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Ferrite hardening response in a low alloy ferrite–martensite dual phase steel

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ABSTRACT

This paper is concerned to investigate in details the variation of ferrite hardening response in conjunction with carbon partitioning developed within ferrite during austenite to ferrite phase transformation in a low alloy ferrite–martensite dual phase (DP) steel. For this purpose, a wide variety of ferrite–martensite DP microstructures consisting different volume fractions of ferrite and martensite have been prepared using step quenching heat treatment processes at isothermal temperature of 600 °C for various holding times. Nanoindentation measurements have been supplemented by energy dispersive X-ray and microprobe wavelength-dispersive spectroscopic analyses to follow the variation of ferrite hardening response and its relation to the carbon concentration of ferrite in the ferrite–martensite DP microstructures. The experimental results showed that the ferrite hardening response is quite variable depending on the progress of ferrite formation in the ferrite–martensite DP microstructures. For a specific ferrite grain in a specific ferrite–martensite DP microstructure, the location nearer to the ferrite–martensite interfaces has been accompanied with a significant higher carbon concentration and simultaneously higher ferrite hardening response in comparison to that of central regions of ferrite grains. These results are rationalized with a higher concentration of carbon within ferrite developed as a consequence of higher carbon entrapment within defected ferrite area generated at early stage of austenite to ferrite phase transformation at more pre-existing defected area of prior austenite grain boundaries, and that the carbon diluted ferrite region is related to the rejection of carbon from interior ferrite area to the ferrite/austenite interfaces developed on the subsequent isothermal holding times.

1. Introduction

Low carbon low alloy ferrite–martensite dual phase (DP) steels are characterized by a ferritic matrix in conjunction with dispersed hardening martensite phase. The remarkable engineering properties of these steels are in association with continuous yielding, high uniform elongation, high ultimate tensile strength, and rapid strain hardening at early stage of plastic deformation [1–3]. These engineering properties are influenced by some of the variable microstructural parameters such as ferrite morphology and ferrite volume fraction, causing a significant variation of ferrite hardening response in low alloy DP steels. Therefore, the hardening behavior of ferrite microphase in ferrite–martensite DP steels has been one of the attractive research areas in physical metallurgy and has been addressed by several investigators [4–7]. Goel et al. [8] have suggested that the transformation of prior austenite to martensite on the subsequent cooling has been associated with the formation of geometrically necessary dislocation in ferrite, which can influence the strain hardening of ferrite in the low alloy DP microstructures. Some of the other investigators [5,9,10] have reported that the work hardening behavior of low alloy ferrite–martensite DP steels are changed with plastic incompatibility between ferrite and martensite microphases. Kumar et al. [11] have also reported that the mechanical behavior of low alloy ferrite–martensite DP steels are related to the size of ferrite grains and concluded that the density of dislocations has been significantly decreased from the ferrite–martensite interfaces to the central region of ferrite grains. Therefore, the hardening response of ferrite in ferrite–martensite DP steels has been reported to be affected with those parameters influencing the formation of geometrically necessary dislocations generated within ferrite during martensitic phase transformation and the role of some other variable parameters such as ferrite morphology, ferrite volume fraction and ferrite carbon concentration on the hardening response of ferrite in DP steels have not been followed considerably. Accordingly, in the present study, it has been tried to find out the influence of ferrite volume fraction and ferrite carbon concentration on the ferrite hardening response in various ferrite–martensite DP microstructures using a commercial grade of AISI4140 steel by means of nanoindentation measurements, EDS and WDS analyses.

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Table 1
Chemical composition of the investigated AISI4140 steel (in wt%).

C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Fe
0.384	0.208	0.673	0.0093	0.0063	0.971	0.154	0.0161	0.0234	Balance

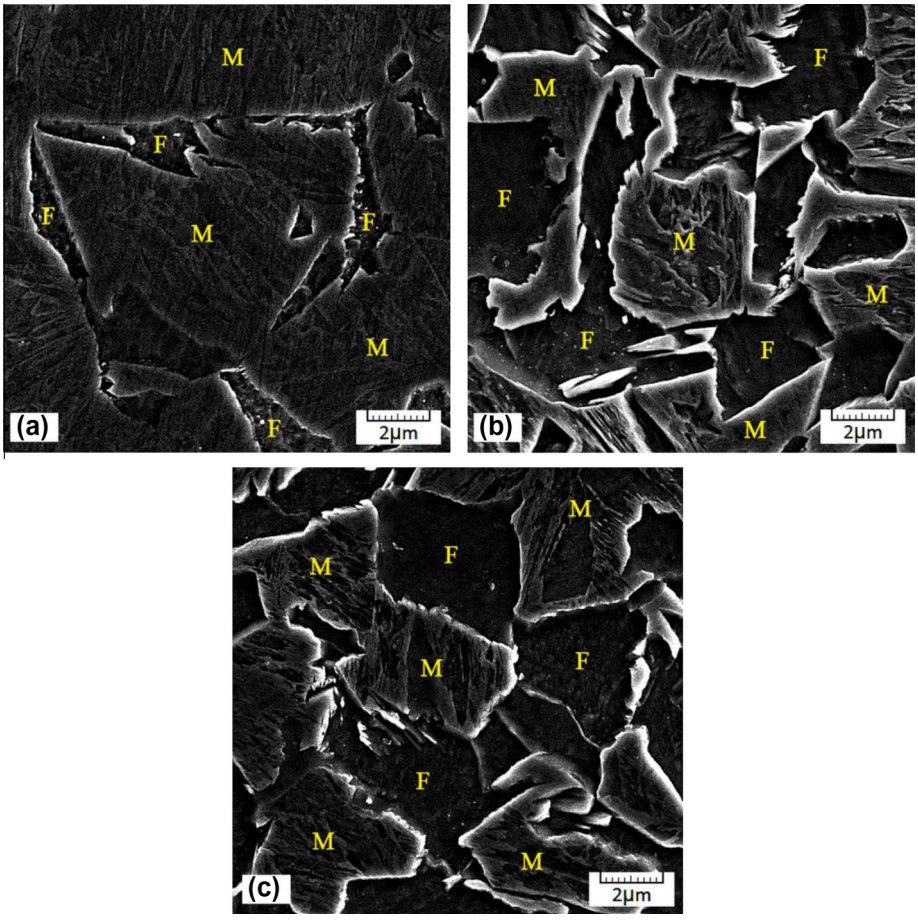

Fig. 1. SEM micrographs showing the progress of ferrite formation in the DP specimens obtained at 600 °C for: (a) 20 s; (b) 25 s; and (c) 35 s. The ferrite and martensite area are marked as F and M symbols, respectively.

Table 2
The results of EDS analysis with the associated standard deviation for carbon concentration within ferrite grains taken from the DP specimens isothermally transformed at 600 °C for 20 (DP 20 s) and 45 s (DP 45 s) holding times. The reported measurements are in accordance with the spot locations marked as A, B, C, etc. in Fig. 2.

Ferrite location	Ferrite EDS number			
	DP 20 s	Standard deviation	DP 45 s	Standard deviation
A	10.6	0.04	10.13	0.12
B	9.72	0.1	9.83	0.07
C	10.27	0.08	9.5	0.04
D	10.4	0.09	9.73	0.09
E	10.66	0.05	10.48	0.14
F	10.78	0.03	11.27	0.05
G	9.4	0.06	11.63	0.13
Average ferrite EDS	10.26	–	10.36	–

2. Material and experimental procedures

In the present investigation, a commercial variant of AISI4140 steel has been used with the chemical composition shown in Table 1. Step quenching heat treatment processes have been applied in order to develop various ferrite–martensite DP microstructures consisting of different volume fractions of ferrite and martensite microphases. The applied heat treatment process has been consisted of the following sequential stages: (a) normalizing after austenitizing at 860 °C for 60 min, (b) re-austenitizing at 860 °C for 60 min to get full homogenous austenite grains, (c) soaking in a 600 °C salt bath for 20–45 s to achieve various ferrite volume fractions, and (d) quenching in a 70 °C hot oil bath to transform all of the metastable austenite to martensite. For each ferrite–martensite DP microstructure, three samples have been heat treated in order to confirm the reproducibility of DP microstructures according to the ferrite and martensite volume fractions. Ferrite and martensite volume fractions have been measured according to the ASTM E562-02 standard [12]. The microstructural observations have been carried out using scanning electron microscopy (SEM) model TESCAN–VEGA-II operating at an accelerated voltage of 15 kV. Both of the spot and line scan energy dispersive X-ray