Time-Temperature-Austenitization Diagram of Hypereutectoid Steel*

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For the purpose of improving the processes of rapid heating and quenching of carbon steel, time-temperature-austenitization diagrams (T-T-A diagrams) were plotted for hypereutectoid steels (with carbon contents: 0.92, 1.28 %). The dimension of specimen, preheat-treatments and experimental procedure were the same as in a previous report on hypoeutectoid steels. The experimental results are as follows:

(1) Periods of time required for starting and finishing of austenitization are almost the same and short in duration for fine-pearlite (F.P.) and spheroidized cementite (S.C.), while it takes a longer time for coarse pearlite (C.P.). S.C. structure of 0.92 % carbon steel has a coarser spheroidized structure than 1.28 % carbon steel, so that the finishing of its austenitization would take a much longer time than other structures.

(2) Compared with T-T-A diagrams of carbon steel (carbon contents: 0.20, 0.40, 0.69, 0.92 and 1.28 %), the time required for starting of austenitization is almost the same, unrelated with carbon contents. The time required for finishing of austenitization becomes shorter with increase in the carbon content of hypoeutectoid steels, while it is almost identical in hypereutectoid steels.

(3) The austenitizing reaction is very rapid in carbon steels than generally considered. On quenching of carbon steels at a specified temperature, a very short holding time is sufficient for quenching and thereby the S.C. structure seems to be effective.

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I. Introduction

Research of austenitizing reaction in steels which are treated by a rapid heating process at temperatures above A_{c1} and held isothermally, is very essential for heat treatment of steels. However, few systematic studies^{(1)~(5)} have dealt with this problem in spite of its importance in rapid heating and quenching. In a previous report⁽⁶⁾, the authors studied the time-temperature-austenitization diagrams (T-T-A diagrams) of hypoeutectoid steels containing 0.20, 0.40 and 0.69 % carbon. In this report a study of the T-T-A diagrams of hypereutectoid steels is carried out.

II. Specimens and Experimental Procedure

Chemical composition of specimens is listed in Table 1, and these specimens were steels made in Sweden.

Table 1 Chemical composition (%) of specimens.

No.	C	Si	Mn	P	S
1	0.92	0.28	0.29	0.024	0.013
2	1.28	0.29	0.24	0.022	0.014

The dimension of specimens, preheat-treatments and experimental procedure were the same as in the previous report on hypoeutectoid steels. That is, the specimens of 3 mm $\phi \times 10$ mm were preheated to

impart different structures; fine pearlite (F.P.), coarse pearlite (C.P.) and spheroidized cementite (S.C.). Preheat-treatment methods and structures of the specimens are shown in Table 2 and Photo. 1, respectively.

Table 2 Pre-heat-treatment of specimens.

No.	Structure	Method of Pre-heat-treatment
1	F. P.	
	C. P.	
	S. C.	
2	F. P.	
	C. P.	
	S. C.	

The specimens were put into a lead bath held at constant temperatures ranging from 760° to 1020°C, held for different durations ranging from 0.3 to 600 sec, and then rapidly quenched in water. Then, Vickers hardness (Hv), microstructures and microhardness (mHv) of the quenched specimens were measured at the subsurface (about 1 mm from the surface) to investigate the transformation of the austenitizing process from pearlite and cementite from which the T-T-A diagram was obtained.

III. Experimental Results and Discussion

1. Changes in hardness

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Relations between the hardness of water quenched No. 1 and No. 2 specimens and the holding time at various austenitizing temperatures are shown in Figs. 1 and 2.

Therefore, the time required for obtaining a maximum hardness in hypereutectoid steel is shorter than in hypoeutectoid steel.

Photo. 1 Preheat-treated structures of specimens.

($\times 400$)

Fig. 1 Relation between hardness and holding time at various austenitizing temperatures of No. 1 specimen.

Fig. 2 Relation between hardness and holding time at various austenitizing temperatures of No. 2 specimen.

It is shown that the increase in hardness becomes faster as the austenitizing temperature rises. The cause of this phenomenon is considered due to the rapid advancement of the austenitizing reaction with the rising austenitizing temperature. Besides, a slight decrease in hardness which was observed after attaining a maximum, might be attributed to the increase in retained austenite of water quenched specimens. Since proeutectoid ferrite is not present in this specimen, the austenitizing reaction takes place only in pearlite.

2. Changes in microstructure

Microstructure and microhardness of water quenched No. 1 specimens austenitized under various conditions are shown in Photo. 2. In the Photo., (i) and (ii) show the structures of specimens austenitized for 3 and 8 sec at 800°C. Indicated in (i) is a mixed structure of pearlite and martensite, partially austenitized at the starting of austenitizing reaction. In this photograph, A shows pearlite, B pearlite including partial martensite, and C martensite (hardness : mHv 542) obtained

by quenching immediately after austenitization. Such low hardness is probably caused by the low carbon content of martensite due to undissolved cementite.

F. P.

(i) 800°C - 3 sec
 (A) P 285 (B) M+P+C 397
 (C) M+C 542

(ii) 800°C - 8 sec
 (A) M 835 (B) M 858
 (C) M 907

S. C.

(iii) 1000°C - 0.5 sec
 (A) F+C 357 (B) M 764
 (C) M 832

(iv) 1000°C - 2 sec
 (A) M 839 (B) M 762

Photo. 2 Microstructure and microhardness under progressive austenitization of No. 1 specimens. Load 100 g. ($\times 400$)

(ii) indicates the structure, quenched after mostly austenitized, wherein its microhardness nearly reaches a maximum value. Both (iii) and (iv) show the quenched structures of S.C., austenitized for 0.5 and 2 sec at 1000°C. (iii) indicates a mixed structure of ferrite, cementite and martensite which is obtained from a specimen partly austenitized. (iv) indicates martensites containing a small amount of undissolved cementite, the austenitizing reaction of which is fairly advanced.

3. T-T-A diagram

T-T-A diagrams of hypereutectoid steels were obtained from the changes in hardness in Figs. 1 and 2. The periods of time required for starting and finishing austenitization were determined by the time for starting the increase in hardness and the time for showing the maximum in hardness, respectively. T-T-A diagrams obtained are shown in Photos. 3 and 4, in which microstructures and hardnesses showing the austenitizing process are shown with A_{c1} temperatures.

The austenitizing reaction in No. 1 specimen having pearlite structure can be explained as follows:

As the holding time is increased,

where P : Pearlite
 F : Ferrite

C : Cementite

A_s : Starting of austenitization

A_f : Finishing of austenitization

(C) : Trace of cementite

The amount of the proeutectoid cementite in this specimen is so small that the existence of the proeutectoid cementite can be neglected here. The austenitizing reaction of No. 1 specimen of S.C. structure, proceeds as follows.

The austenitizing reaction in hypereutectoid steel proceeds rapidly as shown in the T-T-A diagram. For example, the time required for finishing of austenitization is about 9 to 23 sec at 800°C and about 1.3 to 3.2 sec at 1000°C. As related in a previous report⁽⁶⁾, the periods required for starting and finishing of austenitization were measured from the time when the specimens were put into the lead bath, not from the time when specimens attained a specified temperature. It needs about 3.6 to 5.5(*) sec to heat the center of a specimen to the temperature ranging from 800 to 1000°C. Therefore, in case of the austenitizing temperature as high as 1000°C, the austenitizing reaction had already been finished before the center of the specimen reached a specified temperature.

4. Comparison of T-T-A diagrams

(1) T-T-A diagrams of steels with different carbon contents

The results of comparison of the T-T-A diagrams under the same preheat-treatment and with steels different in the carbon content, are indicated in Fig. 3. The periods required for starting and finishing of

Fig. 3 Comparison of T-T-A diagrams of steels with different carbon contents.

austenitization are almost alike, excepting No. 2 specimen of pearlite structure in which the time required for finishing of austenitization at 760°C is longer than that of No. 1 specimen. As regards the S.C. structure,

* It is corrected from 4.3 to 5.3 sec in the Journal of the Japan Institute of Metals, 25 (1961), 519.

Photo. 3 T-T-A diagrams under different pre-heat-treatment of No. 1 specimens.

No. 2 specimen needs a shorter time for finishing than No. 1 specimen contrary to the pearlite structure.

From the preheat-treated structures (Photo. 1) it is clear that No. 1 and 2 specimen of pearlite structure had almost the same lamellar structure, but No. 1 specimen of S.C. structure has a coarser spheroidized structure than No. 2 specimen. If the degree of pre-heat-treatments is equal, T-T-A diagrams of hypereutectoid steels would be almost identical independently of carbon contents.

(2) T-T-A diagrams of steels under different pre-heat-treatments

The results of comparison of the T-T-A diagrams

under different preheat-treatments with the same carbon content, are shown in Fig. 4. The time required for starting austenitization is almost the same, but the finishing time of austenitization in case of No. 1 specimen is the shortest for F.P., next for C.P. and the longest for S.C. In case of No. 2 specimen it takes a short time both for F.P. and for S.C. and a longer time for C.P.

(3) Comparison of T-T-A diagrams of the steels including hypoeutectoid steels

The starting and finishing periods of austenitization for hypoeutectoid and hypereutectoid steels at different austenitizing temperatures under various preheat-

Photo. 4 T-T-A diagrams under different preheat-treatment of No. 2 specimens.

treatments, are indicated in Fig. 5. The time required for starting of austenitization with different carbon contents is almost equal regardless of austenitizing temperatures and carbon contents, except that the time required for starting of austenitization at 760°C is a little longer with increase in the carbon content. The time required for starting of austenitization under different preheat-treatments is almost equal in hypereutectoid steels, but the time for hypoeutectoid steels of S.C. is shorter than those of F.P.

The time required for finishing of austenitization with different carbon contents becomes shorter with the increase in the carbon content up to the eutectoid level. However, in hypereutectoid steels, the time is

almost as same as eutectoid steel, excepting 1.28 % carbon steel in which it is longer than that of 0.92 % carbon steel at 760°C. From the above results it is known that the austenitizing reaction proceeds more rapidly for pearlite than for proeutectoid ferrite. Therefore, the time required for finishing of austenitization is much longer for 0.20 % carbon steel than other steels, because it has a large quantity of proeutectoid ferrite.

In comparison of the finishing time of austenitization under different preheat-treatments, it was found that S.C. needs a shorter time than F.P. for hypoeutectoid steels; however, in the hypereutectoid steels, F.P. needs a shorter time than S.C. contrary to hypoeutectoid

steels. The causes of the above results can be attributed to the existence of massive proeutectoid ferrite in hypoeutectoid steels, by which the finishing time of austenitization for F.P. needs to be longer than that for S.C. However, S.C. structures of hypereutectoid

Fig. 4 Comparison of T-T-A diagrams under different pre-heat-treatments.

Fig. 5 Comparison of starting and finishing times of austenitization of carbon steels under different austenitizing temperatures and pre-heat-treatments.

steels is coarser in spheroidized structure than hypoeutectoid steels. If the degree of spheroidization are identical in hypereutectoid steel, the finishing time of austenitization for S.C. would be shorter than that for F.P.

From the above results, it may be concluded that the finishing time of austenitization is by far shorter in carbon steels than that generally considered. For example, the time required for carbon steels containing 0.69 to 1.28 % carbon is about 9 to 23 sec at 800°C and about 1.3 to 3.5 sec at 1000°C. Even in the 0.20 % carbon steel, the time required for completion of austenitization is about 5.4 to 10 sec at 1000°C. In quenching of carbon steels, therefore, if heated to a specified temperature, a very short holding time can serve quenching sufficiently. As for the preheat-treated structure, the S.C. structure would be more effective than the pearlite structure, in consideration of the shorter austenitizing time and uniform hardening.

IV. Conclusion

(1) T-T-A diagrams of 0.92 % and 1.28 % carbon steels under different preheat-treated structures of F.P., C.P. and S.C. were obtained. From the results, the periods required for starting and finishing austenitization of these steels are found to be very short.

(2) In comparison of these T-T-A diagrams of hypereutectoid steels having different carbon contents and preheat-treated under the same condition, the periods required for starting and finishing austenitization are almost equal. However, in steels having a same carbon content and preheat-treated in a different way, the periods required for starting and finishing austenitization for F.P. and S.C. are shorter than that for C.P.

The S.C. structure of 0.92 % carbon steel is coarser in spheroidized structure than that of 1.28 % carbon steel. Therefore, the finishing time of austenitization for former is longer than the latter.

(3) In comparison of T-T-A diagrams of carbon steels containing 0.20, 0.40, 0.69, 0.92 and 1.28 % carbon, the time required for starting austenitization under different carbon contents is almost equal, unrelated with carbon contents. The time required for finishing austenitization becomes shorter with increasing carbon contents in hypoeutectoid steels. However, in case of hypereutectoid steels, the finishing period is almost the same. As regards the starting and finishing periods of austenitization of hypoeutectoid steels having a same carbon content and differently preheat-treated, S.C. takes a shorter time than F.P., but in the case of hypereutectoid steels it is almost the same.

(4) In quenching of carbon steels, if heated to a specified temperature, a very short holding time is sufficient for quenching. The S.C. structure would be most effective for quenching.