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Improved microstructural homogeneity and mechanical property of medium manganese steel with Mn segregation banding by alternating lath matrix

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ABSTRACT

The influence of Mn segregation banding on the microstructure homogeneity and mechanical property of medium manganese system steels with both equiaxed and lath-like microstructures has been investigated by adding the pre-quenching treatment before the intercritical austenitization and subsequent quenching & partitioning process (IQP). Both the crack observation and KAM characterization in these two types of microstructure intuitively indicate different micro-cracking resistance and in-grain strain accommodation of intercritical ferrite during the deformation. The excessive inhomogeneous microstructure and blocky retained austenite with low stability accelerate the failure of the material with Mn segregation banding. The fine lath-like ferrites with great contact ratio to the surrounding martensites improve the microstructural homogeneity under pre-quenching process. The alternative arrangement of lath-like soft ferrite and hard martensite results in optimal mechanical properties of material with Mn segregation banding.

1. Introduction

Recently, increasing interests have been focused on the quenching and partitioning (QP) [1] process of medium Mn system steels owing to their excellent combination of strength and formability [2–5]. QP process after an intercritical austenitization (IQP) results in the formation of ductile intercritical ferrite and enrichment of austenite-stabilizing elements. Elevated Mn alloying increases the volume fraction of retained austenite (RA), and also leads to both microscopic grain boundary segregation and macroscopic segregation banding. Grain boundary engineering [6–8] mainly concerned with the segregation of manganese on the grain boundary is committed to improving the embrittlement resistance of grain boundary in Medium-Mn steel. While microstructural bandings with the Mn segregation [9–13] can be hardly improved except for a high cost homogenization. As a result of segregation bandings, a complicated deformation behavior of different phase constitution inside various microchemical bandings can be expected, which related to diverse mechanical properties. For example, enhanced formability and ductile fracture of a TRIP steel with obvious segregation was reported, as the banded martensite arrangement leads to the easily deformation of massive ferrite regions [14]. In our previous study, microstructural bandings cannot be fully eliminated under different austenitizing conditions without pre-homogenization treatment, but the microstructure adjustment by utilizing chemical heterogeneity before QP process improves the final mechanical property [15]. In this paper, microscopy and microanalysis techniques are applied on the banding segregation combined with IQP treatment. The deterioration to the properties due to Mn segregation is suppressed, by changing the morphologies of different phases, especially intercritical ferrite, from polygonal to lath-like shape.

2. Experimental procedure

2.1. Material details and heat treatment

Two different initial microstructures retaining Mn segregation banding in medium-Mn steel are designed and prepared for the comparative study under IQP process. The precise composition is: Fe-0.25C-3.08MN-1.5Si-0.054 Nb, wt%. The ingots (30 mm × 75 mm × 100 mm) of 25 kg laboratory smelted steel were reheated to roughly 1200 °C for 1 h and hot rolled to 4.5 mm with the coiling temperature of 650 °C. Rectangular specimens (70 mm × 220 mm) were machined from the cold rolled sheets of 1.5 mm parallel to the rolling direction. The heat treatment experiments were performed on the continuous

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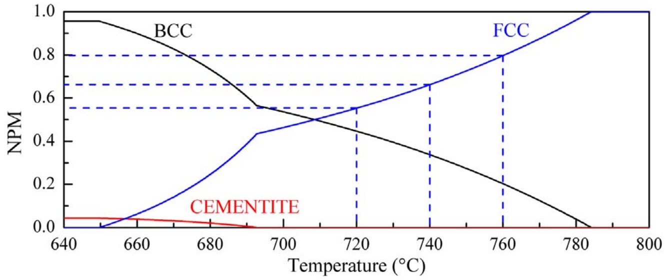

Fig. 1. Phase fraction as a function of temperature of the studied alloy.

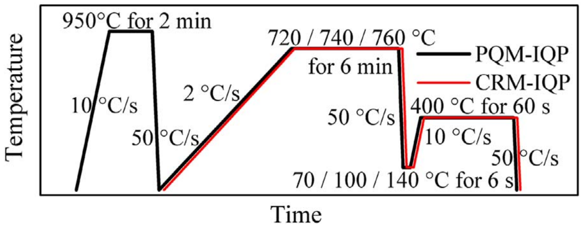

Fig. 2. Schematic of the heat treatment.

annealing simulator (CCT-AY-IIproduced by Ulvac-Riko INC.). Part of the rectangular specimens were pre-quenched (named as PQM) from 950 °C held for a very short time, noticing that the permanent elimination of microstructural banding can be only achieved by high temperature homogenization treatments for a long time [10]. The phase fraction as a function of temperature was calculated by the Thermos-Calc based on the TCFE7, as shown in Fig. 1. Thus, three intercrtical annealing temperatures of 720 °C, 740 °C and 760 °C were designed to obtain the different phase proportions. Partition processing was carried out at 400 °C for 60 s. Different quenching temperatures were designed for each sample. A special quenching temperature for each sample with the highest retained austenite fraction was determined by experimental validation. Another initial microstructure after cold rolling (named as CRM) was also processed by the same treatment, as shown in Fig. 2.

2.2. Microstructural characterization and mechanical testing

To help the understanding, Electron-probe microanalysis (EPMA) of the Mn concentration distribution in the microstructure was carried out using a JEOL JXA8230 SEM. The accelerating voltage was 20 kV, and the beam current in the focused probe was 10 nA. Area scans were performed on a total area of 40 * 30 μm^2 with a step size of 0.1 μm.

Tensile properties were estimated by the uniaxial tensile test with the standard specimen (according to the GB/T 228.1-2010 standard, Gauge length: 50 mm). The tests were performed with a crosshead speed of 2.0 mm/min at room temperature. The resulting microstructures were observed by Zeiss ULTRA 55-type field emission scanning electron microscopy (FE-SEM) after etching with 2% nital. Electron backscatter diffraction (EBSD) was performed on the samples both before and after the tensile test with 20 kV and a step size of 0.05–0.1 μm. EBSD data was processed with Channel 5 software provided by Oxford HKL Technology. The surfaces of the samples for EBSD were electrolytically polished with a negligible internal stress in a mixture reagent of 20% perchloric acid and 80% ethanol with the voltage of 15 V for 20 s. Twin-jet polishing technique (5% perchlorate alcohol at − 30 °C, applied potential of 50 V) was implemented to prepare thin foil samples for the transmission electron microscopy (TEM) observation (JEM 2100).

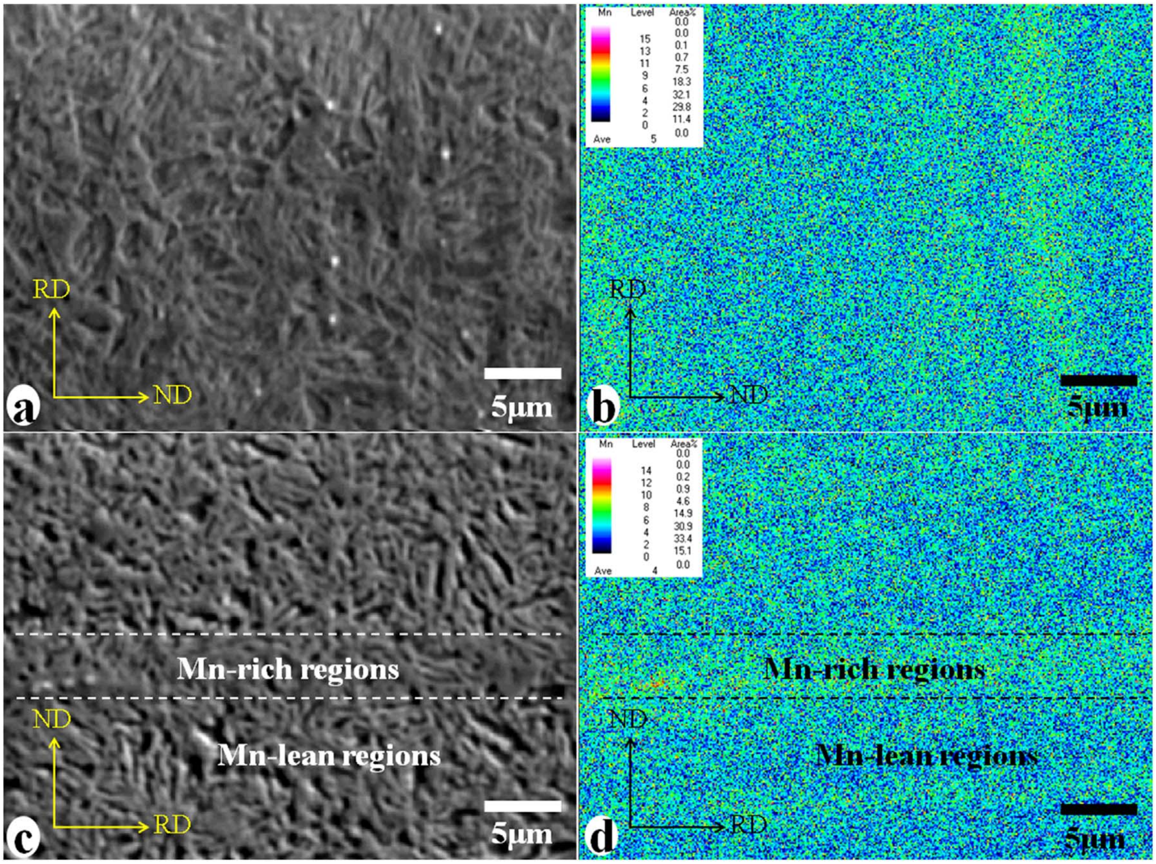

Fig. 3. Electron-probe microanalysis of secondary electron contrast micrograph (a & c) and Mn distribution (b & d) for the microstructure after per-quenching (a & b) and PQM-740QP (c & d) processed Fe-0.28C-3.08MN-1.42Si-0.054 Nb steel. The “RD” and “ND” denote the rolling direction and normal direction, respectively.