

Effect of Thermo-Mechanical Treatment on Mechanical Properties and Microstructure of Fe-31Mn-4Si-2Al-Nb-Ti TWIP Steel

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Abstract. The effect of addition of Nb and Ti also thermomechanical treatment on mechanical properties and microstructure of a twinning induced plasticity (TWIP) steel have been investigated. The results indicated that addition of Nb and Ti enhances strength also increasing cold rolling reduction has been increased strength. The ductility increased with increasing annealing temperature however strength reduced. In centric limit of partial recrystallization regime, maximum increasing in work hardening capacity and also almost high yield strength has been achieved. Therefore, utilization of large cold rolling reduction and subsequently annealing treatment in the centric limit of partial recrystallization region was suggested as an effective method to obtain TWIP steel with an excellent combination of strength and ductility.

Keywords: TWIP Steel, Ti, partial recrystallization, cold Rolling, annealing

1. Introduction

TWInning Induced Plasticity (TWIP) steels containing 25-35 wt% Mn with small additions of Al, and Si have been developed as a promising material for automotive applications [1, 2]. The high Mn content stabilises austenite at room temperature and produces a single phase face centred cubic (fcc) steel with low stacking fault energy (SFE) between 15-40 MJ/m². TWIP steels are characterised by high strain hardening rates leading to ultimate tensile strengths of 600-1000 MPa and total elongations exceeding 50%. The achievement of this combination of mechanical properties challenges the conventional perception of an inverse relationship between strength and ductility and occurs mainly via the lowered SFE producing substantial twinning during plastic deformation. However, the yield strength of TWIP steels is relatively low [3].

Bouaziz et al. [4] found that mechanical twins have a thermal stability during recovery treatment (e.g., holding at 500°C for 3.6 ks), (KS: kilo second) 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.

Wang et al. [5] have been confirmed 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.

Addition of Nb and Ti micro additions to steels could form dispersive nitrides, Carbo nitrides and carbides which are the cause of additional precipitation strengthening what has a particular meaning for steels with austenitic matrix and relatively low yield stress [6].

Therefore, the aim of this study is to clarify the mechanical properties of TWIP steel with utilization of three methods that mentioned above. For this propose the effects of cold rolling reduction and annealing

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temperature on the mechanical properties and microstructural evolutions of Fe–31Mn–4Si–2Al–Nb–Ti TWIP steel were investigated.

2. Materials and Method

A 30-kg and a 10 kg ingot, whose chemical composition is Fe-31Mn-4Si-2Al-Nb-Ti (Nb=0.06,Ti=0.09) and Fe-31Mn-4Si-2Al (in mass percent), respectively; was prepared by vacuum induction melting, homogenized at 1100 °C for 3.6 ks in an argon atmosphere, and plates were hot-rolled to reduction of 50% at the temperatures between 1100 and 900°C. To isolate the influence of Nb and Ti were prepared samples with reduction of 50% and subsequently annealed at 750°C. In order to obtain samples with different cold rolling reductions and recovered-to-fully recrystallized structures, the hot-rolled plate of Fe-31Mn-4Si-2Al-Nb-Ti steel was cold-rolled at room temperature to reductions of 50, 65 and 80% and subsequently annealed at 600, 650, 700 and 750°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 which were prepared according to ASTM E8M at room temperature. All tensile test samples were cut along the rolling direction (RD). Microstructural evaluations were conducted by the optical microscopy (OM) and scanning electron microscopy (SEM).

3. Results and Discussions

Figure.1 shows the Engineering stress-Engineering strain curves of Fe-31Mn-4Si-2Al and Fe-31Mn-4Si-2Al-Nb-Ti steel after 50% cold rolling and annealing at 750°C for 1800 seconds.

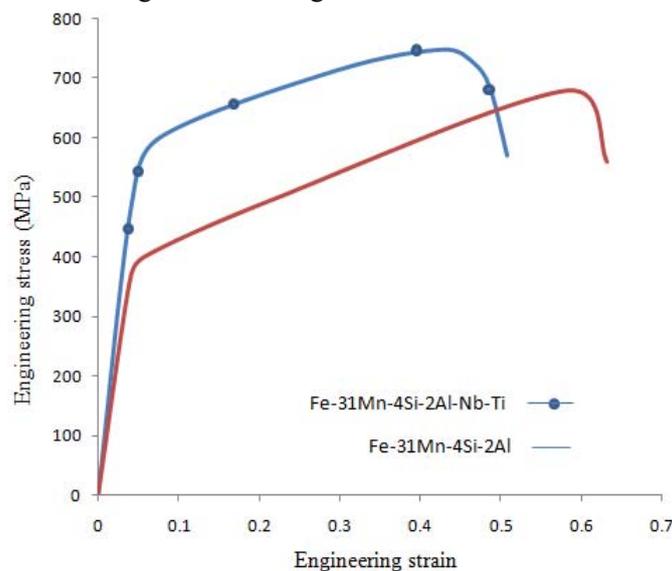


Fig. 1: Engineering stress-Engineering strain curves of Fe-31Mn-4Si-2Al and Fe-31Mn-4Si-2Al-Nb-Ti TWIP steel with 50% cold reduction and annealed at 750°C for 1.8 ks

It is observed that the steel containing Nb and Ti has greater tensile strength and Yield strength than the steel without Nb and Ti. Optical observation showed that the steel containing Nb and Ti provided the smaller grain size. It has been reported [6] that grain size reduction and also precipitation hardening of Nb and Ti precipitations, cause the strengthening of steels.

On the other hand, steel containing Nb and Ti has shown lower work hardening rate than steel without Nb and Ti. Mechanical twin boundaries act as obstacles to the dislocation movement (like grain boundaries) [7]. Reduction of work hardening rate as a result of adding Nb and Ti, despite of their cumulative effect on work hardening rate, has shown that the mechanical twinning was significantly suppressed by the precipitations of these elements.

Figure.2 shows the Engineering stress-Engineering strain curves of Fe-31Mn-4Si-2Al-Nb-Ti TWIP steel after 50%, 65% and 80% cold rolling reduction and annealing at Temperature range of 550°C to 750°C.

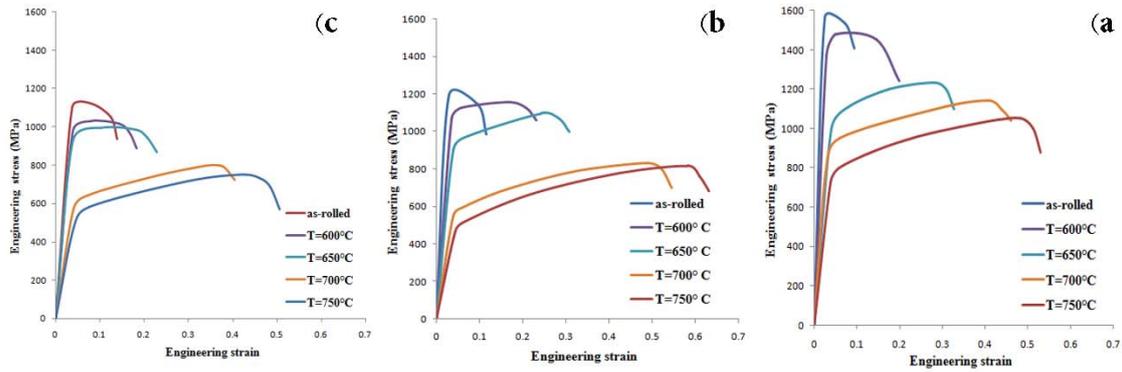


Fig. 2: Engineering stress-Engineering strain curves of Fe-31Mn-4Si-2Al-Nb-Ti TWIP steel with different cold rolling reductions (R) and annealed at various temperatures for 1.8 ks a) R=80% b) R=65% c) R=50%

In as-rolled samples, strength increases with increasing the cold rolling reduction. Increasing annealing temperature reduce the strength and increase the total elongation. Figure.3 shows the microstructure of samples, which is 50% cold rolled and annealed at 600°C, 700°C and 750°C for 1.8 ks.

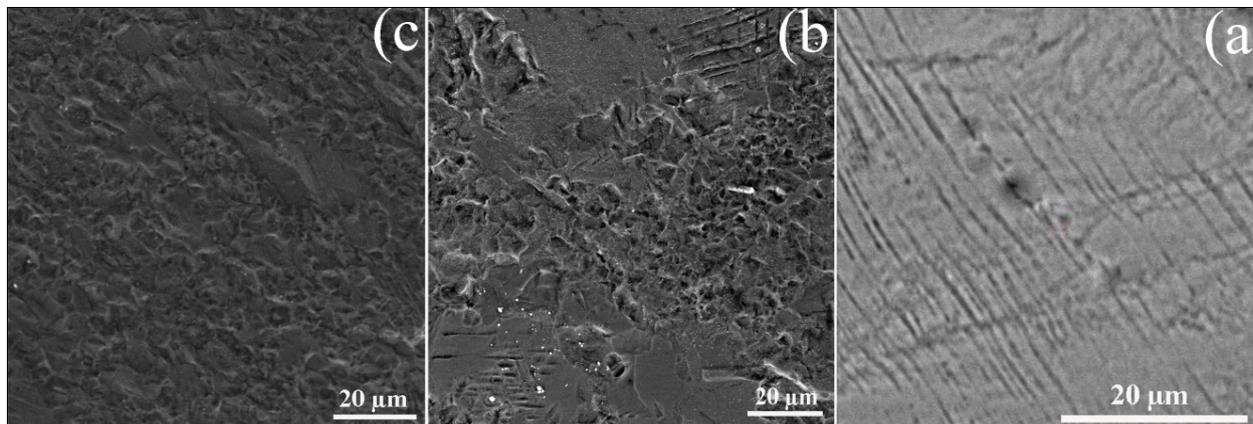


Fig. 3: SEM images of 50% cold rolled and annealed samples for 1.8 ks at a) 600 b) 700 c) 750 temperatures.

Figure 3a (recovery region) shows the recovered microstructure sample containing mechanical twin. Figure 3b (partial recrystallization region) shows the recrystallized grains in matrix containing mechanical twin, which is in agreement with the observations of Bouaziz et al. [4] on an Fe-22%Mn-0.6%C TWIP steel. Figure 3c has only the small amount of the un-recrystallized area. The results of hardness tests and also optical observations showed that the starting temperatures of recrystallization of 50%, 60% and 80% cold rolled samples are 620°C, 640°C and 650°C respectively and ending temperatures of recrystallization are 720°C, 750°C and 775°C respectively.

As-rolled samples and recovered samples provide the higher yield strength. But the ductility in this condition is very low. The maximum value of total elongation is approximately 20%, which is occurred in 80% cold rolled and annealed sample at 600°C. The increase in ductility, attributed to the microstructural changes due to the annihilation of dislocations and formation of sub-boundaries.

On the other hand, the yield strength decreases significantly with annealing samples in grain growth region. With the formation of new grains during recrystallization heat treatment, formed mechanical twin during the cold rolling are lost and severely reduce the yield strength.

It is observed that annealed samples in partial recrystallization region provide acceptable yield strengths. Obtained microstructure with anneal in this temperature range consists of mechanical twin and also recrystallized grains (Figure 3b). Therefore, mechanical twins contribute in strengthening and on the contrary, a recrystallized grain leads to increasing ductility. With increasing annealing temperature the recrystallized fraction increases and as results ductility increases, but strength decreases.

On the other hand, work hardening capacity is one of the important parameters in Industrial applications [8]. Work hardening capacity ($UTS \cdot TEL$) provides a good agreement between tensile strength and ductility. In order to have a

better comparison the work hardening capacity's value has been present in figure 4.

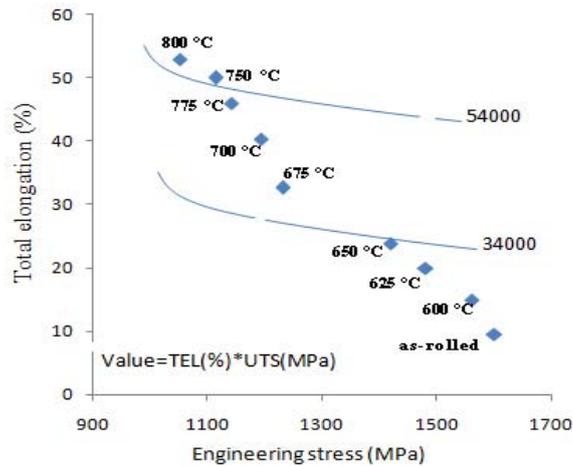


Fig. 4: The comparison between ductility and strength (i.e., TEL vs. UTS) of TWIP.

Steel samples with 80% cold rolled reduction and annealed for 1.8 ks at various temperature

It is observed that, with annealing in the centric partial recrystallization region (650°C to 700°C) significant increase in the work hardening capacity occurs

4. Result

Despite the suppression of forming the mechanical twin, adding Micro-alloy elements Nb and Ti to Fe-31Mn-4Si-2Al TWIP steel increase the tensile strength and the yield strength of cold rolled and annealed sample. In addition, by increasing cold rolling reduction, the strengthening effect of the areas that are not recrystallized during annealing in partial recrystallization region increase. On the other hand, by increasing annealing temperature ductility increases. In contrast, by increasing the annealing temperature to grain growth region, significant drop in yield strength occurs.

In addition, annealing in centric partial recrystallization region has the greatest increase in work hardening capacity.

Consequently, utilization of large cold rolling reduction on Micro-alloyed TWIP steel (Fe-31Mn-4Si-2Al-Nb-Ti) and subsequently annealing treatment in the centric limit of partial recrystallization region was suggested as an effective method to obtain TWIP steel with an excellent combination of tensile strength, yield strength and ductility.

5. Reference

- [1] O. Grassel, L. Kruger, G. Frommeyer, and L. W. Meyer. High strength Fe–Mn–(Al, Si) TRIP/TWIP steels development — properties — application. *International Journal of Plasticity*. 2000, 161: 391-409.
- [2] G. Frommeyer, U. Brux, and P. Neumann. Supra-ductile and high-strength manganese TRIP/TWIP steels for high energy absorption purposes. *ISIJ International*. 2003, 43(3): 438-446.
- [3] S. Kang, Y. S. Jung, J. H Jun, and Y. K. Lee. Effects of recrystallization annealing temperature on carbide precipitation, microstructure, and mechanical properties in Fe–18Mn–0.6C–1.5Al TWIP steel. *Materials Science and Engineering A*. 2010, 527: 745–751.
- [4] O. Bouaziz., C. P. Scott, and G. Petitgand. Nanostructured steel with high work-hardening by the exploitation of the thermal stability of mechanically induced twins. *Scripta Materialia*. 2009, 60: 714–716.
- [5] Y. Wang, M Chen, F. Zhou, and E. Ma. High tensile ductility in a nanostructured metal. *Nature journal*. 2002, 419: 912–915.
- [6] I. Schindler, M. Janosec, E. Mistecky, and P. Suchanek. Effect of cold rolling and annealing on mechanical properties of HSLA steel. *Archives Materials Science and Engineering*. 2009, 36: 41-47.

- [7] G. Dini and R. Ueji, A. Najafizadeh, S.M. MonirVaghefi, Flow stress analysis of TWIP steel via the XRD measurement of dislocation density. *Materials Science and Engineering A*. 2010, 527: 2759–2763.
- [8] G. Dini and R. Ueji, A. Najafizadeh, S.M. MonirVaghefi, Tensile deformation behavior of high manganese austenitic steel: The role of grain size. *Materials and Design*. 2010, 31: 3395–3402.