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Tensile Behavior of Spheroidizing Heat Treated High Carbon Steel

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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^{o}C for 2hr in a box furnace and then annealing at 570^{o}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^{o}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 spheoidized high carbon steel.

Keywords**—**High carbon steel, SK85, pearlite, cementite, shperoidization, 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, spheoridization 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 A_1 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 A_1 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^{o}C for 2 hr in a box furnace and then annealing at 570^{o}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^{o}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 spheoidized 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^{o}C for 2hrs in a box furnace followed by isothermal soaking in salt baths of 570^{o}C and 670^{o}C for 5min respectively.

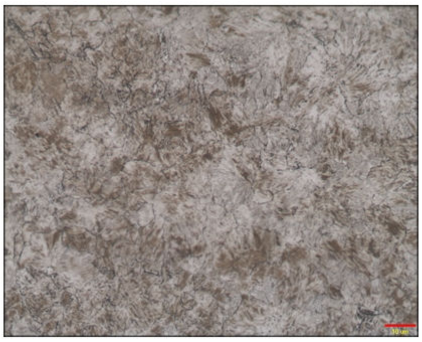

Fig. 1The initial microstructure of SK85 high carbon steel used in this study

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

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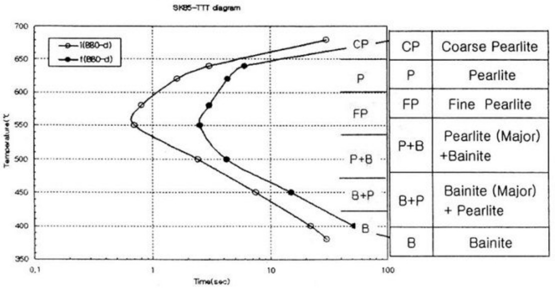
conducted at 720^{o}C for 1, 2, 4, 8, 16, and 32 hrs on these cold rolled plates using a box furnace, followed by water quenching. Scanning electron microscopy (SEM) and optical microscopy (OM) were employed for microstructure observation, especially carbides (cementite fragments), after spheroidization heat treatment, etching the specimens with a Nital solution.



CP	Coarse Pearlite
P	Pearlite
FP	Fine Pearlite
P+B	Pearlite (Major) +Bainite
B+P	Bainite (Major) + Pearlite
B	Bainite

Fig. 2 TTT diagram constructed for SK85 high carbon steel

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;

$$f_{sp} = \frac{A_s}{A_u + A_s} \tag{1}$$

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^{o}C and 570^{o}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 variousannealing 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.

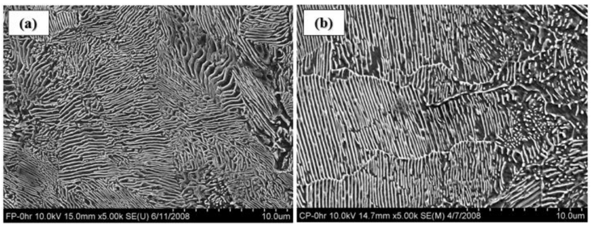


Fig. 3 Microstructures obtained by heat treatment for (a) fine pearlite (FP) and (b) coarse pearlite (CP) specimens

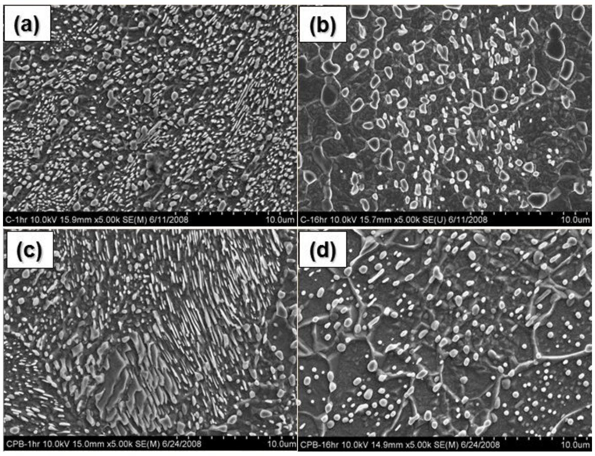


Fig. 4 Appearances of cementites of some selected specimens during spheroidization heat treatment taken fromthe40%-cold-rolled FP specimen annealed for 1hr (a) and 16 hrs (b), and the 30%-cold-rolled CP specimen annealed for 1hr (c) and 16hrs (d) at 720^{o}C

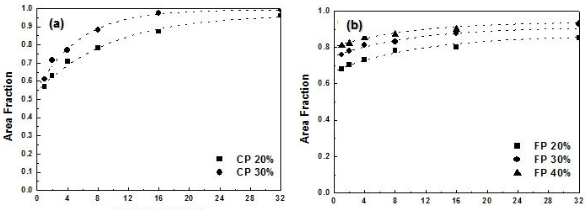


Fig. 5 Fraction of shperoidization as a function of annealing time obtained for FP and CP specimens with various cold reductions.

Mechanical fragmentation by cold rolling apparently expedites spheroidization process of cementites and with cold reduction ratio increased the rate of spheroidization was found to increase. In this case of high cold reduction ratio, coarsening is presumably predominating over fragmentation and spheroidizing. In fact, spheroidization of cementites was 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.

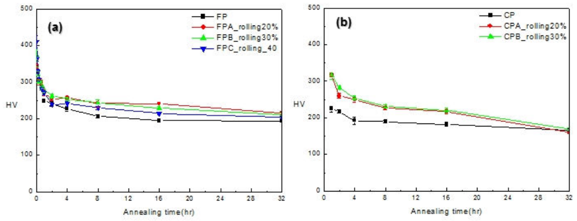


Fig. 6 Hardness as a function of annealing time obtained for cold rolled FP (a) and CP (b) specimens with various cold reductions

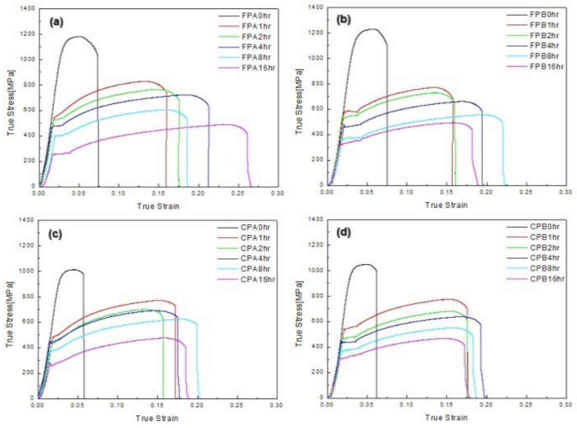


Fig. 7 True stress-true strain curves obtained from 20%-cold-rolled FP (a) 30%-cold-rolled FP, (b) 20%-cold-rolled CP (c) and 30%-cold-rolled CP (d) specimens

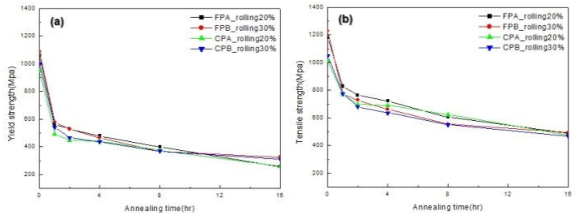


Fig. 8 Tensile test results obtained from cold-rolled and spheroidized FP and CP specimens

Tensile stress-strain curves were illustrated in Fig. 7. It is very interesting to note that 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 as shown in Fig. 7 (b). Similar results were obtained in CP specimens regardless of cold reductions, which can be explained by the fact that under these conditions, coarsening of carbide particles are more predominant over fragmentation as illustrated in Fig. 4(d). It is also apparent from Fig. 7 that yield point phenomena can be observed again after spheroidization. Tensile test results are summarized in Fig. 8, which revealed very similar trend to hardness test results. It is obvious from Fig. 8 that spheroidization process of FP specimens occurs faster than that of CP specimens and finished after 4 hrs, while spheroidization process of CP specimens proceeded after 4 hrs.

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 rations of 0.2 to 0.4, spheroidization heat treatment was carried out at 720^{o}C subcritically for 1 to 32 hrs. As spheroidization annealing proceeded, fragmentation of cementite plates, spheroidization of the cementites 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.

ACKNOWLEDGMENT

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