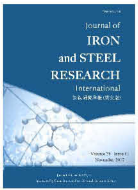
Journal of Iron and Steel Research, International 24 (2017) 1104-1108

Contents lists available at ScienceDirect

Journal of Iron and Steel Research, International

journal homepage: www.chinamet.cn



Tensile behavior and deformation mechanism of quenching and partitioning treated steels at different deforming temperatures

Lian-bo Luo[1,2], Wei Li[1,2], Yu Gong[1,2,*], Li Wang[3], Xue-jun Jin[1,2,**]

[1] Institute of Advanced Steels and Materials, School of Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

[2] Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai Jiao Tong University, Shanghai 200240, China

[3] State Key Laboratory of Development and Application Technology of Automotive Steels, Baosteel Research Institute, Shanghai 201900, China

ARTICLE INFO

Key words:
Quenching and partitioning treated steel
Mechanical property
Deforming temperature
Retained austenite
Work hardening behavior

ABSTRACT

The effects of deforming temperatures on the tensile behaviors of quenching and partitioning treated steels were investigated. It was found that the ultimate tensile strength of the steel decreased with the increasing temperature from 25 to 100 ℃, reached the maximum value at 300 ℃, and then declined by a significant extent when the temperature further reached 400 ℃. The total elongations at 100, 200 and 300 ℃ are at about the same level. The steel achieved optimal mechanical properties at 300 ℃ due to the proper transformation behavior of retained austenite since the stability of retained austenite is largely dependent on the deforming temperature. When tested at 100 and 200 ℃, the retained austenite was reluctant to transform, while at the other temperatures, about 10 vol. % of retained austenite transformed during the tensile tests. The relationship between the stability of retained austenite and the work hardening behavior of quenching and partitioning treated steels at different deforming temperatures was also studied and discussed in detail. In order to obtain excellent mechanical properties, the stability of retained austenite should be carefully controlled so that the effect of transformation-induced plasticity could take place continuously during plastic deformation.

1. Introduction

In order to improve fuel efficiency, reduce emissions and ensure safety for the automobile industry, tremendous efforts have been spent to investigate and develop advanced high strength steels (AHSS) with multiphase microstructures (at least two different constituents such as austenite, ferrite, martensite or bainite)[1-3]. Among the AHSS, the quenching and partitioning (Q&P) treated steel proposed by Speer et al. [4,5] has drawn much more attention and is expected to be a promising candidate for the new generation of AHSS. Through quenching and partitioning treatment, the typical microstructure of the Q&P steel comprises ferrite, carbon-depleted lath martensite and significant amount (about 10 vol. %) of retained austenite (RA)[6].

The Q&P steel can achieve an attractive mechanical property with the combination of ultra-high strength and ductility due to the austenite-to-martensite transformation during the deformation, which is the so-called transformation-induced plasticity (TRIP) effect. It has been extensively explored with respect to the factors that may influence the stability of austenite, which include chemical composition[7,8], austenite grain size[9,10], as well as other constraints such as morphology, residual stress[11-14] and so on. Moreover, deforming temperature is also an important parameter affecting the mechanical properties of the steels. Deforming temperature has a significant effect on the Gibbs free energy of austenite and martensite and determines the transformation behavior of retained austenite during tensile test. Min et al. [15] reported the mechanical stability and transformation behavior of both film and blocky RA at different temperatures.

---

* Corresponding author. Res. Assoc., Ph.D.; Tel.: +86 21 54745567; Fax: +86 21 54745567.
E-mail address: *yugong@sjtu.edu.cn* (*Y. Gong*).
** Corresponding author. Prof., Ph.D.; Tel.: +86 21 54745560; Fax: +86 21 34203098.
E-mail address: *jin@sjtu.edu.cn* (*X.J. Jin*).

Received 17 August 2017; Received in revised form 13 October 2017; Accepted 16 October 2017
Available online 15 November 2017

Furthermore, understanding the effects of deforming temperature on the stability of RA and the tensile behaviors of the Q&P steel is definitely very helpful in the design of the fabrication procedure for this kind of steel. However, as we know, not much work on this research field can be found from literature. Therefore, for the present project, the stability of RA and the tensile behaviors of the Q&P steel at various deforming temperatures ranging from 25 to 400 ℃ were investigated. Moreover, the work hardening behaviors and microstructural evolution of this steel at different temperatures were also discussed in detail.

2. Experimental Procedure

The thin sheets of the commercial Q&P steel used in the present study were supplied by Baosteel. The nominal composition is Fe-0.2C-1.40Si-1.80Mn (wt.%). Tensile tests were carried out on samples with standard dimensions (5 mm in width, 16 mm in gauge length, and 1.0 mm in thickness, as seen in Fig. 1) in a Zwick Z100 universal testing machine at a constant strain rate of 5.2×10^{-4} s^{-1}. The testing temperatures include 25, 100, 200, 300 and 400 ℃. For warm deformation, the tensile bar was put in an open air furnace at 100, 200, 300 or 400 ℃ and held there for 10 min to make it homogeneous at the desired temperatures prior to tensile test. Scanning electron microscope (SEM) samples were etched in a 4 vol.% nital solution and observed in a TESCAN VEGA 3 SEM for microstructural analysis.

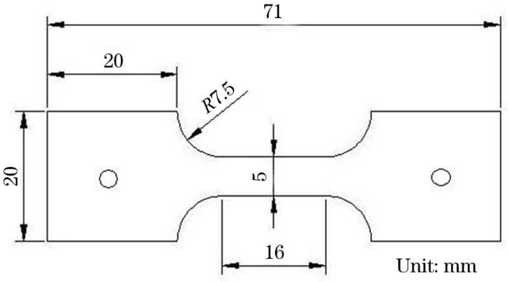


Fig. 1. Schematic diagram of sample for tensile test.

In order to determine the volume fraction and the average carbon content of RA, X-ray diffraction (XRD) experiments were performed with a scanning speed (2θ) of 5(°)/min in a D/max 2550 X-ray diffraction analyzer. The average carbon concentration of RA was obtained using the following equation[16,17]:

$$a_\gamma=0.3556+0.00453x_{\mathrm{C}}+0.000095x_{\mathrm{Mn}}+0.00056x_{\mathrm{Al}} \quad (1)$$

where, x_{C}, x_{Mn} and x_{Al} are the concentrations (wt.%) of carbon, manganese, and aluminum in RA, respectively.

To evaluate the volume fractions of RA at 25 ℃, a Quantum design physical property measurement system (PPMS-9T EverCool-II) was used to measure the magnetization of the samples. The sample size is 2 mm × 2 mm × 1.0 mm. A magnetic field ranging from 0 to 5 T was applied onto the samples by a step size of 0.25 T. The volume fraction of RA (f_γ) was calculated by the following equation[18]:

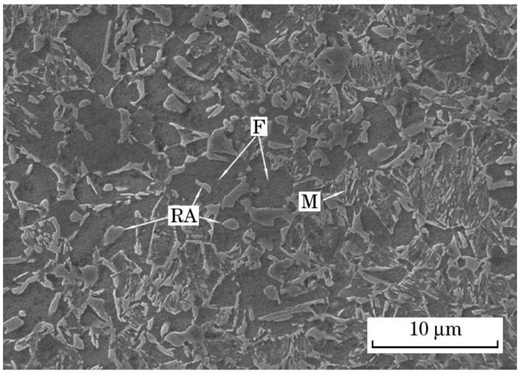
$$f_\gamma=1-\beta\frac{M_{\mathrm{s}}(c)}{M_{\mathrm{s}}(f)} \quad (2)$$

where, $M_{\mathrm{s}}(c)$ is the saturation magnetization of the tested sample; and $M_{\mathrm{s}}(f)$ is the saturation magnetization of the austenite-free sample. $M_{\mathrm{s}}(c)$ and $M_{\mathrm{s}}(f)$ were obtained by fitting the magnetization curves. β is the ratio of the saturation magnetization of the austenite-free sample to that of ferrite and this parameter is set to 0.987 for the present steel.

3. Results and Discussion

3.1. Microstructure

Fig. 2 shows the SEM microstructure of as-received Q&P steel. The Q&P steel mainly consists of three phases, i.e. ferrite, martensite and RA. The lath-like martensite was homogeneously distributed in the ferrite matrix. The RA particles can be observed in different regions, such as in the ferrite grains, in the martensite or on the phase or grain boundaries. The average size of RA is (1.33±0.33) μm measured by linear intercept method.



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

Fig. 2. SEM microstructure of as-received Q&P steel.

3.2. Mechanical properties

Fig. 3(a) shows the engineering stress *vs.* strain curves of the steels tested at different temperatures. The mechanical properties, including tensile strength, total elongation, and product of tensile strength and total elongation (PSE) are presented in Fig. 3(b). It can be seen that the tensile strength decreases when the temperature increases from 25 to 100 ℃. Then, the tensile strength increases to the maximum at 300 ℃ and declines by a significant extent when the temperature further reaches 400 ℃. The total elongations (around 32%) of the Q&P steels tested at