JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2016, 23(2): 130-137

Work Hardening Behavior and Stability of Retained Austenite for Quenched and Partitioned Steels

Cun-yu WANG[1,2], Ying CHANG[3], Jie YANG[4], Wen-quan CAO[1], Han DONG[1], Yi-de WANG[2]

(1. Central Iron and Steel Research Institute, Beijing 100081, China; 2. Taiyuan Iron and Steel Group Co., Ltd., Taiyuan 030003, Shanxi, China; 3. National Key Laboratory of Industrial Equipment Structural Analysis, School of Automotive Engineering, Dalian University of Technology, Dalian 116024, Liaoning, China; 4. Society of Automotive Engineers of China, Beijing 100055, China)

Abstract: Both microstructure and mechanical properties of low alloy steels treated by quenching and partitioning (Q&P) process were examined. The mixed microstructure of martensite and large-fractioned retained austenite (about 27.3%) was characterized and analyzed, excellent combinations of total elongation of 19% and tensile strength of 1835 MPa were obtained, and three-stage work hardening behavior was demonstrated during tensile test. The enhanced mechanical properties and work hardening behavior were explained based on the transformation-induced plasticity effect of large-fractioned austenite.

Key words: Q&P process; work hardening; retained austenite; martensite; mechanical property; TRIP effect

Based on the requirements for vehicle's mass reduction and safety improvement, high-strength steels combined with adequate ductility and formability, such as dual-phase (DP), transformation-induced plasticity (TRIP) and complex steels, have been developed[1,2]. The third-generation automotive steels with higher value of $R_m \times A$, i.e. the product of tensile strength (R_m) and total elongation (A), and lower cost have attracted great attention in recent years, and the mechanical properties of both R_m above 1500 MPa and $R_m \times A$ more than 30 GPa · % are the important objects for the third-generation automotive steels[3-5].

Speer et al.[6,7] proposed a novel heat treatment process, i.e. the so-called quenching and partitioning (Q&P) process, aiming to produce steels with mixed microstructure of martensitic matrix and carbon-enriched austenite to improve the mechanical properties of high strength steels. Q&P process involves mainly quenching step and partitioning step. The former is to quench the austenized steel to a temperature between the M_s (martensite-start temperature) and M_f (martensite-finish temperature) so as to create a mixture of martensite phase and untransformed austenite phase; the latter is to reheat directly to a higher temperature to make the untransformed austenite stable, during which carbon is expected to be rejected from supersaturated martensite phase into austenite phase. Finally, the steel is quenched to room temperature after Q&P process. A certain volume fraction of stable retained austenite contributes to the high strength and good ductility for Q&P steels[4,8-13].

The austenite-to-martensite transformation can induce high hardening rate during deformation, which can improve both strength and ductility[14-16]. It is found that $R_m \times A$ increases almost linearly with increasing austenite fraction, with an increment of 0.6—0.7 GPa · % per 1% γ[4]. In this paper, the Q&P processes were applied to low alloy steels, which is an attempt to obtain large-fractioned retained austenite and improve the ductility of ultra-high strength

Foundation Item: Item Sponsored by Youth Science Funds of China (51101036); National Basic Research Program of China (2010CB630803); National Key Technology Support Program of China (2013BAE07B05)

Biography: Cun-yu WANG, Doctor, Senior Engineer; **E-mail**: wangcunyu@ec-cisri.com.cn; **Received Date**: July 21, 2014

steel through TRIP effect of retained austenite.

1 Experimental Procedure

Two low alloy steels were melted in a vacuum induction furnace, and forged into bar with diameter of 16 mm. The compositions of tested steels are given in Table 1. Different carbon contents were used to evaluate the strength of steels and the stability of retained austenite. Meanwhile, Ni was added to improve the stability of retained austenite, and Mo and V were added to improve the strength of steels. Also, Nb was applied to refine grain size.

Table 1 Chemical compositions of tested steels mass%

Steel	C	Si	Mn	Cr	Ni	Mo	V	Nb	S	P
A	0.2	1.75	0.290	1.00	2.86	0.30	0.08	0.05	0.001	0.006
B	0.4	1.70	0.027	1.05	1.83	0.62	1.68	—	0.001	0.005

The specimens went through Q&P treatment as follows: the specimen was heated to 900 ℃, held for 15 min, and then quenched in salt bath to quenching temperatures of 330 ℃ for steel A and 250 ℃ for steel B, respectively, held for 1 min, partitioned at 500 ℃ for 1 min in another salt bath, and finally quenched into water at room temperature. For comparison, traditional quenching and tempering (Q&T) processes were carried out as well: austenitizing at 900 ℃ for 15 min, quenching in oil at room temperature, and then tempering in a muffle furnace at 300 ℃ for 2 h.

Tensile test was performed at strain rate of 10^{-3} s^{-1} on the dog-bone shaped specimens with gauge length of 25 mm and diameter of 5 mm in an Instron machine (WE-300). The volume fractions of retained austenite were measured by X-ray diffractometer (XRD). Specimens were ground and mechanically polished, and then electrolytically polished in the mixture of chromic acid and distilled water (1 : 9). Specimens were scanned over a 2θ ranging from 45° to 115° with a step size of 0.02° and dwelling time of 2 s in PHILIPS APD-10 XRD, operated at 35 V and 35 mA with a graphite monochromatic and filtered cobalt radiation. Both austenite peaks of {200}, {220}, and {311} and ferrite peaks of {200} and {211} were measured so as to calculate the volume fraction of austenite of each peak V_i based on Eq. (1), which is the average of V_i.

$$V_i = \frac{1}{1+G(I_\alpha/I_\gamma)} \tag{1}$$

where, I_α and I_γ are the integrated intensity of ferrite and austenite peaks, respectively. The G value for each peak was used as follows: 2.5 for $I_\alpha(200)/I_\gamma(200)$, 1.38 for $I_\alpha(200)/I_\gamma(220)$, 2.02 for $I_\alpha(200)/I_\gamma(311)$, 1.19 for $I_\alpha(211)/I_\gamma(200)$, 0.06 for $I_\alpha(211)/I_\gamma(220)$, and 0.96 for $I_\alpha(211)/I_\gamma(311)$. Moreover, carbon content in austenite phase was calculated by Eq. (2)[17].

$$a_0 = 3.555 + 0.044x \tag{2}$$

where, a_0 is austenite lattice parameter, nm; and x is carbon content, mass%. The lattice parameter was estimated from an average based on the austenite peaks of {220} and {311}.

The microstructures were characterized by scanning electron microscope (SEM, S-4300) and transmission electron microscope (TEM, H-800), respectively. For the microstructure observation in scanning electron microscopy, samples were ground and polished mechanically, and then etched by 2% nital for 30 s. For the microstructure examination in transmission electron microscopy, samples were firstly ground mechanically to a thickness of about 0.04 mm, and then were electro-polished in a twin-jet machine in a solution of 5% perchloric acid and 95% alcohol at about −20 ℃.

2 Results and Discussion

2.1 Microstructure characterization

Both steels were processed by different heat treatments. The microstructures characterized by SEM are shown in Fig. 1. For the specimens treated by Q&P process (Figs. 1(a) and 1(b)), not only lath martensite but blocky phase with size of 1 μm to 3 μm can be observed, and the blocky phase is difficult to be examined without further heat treatment. For the specimens treated by Q&T process, traditional lath martensite is obtained, and the block and packet in microstructure can be clearly observed, as shown in Figs. 1(c) and 1(d). The fine microstructure of blocky phase in Q&P processed specimens can be obtained after tempering at 200 ℃ for 1 h (Fig. 2). It is well known that the tempered martensite is prone to be etched due to the precipitation nucleation and growth of the cementite, while the fresh martensite is difficult to be etched. According to the difference, it can be concluded that the easily etched