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Effect of deformation on the evolution of spheroidization for the ultra high carbon steel

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Abstract

The hot compression tests were performed on the ultra high carbon steel to investigate the spheroidization mechanism. Several processing routes were designed for this purpose. The experiment results showed that when the samples were austenitized at 1150 °C for 1 min, cooled to 700 °C (above Arcm) with rate of 20 °C/s, deformed with reduction of 60%, cooled with rate of 0.2 °C/s to 550 °C, the excellent spheroidized structure was obtained. The formation of spheroidized cementite is related with the energy stored in the form of dislocations, the breakup or bended cementite and pearlite directly formed during deformation. The lower the deformation temperature (above Arcm) and the longer the cooling time is, the more and better the spheroidized structure can be obtained.

Keywords: Ultra high carbon steel; Spheroidization; Deformation; Transformation

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1. Introduction

Ultra high carbon steel, due to its brittleness, has been neglected for many years for the factories. But in recent years, much attention has been paid to it because of its promising room-temperature mechanical properties [1–4] and superplasticity [5,6]. If the ultra high carbon steel is supplied from the factories in the spheroidized condition, the steel has better machinability and brittleness can be improved. So many researchers' attentions were focused on the study of the spheroidization mechanism for the ultra high carbon steels to obtain excellent spheroidized microstructure.

In fact, the spheroidization methods had been studied before 1930 [7]. From then on more and more scientists began to study it. Among them, Hewit [8] developed the continuous-cool spheroidal annealing and isothermal spheroidal annealing methods based on the work of Heron [9], but these methods need quite long time and so they are not economical. The other's results showed that when the pearlite formed in a non-cooperative mode [10–13], the products would have fine arrays of spheroidized cementite and ferrite, which has good superplastic property. The transformation is always referred as a divorced eutectoid transformation (DET). Walser and co-workers [10] found that when the ultra high carbon steel in the hot and worm working (HWW) condition was austenitized at just above A1 for a relatively short time and cooled in air, a fully spheroidized structure was obtained. During this course, he used the mechanism of the DET. But this process is intricate and difficult to be controlled. When the deformation is imported to the ultra high carbon steel after austenization and during air cooling, which is called divorced eutectoid transformation associated deformation (DETAD), the ferrite grain size would be finer than the sample after DET processing.

Grossmann and Bain [14] believe that the spheroidized microstructure may be from the austenite in which there are many nuclei. These nuclei are likely to be former carbides. Recently, many articles [15–17] reported how to promote spheroidization through the control of DET. However, these studies almost concentrated on the two phase region, there are not enough studies on the effect of deformation on spheroidization of the supercooling austenite for the ultra high carbon steels, i.e. the samples will be deformed above Arcm. Thus, in this paper, the evolution of spheroidization of the deformed austenite for the ultra high carbon steel will be discussed in detail.

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2. Material and methods

Ultra high carbon steel was prepared, in this experiment, to study the evolution of spheroidization. Table 1 shows the chemical compositions of the material used in this experiment. Thermo-Calc software was used to compute the Acm of the ultra high carbon steel, the Arcm was measured by the Gleeble2000 testing machine by using the hot dilation method. The results were that the Acm is 865 °C and the Arcm is about 600 °C with cooling rate of 20 °C/s. The materials firstly were forged to rods with diameter of 15 mm and length of 1 m. Then, the rods were machined to samples with 10 mm in diameter and 15 mm in length for the hot compression tests. The tests were performed on the Gleeble1500 and Gleeble2000 testing machines with different processing routes (Fig. 1). Some of the specimens were austenitized for 1 min at 1150 °C, cooled to 700 °C with rate of 20 °C/s (the microstructure is austenite), then cooled to different temperatures directly with rate of 0.2 °C/s, quenched in water to compare with the specimens deformed at 700 °C followed by cooling with rate of 0.2 °C/s to different temperatures, quenched in water. The aim is to make clear the effect of deformation on the evolution of spheroidization. In order to study the influence of deformation temperature on the evolution of spheroidization, the test that the specimen deformed at 750 °C and slowly cooled to 730 °C with rate of 0.2 °C/s was done. Finally, the different reductions (20 and 40%) followed by slow cooling tests, the various strain rates tests followed by immediately water quenching were executed to study the influence of reduction and the strain rate on the evolution of spheroidization. After those experiments, all the specimens were cut in halves by using the line-incising method to study the center microstructure. After polished and etched in 3% Nital, the central microstructure of the samples were observed with S-4300 SEM to investigate the evolution of spheroidization.

Table 1
Chemical compositions of the ultra high carbon steel

	Composition				
	C	Si	Mn	S	P
Weight percentage (%)	1.11	0.28	0.66	0.002	0.007

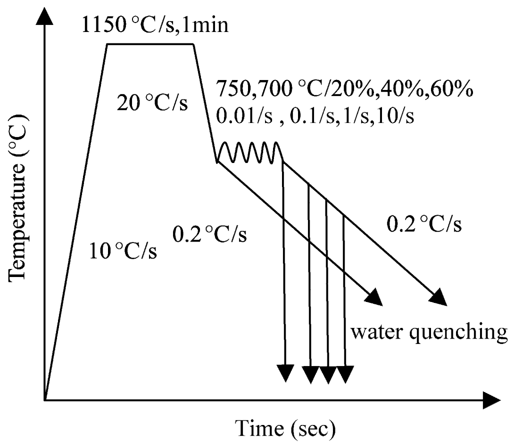

Fig. 1. Schematic illustration of the processing routes.

3. Experiment results

3.1. Microstructure evolution without deformation

In order to fully understand the effect of the deformation on the evolution of spheroidization, firstly undeformation test was executed. The samples were cooled to 700 °C with rate of 20 °C/s, at which temperature the austenite was in supercooling condition, then cooled to different temperature (680, 640 and 600 °C) with rate of 0.2 °C/s. Fig. 2 is the SEM microstructure photographs of the undeformed specimens. From Fig. 2, it can be seen that when the specimen cooled to 680 °C proeutectic cementite and pearlite occurred. The micrograph of pearlite is obscure. The reason is that the lamellar cementite had not formed completely, so the transformation almost began at 680 °C. With the temperature decreasing and cooling time increasing, the amount of transformed austenite increased. Typical pearlite that consists of ferrite and cementite formed (Fig. 2b). Particularly when the specimen was cooled to 600 °C some breakup cementite formed, which may be influenced by the friction stress and the slower cooling rate. As a result, there is not any trace of spheroidization. Thus, the ultra high carbon steel is difficult to be spheroidized during slow cooling from 700 to 600 °C with rate of 0.2 °C/s without deformation.

3.2. Effect of deformation temperature on spheroidization

It is well known that the deformation of steel materials at lower temperature can lead to more defects (mainly in the form of dislocations) than the deformation at higher temperature. In other words, more deformation energy was stored in the specimens at lower temperature. In fact, this experiment aims to study the effect of deformation stored energy on the evolution of spheroidization. The specimens were austenitized at 1150 °C for 1 min, cooled to 700 °C with rate of 20 °C/s (the microstructure is austenite), deformed, slowly cooled to different temperatures with rate of 0.2 °C/s, quenched in water. The results of this experiment are shown in Fig. 3. After the sample was deformed with reduction of 60% at 700 °C, cooled to 690 °C, large amounts of supercooling austenite transformed, a lot of proeutectic cementite and pearlite (Fig. 3a) occurred. The proeutectic cementite precipitated at the grain boundary while pearlite formed along the cementite at the grain boundary. After cooled to 690 °C, there was still some untransformed austenite. Fig. 3b is the magnified photograph of Fig. 3a at the prior austenite grain boundary. Some of the cementite was broken up (Fig. 3b). Fig. 3c is the magnified photograph of the position (1) in Fig. 3a. The cementite, the size of which is only about 30 nm, is particle-shaped at the center. During deformation and cooling, the pearlite formed along proeutectic cementite in all directions to the interior austenite grain, which can lead to the various pearlite colonies cross each other at the center, i.e. the cementite at the center belongs to several pearlite colonies. Its formation may be caused by the residual stress. With the effect