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Processing twining induced plasticity steel through simple shear extrusion

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ABSTRACT

Microstructure and deformation behavior of twinning induced plasticity steel processed by simple shear extrusion are investigated. Two appropriate dies with the maximum distortion angle of 30° and 45° are designed and constructed. Results show that the twin fraction increases while the twin spacing decreases as the equivalent strain rises in the deformation channel. The hardness reaches to its maximum at the middle of the deformation channel and decreases in the second half of the channel due to reversal straining. A similar trend is observed for dislocation density. The crystallite size is determined as 710 nm and 500 nm after one pass of simple shear extrusion with maximum distortion angle of 30° and 45°, respectively.

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1. Introduction

Twining induced plasticity (TWIP) steel is a promising high strength material that is attracted in automotive industries. The high level of manganese in these steels causes the stability of the FCC structure and decreases the stacking fault energy (SFE) [1]. SFE controls the ease of cross-slip for screw dislocations and thus dictates the mode of deformation. Mechanical twinning is a deformation mechanism competitive to dislocation glide. At low values of SFE, cross-slip becomes more difficult and mechanical twinning is the favored deformation mode [2]. It is reported that twinning occurs when the SFE is in the range of 18–45 mJ/m^2 [3,4] while slip takes place when the SFE is higher than 45 mJ/m^2 [1]. The strength of the TWIP steel is attributed to the twinning mechanism and alloying elements that increase the stress by interfering the movement of dislocations during deformation [5].

The microstructure and deformation behavior of TWIP steel has been interested by many researchers such as in Refs. [5–9]. However, plastic strain imposed to this material is almost restricted to about 60%. As a result, the microstructure and mechanical properties of TWIP steel at relatively large plastic strains needs to be investigated. Severe plastic deformation (SPD) is a well-known method through which large plastic strains can be imposed into the material [10]. However, there are few reports showing that severe plastic deformation of relatively high strength materials such as TWIP steel is difficult due to the segmented flow [11,12]. Lately, the present authors have published a paper [13] on the possibility of processing TWIP steel through two severe plastic deformation techniques, equal channel angular pressing (ECAP) and simple shear extrusion (SSE) [14]. Results showed that TWIP steel could be successfully processed by simple shear extrusion while equal channel angular pressing leads to the segmented flow. Nonetheless, the investigation of the microstructure evolution and deformation behavior was left to another work.

Accordingly, the present paper is a complement to the authors' previous works [13]. The microstructure evolution and deformation behavior of TWIP steel are investigated during SSE. The crystallite size and dislocation density are characterized by metallography and X-ray diffraction using the modified Williamson–Hall method. Hardness test is used for evaluating the mechanical properties in the deformation channel.

2. Materials and methods

The material used in this study was an Fe–22Mn–3Si–Al austenitic TWIP steel that its chemical composition is presented in Table 1. The material was received in the form of a cast ingot. SSE samples with dimensions of 10 mm × 10 mm × 30 mm were prepared from the cast ingot. To get a fully recrystallized microstructure, all samples were annealed before pressing at 1150 °C for 2 h.

During SSE, the sample is passed through an extrusion channel under simple shear mode of deformation. The square cross section is deformed to a parallelogram shape with maximum distortion angle at the middle of the channel and returned to square at the outlet [13,14]. A bisection die with the ability of changing the maximum distortion angle, α_{max}, was designed and constructed. The maximum distortion angles used for this study were 30° and 45°. For simplicity, dies with the maximum distortion angles of 30° and 45° will be referred to SSE-30 and SSE-45, respectively. The

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Table 1
The chemical composition of TWIP steel used in the present study. All commotions are in weight percent (wt.%).

C	Si	Mn	P	S	Cr	Mo	Ni
0.491	2.700	22.00	0.044	0.057	0.172	0.157	0.95
Al	Cu	Co	Ti	V	W	Fe	
0.800	0.073	0.004	0.002	0.023	0.022	68.11	

length of the deformation zone was considered as 60 mm. The accumulative equivalent strain inserted after each SSE pass is determined by [14]

$$\varepsilon_{eq} = \frac{2\tan\alpha_{\max}}{\sqrt{3}} \quad (1)$$

Therefore, the strain after one pass of SSE-30 and SSE-45 is calculated as 0.666 and 1.155, respectively. The imposed strain in SSE-45 is about two times larger than that inserted during one pass of ECAP with an intersecting channel angle of 120°. By considering the constant ram speed of 0.1 mm/s and the length of the deformation zone (60 mm), the deformation time for all specimens is 600 s. Therefore, the average strain rate in SSE-30 and SSE-45 is determined as 0.0011 and 0.0019 s^{-1}, respectively.

The microstructure evolution and mechanical properties of the material in the deformation zone was examined at different locations from the entrance to the exit channel. For SSE-30, six and for SSE-45, nine locations were chosen, as shown schematically in Fig. 1. The distance of these locations from the channel entry and the corresponding equivalent strains are summarized in Table 2. The cumulative equivalent strain at each location is obtained by consideration of the distortion angle at every section of the die [14]. Samples were wrapped with Teflon tape and extruded for one pass at room temperature. Repetitive pressing of the same samples was attempted. However, it needed the loads that were beyond the capacity of the pressing machine used in this study.

An optical microscope was used for microstructural investigations. For this purpose, the surface of the samples was mechanically polished and etched in Nital-20%. The volume fraction of twins was measured by the method of point counting using micrographs [15]. Based on the method, 26 traverses were selected. Each traverse consists of 33 points. Linear intercept method was used to calculate the average twin spacing. To obtain acceptable data for both average twin spacing and twin volume fraction at least five samples were examined for each section. For measuring the twin fraction and spacing, an enlarged picture of micrographs was used to specify the twins clearly and then the number of intersecting points was counted using the linear intercept method.

The Vickers hardness method was used for hardness testing. The hardness measurements were taken by applying a load of 3 kg for 10 s (ASTM E92-82(2003)e2 [16]) along the central horizontal and vertical lines of the sections perpendicular to the pressing axis.

The XRD measurements were conducted in the range of 40–100° for 2θ at room temperature by a Philips X-ray diffractometer. It was equipped with a graphite monochromator using Cu Kα operated at 40 kV and 30 mA. The step size for all samples was chosen as 0.02°/s. After background subtraction, all profiles were fitted with Voigt function [17] using Fityk software and the full-width at half maximum (FWHM) for all peaks was measured. The results were analyzed using the modified Williamson–Hall (W–H) methods [18].

The broadening of X-ray diffraction profiles in a real crystal is due to small size of crystallites and the strain of lattice defects such as dislocations. The size and dislocation density can be analyzed by the modified W–H method through an equation of the form [18]

$$\Delta K = \frac{0.9}{D} + \left(\frac{\pi M^2 b^2}{2}\right)^{\frac{1}{2}} \rho^{\frac{1}{2}} K\overline{C}^{\frac{1}{2}} + O(K^2\overline{C}) \quad (2)$$

where D is the crystallite size, ρ is the dislocation density, M is a constant depending on the effective outer cut-off radius of dislocations [19], $\overline{C}$ is the average contrast factor of dislocations [20] and O stands for higher order terms in $K^2\overline{C}\cdot K = 2\sin\theta/\lambda$ where θ is the diffraction angle and λ is the wavelength of X-rays. $\Delta K = \cos\theta[\Delta(2\theta)]/\lambda$ where $\Delta(2\theta)$ is the FWHM of the diffraction peaks.

3. Results and discussion

The micrograph of TWIP steel in the annealed condition is represented in Fig. 2. The average grain size was measured as about

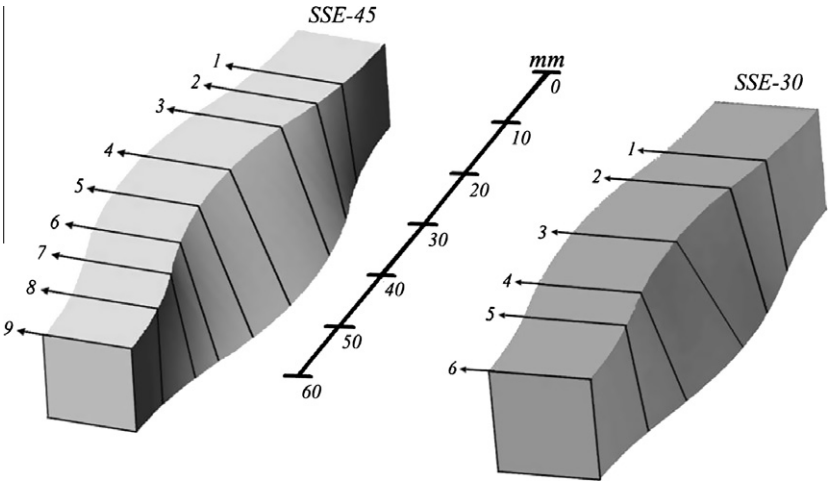

Fig. 1. Schematic presentation of SSE-45 (left) and SSE-30 (right) samples in the deformation channel. Selected locations for microstructure and hardness investigation are also included.

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