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# Improved tensile properties of partially recrystallized submicron grained TWIP steel

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ABSTRACT

The effects of cold rolling reduction and annealing temperature on the mechanical properties of twinning induced plasticity (TWIP) steel have been investigated. The results indicated that the strengthening effect of unrecrystallized areas with a high density of nano-scale mechanical twins increased with increasing cold rolling reduction. In addition, the ductility also increased with increasing annealing temperature. Therefore, utilization of large cold rolling reduction and subsequently annealing treatment in the partial recrystallization region was suggested as an effective method to obtain submicron grained TWIP steel with an excellent combination of strength and ductility.



## 1. Introduction

In the past decade, a new group of low stacking fault energy (SFE) alloys such as transformation induced plasticity (TRIP) steels and twinning induced plasticity (TWIP) steels has been developed. TWIP steels with Mn content of 20–30% provide a great potential in automotive industry owing to their superior combination of strength and ductility as a result of the formation of mechanical twins during deformation [1–3].

Although, it has been reported [4] that ultrafine grained bcc steels exhibit significantly high strength and limited elongation (a uniform elongation of a few percent), our previous studies [5,6] indicated that grain refinement of Fe–31Mn–3Al–3Si TWIP steel down to 1.8 µm provides high strength (a yield strength of 543 MPa and an ultimate tensile strength of 811 MPa) with large ductility (a total elongation of 52%). This result implies an idea: possibility of submicron grained TWIP steel development with an adequate combination of strength and ductility. The extrapolation of the fitted Hall–Petch relationship for Fe–31Mn–3Al–3Si TWIP steel [5] towards finer grain sizes indicated that submicron grained TWIP steel with an average grain size of about 210 nm has a yield strength of more than 1GMPa. Usually, severe plastic deformation techniques are utilized to obtain ultrafine grained materials [4]. However, these techniques have not been established yet as large scale industrial processes.

As a first alternative method, due to Bouaziz et al. [7] recovery treatment of cold rolled TWIP steel that contains a high density of mechanical twins, it may be useful in achieving high strength-ductility. They found that nano-scale mechanical twins have a thermal stability during recovery treatment (e.g., holding at 500 °C for 3.6 ks) and so mechanical twin boundaries contribute to the strengthening of metal (just like grain boundaries) during further deformation while ductility is improved by decreasing dislocation density as a result of recovery treatment.

As a second method, Wang et al. [8] have been suggested that a bimodal grain size distribution consisting of a mixture of both ultrafine and fine grains may be also effective in achieving the best combination of strength-ductility in ultrafine grained materials. Therefore, the aim of this study is to clarify the mechanical properties of TWIP steel with utilization of both methods. For this propose the effects of cold rolling reduction and annealing temperature on the mechanical properties and microstructural evolutions of Fe–31Mn–3Al–3Si TWIP steel were investigated.

## 2. Experimental procedures

Hot rolled steel sheets with 5.7 mm in thickness and a chemical composition of Fe–31Mn–3Al–3Si were used in this study. In order to remove the inhomogeneous microstructures, as-received sheets were heated at 1100 °C for 3.6 ks. In order to obtain samples with different cold rolling reductions and recovered-to-fully recrystallized structures, the homogenized plates were cold rolled to reductions of 60, 70 and 80% and subsequently annealed at 500, 550, 575, 600, 625, 650 and 700 °C for 1.8 ks and then air-cooled.

Tensile tests were carried out with a strain rate of $10^{-3}$ $s^{-1}$ using test pieces with 20 mm gage length, 4 mm gage width and 1 mm gage thickness at room temperature. All tensile test samples were cut along the rolling direction (RD). Microstructural evaluations were conducted by the optical microscopy (OM) and transmission election microscopy (TEM).

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## 3. Results and discussion

Fig. 1 shows the microstructural evolutions of some 80%-cold rolled and annealed samples at different temperatures for a holding time of 1.8 ks. The microstructure of annealed sample at 550 °C (Fig. 1a) shows a band like lamellar structure (twin/matrix) which is similar to the structure in other cold rolled TWIP steels [9]. Some shear bands are also visible. There is no evidence of recrystallized areas. At 600 °C, recrystallized grains appeared in the deformation microstructure (Fig. 1b). The recrystallized areas have few dislocations and the average grain size is around 450 nm. The present of submicron grains in the microstructure of partially recrystallized

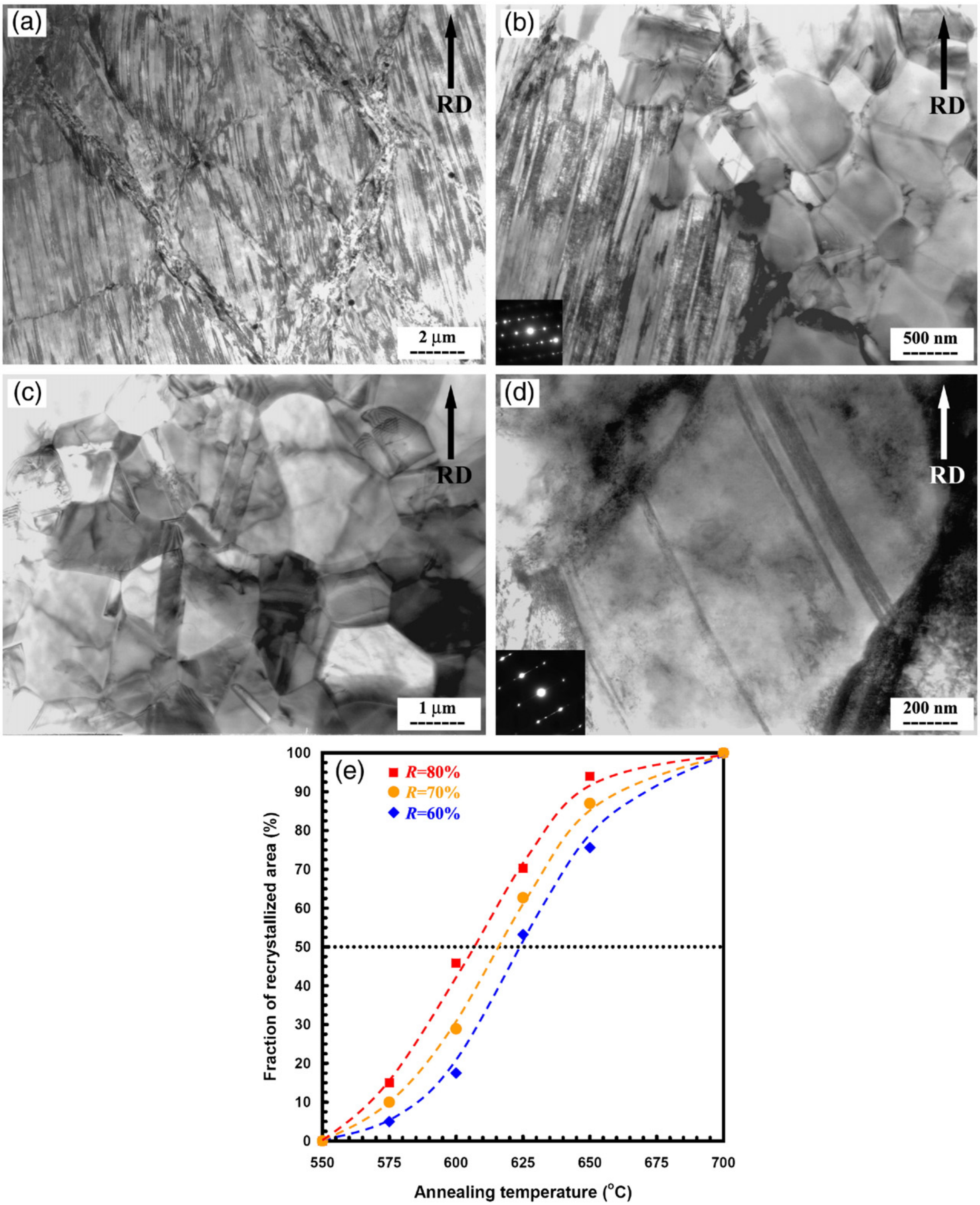


**Fig. 1.** (a–d) TEM micrographs of 80%-cold rolled and annealed samples for 1.8 ks at, a) 550 °C, b) 600 °C, c) 700 °C d) 700 °C and tensile strained to 25% and e) the effect of cold rolling reduction ($R$) on the recrystallization kinetics of Fe–31Mn–3Al–3Si TWIP steel.