

Carbon and Manganese Effects on Quenching and Partitioning Response of CMnSi-Steels

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ABSTRACT

Quenching and partitioning (Q&P) is a novel heat treatment to produce third generation advanced high-strength steels (AHSS). The influence of carbon on mechanical properties of Q&P treated CMnSi-steels was studied using 0.3C-1.5Mn-1.5Si and 0.4C-1.5Mn-1.5Si alloys. Full austenitization followed by two-step Q&P treatments were conducted using varying partitioning times and a fixed partitioning temperature of 400 °C. The results were compared to literature data for 0.2C-1.6Mn-1.6Si, 0.2-3Mn-1.6Si and 0.3-3Mn-1.6Si Q&P treated steels. The comparison showed that increasing the carbon content from 0.2 to 0.4 wt pct increased the ultimate tensile strength by 140 MPa per 0.1 wt pct C up to 1611 MPa without significantly decreasing ductility for the partitioning conditions used. Increased alloy carbon content did not substantially increase the retained austenite fractions. The best combinations of ultimate tensile strength and total elongation were obtained using short partitioning times. Comparison with higher manganese alloys showed that an increase in manganese content from 1.5 to 3 wt pct increased both UTS and TE while an increase in carbon content mainly increased UTS.

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INTRODUCTION

Over the last decade, advanced high-strength steels (AHSS) have received an increasing amount of attention to enable car body weight reduction. Current research focuses on the development of third generation AHSS aiming at filling the gap between first and second generation AHSS [1]. Several grades have been identified as of interest including high-manganese transformation induced plasticity (TRIP) steels and quenching and partitioning (Q&P) steels [1].

Q&P processing was originally proposed by Speer *et al.* [2] and Q&P steels have shown promising combinations of strength and formability [3, 4]. The microstructure of Q&P steels typically includes martensite and significant amounts of retained austenite. The Q&P process can be divided into different steps. The first step involves either full austenitization or intercritical annealing followed by an initial quench to a temperature between the M_s and M_f temperatures. The final step is a so-called partitioning step either at the initial quench temperature (1-step Q&P) or at an elevated partitioning temperature (2-step Q&P). During the partitioning step, carbon diffuses from martensite to austenite thus stabilizing latter. Finally, the steel is water quenched to room temperature and additional fresh martensite may form.

Carbon plays an important role in the Q&P process. Carbon increases the strength of martensite, and decreases the M_s temperature which, in part, enables austenite retention at room temperature if sufficient carbon enrichment of austenite occurs during Q&P. Thus far, a systematic study of the effects of bulk carbon content has not been reported and is the focus of the present contribution.

EXPERIMENTAL PROCEDURE

Two alloy compositions, 0.3C-1.5Mn and 0.4C-1.5Mn shown in Table 1, were investigated and the results were compared to data reported earlier [5] for compositions shown in Table 2. The 0.3C-1.5Mn and 0.4C-1.5Mn steels were received in the cold-rolled state with a thickness of 1 mm and tensile specimens were machined in the rolling direction according to the ASTM-E8 standard geometry [6]. A50 tensile specimen geometry was used for tests cited in [5] and tensile elongations from the A50 specimen geometry were converted to correspond to ASTM-E8 specimen geometry by using the Oliver formula:

$$A_r = 2A \left(\frac{\sqrt{S_0}}{L_0} \right)^{0.4} \quad (1)$$

where S_0 is the original cross-sectional area, L_0 the original gauge length, A_r the elongation for gauge length L_0 , and A the elongation on a proportional gauge length of $5.65\sqrt{S_0}$. The ASTM-E8 specimen geometry was used in [4] for the alloys containing 3 wt pct manganese.

Table 1. Chemical Compositions of Studied Alloys in wt pct.

Designation	C	Mn	Si
0.3C-1.5Mn	0.28	1.48	1.48
0.4C-1.5Mn	0.38	1.54	1.48

Table 2. Chemical Compositions of Alloys Reported in Literature in wt pct [4, 5].

Designation	C	Mn	Si
0.2C-1.5Mn	0.20	1.63	1.63
0.2C-3Mn	0.20	3.00	1.60
0.3C-3Mn	0.29	2.95	1.59

The tensile specimens were Q&P processed using heat treating salts and the heat treating matrix used for all the alloys is shown in Table 3. The employed optimum quench temperatures were calculated according to the methodology proposed by Speer *et al.* [2] and the results are presented in Figure 1. One tensile specimen per Q&P process condition was tested and analyzed. It should be noted that the calculated optimum quench temperatures for the 0.2C-1.5Mn and 0.3C-1.5Mn alloys are similar although greater austenite fractions are predicted for the 0.3C-1.5Mn alloy.

Table 3. Heat Treating Matrix for Studied Alloys.

Designation	Annealing (°C)	Quenching (°C)	Partitioning (°C)	Partitioning Times (s)
0.2C-1.5Mn	850	240	400	10-300
0.3C-1.5Mn	850	242	400	10-300
0.4C-1.5Mn	820	225	400	10-300

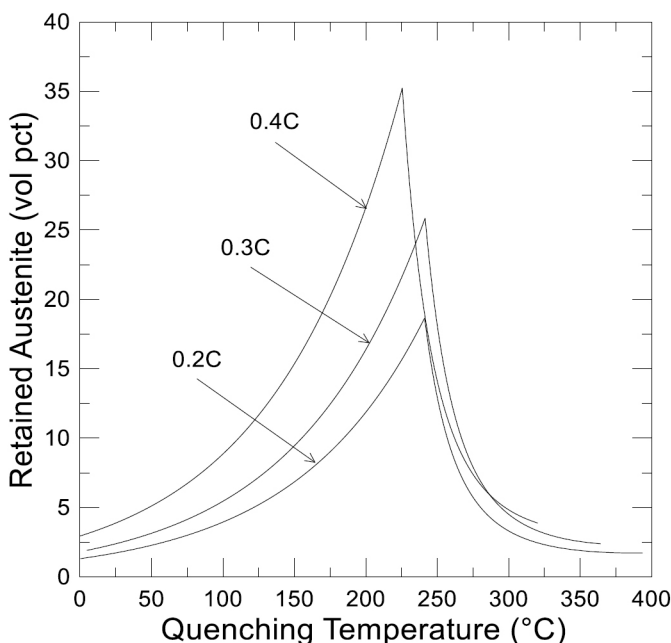


Figure 1. Predicted optimum quench temperatures for the 0.2C-1.5Mn, 0.3C-1.5Mn and 0.4C-1.5Mn alloys.

Tensile properties of the 0.3C-1.5Mn and 0.4C-1.5Mn specimens were assessed by uniaxial tensile testing. After tensile testing, a sample of approximately 12.5 by 20 mm was cut from the tensile specimen grip end for retained austenite measurement using X-ray diffraction (XRD). The samples were ground to 1200 grit and chemically thinned for 10 minutes using a solution of 50 parts of water, 50 parts of 30 pct hydrogen peroxide and 1 part of 48 pct hydrofluoric acid. Austenite fractions were measured with XRD using a Phillips X-pert diffractometer. The diffractometer used filtered copper radiation with an accelerating voltage of 45 kV and an operating current of 40 mA, an X'celerator detector and a 1 degree slit. Scans covered 2-theta angles from 40 to 110 degrees. The austenite content was calculated using four austenite and four ferrite peaks according to the SAE method: {111} {200} {220} {311} and {110} {200} {211} {220}, respectively [7]. The position of austenite peaks {220} and {311} and their relationship to the lattice parameter were used to determine the austenite carbon content according to [8]:

$$a_0 = 3.555 + 0.044x_c \quad (2)$$

where a_0 is the lattice parameter in Ångströms and x_c is the carbon content in wt pct. The retained austenite fractions for the 0.2C-1.5Mn alloy were measured using magnetic saturation [5].

RESULTS AND DISCUSSION

Figures 2, 3, 4 plot the evolution of ultimate tensile strength (UTS), 0.2 pct offset yield strength (YS) and total elongation (TE) as a function of partitioning time and the respective values are presented in Tables 4 and 5. Table 4 also includes the uniform elongation (UE) values.

Figure 2 shows the evolution of UTS as a function of partitioning time. UTS increases with increasing carbon content and decreasing partitioning time. If the UTS values from all of the conditions in Table 4 are considered, an average increase of 140 MPa per 0.1 wt pct C is observed.

The effect of carbon content and partitioning time on YS is shown in Figure 3. The highest values for YS are again obtained for the 0.4C-1.5Mn alloy. For the 0.2C-1.5Mn and 0.3C-1.5Mn alloys the YS seems to first increase and then decrease with increasing partitioning time whereas the YS for the 0.4C-1.5Mn alloy increases with increasing partitioning time. If the YS values from Table 4 are averaged for each alloy, an average increase of 110 MPa per 0.1 wt pct C is observed.

Figure 4 shows the carbon content and partitioning time effects on TE. Similar TE values ranging from 7 to 15 pct were measured for all alloys and the highest TE value was measured for the 0.2C-1.5Mn alloy, albeit at lower strength. In general, the TE values decrease with increasing partitioning time.