MATERIALS CHARACTERIZATION 81 (2013) 56–67

Available online at www.sciencedirect.com

SciVerse ScienceDirect

www.elsevier.com/locate/matchar

Effects of Mn, Si and Cr addition on the dissolution and coarsening of pearlitic cementite during intercritical austenitization in Fe-1mass%C alloy

Guo-Hong Zhang[a, 1], *Jae-Yong Chae*[a], *Kwan-Ho Kim*[b], *Dong Woo Suh*[a,*]

[a] *Graduate Institute of Ferrous Technology, Pohang University of Science and Technology, Pohang 790–784, Republic of Korea*
[b] *Technical Research Laboratories, POSCO, Pohang, Republic of Korea*

ARTICLE DATA

Article history:
Received 31 December 2012
Received in revised form
25 March 2013
Accepted 14 April 2013

Keywords:
Hypereutectoid steel
Cementite
Dissolution
Coarsening
Alloying

ABSTRACT

In order to promote the understanding of the influence of an alloying element on the spheroidization of hypereutectoid steels, the effects of Mn, Si and Cr addition on the dissolution and coarsening kinetics of cementite from pearlitic structure during intercritical austenitization in Fe-1 mass% C alloy have been studied. The spheroidization of cementite lamellae and the kinetics of cementite dissolution are retarded by the addition of Mn or Cr but the influence of Si addition is not remarkable. The coarsening rate of cementite and the final cementite particle size after isothermal austenitization for 3600 s is considerably reduced by the addition of an alloying element. Mn and Cr are more effective than Si in retarding the coarsening of cementite particles and refining the cementite particle size, but the distribution of cementite particles in the Mn-added alloys is inhomogeneous.

1. Introduction

Hypereutectoid steels, such as tool steels and bearing steel, are usually subjected to spheroidization annealing before cold forming to obtain spheroidized microstructure consisting of finely distributed globular cementite in ferrite matrix. The main purpose of this heat treatment is to reduce the hardness and thus provide a good workability [1]. The spheroidization process of hypereutectoid steels is comprised of an intercritical austenitization between the A_1 and A_{cm} temperatures and a subsequent slow cooling. During the intercritical austenitization of hypereutectoid steels with initial pearlite structure, the ferrite transforms to austenite and the cementite lamellae are gradually fragmented, change into round shape and partially dissolved. In prolonged reaction time, coarsening of the globular cementite particles occurs. Upon slow cooling, austenite with cementite particles transforms to a mixture of ferrite and spherical cementite by a reaction known as divorced eutectoid transformation (DET).

The addition of substitutional alloying element has a significant influence on the spheroidization of hypereutectoid steels. Nakano et al. [2] reported that an increase of Cr content in 0.8C steel (all concentrations are in mass % unless stated differently) makes it easy to obtain fully spheroidized structure. But in V or Mo added steel, lamellar pearlite has been observed even after low-temperature austenitization. They concluded that it was because the carbide survived in austenite is different from that precipitated during cooling subsequent to the austenitization. Kim et al. [3] found that an increase of Si content in high carbon Cr bearing steel retards the spheroidization of cementite. They

---

* *Corresponding author at: Graduate Institute of Ferrous Technology, Pohang University of Science and Technology, 77 Cheongam-ro, Nam-gu, Pohang, Gyeongbuk, 790–784, Republic of Korea.* Tel.: +82 54 279 9030; fax: +82 54 279 9299.
E-mail address: dongwoo1@postech.ac.kr (D.W. Suh).

[1] Current address: International Research Institute for Steel Technology, Wuhan University of Science and Technology, Wuhan 430081, China.

1044-5803/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.matchar.2013.04.007

suggested that the increase of Si content enlarged the volume fraction of cementite at austenitization temperature, which possibly results in the incomplete spheroidization. Beswick [4] studied the effect of Cr in the 1C bearing steels and demonstrated that increased Cr produced finer cementite. He attributed this effect to a finer pearlite lamellar spacing in the initial microstructure. Verhoeven [5] studied the alloying effect on the spheroidization of 1.6C steels systematically. He found that the addition of Mn, Ni or Cr could reduce the final cementite size in the spheroidized condition compared to that in Fe–C alloy and Cr was most effective followed by Mn and Ni. But he pointed out that the final cementite particle size was not controlled by the initial pearlite lamellar spacing but by the rate of spheroidization of the cementite lamellae during intercritical austenitization. The carbide forming elements, Cr and Mn, are probably more effective in reducing the spheroidization rate of the cementite lamellae than the non-carbide forming element Ni. However, the detailed influence of alloying element on the spheroidization of hypereutectoid steels is not clearly understood yet.

It is well known that there is no nucleation of cementite particles during the DET reaction because the spheroidized cementite grows directly from the pre-existing tiny cementite particles in austenite matrix [5,6]. Accordingly, the final cementite size after spheroidization annealing is dependent strongly on the size and the distribution of cementite retained after intercritical austenitization. In order to promote the understanding of the alloying effect on the spheroidization of hypereutectoid steels, it is necessary to clarify the influence of alloying element on the dissolution and coarsening of cementite from pearlitic structure during intercritical austenitization. Even with extensive studies on the cementite dissolution in austenite [7–16], especially for the SAE 52100 bearing steel containing 1.5Cr, the influence of Mn and Si has not been paid much attention.

In this study, the dissolution and coarsening behavior of cementite from pearlitic structure during intercritical austenitization was investigated in Fe–1C binary alloy and three Fe–1C–1.5X (X=Mn, Si, Cr) ternary alloys. The effect of Mn, Si and Cr addition to Fe–1C alloy on the dissolution and coarsening of pearlitic cementite is discussed on the basis of thermodynamic and kinetic considerations.

2. Experimental and calculation procedures

2.1. Experimental procedures

An Fe–1C binary alloy and three Fe–1C–1.5X (X=Mn, Si, Cr) ternary alloys were used in this study. They are designated hereafter as 1C, 1.5Mn, 1.5Si and 1.5Cr alloy, respectively. The chemical compositions of these alloys and the calculated A_{cm} temperatures by ThermoCalc software [17] using TCFE6 database are shown in Table 1. The alloy ingots were prepared by vacuum melting, and were hot-rolled into 20 mm thick plates between 1173–1473 K. Bars cut from the hot-rolled ingots were homogenized at 1523 K in an Ar-filled silica tube for 86.4 ks. Cylindrical specimens with 3 mm diameter and 10 mm length were machined from the homogenized bar for heat treatment in a quench dilatometer.

Table 1 – Chemical compositions of the studied alloys and A_{cm} temperatures calculated by ThermoCalc (mass percent).

Alloy	Composition (mass percent)				A_{cm}(K)
	C	Mn	Si	Cr	
1C	0.96	–	–	–	1078
1.5Mn	0.95	1.55	–	–	1078
1.5Si	1.02	–	1.55	–	1140
1.5Cr	1.02	–	–	1.45	1187

In order to fairly compare the effect of alloying element on the dissolution and coarsening of pearlitic cementite, it is necessary to exclude other factors than the alloying effect. Since the initial pearlite interlamellar spacing and the volume fraction of cementite in austenite matrix are known to have important influence on the dissolution and coarsening kinetics of cementite particles [18,19], an appropriate heat treatment procedure should be designed to eliminate any influences from them. Firstly, the following heat treatment was carried out to obtain fully pearlitic microstructure; specimens were austenized at 1373 K for 600 s, cooled rapidly to various isothermal pearlite transformation temperatures and then held for 300 s before quenched to room temperature. The interlamellar spacings at different transformation temperatures were examined, and the appropriate pearlite transformation temperature was determined to control the mean true interlamellar spacing of pearlite in each alloy nearly the same. For the intercritical austenitization, the pearlitic specimens were reheated to the temperature below A_{cm} at a rate of 5 K/s followed by isothermal holding for 0, 10, 100, 300, 600, 1800 and 3600 s, and subsequent quenching (100 K/s) to room temperature by helium jet. The intercritical austenitization temperature is chosen to make the equilibrium cementite fraction at that temperature similar for each alloy. The isothermal temperature for pearlite transformation, the mean true interlamellar spacing, the intercritical austenitization temperature and the calculated equilibrium cementite fraction at the austenitization temperature for each alloy are summarized in Table 2.

Microstructure of specimen was observed using field-emission scanning electron microscope (FE-SEM) with a sample etched with 2% nital after mechanical polishing. The mean true interlamellar spacing of pearlite was measured by a circular test line method [20]. A test circle of diameter d_c is drawn in a single pearlite colony. The number n_d of cementite lamellae intercepted by the diameter was counted. Then, the true interlamellar spacing can be calculated from the equation

$$\lambda_t = \frac{\pi d_c}{4 n_d} \tag{1}$$

The mean true interlamellar spacing of pearlite is the average of more than 40 such measurements for each specimen. The cementite fractions and particle sizes after isothermal austenitization for various times were measured by image analysis of SEM micrographs. The area (A) of a two-dimensinal section at the polished plane was measured for each particle, and converted to an equivalent circle radius ($r = \sqrt{A/\pi}$). And then, the mean particle radius and area fraction of cementite could be determined. The total number of measured particles ranged from 500 to 3000, depending on the alloy and isothermal holding time.