Structure Dependence upon the Austenizing Process of 0.68 Percent Carbon Steel*

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The course of transformation of 0.68% carbon steel after rapid heating to austenizing temperatures has been investigated using hardness measurements, microscopic and dilatation techniques. The steel specimens used for the investigation have lamellar with, and spheroidized pearlites and a structure consisting of spheroidized pearlite with graphite nodules. The austenizing curves obtained from the hardness measurements of spheroidized specimens show a sigmoid shape, on the other hand, austenizing for lamellar specimens is completed more quickly after a certain incubation period. The explanation of the time required to complete the transformation for the structural variables as a function of ferrite-cementite interfacial area is not sufficiently conclusive.

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I. Introduction

There have been many investigations\(^{(1)(2)}\) reported for the transformation of austenizing to pearlite of plain carbon steels, but few on isothermal transformation of pearlite to austenite. But details of the austenizing phenomena of steels are more important in quenching practice. Arnold and Williams\(^{(3)}\) suggested that the austenite was formed by nucleation and growth. Wall dow\(^{(4)}\), Grossman\(^{(5)(6)}\), Davenport and Bain\(^{(7)}\), and Bayertz\(^{(8)}\) have established that the location of the austenite nuclei is primarily in the interfaces of the ferrite-cementite lamella. But, details of the observation of these studies is not clear.

Previous works were made at different transformation conditions only on lamellar pearlite\(^{(9)\cdots(11)}\) or spheroidized pearlite\(^{(12)\cdots(14)}\) but no attempt was made to determine the influence of various initial structures upon the transformation kinetics. However, in the case of continuous quenching practice, the influences of initial structure of specimens used on the equality of products seems to have a considerably effect. Hence, the present investigation has been carried out.

II. Material Preparations

Chemical composition of the specimens is given in Table 1. Steel wire 3.0 mm in diameter was cut into lengths about 25 mm and the following heat treatments were used to make the various structure for the specimens.

(a) Lamellar parlitic structure: at 800°C for 1 hr→furnace cooled.
(b) Sorbitic structure: at 800°C for 1 hr→quenched in a lead bath at 600°C and held for 15 seconds in the same bath→water cooled.

<table>
<thead>
<tr>
<th>Table 1 Chemical composition wt %</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
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<td>0.68</td>
<td>0.13</td>
<td>0.44</td>
<td>0.090</td>
<td>0.035</td>
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(c) Spheroidized pearlitic structure: at 800°C for 1 hr → oil quenched → 710°C for 80 hr → furnace cooled → at 710°C for 38 hr → furnace cooled → at 710°C for 51 hr → furnace cooled.

(d) Spheroidized pearlitic structure containing graphite nodule: at 800°C for 1 hr → oil quenched → at 685°C for 120 hr → furnace cooled.

The microstructures are shown in Photos. 1, 2, 3 and 4, respectively.

III. Experimental Methods

750°C, 800°C, 850°C and 900°C were used as austenizing temperatures.

The specimens was quickly immersed in the bath and after a predetermined time in the lead bath, the specimens were quenched very quickly in 25°C brine.

Hardness measurements and microscopic tests of specimens in various stages of austenizing were made on a longitudinal cross-section. The hardness was measured with a Vickers hardness tester with a 10 kg load, and impressions were very carefully made in the center of the cross-section. As a check on the austenizing phenomena in the specimen obtained by means of microscopic examinations and hardness measurements, the dilatation during the austenizing treatment was measured by the dilatometer as shown in Fig. 1. Specimen was used for the measurement of 2 mm in diameter and 20 mm in length.

IV. Results

Hardness: Figs. 2, 3, 4 and 5 show the variation of the hardness with austenizing time of specimens with different kinds of initial structure. From the results of the hardness measurements, they are shown that the rate of austenite formation is very much affected by the initial structure of the specimen and the rate of austenizing for lamellar pearlitic is greater than for spheroidized pearlitic. Furthermore, in the case of a spheroidized pearlite containing graphite nodules, a very long time is necessary to arrive at the austenite state of equilibrium. As shown in Figs. 4 and 5, the changes of hardness in specimens consisting of spheroidal cementite slowly increase with increasing time at any austenizing temperatures, but in the cases of specimens consisting of a lamellar pearlitic structure (Figs. 2 and 3), the increase of hardness quickly appears after a certain incubation period. The curves for the hardness measurement for each specimen appreciably drop after rising to a maximum value at once and from that time on the curves return against the maximum value.

Microscopic results: Micrographs at various stages of the austenizing process for each specimen with different kinds of initial structures are shown in Photos. 5 to 9. As shown in Photo. 5, in the case of lamellar
pearlites, the course of austenizing starts at pearlite-ferrite boundaries or pearlite colony boundaries and here, the pearlite areas disappear from the structure quickly. On the other hand, in the case of spheroidized various stages of austenizing processing not appear as ordinary martensitic structures with a clear needlelike shape. But the amount of free ferrite and carbide gradually decrease with increasing time. And the

pearlites, the location of the austenite nuclei is primarily in the interfaces of the ferrite-cementite particle. As shown in Photo. 6 (a), Photo. 7 (a) and Photo. 8 (a), the specimens quenched in brine from amount and degree of the dark colour of the transformed parts of the specimen increases with increasing time. Against this, in the specimen containing graphite nodules, needlelike martensitic structure seldom
appeared in the transformed parts around the undissolved graphite nodules (Photo. 9 (b)). These changes of microstructure in specimens quenched from various stages of the austenizing process closely corresponded to the first deflection in length due to a change due to the austenizing of the specimen and that the second slight contraction is attributed to take a uniform distribution of the carbon in the austenite. Also, as in the cases of sorbitic structure and spheroidized pearlite, the same behaviors are observed.

On the other hand, in the case of the spheroidized pearlite containing graphite nodule, as shown in Fig. 7, the curves indicate abnormal expansion with subsequently contraction corresponded to austenizing. This expansion seems to correspond with a decrease of the white coloured parts around the undissolved graphite.

V. Discussions

Fig. 8 shows the isothermal austenizing time dependence upon the progress of the transformation in partly transformed specimens determined by the hardness measurement. As indicated in Fig. 8, the speed of austenizing for lamellar pearlit es is greater than the spheroidized pearlit es and sorbite specimen gives a more rapid transformation than lamellar pearlite. The same effects have previously been established by Robertz et al(10), Labib et al(11) and also Hultgren(15).

From the results of the hardness measurements in

specimens corresponding expand to arriving at the temperature of the lead bath, curves indicate that the specimens slowly contract with subsequent comparative rapid in deflation. Thus it is thought that the

results of the hardness measurement.

Dilatation results: Fig. 6 shows the isothermal dilatation curves obtained at 750°C, 800°C, 850°C and 900°C for the lamellar pearlite specimen. After

(a) 750°C for 100 seconds.
(b) 750°C for 3000 seconds.

Photo. 6 Austenizing for lamellar pearlite structure. (×600)

Photo. 5 Electron micrograph of a lamellar pearlite specimen austenized at 750°C for 35 seconds. (×8000)

Fig. 5 The Vickers hardness vs. the logarithm time curves at different austenizing temperatures for spheroidized pearlite containing graphite nodules.

(15) A. Hutgren: Trans. ASM, 16 (1927), 227.
(16) A. Pomp und R. Wizkander: Mitt. KWI, 8 (1926), 55.
Figs. 4 and 5, in the cases of spheroidized pearlites and the structure consisting of spheroidized pearlite with graphite, it is concluded that austenite transformation has a sigmoid shape, which characteristic of surface around the spherical carbide (i.e., a surface just on the phase boundary). But, in the case of a lamellar pearlitic structure, the course of transformation began at the pearlite colony boundary or the isothermal reaction curves for general nucleation and growth process. Against this, the austenizing curves obtained from the hardness measurement for the lamellar specimen is completed more quickly after a certain incubation period. On the other hand, as observed by microscopic examination, the austenizing in spheroidized pearlites will certainly start at the ferrite-pearlite phase boundary, but is not observed in the ferrite-cementite interfaces.

Let us now consider the relation between the cementite-ferrite interfacial area and the form of the cementite existing in the matrix. We can assume that a large sphere of pearlite consists of the lamellar cementite, which is thickness $h$ mm. When a number
of the lamellar cementite contained in this sphere is 
\( n+1 \), the sum total of the ferrite-cementite interfaces 
can be written in the form

\[
S = \frac{D}{3} \left( \frac{12}{4} \pi \frac{D^3}{n} - \frac{1}{12} n(n+2)(n+1)(8n^2 \pi) \right)
\]  
(1)

Consequently we have

\[
N = \frac{C - 0.035}{0.85 - 0.035} \frac{1}{\pi D^3}
\]
\[
S_i = S \cdot N
\]
\[
= 16 \left( \frac{1000C - 35}{8.5} \right) \left( \frac{1}{64h^2} - \frac{1}{D^3} \right) h (\text{mm}^3)
\]

(4)

If all of the carbide existing in the sphere change lamellar cementite into spherical cementite having a diameter \( d \), the sum total of the ferrite-cementite interfacial area per unit volume is

\[
S_0 = \frac{3}{4} \left( \frac{1000C - 35}{315} \right) \frac{1}{d}
\]

(5)

From Equations (4) and (5), we have

\[
S_0/S_i = \frac{3}{1 - 64h/D^2} \frac{h}{d} = \frac{3h}{d}
\]

(6)

Here, it was observed that the thickness of the lamellar cementite in the specimen investigated is approximately 0.3 to 0.4 \( \mu \), and that the size of the cementite in the spheroidized pearlite is 0.9 to 1.3 \( \mu \).

Substituting these mean values into Eq. (6),

\[
S_0/S_i = 1/1.1
\]

This means that the sum total of the ferrite-cementite interfacial area in the lamellar pearrites tested not particularly different from that of the spheroidized pearrites. However, the time required to complete austenizing in lamellar pearrites is equal to about 1/3.3 times that of the spheroidized pearrites (an example, the time required to complete austenizing at 800°C is 100 and 300 sec, respectively). This also means that the rate of the austenizing reaction per unit interface for lamellar pearrites is more rapid than that of the spheroidized pearrites. And it indicate that the above tendency is more accelerated by the fact that the course of austenizing in lamellar pearrites goes on spreading from the pearlite boundary. A further consideration of the ferrite-cementite interfacial energy would be needed to explain the above difference upon the austenizing process in both structures of lamellar pearrites and spheroidized pearrites.

In addition, the course of the isothermal transformation of lamellar pearlite to austenite, at least in the present specimen with 0.68% carbon, is

\[
\text{pearlite} \rightarrow \text{proeutectoid } \alpha + \alpha + \text{Fe}_3\text{C} \rightarrow \alpha + \alpha + \text{Fe}_3\text{C} + \gamma \rightarrow \alpha + \gamma + \gamma
\]

in the case of spheroidized pearlite

\[
\alpha + \text{Fe}_3\text{C} \rightarrow \alpha + \text{Fe}_3\text{C} + \gamma \rightarrow \text{Fe}_3\text{C} + \gamma \rightarrow \gamma
\]

and in the case of spheroidized pearlite with graphite

\[
\alpha + \text{Fe}_3\text{C} + G \rightarrow \alpha + \text{Fe}_3\text{C} + G + \gamma \rightarrow \text{Fe}_3\text{C} + G + \gamma \rightarrow \gamma + G \rightarrow \gamma
\]

VI. Conclusion

It must be concluded that the rate of formation of austenite is greatly influenced by the initial structure.
Thus, a fine pearlite gives a more rapid transformation than a coarse one and yet the difference of the both initial structure is not very large.

For the same steel, when the thickness of cementite in lamellar pearlites is nearly equal to the diameter of the cementite in the spheroidized pearlite, the speed of formation of austenite for the lamellar pearlite gives a more rapid transformation than the spheroidized pearlite.

The kinetics of austenizing for lamellar pearlites differs from that of specimens with spheroidized cementite.