THE CHARACTERISTICS OF STRAIN INDUCED TRANSFORMATION IN MEDIUM CARBON STEELS

BY

C. CHIEN*1, Y. T. WANG*2, C. Y. HUANG*3

SYNOPSIS:

In this study, the strain effects on the phase transformation and hardness of medium carbon steels (S50C) was investigated by using computer-aided steel simulation and the dilatometer. It has been well known that the deformation on austenite around Ar3 temperature has profound influences on the microstructure and the phase transformation evolution of the medium carbon steel. Therefore, the effects of different strain levels and deformed at different temperatures were discussed in this study. The microstructure as well as the hardness of the S50C steels were observed by OM/SEM and measured by Rockwell hardness test, respectively. It was found that as the strain energy increases, the volume fraction of ferrite and pearlite which replaces martensite, especially the ferrite phase, will increases resulting in the hardness of S50C steel decreases significantly. The degree of grain refinement also elevates since the nucleation sites increase. When the applied energy is high enough, the pearlite colonies are broken into fragments, and the hardness drops further.

Keywords: Medium carbon steel, Martensite transformation, Grain refinement, Hardness, Dilatometer

*1 Engineer, Iron and Steel R&D Dept., China Steel Corporation, Kaohsiung, R.O.C.
*2 Scientist, Iron and Steel R&D Dept., China Steel Corporation, Kaohsiung, R.O.C.
*3 Manager, Iron and Steel R&D Dept., China Steel Corporation, Kaohsiung, R.O.C.
1. Introduction

Medium carbon steels, by definition, have carbon content larger than 0.2%. Medium carbon steels have been widely applied in springs, spatulas, cutting tools, clamps, pin, and other parts which need to be abrasion resistant. This is because the high carbon content in medium carbon steels make them strong and hard to be processed [1]. The most common way to make the medium carbon steels soft and formable is spheroidization process [2-4]. However, spheroidization process is energy and time consuming. Therefore, the long-term problem of medium carbon steel has been the excessive hardness leading to processing difficulties. To solve this problem completely, the increasing of soft phases, like ferrite and pearlite, is necessary [5-8]. In this study, the deformation temperature and strain effects on the phase transformation of medium carbon steels (S50C) was investigated by using simulation and the quenching and deformation dilatometer.

2. Experiments

The chemical composition of the S50C steel was listed in Table 1. In this experiment, the phase evolution and properties variation applying different deformation temperatures and strain levels were investigated. In this investigation, the computer-aided steel simulation was conducted first. The simulation predicted the transformation temperatures and critical cooling rate. Based on the phase transformation and microstructure, the simulation result also showed the hardness prediction. Because the core concept of this research was combining computer-aided steel simulation and different process routes by dilatometer, the thermal process routes were conducted by the quenching and deformation dilatometer DIL 805A/D. The dilatometer specimens were with a dimension of 5 mm in diameter and 10 mm in length.

Figure 1 showed the thermal cycles for the simulated thermo-mechanical treatment in the dilatometer. First, the specimen was heated to 1000°C, which was well above the austenitization temperature, for 180 seconds to get full austenite structure. Then, the specimen was slowly cooled to three individual temperature, and different deformation strain was applied as shown in Fig. 1. Finally, the specimen was quenched to room temperature with cooling rate of 60 °C/s to preserve the microstructure.

Table 1  Chemical Composition of the S50C steel (in wt%)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.47~0.53</td>
<td>0.15~0.35</td>
<td>0.60~0.90</td>
<td>&lt;0.030</td>
<td>&lt;0.035</td>
</tr>
</tbody>
</table>
3. Results and Discussions

3.1 The computer-aided simulation results for different deformation strain

Figure 2 shows the computer-aided simulation results for different deformation strain. From Fig. 2(a), with cooling rate of 60 °C/s and no deformation strain applied, the ferrite and pearlite transformations will not occur. Therefore, the microstructure will be full martensite when the specimen is quenched to room temperature. However, when the low deformation strain is applied, for example 5% shown in Fig. 2(b), the continuous cooling transformation (CCT) curves are shifted to the shorter time side. From Fig. 2(b), we can predict the microstructure of low deformation specimen is less martensite and with other phases, and the hardness is lower than that of no deformation one because the ferrite and pearlite transformations happened. Actually, in the simulation result, the hardness of no deformation specimen is 60 HRC and that of low deformation specimen is 47 HRC.

Fig. 2(c) demonstrates the CCT curves when high deformation strain is applied. As Fig. 2(c) shown, the CCT curves are shifted to the much shorter time side, and the martensite transformation disappears. From the simulation result in Fig. 2(c), we can predict the microstructure of high deformation specimen is lots of ferrite and pearlite phase present and almost no martensite shown, and the hardness must be lower than no and low deformation ones. In the simulation of Fig. 2(c), the hardness of high deformation specimen is 33 HRC. In fact, the volume fraction of ferrite and pearlite phase of high deformation specimen in Fig. 2(c) is 13% and 87%, respectively.
Figure 2 The computer-aided steel simulation results of (a) no deformation strain, (b) low deformation strain, and (c) high deformation strain.

3.2 The metallographic images of different deformation strain and temperatures

Figure 3, 4 and 5 are the metallographic images of different deformation strain at 890 °C, 850 °C and 810 °C, respectively. In metallographic images, the white, bulk phase is martensite, and the dark phase is almost pearlite and ferrite. The metallograph of deformation specimen shows other phases different from martensite, the dark phases. As the photos show that the volume fraction of martensite decreases as the deformation strain increases because the ferrite and pearlite transformations occur. In addition, one can observe from Figs. 3, 4 and 5 that the ferrite and pearlite appear as the deformation strain increases shown in the zoom SEM images.
The metallograph of high deformation specimen shows almost no martensite, especially in Fig. 5. As compared with the simulation results from Fig. 2, the hardness, measured by Rockwell hardness test, of no deformation specimen, low deformation specimen and high deformation specimen is 57 HRC, 47 HRC and 30HRC, respectively. From metallographic images and the hardness, we can say the simulation results corresponds with the experimental data. Compared with Figs. 3, 4 and 5, it can be observed that at the lowest deformation temperature, the rate of decrease of martensite fraction and increase of ferrite/pearlite fractions are both fastest, also shown in Fig. 6. It can be observed that the more effect of the deformation strain is as the lower the temperature is. The reason of the phase evolution is the deformation strain can raise the Gibb free energy of austenite. Therefore, the austenite is so unstable that it can not survive for martensite transformation. The effect of raising the Gibb free energy of austenite is more significant when the deformation temperature is lower because the austenite is the high temperature stable phase. It means the stability of austenite reduces as the temperature decreases. The deformation also reduce the Gibb free energy of ferrite and pearlite, especially the ferrite. That results in the increase of volume fraction of ferrite. In addition, the degree of grain refinement elevates since the nucleation sites increase as the deformation strain energy increases. When the applied energy is high enough, the pearlite colonies are broken into fragments, and the hardness drops further as shown in zoom SEM image in Fig. 5. Figure 7 shows the summary of the experimental results. As the Fig. 7(a) shown, the deformation strain can refine the grain size from 60 μm to 10 μm. The deformation strain also reduce the hardness, from 57 HRC to 30 HRC as shown in Fig. 7(b).

Figure 3 The metallographic images of different deformation strain at 890 °C. In this images, phases were identified by M (martensite), P (pearlite) and F (ferrite), respectively.
Figure 4 The metallographic images of different deformation strain at 850 °C.

Figure 5 The metallographic images of different deformation strain at 810 °C.
4. Summary

Figure 6 The volume fraction of white phase vs. deformation strain.

Figure 7 The summary of the experimental results: (a) grain size, (b) hardness vs. deformation strain.
In this study, the deformation temperature and strain effects on the phase transformation of medium carbon steels (S50C) was investigated by using simulation and the quenching and deformation dilatometer. The microstructure as well as the hardness of the S50C steels were also provided. The deformation can shift CCT to shorter time, refine the grain size and reduce the hardness significantly. In addition, the volume fraction of martensite decreases and that of pearlite and ferrite increases as the deformation strain increases. This is because the deformation strain can raise the Gibb free energy of austenite which is so unstable that it can not survive for martensite transformation. The effect is more significant when the deformation temperature is lower. Fortunately, the simulation results highly corresponds with both the experimental data and metallographic images. This successful study of phase evolution provides us a clue to avoid martensite appearing. Therefore, the processing difficulties of medium carbon steel might be solved in the future.

References