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Short communication

Observation of pseudoelasticity in a cold rolled Fe–Ni–Mn martensitic steel

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ABSTRACT

In this research, the reverse transformation of martensite to austenite and pseudoelastic behavior in Fe–10Ni–7Mn (wt%) lath martensitic steel were investigated under different amounts of cold rolling. The results indicated that the transformation of stress-induced austenite to epsilon martensite is responsible for pseudoelastic behavior in 80% cold rolled specimen.

1. Introduction

Iron based shape memory alloys (SMAs) such as Fe–Mn–Si and Fe–Ni–Mn-based alloys have attracted much attention recently among several series of shape memory alloys. Due to their low cost, wide transformation hysteresis, high elastic stiffness and strength and etc., they have been considered for a wide variety of structural applications such as damping materials, clamping or coupling devices, pipe joints and rail couplings [1–5]. The shape memory effect (SME) in these alloys is known to be based on the stress-induced transformation from austenite (fcc) to epsilon martensite (hcp) at low and intermediate temperature and the reverse transformation (hcp to fcc) by heating up to a temperature over the A_s [1,2,6]. Moreover, the iron based SMAs were reported being able to exhibit the unique property of pseudoelasticity [2,7–9]. The alloy's stacking fault energy (SFE), the microstructure and texture of the austenite phase are the main parameters that affect the SME and pseudoelasticity [9–11].

Fe–10Ni–7Mn (wt%) low carbon martensitic steel is a high strength steels that exhibits fcc to hcp transformation and its reversion due to low SFE [2,12–14]. In order to observe the SME and pseudoelastic behavior in this alloy, it is necessary to introduce the austenite phase in the martensite matrix [2,6,14]. Austenite in iron based alloys could be induced thermally or displacevly depends on the process is applied. Most of the studies on the pseudoelastic behavior in iron based shape memory alloys have been focused on alloys with an original austenitic microstructure and so far, there is no deep understanding about pseudoelasticity of austenite induced by shear transformation, e.g., through heavy deformation. The aim of this research is to study pesudoelastic behavior with respect to the characteristics of austenite induced by different amounts of cold rolling in Fe–10Ni–7Mn (wt%) fully lath martensitic steel.

2. Experimental materials and procedures

A Fe–10Ni–7Mn (wt%) low carbon martensitic steel in solution annealed condition was used as starting material. Two specimens were cut from the starting material and then subjected to 40% and 80% cold rolling.

Microstructures were characterized by X-ray diffraction (XRD) analysis using Cu-K_α radiation with a step scanning rate of 0.02° per 3.6 s, electron backscatter diffraction (EBSD), and Transmission electron microscopy (TEM). The pseudoelastic behavior and strain hysteresis of specimens were examined by applying cyclic tensile loading–unloading test at constant speed of 1 mm min^{-1} using an extensometer at room temperature.

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3. Results and discussion

3.1. Austenite formation under cold rolling

Fig. 1 Shows X-ray diffraction pattern of the starting material subjected to different amount of cold rolling. According to Fig. 1 (a) and (b), for the solution annealed and 40% cold rolled specimens, only the peaks corresponding to α′ martensite are detected. However, by applying 80% cold rolling, beside the peaks related to α′ martensite, an additional small peak corresponding to 2θ angle of 43.7° is observed which is attributed to the (111) plane of austenite (γ) as illustrated in Fig. 1(c). The volume fraction of reversed austenite after 80% cold rolling was measured about 8% by XRD measurement. Although the (111) peak of austenite in Fig. 1(c) is very small and difficult to distinguished but the presence of austenite is confirmed by EBSD measurement. The results presented in Fig. 2 show a section of phase maps for the solution annealed, 40% and 80% cold rolled specimens. The phase maps of 80% cold rolled specimen (Fig. 2(c)), presents fine austenite, while the solution annealed and 40% cold rolled specimens are austenite free which is in good agreement with XRD result.

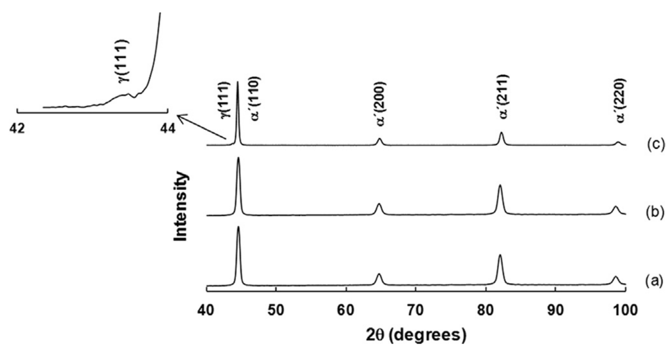

Fig. 1. XRD spectra of (a) solution annealed, (b) 40% cold rolled; and (c) 80% cold rolled specimens.

It has been reported that during severe deformation at room temperature, austenite can be formed from martensite by displacive mechanism [15]. Deformation in the present study was carried out at room temperature and sample was not heated explicitly therefore, the formation of austenite implies reverse transformation. It has been shown that the austenite reversion is possible even at room temperature if the deformation energy stored in material could provide the required driving force for reverse transformation [16]. Comparing X-ray diffraction patterns and EBSD maps of the 40% and 80% cold rolled specimens conceived that the deformation energy through 40% cold rolling is insufficient for providing the driving force of reverse transformation whereas it can be sufficed by 80% cold rolling.

TEM images of the solution annealed and 80% cold rolled conditions are shown in Fig. 3. Fig. 3(a) shows a bright field TEM image of the solution annealed specimen representing a microstructure consisting of lath martensite with high dislocation density. Bright field TEM image of the 80% cold rolled specimen and denoted austenite and martensite phases are shown in Fig. 3(b). Insets of Fig. 3(b) show selected area diffraction (SAD) patterns obtained from the circled areas in martensite (I) and austenite (II) regions that respectively indicate the indexed spots corresponding to bcc and fcc crystal structure. Configuration of TEM observations, EBSD maps and XRD analysis confirm the formation of stress-induced reversed austenite in the microstructure of the present studied steel under 80% cold rolling.

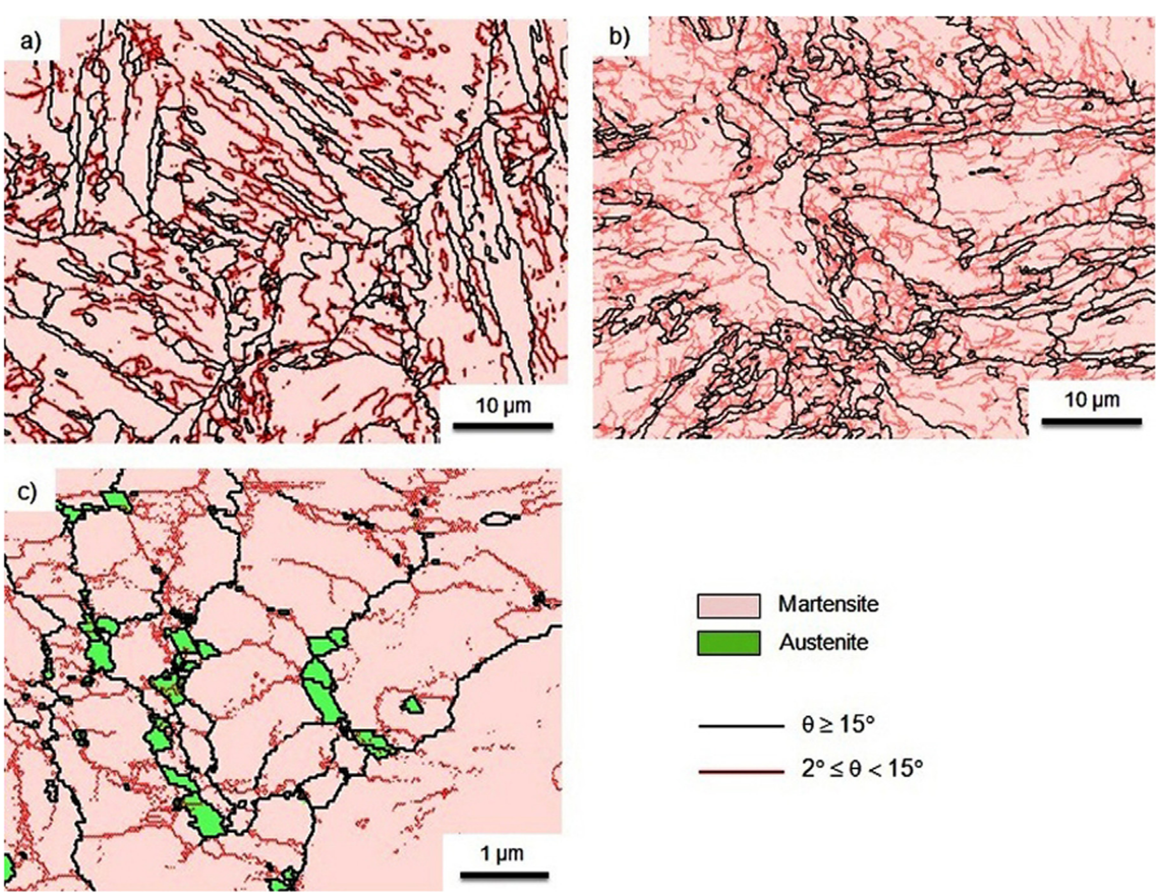

Fig. 2. Phase maps of (a) solution annealed, (b) 40% cold rolled; and (c) 80% cold rolled specimens.