the generation of high angle grain boundaries. Besides the grain boundaries, coherent twin boundaries can also be employed to refine grains. A successful example is the pure copper containing nano-scaled twins [12,13], where yield strength of this nano-twinned copper can reach 900 MPa [12,14]. Compared to grain boundaries, coherent twin boundaries have a lower energy and, hence, better thermal stability [12].

$\{10\bar{1}2\}$ twinning constitutes one of the main deformation modes of Mg alloys at room temperature [4,15,16]. For example, in a hot rolled plate with a strong basal texture, compressive loading along the RD or TD leads to deformation dominated by $\{10\bar{1}2\}$ twinning [4,15]. As the size and fraction of $\{10\bar{1}2\}$ twins can be tailored by strain level [15,17–19], the $\{10\bar{1}2\}$ twins created during pre-straining were used to refine grains and harden Mg alloys in several recent publications [20–25]. It was found that both the tension and compression yield strengths along certain directions can be effectively improved [20,21,23,25]. However, for Mg alloys containing such $\{10\bar{1}2\}$ twins, detwinning is a predominant deformation mechanism under certain loading conditions, e.g. a reverse reloading or a strain path changed reloading [26,27]. Detwinning of the pre-exist twins is a process of twin boundary migration and has a quite low activation stress [27], and the studies by [26–28] stand out as typical examples of the low yield strength during detwinning predominant deformation. Thus, a structure containing only $\{10\bar{1}2\}$ primary twins (PTs) cannot harden Mg alloys in three dimensions.

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* Corresponding author. Fax: +86 2365106407.
E-mail address: ycxin@cqu.edu.cn (Y. Xin).

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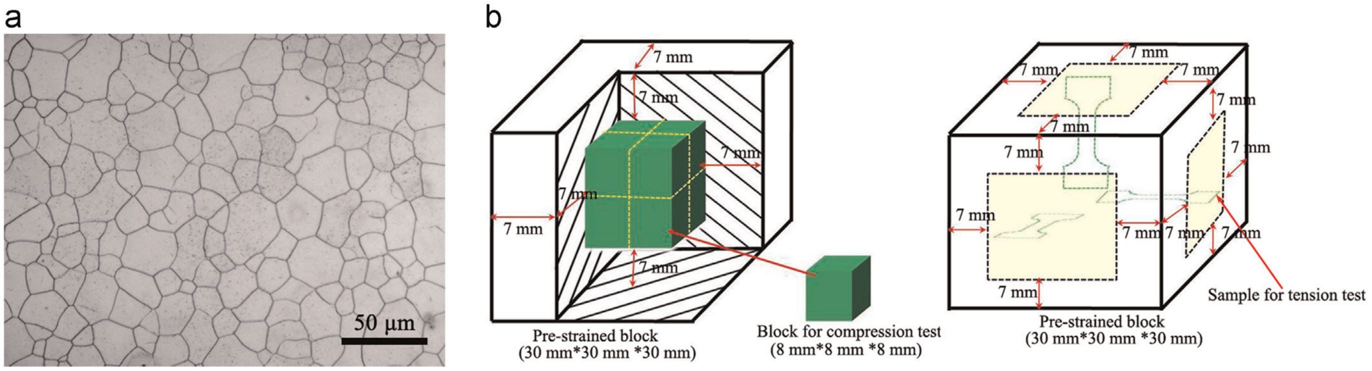

Fig. 1. (a) Optical micrograph of the as-used plate of Mg alloy AZ31 and (b) schematic diagrams showing the preparation of specimens for tension and compression tests from the pre-strained blocks.

Table 1
The designation of samples and the corresponding pre-straining conditions.

Samples	Compression along the TD (%)	Compression along RD (%)
TD2.5–RD2.5%	2.5	2.5
TD2.5–RD4.5%	2.5	4.5
TD2.5–RD7.0%	2.5	7.0

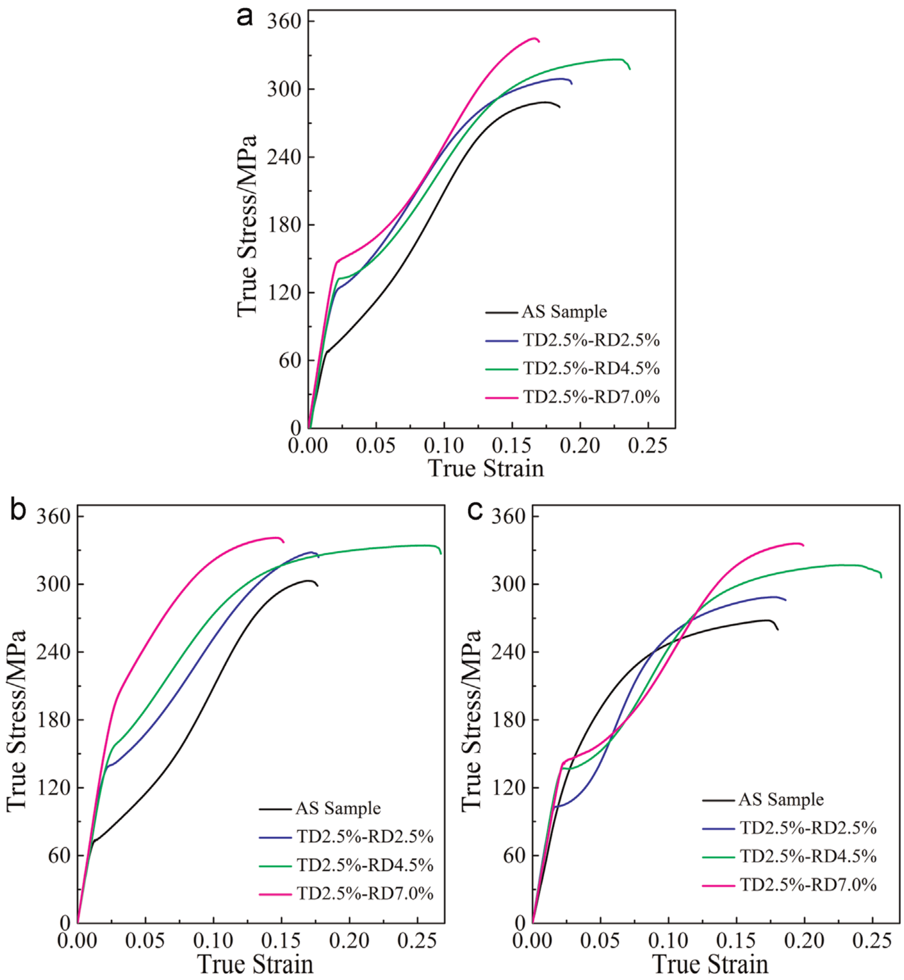

Fig. 2. Stress–strain curves of the pre-strained samples under compressions along (a) the TD, (b) the RD and (c) the ND. For comparison, that of the initial hot rolled plate (AS sample) are also given.

Recently, it has been reported that $\{10\bar{1}2\}$ twinning can also take place in the $\{10\bar{1}2\}$ PTs, forming $\{10\bar{1}2\}$-$\{10\bar{1}2\}$ secondary twins (STs) [20,21]. Previously, a composite twin structure containing both PTs and STs was found to harden Mg alloy more effectively [23,29,30]. The presence of STs can reduce the activity of detwinning. However, in those publications, only the mechanical properties under tension or compression along one direction have been addressed. A composite twin structure has several types of twins as well as residual matrix, which have different orientations with each other. As slip, twinning and detwinning in Mg alloys are highly dependent on the loading paths and crystallographic orientations, deformation behavior and mechanical properties of a