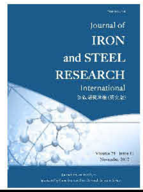
Journal of Iron and Steel Research, International 24 (2017) 1125—1130

ScienceDirect

Contents lists available at ScienceDirect

Journal of Iron and Steel Research, International

journal homepage: www.chinamet.cn



Effects of strain states on stability of retained austenite in medium Mn steels

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ARTICLE INFO

Key words:
Medium Mn steel
Strain state
Retained austenite
Stability
Stacking fault
Twin martensite

ABSTRACT

Based on uniaxial tensile and plane strain deformation tests, the effects of strain states on the stability of RA (retained austenite) in medium Mn steels, which were subjected to IA (intercritical annealing) and Q&P (quenching and partitioning) processing, were investigated. The volume fractions of RA before and after deformation were measured at different equivalent strains. The transformation behaviors of RA were also investigated. The stability of RA differed across two different transformation stages at the plane strain state: the stability was much lower in the first stage than in the second stage. For the uniaxial tension strain state, the stability of RA corresponded only to a single transformation stage. The main reason was that there were two types of transformations from RA in the medium Mn steel for the plane strain state. One type was that the martensite originated in the strain-induced stacking faults (SISF). The other type was the strain-induced directly twin martensite at a certain equivalent strain. However, for the uniaxial tension state, only the strain-induced twin martensite was observed. Dislocation lines and dislocation tangles were also observed in specimens deformed at different strain states. In addition, complex microstructures of stacking faults and lath-like phases were observed within a grain at the plane strain state.

1. Introduction

Energy conservation and emission reduction in the form of lightweight automobiles is the main strategy adopted by the automobile industry to solve the problems of environmental pollution and energy shortage. The application of AHSS (advanced high strength steel) such as TWIP (twinning induced plasticity) steel and TRIP (transformation induced plasticity) steel has become a new trend to this end[1,2]. TWIP steel is especially appealing because of its high tensile strength and ductility[3]. However, the high cost and difficulties in its production currently hinder its application in the automobile industry[4]. Therefore, automotive material researchers have increasingly focused on medium manganese (Mn) steels. Previous studies revealed that many medium Mn steels with a Mn content in the range of 3%—12% exhibited high strength, excellent plastic elongation, and large energy absorption capability[5-8]. Some medium Mn steels have even shown similar or superior properties compared to the TWIP steels[4].

At present, medium Mn steels are the ideal materials for automobile manufacturing. The carbon and manganese atoms are gathered in austenite during the IA (intercritical annealing) and Q&P (quenching and partitioning) processing. The application of the combined IA and Q&P (IA+Q&P) processing leads to excellent mechanical properties and optimizes the distribution of retained austenite (RA), resulting in an increase in the stability of RA in medium Mn steels. Based on Cooman et al.[9], the attractive mechanical properties of IA+Q&P processing medium Mn steel were obtained without any decrease in the strength-ductility balance. They believed that the above-mentioned phenomenon was due to the presence of primary α' lath martensite in the microstructure after IA+Q&P processing. Li et al.[10] found that RA was distributed at four different locations in the microstructure after IA+Q&P processing. The results showed that at the early stage of deformation, the RA transformed easily at the triple edges and in the twinned austenite, while

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Received 11 August 2017; Received in revised form 27 September 2017; Accepted 29 September 2017
Available online 15 November 2017
1006-706X/

the RA either embedded completely in a single ferrite or at the boundaries between martensites rotated without any transformation. Song et al.[11] reported that after IA + Q&P processing, the RA could progressively transform into martensite during the whole deformation process; this resulted in a good combination of strength and ductility, and contributed to a high product of strength and elongation (PSE) of 31.9 GPa · %.

As is well known, RA plays an important role in martensite transformation during plastic deformation of TRIP steels[12]. Previous studies showed that the stability of RA was mainly affected by (1) the grain size[13,14], (2) C and Mn concentrations[13,15], (3) morphology and distribution of RA[16], (4) constrain effect from the phases surrounding the austenite[17], and (5) strain state in correlation with the loading direction[18]. These effects were also expected to play a significant role in the stability of RA in the medium Mn steels. Research into the effect of grain size and Mn concentration on austenite stability showed that the non-uniform distribution of Mn could lead to different degrees of austenite stability in the steels. It was observed that the austenite stability decreased with an increase in grain size. Previous studies on the morphology of RA suggested that the ultrafine RA lamellae stability was suitable for a steady and gradual martensite transformation. On the other hand, the presence of blocky RA played a major role in the initiation of voids, which were formed by an abrupt transformation of the low stability RA into martensite. The influence of microstress on RA stability in TRIP steels has been investigated by uniaxial tension, plane strain, and biaxial tension tests[18]. It could only be concluded with regard to the stability of RA that those at the uniaxial tension state displayed the least amount of variation, while those at the biaxial tension state showed the greatest change, and the extent of variation was moderate for those at the plane strain state. However, there are few reports on the effect of strain state on the stability and transformation mechanism of RA, especially for the medium Mn steel with metastable RA processed by IA+Q&P.

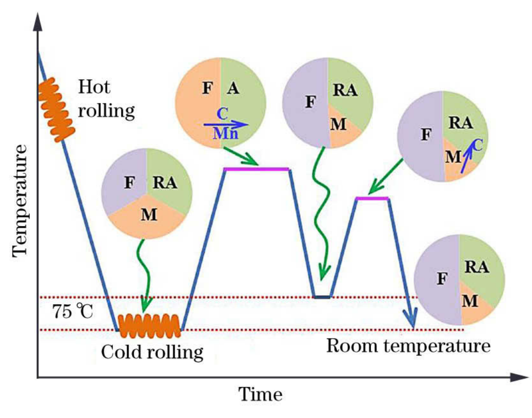
The main objective of the present work is to better understand the effect of strain states on the stability of RA in the medium Mn steel processed by IA+Q&P. The uniaxial tensile tests and plane strain tests were carried out using a universal tensile machine and a cold rolling testing machine, respectively. X-ray diffraction (XRD) was employed to quantify the evolution of RA fraction as a function of strain. Finally, transmission electron microscopy (TEM) was used to investigate the transformation behaviors of RA.

2. Experimental Procedure

The medium Mn steel used in this study was melted in a vacuum induction melting furnace under argon atmosphere. The exact chemical composition is shown in Table 1. The ingots were forged into several billets with dimensions of 70 mm × 80 mm × 35 mm, which were then subjected to hot rolling. The hot-rolled steels with a final thickness of 3 mm were cold rolled to a thickness of 1.2 mm, followed by IA + Q&P processing. A schematic of the IA + Q&P processing of the medium Mn steel used in this study is shown in Fig. 1. The critical transformation temperatures were determined with a DIL805 quenching dilatometer, using cylindrical specimens with diameter of 4 mm and length of 10 mm. The results showed that the austenite-starting temperature (A_{c1}) and austenite-finishing temperature (A_{c3}) are 582 and 745 ℃, respectively. The martensite-starting temperature (M_s) is 175 ℃. Therefore, the optimum IA+Q&P heat treatment was commenced with an IA temperature of 660 ℃ for 10 min, followed by cooling to 75 ℃ for 10 s at the rate of 50 ℃/s. Subsequently, the specimens were reheated to the partitioning temperature of 450 ℃, followed by isothermal holding for 60 s, and then directly quenched at the rate of 50 ℃/s to room temperature.

Table 1
Chemical compositions of tested steels (wt.%)

C	Si	Mn	Fe
0.22	1.53	6.83	Balance



F—Ferrite; M—Martensite; RA—Retained austenite.

Fig. 1. Schematic of IA+Q&P processing for medium Mn steel used in this study.

The uniaxial tensile tests were conducted using an MTS universal testing machine. The medium Mn steel plates after IA+Q&P processing were cut into dog-bone tensile specimens by a wire cutting machine. The specimens had a gauge length of 15 mm along the roll-