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Microstructure characterisation of a low density steel by transmission electron microscopic study

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ABSTRACT

The microstructure including precipitates in a low density steel containing 3.3Mn–6.6Al–0.18C (wt%) was investigated using transmission electron microscopy under two heat treatment conditions of annealing (850 °C, 1 min.) and annealing + ageing (400 °C, 10 min.). The phases identified by electron diffraction patterns were ferrite (α), austenite (γ), κ-carbides and M_3C type compounds. Ferrite was the matrix of the microstructures. The κ-carbides were found to contain on average 9.9 wt% Mn and have the following orientation relationship with ferrite: $(2\,2\,0)_\alpha \parallel (2\,0\,0)_\kappa$ with $[1\,1\,2]_\alpha \parallel [0\,1\,1]_\kappa$ and $(1\,1\,0)_\alpha \parallel (1\,1\,1)_\kappa$ with $[1\,1\,2]_\alpha \parallel [0\,1\,1]_\kappa$. Coarsening of κ-carbides was observed in the annealed + aged condition as compared to the annealed condition. The solubility of Al and Mn in bcc ferrite and fcc austenite were determined. The κ-carbides consisted of a wide compositional range of Mn and Al.

1. Introduction

Low density steels are promising materials for automotive applications in order to achieve direct weight reduction and increase in specific stiffness. Usually a high amount of aluminium (>6.5 wt%) is added to reduce the density values of steels. Low density steels with Mn addition have received interest mainly because of their potential of generating multiphase microstructures leading to interesting mechanical properties. Many researchers have studied the phase equilibria and mechanical properties of Fe–Mn–Al–C systems with Mn content ranging from 10 wt% to 30 wt% and Al content up to 10 wt% [1–10]

The present investigation was on a duplex low density steel containing 3.3Mn–6.6Al–0.18C (wt%) which exhibited 7.5% density reduction [11]. The phase equilibria of Fe-Mn-Al-C which had a similar composition to the present study were particularly investigated by Lee et al. and Seol et al. [12,13] found that non-stoichiometric κ-carbide $(Fe,Mn)_3(Fe,Al)C_x$ were present in an Fe–3.0Mn–5.5Al–0.3C (wt%) alloy using transmission electron microscopy (TEM) and atomic probe tomography (ATP). They also suggested that the chemical compositions of the κ-carbide depend on the annealing temperatures [13]. However, in these investigations κ-carbide was considered to be the only carbide type present in the equilibrium system and other carbides such as cementite were omitted from thermodynamic calculations. As a consequence, this could have influenced their judgements on the interpretation of results. Furthermore, since no phase identification by using electron diffraction pattern was carried out [12,13] it was not absolutely certain that the phase equilibrium results of Fe–Mn–Al–C system reported by Le et al. and Seo et al. were correct in their entirety.

In view of the above, the present TEM study was undertaken to identify all the primary phases and secondary phases present in the investigated steel under two heat treated conditions. Contrary to the previous studies, it was found that carbides other than κ-carbide are present in the Fe–Mn–Al–C alloy.

2. Experimental

A steel with composition Fe–3.3Mn–6.6Al–0.18C (wt%) was made in a vacuum induction furnace and cast in the form of laboratory ingots (200 mm × 110 mm × 100 mm). The ingots were reheated at 1250 °C for 1 h, and then hot rolled from 100 mm to 3 mm thickness employing an intermediate reheating at the same temperature. A finish rolling temperature of 900 °C was maintained. Then, the hot rolled strips were cooled on a run-out table to 400 °C followed by furnace cooling to room temperature. Next, the strips were pickled in HCl solution at 85 °C to remove the oxide scales from the surface. Subsequently, the 3 mm-gauge strips were cold rolled to 1 mm thickness with a reduction of 1 mm per pass. The cold rolled sheets were annealed in a programmable furnace at 850 °C with a soaking time of 1 min, and then quenched to room temperature. Some of the

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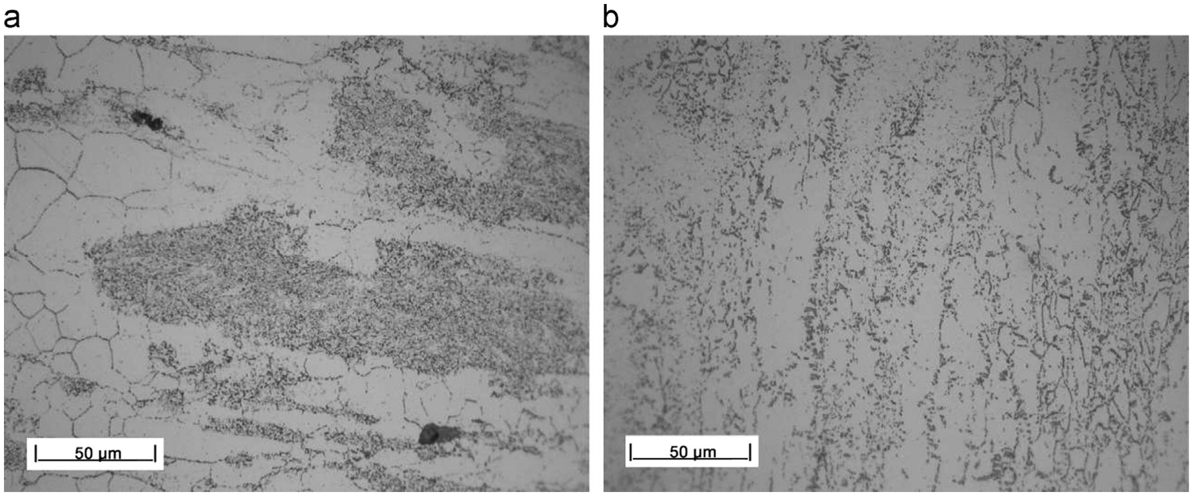

Fig. 1. Optical micrographs showing the overall microstructures of the samples in (a) annealed, and (b) annealed + aged condition.

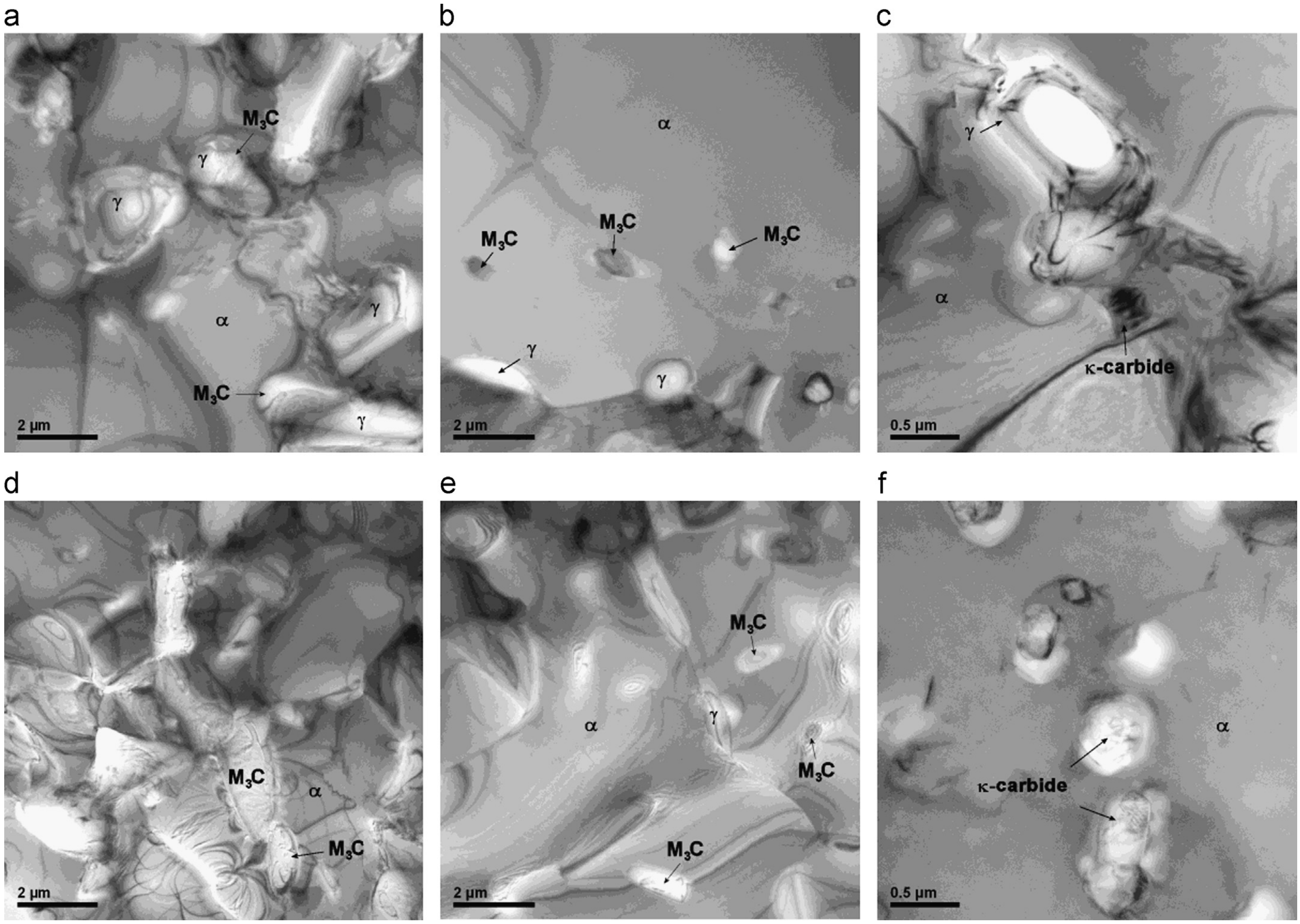

Fig. 2. TEM images showing general microstructure and morphologies of ferrite, austenite, M_3C cementite and κ-carbides in thin foils of ((a)–(d)) annealed, and ((e)–(h)) annealed + aged samples. M designated to Fe, Mn, and Al.

annealed samples were rapidly cooled to 400 °C and subjected to an ageing for 10 min before quenching to room temperature. Typical microstructures of these two different heat-treated steels are shown in Fig. 1.

TEM studies were performed to identify all the primary and secondary phases present in the annealed and annealed + aged conditions of the steel. The carbon extraction method was used to study the compositions of secondary phases and their dimensions.