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Effect of retained austenite stability and morphology on the hydrogen embrittlement susceptibility in quenching and partitioning treated steels

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ABSTRACT

The effect of retained austenite (RA) stability and morphology on the hydrogen embrittlement (HE) susceptibility were investigated in a high strength steel subjected to three different heat treatments, i.e., the intercritical annealing quenching and partitioning (IAQP), quenching and partitioning (QP) and quenching and tempering (QT). IAQP treatment results in the coexistence of blocky and filmy morphologies and both QP and QT treatments lead to only filmy RA. No martensitic transformation occurs in QT steel during deformation, while the QP and IAQP undergo the transformation with the same extent. It is shown that the HE susceptibility increases in the following order: QT, QP and IAQP. Despite of the highest strength level and the highest hydrogen diffusion rate, the QT steel is relative immune to HE, suggesting that the metastable RA which transforms to martensite during deformation is detrimental to the HE resistance. The improved resistance to HE by QP treatment compared with IAQP steel is mainly attributed to the morphology effect of RA. Massive hydrogen-induced cracking (HIC) cracks are found to initiate in the blocky RA of IAQP steel, while only isolate voids are observed in QP steel. It is thus deduced that filmy RA is less susceptible to HE than the blocky RA.

1. Introduction

Introducing carbon enriched metastable retained austenite (RA) into martensitic matrix by quenching and partitioning (Q&P) treatment is proved to be promising to develop multiphase high strength steels without compromising its ductility [1–3]. The resulting transformation induced plasticity (TRIP) effect upon deformation contributes to the enhanced work hardening rate and thus increases the ductility [4]. Unfortunately, this high strength steel is most vulnerable to hydrogen embrittlement (HE) [5,6] and the role of RA on the HE in this multiphase steel has not been fully understood.

The current understanding of HE susceptibility with respect to microstructure increases in the following order: ferrite, lower bainite, quenched and tempered martensite, pearlite, spheroidized microstructure and martensite [7,8]. However, RA has not yet been taken into account because of the contradictory results. Given that it is the diffusible hydrogen that causes degradation, RA is expected to mitigate HE susceptibility by acting as beneficial hydrogen trap that immobilizes the diffusible hydrogen due to its high hydrogen solubility and low hydrogen diffusivity [9–11]. Correlations between RA and the improved resistance to HE have been observed in numerous high strength steels [12–15]. However, conflicting results are also reported, considering that the transformed fresh untempered martensite associated with the RA is most susceptible to HE [16–18]. The combined effects of locally high internal stress, non-uniform hydrogen distribution and high number of unpinned dislocations due to the transformation cause the initiation of many transgranular HIC cracks at the M/A interface [6]. In view of these two conflicting arguments, it is hypothesized that RA austenite can act as beneficial hydrogen traps providing that no transformation occurs during deformation [19]. Thus, the stability of RA on the HE susceptibility in Q&P steels should be thoroughly investigated to help clarify this assumption.

Of many factors affecting the stability of RA in Q&P steel, the morphology plays the dominant one [4,20]. It is reported in Q&P steel containing RA with two morphologies (blocky and filmy) that the TRIP effect first takes place in the blocky RA while the filmy RA is too stable to transform at strains up to 12% [4]. Blocky type refers to the RA with a regular shape that is situated either within ferrite or along ferrite grain boundary while filmy type is the RA with mean width of 100 nm that is surrounded by lath martensite

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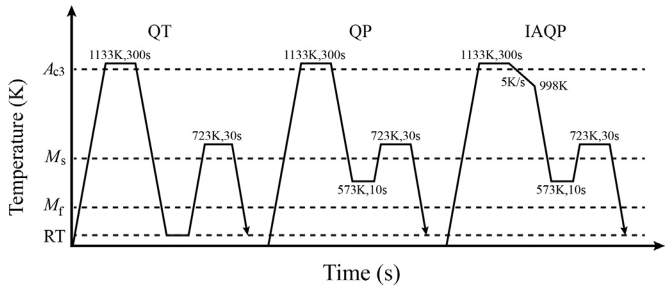

Fig. 1. Heat treatment schedules. QT: quenching and tempering; QP: quenching and partitioning; IAQP: intercritical annealing quenching and partitioning; RT: room temperature.

[6]. Moreover, the blocky and filmy RA may play different roles in response to hydrogen, considering that filmy RA contributes to the enhanced HE resistance of lath martensitic steel [14]. Generally, for Q&P steel with the same chemical composition, the morphology of RA could be regulated by adjusting the austenitizing temperature: fully austenitizing results in filmy RA only while partial austenitizing leads to both blocky and filmy RA [21]. Thus, it is the goal of this study to address the morphology effect of RA on the HE susceptibility in Q&P steels.

2. Experimental methods

2.1. Materials and heat treatments

Cold-rolled steel sheet of 1.4 mm thickness with chemical composition Fe-0.22C-1.40Si-1.80Mn (in wt%) was used in this study. Three heat treatments (as shown in Fig. 1) were performed to introduce RA with various stability and morphology. The microstructures are hereafter referred to as QT, QP and IAQP, respectively.

2.2. Microstructure characterization

Microstructure characterization was performed using scanning electron microscopy (SEM, TESCAN, Czech) and Transmission electron microscopy (TEM, JEOL, Japan). The volume fraction of RA in the three steels was measured by X-ray diffraction (XRD, Rigaku Ultima IV) with a Cu$K_{\alpha1}$ radiation operating at 40 kV and 30 mA. The evolution of RA of the samples before and after tensile testing was quantitatively determined by means of magnetization measurement in a Quantum Design Physical Property Measurement System (PPMS–9T (EC-II)) [22]. SEM examination of hydrogen induced cracking was performed on the longitudinal cross section of fractured specimen, etched with 2% nital solution.

2.3. Hydrogen charging and mechanical tests

Hydrogen was electrochemically charged into the specimens in an aqueous solution of 0.25 m H_2SO_4 containing 0.5 g L^{-1} thiourea at 15–60 mA cm^{-2} for 5 min at room temperature. Tensile test coupons with a 25 mm gage length, 6 mm width and 1.4 mm thickness were prepared according to ASTM-E 8 M-04, polished with 2000 SiC grit papers. Slow strain-rate tensile (SSRT) tests were conducted immediately after hydrogen charging on Zwick Z100 universal testing machine at a constant strain rate of 10^{-5} s^{-1} at 298 K. Fractography was undertaken using SEM (TESCAN, Czech) operated at 20 kV.

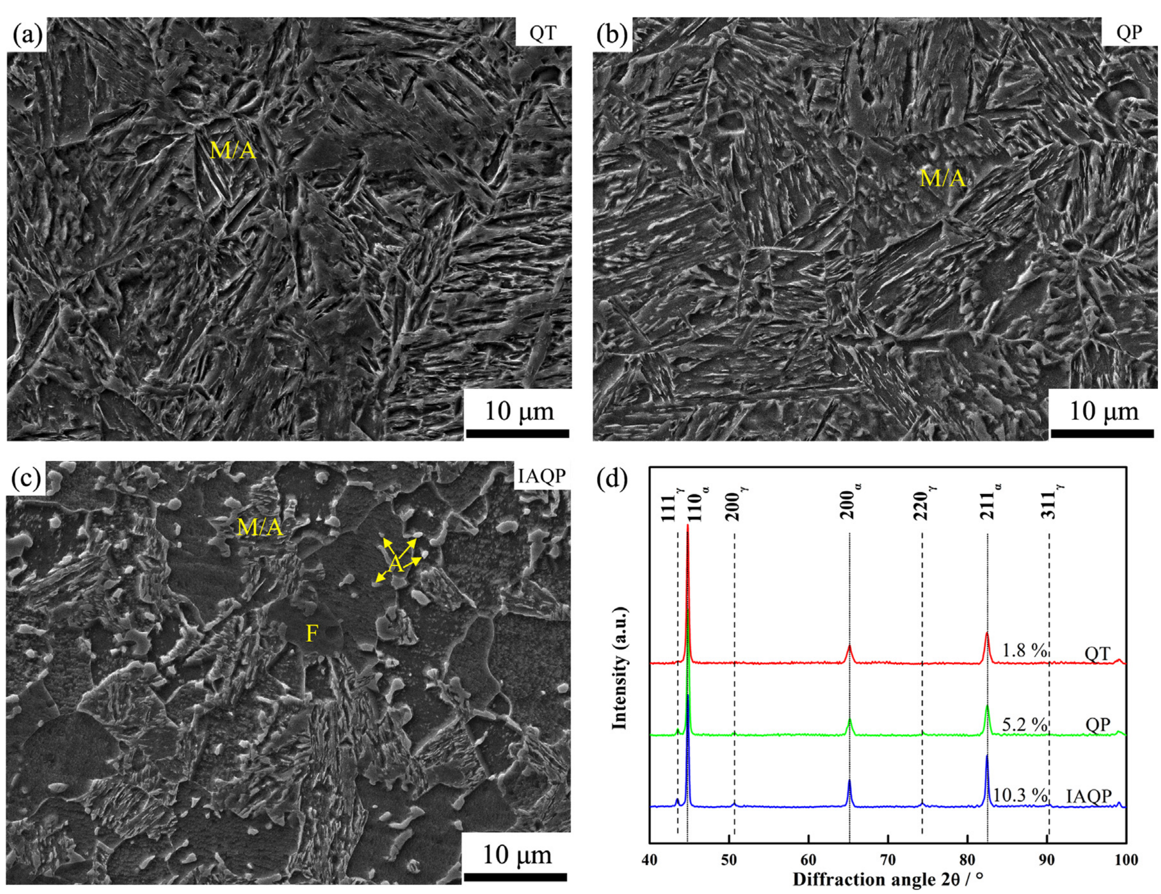

Fig. 2. SEM micrographs of (a) QT, (b) QP and (c) IAQP samples. (d) XRD spectra of the samples treated by QT, QP and IAQP processes. F, A and M/A represent regions interpreted as ferrite, retained austenite and martensite/austenite island.