Manganese partitioning in low carbon manganese steel during annealing

J. Lis, A. Lis, C. Kolan*

Institute of Materials Engineering, Czestochowa University of Technology, 19 Armii Krajowej, 42-200 Czestochowa, Poland

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ABSTRACT

For 6Mn16 steel experimental soft annealing at 625 °C for periods from 1 h to 60 h and modeling with Thermo-Calc were performed to estimate the partitioning of alloying elements, in particular Mn, between ferrite, cementite and austenite. Using transmission electron microscopy and X-ray analysis it was established that the increase of Mn concentration in carbides to a level 7%–11.2% caused a local decrease of the Ac_1 temperature and led to the presence of austenite around the carbides. Thus, after cooling, small bainite–martensite or bainite–martensite-retained austenite (BM-A) islands were observed. A dispersion of carbides and a coarsening process were observed. The measured amount of Mn in the carbides was in good agreement with theoretical predictions.

1. Introduction

In the late 1970s the multiphase steels were introduced as replacements for the ferritic–pearlitic steels used widely for autobody parts. The microstructure of the multiphase steel consists of a polygonal ferrite matrix with bainite and martensite-retained austenite islands. Stabilization of retained austenite after continuous cooling from intercritical temperature in the $\alpha+\gamma$ field is achieved by increasing the amount of manganese and silicon or aluminum in the chemical composition of low carbon steel [1–4]. Results have been presented indicating Mn partitioning among ferrite and austenite during intercritical annealing of low carbon steel containing 2.67% Mn [5]. The ratio of the Mn content in the austenite to the Mn amount in the ferrite was determined. It was found that to achieve an equilibrium balance of Mn partitioning a very long heat treatment time was needed — greater than 300 h. For industrial applications this is a prohibitively long intercritical annealing time to produce the dual-phase $\alpha+\gamma$ structure. In order to explore means for shortening the intercritical annealing time to achieve effective Mn enrichment in the austenite, attention was given to annealing the steel below the Ac_1 temperature to see if that offered improvement. In that temperature range cementite would be enriched in manganese and then during subsequent ($\alpha+\gamma$) annealing, a higher Mn concentration might be achieved through cementite dissolution in the austenite.

The low carbon (0.06% C) high Mn (4% Mn) steel used for the current investigation was annealed below the Ac_1 temperature to enrich the Mn in the cementite and to change very small particles of cementite into austenite islands which were intended to serve as nucleation sites for austenite transformation during the subsequent intercritical annealing. It was believed that cementite enriched in Mn may ensure a higher Mn concentration in the austenite during intercritical annealing in shorter time. Thus the effect of annealing time below Ac_1 was investigated with respect to its influence on Mn concentration in the dispersed carbides. It was assumed that the resulting alloyed cementite would act as heterogeneous nucleation sites for austenite formation, thereby enhancing the amount and dispersion of austenite islands during the next intercritical annealing.

2. Experimental

Bainitic low carbon 6Mn16 steel after controlled rolling was used for these investigations. Its chemical composition is given in Table 1.

* *Corresponding author*. Tel.: +48 34 3250624; fax: +48 34 3250721.
E-mail addresses: lis@mim.pcz.czest.pl, lisj@wip.pcz.pl (A. Lis).

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Table 1 – Chemical composition (wt.%) of the 6Mn16 steel

Grade	Element (wt.%)											
6Mn16	C	Mn	Si	P	S	Cr	Ni	Cu	Mo	Nb	Al	Ti
	0.049	3.97	0.37	0.003	0.009	0.01	0.17	0.02	0.02	0.02	0.02	0.017

The critical temperatures Ac_1=650 °C and Ac_3=821 °C were determined with an 805A/D dilatometer made by Bähr. The annealing temperature 625 °C was chosen to be just below the Ac_1 temperature. The annealing time was varied as 1, 3, 10, and 60 h. After annealing, the microstructure of the steel and Mn partitioning between the various phases was characterized by transmission electron microscopy with Philips 301 and Philips CM20 microscopes, equipped with an EDS attachment. X-ray diffraction examinations were done for specimens annealed for 10 and 60 h at 625 °C with a Seiferd XRD-3003 Diffractometer. Dispersion of the carbide particles was characterized by stereological measurements of their imprints on carbon replicas using software Met-Ilo. A method of Ferret chords in 36 directions projected on the X and Y-axes was applied. From these data an average D_{min}, and correspondingly D_{max} values were established for the measured particles. The amount of chords needed to evaluate the mean chord value with a probability of 95% and relative error of 10% was determined using Eq. (1) [6]

$$n_\beta = \frac{2t_\alpha^2}{\gamma^2}(1 - \bar{L}_\beta) \quad (1)$$

where: $1-\alpha=0.95$

t_α 1.96
γ 0.1 relative error
$\bar{L}_\beta$ Estimated volume fraction of carbides, and
n_β Number of chords

For $\bar{L}$ in the range 0.36–0.44%, as determined after annealing the 6Mn16 steel at 625 °C/1 h, 800 chords were taken from 32 areas having at least 25 particles on each photograph. Software Met-Ilo was used at an image described by 512×512 pixels. Thus for a 90-mm photo line viewed at an applied magnification of 5900× and 512 pixels one can distinguish a single pixel, which represents 29 nm. Hence, the analyses could only take into account particle sizes greater than 30 nm.

3. Results and Discussion

3.1. *Quantitative Characterization of Carbide Size and Distribution*

The carbide distributions and their binary images from carbon replicas are shown in Fig. 1. The use of binary images was necessary for particle quantification with the Met-Ilo program. It was concluded that after annealing at 625 °C the carbide chord distribution may be described by logarithmic-normal histograms for annealing times of 1, 3 and 10 h. The mathematical

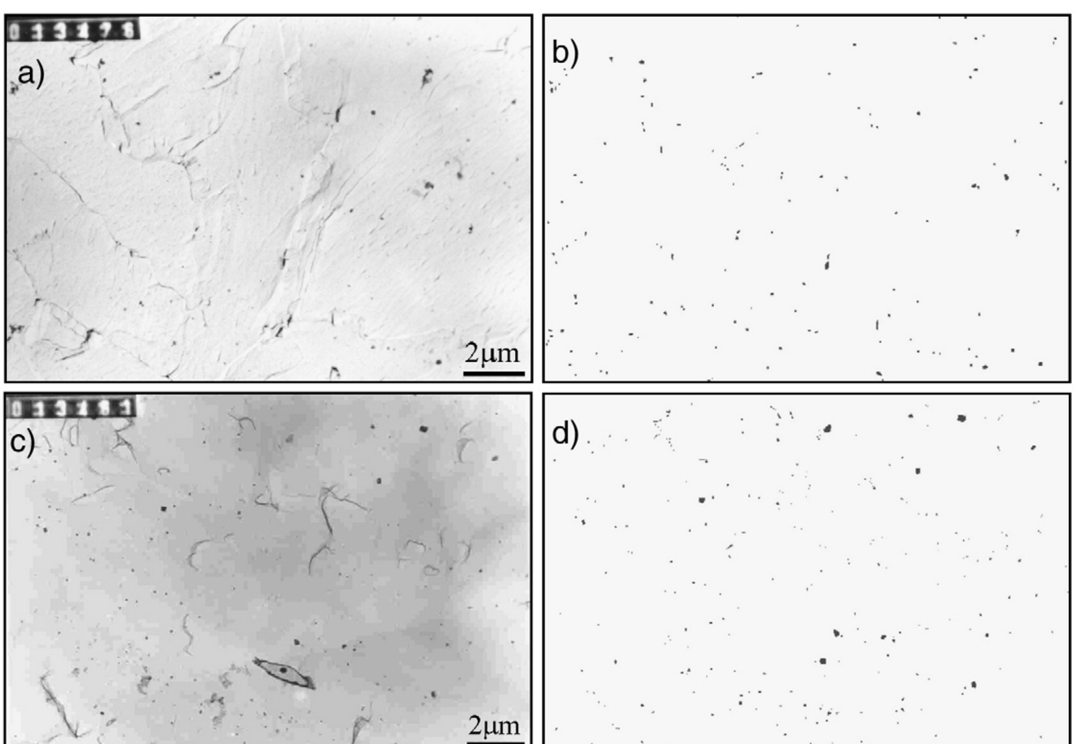

Fig. 1 – Carbides morphology and their binary images for 6Mn16 steel annealed at 625 °C for: a) and b) 1 h; c) and d) 10 h.