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Effects of Bainite Isothermal Temperature on Microstructure and Mechanical Properties of a δ-TRIP Steel

Xu Xin[1, 2], Liu Rendong[2], Xu Baoyu[1], Yi Hongliang[1], Wang Guodong[1]

[1]The State Key Laboratory of Rolling and Automation, Northeastern University, Shenyang110819, P.R. China
[2]Angang Steel Co., Ltd. Technology Centre, Anshan114009, P.R. China

ag_xuxin@126.com

Abstract. In this work, the microstructure, properties and retained austenite characteristics of a δ-TRIP steel containing 3.0% Al at different isothermal temperatures in the bainite region were researched by means of scanning electron microscopy, tensile test and XRD. The evolution of austenite and the effect on microstructure and mechanical properties were investigated. The results show that the high Al element in δ-TRIP steel can effectively inhibit the precipitation of carbides in austenite and obtain more stable austenite which can lead to an excellent combination of elongation and tensile strength. When the isothermal temperature is 400 °C, the comprehensive mechanical properties are the best, the tensile strength reaches 800 MPa, and the elongation exceeds 40%.

1. Introduction

With the requirements of energy saving, environmental protection and safety in the automotive industry, lightweight body has become an inevitable choice [1], and the steel industry has also been developed to produce a new generation of automotive steel with high strength and excellent forming performance [2].

At present, major steel companies are committed to the development of the third generation of automotive steel, the representative steels are mainly quenching and partitioning(Q&P) steel, medium manganese steel and δ-TRIP steel [3-5]. Among them, δ-TRIP steel, as a typical third-generation automobile steel, promotes the formation of δ-ferrite by adding Al element, and can also hinder the precipitation of carbides, thereby forming stable retained austenite, achieving a perfect match between strength and plasticity [6]. Therefore, δ-TRIP steel has broad application prospects. In this paper, a new type of δ-TRIP steel with tensile strength of over 800 MPa and total elongation of more than 40% has been designed. The effects of bainite isothermal temperature on the microstructure and properties of δ-TRIP steel is studied.

2. Material and procedure

In this paper, the experimental δ-TRIP steel was casted into an 80 kg ingot using a vacuum induction melting furnace and rough rolled to a cross-sectioned dimension of 35 mm × 150 mm× 300 mm square slabs. The chemical composition of the steel in wt.% was Fe-0.40C-0.21Si-1.01Mn-2.89Al. The slabs were completely austenitizing at 1200 °C for 2 hours and then hot rolled into a 3.0 mm sheet by seven passes on a reversing hot rolling mill, and the final rolling temperature was set at 850 °C, then air cooled to room temperature. The hot-rolled plates were pickled by 10% hydrochloric acid and then cold rolled to 1.5mm.

A rectangular specimen of 220 mm × 120 mm × 1.5 mm was cut along the rolling direction on the cold-rolled sheet, and the heat treatment process of specimens was performed on a continuous annealing simulation machine. In order to study the effects of bainite isothermal temperature on microstructure and properties of δ-TRIP steel, three as-cold-rolled specimens were kept at the critical zone temperature (820°C) for 5 min, then cooled to the bainite transformation zone with a 20 °C/s rate, which involved isothermally holding at 375、400、425°C for 10min, respectively. The annealing process is shown in figure 1.

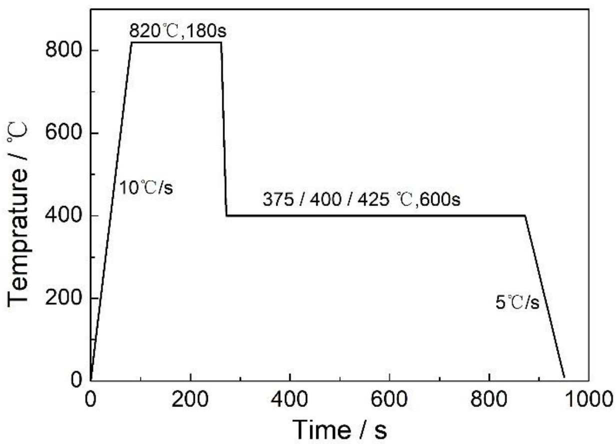

Figure 1. Schematic of annealing process of the experimental δ-TRIP steel.

The annealed samples were processed into tensile specimens with a gauge length of 50 mm according to the national standard GB/T 228.1-2010, and the prepared tensile specimens were subjected to tensile tests using the Zwick Z100 material test system. Microstructure of specimens was examined by SUPRA 55 scanning electron microscope (SEM). The D5000 X-ray diffractometer was used to obtain the diffraction pattern; the formula of retained austenite content was as follows [7]:

$$V_r = {1.4I_r}/{(I_\alpha + 1.4I_r)} \tag{1}$$

where V_r is the volume fraction of retained austenite; I_r is the average integrated intensity of the austenite at {200}, {220}, and {311} plane diffraction peaks; I_α is the average integrated intensity of ferrite at {200},{211} plane diffraction peaks. The carbon content of retained austenite is calculated by the following formula [7]:

$$W_c = {(a_r - 3.578)}/{0.033} \tag{2}$$

where W_c is the mass fraction of carbon in retained austenite, %; a_r is the lattice constant of retained austenite.

3. Results and discussion

3.1. Effect of bainite isothermal temperature on microstructure

The microstructure of the experimental δ-TRIP steel samples at different isothermal temperatures in the bainite region is shown in figure 2. It can be seen from figure 2 that the microstructure of the three specimens is relatively fine, mainly composed of ferrite, bainite and retained austenite. Since the annealing temperature and soaking time of the samples are identical, the proportion of ferrite should theoretically be consistent [8]. With the bainite isothermal temperature increasing, the ratio of bainite and retained austenite changes accordingly. When the bainite isothermal temperature is at 375 °C, due to the lower temperature, some austenite may transform into martensite after the bainite transformation, and the retained austenite content in the sample is low, so the tensile strength is highest. When the bainite isothermal temperature is raised to 400 °C and 425 °C, most of the austenite in the sample is transformed into bainite.

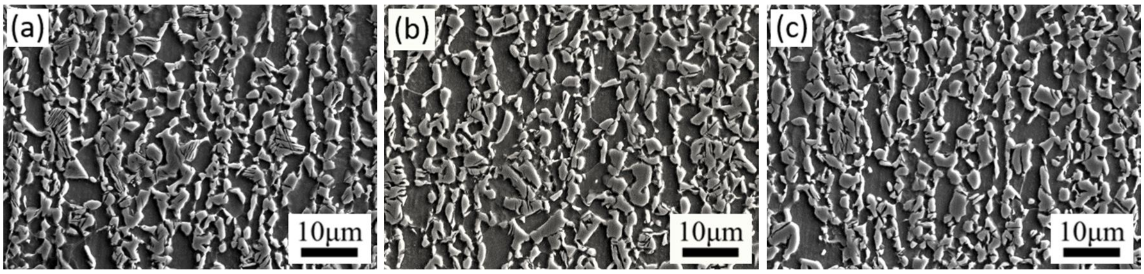

Figure 2. SEM micrographs of δ-TRIP specimens at different bainitic isothermal temperatures (a) 375°C; (b) 400°C; (c) 425°C.

When the bainite isothermal temperature is at 375 °C, the Carbon diffusion is limited, resulting in insufficient Carbon enrichment in austenite, and the stability of retained austenite is deteriorated. Some of the austenite is transformed into martensite in the subsequent cooling process after bainite isothermal transformation. Finally, less retained austenite is obtained at room temperature. When the bainite isothermal temperature is raised to 400 °C, the rate of Carbon diffusion from ferrite to austenite is accelerated. During the bainite isothermal treatment, the austenite completes carbon enrichment, which increases the stability and content of retained austenite [9]. When the bainite isothermal temperature is raised to 425 °C, the austenite is more easily transformed into bainite, so that the amount of retained austenite finally obtained is slightly lower than that at 400 °C.

3.2. Effect of bainite isothermal temperature on mechanical properties

Figure 3 shows the mechanical properties of the experimental steel at different isothermal temperatures in bainite regions. It can be seen that the isothermal temperature in the bainite region has a great effect on the mechanical properties of the experimental steel [10]. When the isothermal temperature in the bainite region is 375 °C, the yield strength of the specimen is 544 MPa, the tensile strength is up to 831 MPa, and the elongation of the specimen is 33.1%. As the bainite isothermal temperature increases, the tensile strength of the specimen decreases while the elongation increases. When the bainite isothermal temperature is at 400 °C, the yield strength and tensile strength of the specimen are 550 MPa and 794 MPa respectively, and the elongation is significantly improved, reaching 40.6%. When the isothermal temperature continues to rise to 425 °C, the yield strength and tensile strength change little, 543 MPa and 781 MPa respectively, and the elongation rate is also reduced to 37.9%. It can be seen that when the bainite isothermal temperature is at 400 °C, the comprehensive mechanical properties of the sample are the best, and the product of strength and elongation reaches a maximum value of 32.2 GPa·%.

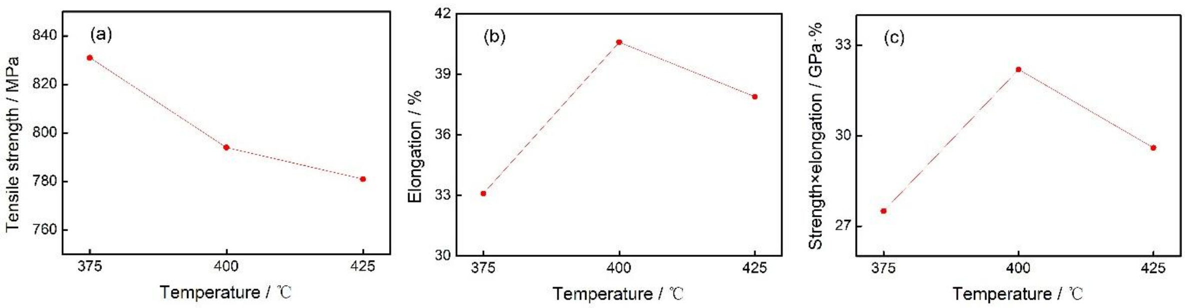

Figure 3. Mechanical properties of δ-TRIP specimens at different bainitic isothermal temperatures

(a) tensile strength; (b) elongation; (c) product of strength and elongation.

In δ-TRIP steel, ferrite is softer than bainite [11], when the experimental steel is subjected to stress during the stretching process, the yield first occurs in the ferrite matrix [12]. Although the bainite isothermal temperature rises to 400 °C and 425 °C, the yield strength of δ-TRIP specimens doesn't change much, because the ferrite ratio was theoretically the same. For δ-TRIP steel, the volume fraction and stability of retained austenite in the specimen will greatly affect the mechanical properties.

3.3. Effect of isothermal temperature on austenite characteristics

Table 1 shows the volume fraction and carbon content of retained austenite in the specimens at different bainite isothermal temperatures calculated from the relevant data. It can be seen from table 1 that when the isothermal temperature in the bainite region is 400 °C, the volume fraction of retained austenite reaches a maximum value of 15.9%. In δ-TRIP steel, the high content of Al plays an important role in the stabilization of austenite, thus providing a condition for retained austenite content increasing [13].

Table 1. Volume fraction and carbon content of retained austenite of δ-TRIP specimens under different bainitic isothermal temperatures.

Bainitic isothermal temperature / °C	Retained austenite amount / vol.%	Carbon content of retained austenite / wt.%
375	11.6	1.97
400	15.9	2.03
425	13.2	2.12

Even the isothermal temperature of 375 °C is higher than the Ms point. Due to the larger phase change driving force, a large amount of austenite transforms, and the volume fraction of retained austenite at room temperature is small. With the bainite isothermal temperature increases, the driving force of bainite transformation decreases, the carbon diffusion accelerates, the carbon content of retained austenite increases, and the stability of retained austenite increases.

Figure 4 shows the gradient of retained austenite content distribution in different regions of the specimens after stretching. It can be seen that much of the austenite does undergo martensitic transformation during deformation, this part of the austenite transformation not only improves the plasticity of the steel, but also increases the strength of the steel [14]. At the same time, some of the austenite is retained even at a distance less than about 5mm away from the point of fracture, it indicates that there is much relatively stable retained austenite in the specimens.

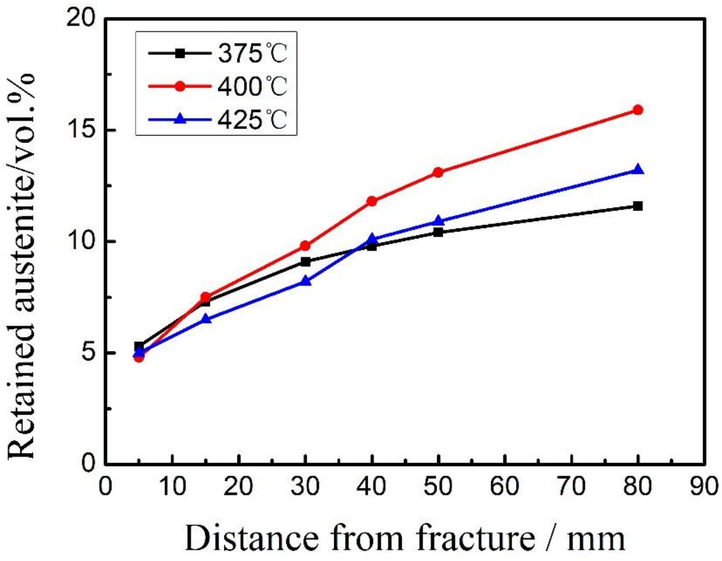

Figure 4. Retained austenite in different regions after fracture in tensile specimen.

4. Conclusions

This study examined the retained austenite stability of a δ-TRIP steel with different bainitic isothermal temperatures. The main findings of the investigation are as follows:

(1) Aluminum is a strong austenite stabilizing element, which is beneficial to the formation of retained austenite, thereby increasing the retained austenite content at room temperature.

(2) With the increase of bainite isothermal temperature, the proportion of ferrite in the microstructure of δ-TRIP steel is basically unchanged, and the ratio of bainite and retained austenite changes, which determines the different mechanical properties of TRIP steel;

(3) In δ-TRIP steel, retained austenite is the key to product of strength and elongation. When the bainite isothermal temperature is at 400℃, the volume fraction of retained austenite is the highest, reaching 15.9%, and the product of strength and elongation exceeds 32.2GPa%.

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