EXTENDED ABSTRACT

TWIP-effect and thermo-mechanical treatment of a stable high-manganese austenitic stainless steel

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Abstract: Austenitic carbon steels that exhibit excellent mechanical properties due to the twinning-induced plasticity effect have been studied extensively. On the other hand, austenitic stainless steels usually achieve good strength and ductility via transformation-induced plasticity. However, relying on martensite transformation for strength may cause problems such as delayed cracking. Therefore, the twinning behavior of a stable low-nickel high-manganese austenitic stainless steel (Type 201Cu) was studied. The steel showed extensive twin formation during deformation, which was observed using SEM-EBSD and HR-TEM. Consequently, a high strain hardening rate was seen, which can be attributed to the dynamic Hall-Petch effect. However, the yield strength was low as is typical for austenitic steels in the annealed condition. The yield strength was increased markedly by taking advantage of the twinned microstructure and the stability of the twins during annealing. Cold-rolling to a 33% reduction and annealing at 600℃ for an hour led to high yield strength together with good uniform elongation. The thermo-mechanical treatment reduces the effective grain size via mechanical twinning, but leaves some strain hardening capacity via the dislocation slip mechanism.

Key words: Twinning, Stainless steel, TEM, EBSD, Mechanical properties

1. Introduction

Austenitic stainless steels usually achieve good mechanical properties via the TRIP-effect [1]. However, martensite can cause delayed cracking [2]. Stable carbon steels exhibiting the TWIP-effect are of great interest for example to the automotive industry and have been studied extensively [3]. TWIP in stainless high-manganese steels is a less studied topic [4]. Annealing a stainless steel prone to twinning is studied in this paper, because promising results have been observed in TWIP carbon steels [5,6].

2. Methods

A stable austenitic stainless steel was investigated. It is a low-nickel high-manganese variant with a significant amount of copper. The chemical composition can be seen in Table 1. Narrow strips were cold-rolled in small increments until the targeted cold-reduction of 33% was achieved.

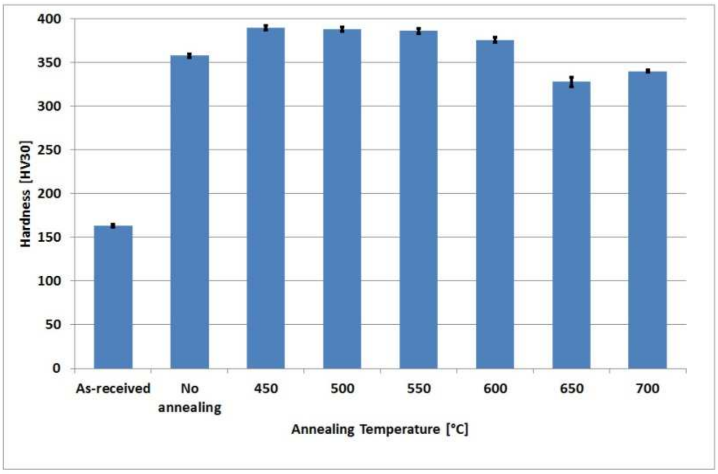
Table 1. Chemical composition of the investigated steel.

Grade	C	Mn	Cr	Ni	Cu	N	Mo	S
201Cu	0,047	5,7	17,3	4,7	2,39	0,107	0,21	0,002

The cold-rolled material was annealed at various temperatures for 60 min and the Vickers-hardness was measured with a load of 30 kg. Metallography samples were mechanically polished and electrolytically etched with 40 ml distilled water (H_2O) and 60 ml of 65% nitric acid (HNO_3) solution. A voltage of 1 V was used for 30 s. Stresstech X3000 X-ray diffraction apparatus was used to determine the peak shift and peak broadening of selected samples. Tensile tests were performed in rolling direction according to EN 10002-1 using a strain rate of $3 \cdot 10^{-4}$ /s. SEM-EBSD and TEM were used to image the microstructure. EBSD samples were mechanically polished down to 1 µm diamond paste and the deformation layer was electrolytically etched away using A2 etchant and a 30 V potential difference. TEM samples were mechanically ground to 30 µm thickness using a Gatan Disc Grinder and ion milled in a Gatan 691 PIPS apparatus. Finally, pitting corrosion potential in an aqueous 0,35% NaCl solution was measured at room temperature using a Gamry 600 corrosion cell.

3. Results

Vickers-indentation shows that hardness increases dramatically from the as-received condition when the steel is cold-rolled to a 33% reduction. Annealing at 450-600℃ increases the hardness even further, but it begins to drop when the annealing temperature is 650℃ or above (Figure 1). Tensile tests confirm the increased resistance to plastic deformation caused by low-temperature annealing. Simultaneously, uniform elongation is enhanced (Figure 1).



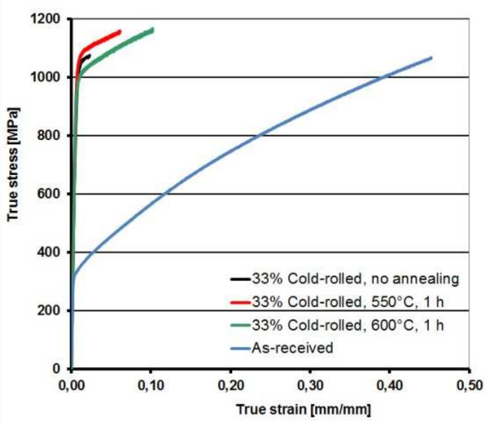


Figure 1. Hardness (left) and tensile behaviour (right) for different thermo-mechanical treatments.

Minor changes in the recovered microstructure are apparent from the micrographs when the annealing temperature exceeds 600℃, but the recrystallized fraction is very low (Figure 2).

The compressive stresses introduced during cold-rolling are relaxed as the annealing temperature rises. Peak broadening is evident even when residual stresses have returned to baseline values indicating crystal defects are still present (Figure 2).

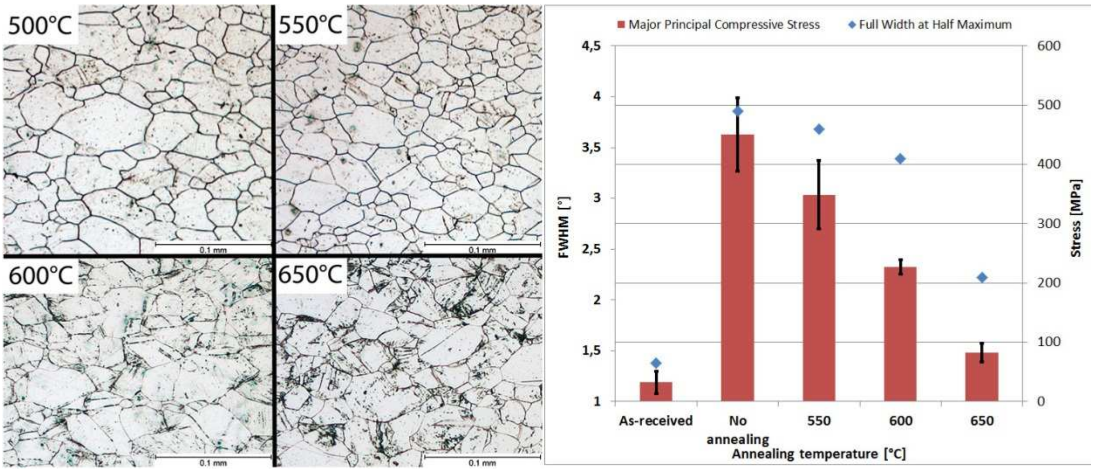


Figure 2. Cold-rolled samples annealed at different temperatures and etched to reveal grain boundaries (left). Residual stress and peak broadening for different treatments (right).

The deformed microstructure shows extensive twinning, which explains the high strain hardening rate of the as-received material. The EBSD scan was not able to index all twin boundaries and TEM was used to distinguish finer details (Figure 3). HR-TEM confirms changes in crystal orientation at the twin boundaries (Figure 4).

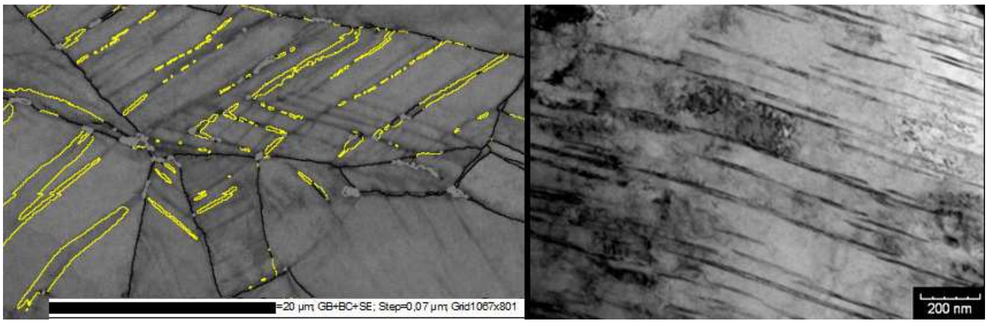


Figure 3. EBSD microgragh of the deformed structure showing twin boundaries in yellow (left) and TEM micrograph (right).

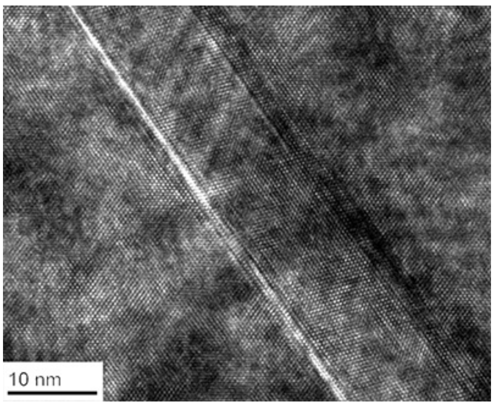


Figure 4. HR-TEM image showing the twins to be approximately 10 nm wide.

Annealing can affect the corrosion resistance of stainless steels via formation of precipitates. Pitting corrosion potential was measured for samples annealed at different temperatures. Annealing at temperatures above 550℃ for one hour reduced the pitting corrosion potential from 495±27 to 358±95 mV (SCE).

4. Discussion

Cold-rolling and annealing a stable Type 201Cu austenitic stainless steel resulted in high hardness and yield strength combined with good uniform elongation. Bundles of fine twins were observed in the microstructure even after annealing, which explains the high strength. Elongation improved after annealing due to the relaxation of residual stresses and a lower concentration of crystal defects was seen. However, the thermal treatment affects adversely the corrosion properties.

5. References

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