Tensile Behavior of Spheroidizing Heat Treated High Carbon Steel

Seok Hong Min, Tae Kwon Ha

Abstract—Spheroidization heat treatment was conducted on the SK85 high carbon steel sheets with various initial microstructures obtained after cold rolling by various reduction ratios at a couple of annealing temperatures. On the high carbon steel sheet with fine pearlite microstructure, obtained by soaking at 800°C for 2hr in a box furnace and then annealing at 570°C for 5min in a salt bath furnace followed by water quenching, cold rolling was conducted by reduction ratios of 20, 30, and 40%. Heat treatment for spheroidization was carried out at 600 and 720°C for the various time intervals from 0.1 to 32 hrs. Area fraction of spheroidized cementite was measured with an image analyzer as a function of cold reduction ratios and duration times. Tensile tests were carried out at room temperature on the spheroidized high carbon steel.

Keywords—High carbon steel, SK85, pearlite, cementite, spheroidization, tensile behavior.

I. INTRODUCTION

HIGH carbon steel generally contains C contents ranging from 0.3 to 1.2 % in weight percent. This alloy considers very important in fabricating parts of automobiles, industrial machines, and machining tools. In the production of high carbon steel, spheroidization heat treatment is crucial to guarantee formability and quality of products. Spheroidization heat treatment is conducted by soaking the steel with ferrite/martensite microstructure at a high temperature so that the shape of carbides or cementites in ferrite matrix becomes spherical by the diffusion of carbon atoms [1]-[3]. Spheroidized microstructure is the most stable one of steels and well known to give rise to a good ductility. As mentioned by Luzginova et al. [4], two types of spheroidization annealing are often used. (1) Subcritical annealing of steels below the A1 temperature, which is mainly applied for hypoeutectoid steels. During subcritical annealing of steels with an initial pearlite structure, the cementite lamellae break up into spheroids driven by the reduction in surface energy. (2) Intercritical spheroidization above A1 temperature, which is mainly applied for hypereutectoid steels in order to spheroidize and partially dissolve the grain boundary cementite. Therefore, the final microstructure of spheroidized hypereutectoid steels usually contains a bimodal distribution of cementite particles, where large particles are located mainly on austenite grain boundaries. It is reported that the rate of dissolution of the cementite lamellae also depends on the surrounding conditions [5].

In the present study, the tensile properties of spheroidized high carbon steel were investigated. Spheroidization heat treatment was conducted on the SK85 high carbon steel sheets with various initial microstructures obtained after cold rolling by various reduction ratios at a couple of annealing temperatures. On the high carbon steel sheet with fine pearlite microstructure, obtained by soaking at 800°C for 2hr in a box furnace and then annealing at 570°C for 5min in a salt bath furnace followed by water quenching, cold rolling was conducted by reduction ratios of 20, 30, and 40%. Heat treatment for spheroidization was carried out at 600 and 720°C for the various time intervals from 0.1 to 32 hrs. Area fraction of spheroidized cementite was measured with an image analyzer as a function of cold reduction ratios and duration times. Tensile tests were carried out at room temperature on the spheroidized high carbon steel.

II. EXPERIMENTAL PROCEDURES

The chemical compositions of SK85 high carbon steel used in this study were 0.83C, 0.2Si, 0.43Mn, 0.008P, and 0.001S in weight fraction. The thickness of plates was 4mm and the microstructure observation revealed a nearly bainite structure caused by hot rolling followed by intermediate cooling as shown in Fig. 1. Using these hot rolled plates and TTT diagram of SK85 steel shown in Fig. 2, various microstructures such as fine pearlite and coarse pearlite was obtained by austenitizing at 800°C for 2hrs in a box furnace followed by isothermal soaking in salt baths of 570°C and 670°C for 5min respectively.

Fig. 1 The initial microstructure of SK85 high carbon steel used in this study

To investigate the effect of cold reduction ratio on the decomposition rate of cementite, cold rolling was carried out on the heat treated plates with coarse and fine pearlite structures by reduction ratios from 0.2 to 0.4. Spheroidization annealing was
conducted at 720°C for 1, 2, 4, 8, 16, and 32 hrs on these cold rolled plates using a box furnace, followed by water quenching. Scanning electron microscopy (SEM) and optical microscopy (OM) were employed for microstructure observation, especially carbides (cementite fragments), after spheroidization heat treatment, etching the specimens with a Nital solution.

Using the SEM micrographs, fraction of spheroidized carbide was calculated utilizing TDI® Plus 5.0 image analyzer. Fraction of spheroidized carbide was defined by the following equation;

$$ f_{sp} = \frac{A_s}{A_u + A_s} \quad (1) $$

where $f_{sp}$ is spheroidized fraction of cementite, $A_s$ the area fraction of spheroidized cementite, and $A_u$ the area fraction of unspheroidized cementite. In the evaluation, carbides with aspect ratios under 5:1 were classified as spheroidized ones and 10 fields of 5K magnification for each condition were used.

A series tensile and hardness tests were conducted at room temperature on the specimens heat-treated at various conditions. Dimensions of tensile specimens were 27mm in length and 5mm in width and the initial strain rate used in this study was $10^{-4}$ s$^{-1}$. Vickers hardness tests were carried out under the load of 980mN.

III. RESULTS AND DISCUSSION

Typical microstructures of coarse pearlite (CP) and fine pearlite (FP) obtained by heat treatment at 670°C and 570°C for 5min respectively in this study are shown in Fig. 3. It is apparent that the colony size and lamellar spacing increased with soaking temperature increased. In fact, as the temperature of salt bath decreased in the isothermal soaking treatment, the amount of bainite phase, nonequilibrium one, appeared to increase. In this case, spheroidization of carbides needs precipitation of carbides and very long soaking time [6]. Fragmentation of cementite plates could help expedite decomposition of cementites [7]. In this respect, especially for the application in the production line, it is recommended that the fine pearlite should be used as the starting microstructure.

As spheroidization annealing proceeded, fragmentation of cementite plates, spheroidization of the cementites platelets, and coarsening were observed consecutively as selectively illustrated in Fig. 4 for FP and CP specimens with various annealing times. It is interesting to note that some cementites with high aspect ratio can still be observed even after annealing for 16 hrs. Fig. 5 shows the results of image analysis of area fraction of carbides on FP and CP specimens. It is apparent that spheroidized fraction of FP is much higher than that of CP and the rate of spheroidization increases with cold reduction ratios.

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机械变形的冷压明显加快了石墨化过程，使得石墨化程度显著提高。在高冷压比的情况下，碳化物的破碎和石墨化是主要的形变模式。石墨化需要在生产线上使用细片状石墨，以获得更好的性能。
completed after 1 hr of annealing as shown in Fig. 4. Variation of hardness with annealing time was given in Fig. 6, in which hardness of the steel clearly appeared to decrease with spheroidization of cementite in connection with Fig. 5. Hardness of FP specimen appears much higher than those of CP.

IV. CONCLUSIONS

Tensile behavior of the spheroidization heat treated SK85 high carbon steel was investigated in this study. After cold rolling of coarse and fine pearlite specimens by reduction ratios of 0.2 to 0.4, spheroidization heat treatment was carried out at 720°C subcritically for 1 to 32 hrs. As spheroidization annealing proceeded, fragmentation of cementite plates, spheroidization of the cementite platelets, and coarsening were observed consecutively. Elongation of cold rolled specimens dramatically increases with spheroidization annealing time. With increasing cold reduction in FP, ductility decreased with increased annealing time after 8 hrs, which can be explained by the fact that under these conditions, coarsening of carbide particles are more predominant over fragmentation.

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REFERENCES