Thermal Stability of Austenite and Properties of Quenching & Partitioning (Q&P) Treated AHSS

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Abstract

A Fe-0.2C-1.87Mn-1.42Si-0.0405Al steel subjected to an appropriate Quenching & Partitioning treatment (Q&P) exhibits the combination of high tensile strength (1311 MPa) and high elongation (13.6%). The thermal decomposition of retained austenite in the as-treated steel has been studied at an elevated temperature of 500°C by means of differential scanning calorimetry (DSC). Activation energy has been obtained by performing a Kissinger analysis method. The DSC results show that the activation energy of thermal decomposition of the retained austenite in this Q&P steel is 221.3 KJ/mol, which is in a good agreement with the result of retained austenite in similar chemical composition steel subjected to a TRansformation Induced Plasticity (TRIP) treatment. This investigation helps to investigate the stability of retained austenite in Q&P steels upon cooling or under external stress.

Keywords: Quenching & Partitioning (Q&P), differential scanning calorimetry (DSC), Kissinger analysis method

1. Introduction

Over the years, researches on advanced high strength steels (AHSS) have led to the development of steels with improved properties as required by the automobile designs optimized for fuel efficiency and safety (De Moor 2010). Several types of AHSS, such as dual-phase (DP) (Son, Lee et al. 2005) steel and TRIP (De Cooman 2004; Jacques, Furnémont et al. 2007; Lani, Furnémont et al. 2007; Shi, Sun et al. 2010) steel with a carbon content of 0.05–0.2wt%, present good combination of strength (500–1000 MPa) and elongation (15–40%) together with relatively high product of strength and elongation (PSE) (near 20,000 MPa%) in comparison with conventional high strength low alloy (HSLA) steels. Quenching & Partitioning (Q&P) process, which was proposed by Speer et al., has been...
suggested as a cost effective process due to less amounts of alloying elements along with affordable heat treatment (Speer, Matlock et al. 2003; Speer, Edmonds et al. 2004). In contrast to conventional quenching and tempering process, the Q&P treatment introduced a procedure to control the volume fraction of retained austenite that can be stabilized using carbon content present in the martensite at quenching temperature. The degree of stability for retained austenite is one of the key factors to secure a good combination of strength and ductility of Q&P steel (Speer, Matlock et al. 2003). The thermal stability of the austenite during partitioning is of importance during Q&P treatment, an exothermic peak of austenite decomposition was observed in the temperature range of 400°C to 500°C by means of differential scanning calorimetry (DSC) (De Moor 2010). The mechanical stability of retained austenite in Q&P steel, including work hardening behavior, is well studied in the literatures (De Moor, Lacroix et al. 2008; Gibbs, De Moor et al. 2011). However, the thermal stability of retained austenite has not been reported in much detail. This work is aimed to study the thermal stability of retained austenite in Q&P steel during tempering at elevated temperature by means of DSC.

2. Experiment procedures

The composition of the tested steel is (mass percent %): C, 0.20; Si, 1.42; Mn, 1.87; Al, 0.0405; P, 0.012; S, 0.0006; Fe, balance. The as-forged steel from Baosteel was subjected to Q&P process, that is, the steel was austenitized at 900°C for 5 minutes, followed by quenching into salt bath at 320°C for 60 seconds, then further quenched into water at room temperature, hereafter called “Q&P 320-60”. Specimens with full martensite were prepared by quenching into liquid nitrogen after the as-forged steel austenitized at 900°C for 5 minutes, hereafter called “LNQ”.

Mechanical properties were measured on a Zwick T1-FR020TN A50 tensile testing machine (Ulm, Germany) at the strain rate of 10⁻³s at room temperature. The microstructure examination of the samples was conducted using a Nikon EPIPHOT 300 optical microscope (OM) after conventional nital etching.

The volume fraction of austenite at room temperature was determined by X-ray diffraction (XRD) with Cu-Kα radiation using a D/max-2550 X-ray diffractometer based on a direct comparison method of the integrated intensity of (200)γ, (220)γ and (311)γ austenite peaks and (200)α and (211)α ferrite peaks.

Differential scanning calorimetry (DSC) has recently been used (Cheng, Brakman et al. 1988; Morra, Böttger et al. 2001) to study the kinetics of phase transformation. The kinetic parameters of austenite decomposition (E, Ko, and Avrami index n) have been determined for several steels under the assumption that nucleation and growth follow the Johnson- Mehl-Avrami-Kolmogorov (JMAK) law (Avrami 1939). To study the kinetics of austenite decomposition, the as-treated specimens were cut into discs (1.3mm in height, 3.5mm in diameter). Specimens were heated from 25°C to 500°C at a heating rate of 5, 10, 15, 20K/min in DSC chamber, and then cooled to 25°C at a rate of 40K/min. A Kissinger method (Kissinger 1957) is applied to determine activation energy E which will be discussed later with the results.

3. Result and discussion

Fig. 1 shows the optical morphology of LNQ and Q&P 320-60, Fig. 1 (a) shows the LNQ specimen with the general feature of lath-like martensite, which is composed of full martensite after quenching into liquid nitrogen. Fig. 1 (b) shows the morphology of Q&P treated steel with about 55% martensite and 45% bainite and retained austenite plus carbide precipitates, but the retained austenite and carbide precipitates could not be distinguished by optical microscopy method due to limited resolution in metallography. Some literatures (Speer, Edmonds et al. 2004; Clarke, Speer et al. 2008; Li, Lu et al. 2010) reported there maybe bainite formation during the partitioning process, especially partitioning for a longer time.
Fig. 2 shows the XRD spectra of the steels after Q&P 320-60 and LNQ treatment, the volume fraction of retained austenite in Q&P 320-60 and LNQ were estimated to be 10.6% and 1.5%, respectively.

Fig. 3 shows the mechanical properties (a) and work hardening exponent curves (b) (c) of Q&P 320-60 and LNQ. Q&P 320-60 exhibits high tensile strength (1311MPa) and high elongation (13.6%), it can be seen that Q&P treated sample possesses lower strength but significantly higher elongation than LNQ treated specimen. The work hardening exponent values (n) of LNQ and Q&P 320-60 are 0.033 and 0.085, respectively. It can be seen that the work hardening exponent values (n) of two specimens decrease dramatically at elastic stage, then decrease slowly and sustain steady values during uniform deformation. A larger n value and broader range of uniform deformation of Q&P 320-60 indicate it has the relatively better TRIP effect than LNQ due to the TRIP and DARA (Zhang, Zhang et al. 2011; Wang, Zhang et al. 2012) effect of the retained austenite which block the further propagation of cracks and postpone the fracture.

An overview of calorimetric results established by heating with four different heating rates presents in Fig. 4. The DSC raw data of each experiment consists of first run with the LNQ and Q&P 320-60 specimens, and rerun with the same Q&P 320-60 specimen. There are exothermic peaks in the curves of Q&P 320-60 first run with different heating rates in the temperature range of 400°C- 500°C while there is no exothermic peak in the Q&P 320-60 rerun curve and LNQ curve. It can be deduced that exothermic peaks are of austenite decomposition.

The different slopes of the individual curves are causes by different masses of measured samples, and the effect can be eliminated by the different profile between first and rerun scanning for Q&P 320-60 specimens. It is assumed that decomposition of all the retained austenite has completed during the first run, and profile of rerun was used as baseline for the further data evaluation. The activation energy E for a reaction is determined by Kissinger analysis(Kissinger 1957) according to equation(1):

$$\ln\left(\frac{T^2}{\Theta}\right) = \frac{E}{RT} + \ln\left(\frac{E}{R\kappa}\right)$$

(1)
With T is the temperature of austenite decomposition, $\Theta$ is the heating rate, R is the universal gas constant and $K_0$ is the pre-exponential factor. In this method, the temperature of exothermic peak is used as an approximation for the temperature of austenite decomposition for simplicity.

Fig. 5 shows the plots of $\ln(T^2/\Theta)$ versus $1/T$ for the austenite decomposition peaks. The activation energy of austenite decomposition was determined to be $221.3 \pm 5$kJ/mol, the thermal decomposition temperature of retained austenite in the tested Q&P steel is in the range of 400°C to 500°C, which is in agreement with that in the TRIP steel (activation energy 212 kJ/mol, austenite decomposition temperature is 350°C-550°C)(Shi, Li et al. 2008). The thermal decomposition temperature range of retained austenite in quenched steels(activation energy 135-156 kJ/mol) is about 250°C-350°C(Van Genderen, Isac et al. 1997). It seems that the thermal decomposition activation energy of retained austenite in Q&P steel is in good agreement with TRIP steel and relatively higher than quenched steels. Chemical stabilization is believed to be the main reason because carbon is the austenite stabilizing element, which is enriched up to the range of 1.0~2.0% (mass percent) during the partitioning(Speer, Matlock et al. 2003). In addition, manganese being an effective austenite stabilizing element can also shift the decomposition temperature toward higher temperatures(Morra, Böttger et al. 2001). Thermal stability of retained austenite in Q&P treated low carbon steels is believed to have the correlation with the stability of retained austenite upon cooling or under external stress. The detail microstructure dependent stability of retained austenite along with its relation with mechanical properties needs further investigation.

4. Conclusions

(1) A Fe-0.2C-1.87Mn-1.42Si-0.0405Al steel subjected to an appropriate Q&P treatment exhibits the combination of high tensile strength (1311MPa) and relatively high elongation (13.6%).

(2) The thermal decomposition of retained austenite of Q&P steel was investigated by DSC. The peaks corresponding to thermal decomposition of retained austenite in the tested Q&P steel is in the range of 400-500°C, and the activation energy is evaluated as $221 \pm 5$kJ/mol. The thermal decomposition temperature range and activation energy of retained austenite in Q&P steels indicates relatively high thermal stability of retained austenite in Q&P steels.

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References


