The Effect of Austenitizing Conditions on the Mechanical Properties and on Hardenability of Hardened Carbon Steel*

By Kazuaki Iijima**

The present study was performed to determine the effect of austenitizing conditions on the mechanical properties and hardenability of hardened eutectoid carbon steel, and ascertained the relation between those properties and the austenitic grain size.

The mechanical properties were obtained from as-hardened 0.80 % C steel by a torsion test, and the hardenability from 0.85 % C steel by a Jominy test.

The austenitizing conditions were affected by austenitizing temperatures and periods, and austenitizing temperatures in the prior heat treatment.

The results obtained were as follows :

(i) With the increase of the austenitizing temperature, the toughness of hardened steel decreased, the hardenability increased, and the austenitic grain size became coarser ; (ii) prolongation of the austenitizing time gives the same effect on those properties as does the increase of austenitizing temperature, but in some cases, an abrupt change in toughness and hardenability regardless of the austenitic grain size was observed ; (iii) even when the austenitizing temperature for final hardening was held constant (800°C), the toughness and the hardenability were found to be remarkably affected by the austenitizing temperature for such prior heat treatment as annealing, hardening or hardening followed by annealing ; with the increasing austenitizing temperature, the toughness decreased and the hardenability increased. But in all cases, the austenitic grain size was scarcely affected by the prior heat treatment ; (iv) the above results suggest that the decrease in toughness and the increase in hardenability due to over-heating may be attributed not only to the austenitic grain coarsening but also to some changes in the austenite caused by the overheating process itself.

(Received April 19, 1963)

I. Introduction

It is well known that the toughness-decrease and the hardenability-increase appear when the austenitizing temperature rises in hardening steels. These phenomena are generally considered to be attributable to the austenitic grain coarsening by overheating^{(1)~(7)}.

However, this opinion has some questions regarding the toughness. According to Herres et al⁽⁸⁾, the toughness of hardened steel is much more affected by grain boundary precipitates due to overheating than by the austenitic grain size itself. Bullens⁽⁹⁾ also related that the toughness of hardened steels is probably affected by the solution or precipitation of some elements involved in steels occurring in accordance with the austenitic grain growth, and the effect of the austenitic

grain size is not so serious as it is believed.

To ascertain the relationship between toughness, hardenability and austenitic grain size of hardened steel, the author investigated the effect of austenitizing conditions, such as austenitizing temperature, austenitizing time and prior heat treatment on these properties, using eutectoid plain carbon steels.

II. Experimental Procedure

1. Steels investigated

The analysis of the steels used in the experiment is given in Table 1.

Table 1 Chemical composition of specimens (wt %).

C	Si	Mn	P	S
0.80	0.22	0.38	0.029	0.009
0.85	0.30	0.40	0.018	0.018

0.8 % C steel was used for torsion test pieces, while 0.85 % C steel for hardenability test pieces. The dimensions of these test pieces are illustrated in Fig. 1 (a), (b).

2. Experiment method

(1) Heat treatment

(i) The effect of austenitizing temperature

Torsion test pieces were hardened after being austenitized over the temperature range from 750 to 1100°C, and hardenability test pieces were end-quenched after being austenitized over the temperature range from

* Presented at the Forty-first Convention of the Institute, held in Tobata, October, 1957 (on mechanical properties), and the Forty-third Convention of the Institute, held in Nagoya, October, 1958 (on hardenability). This paper was published in the Journal of the Japan Institute of Metals, 26 (1962), 412 (in Japanese).

** Railway Technical Research Institute, J. N. R., Tokyo.

- (1) E. S. Davenport, E. L. Roff and E. C. Bain : Trans. ASM, 22 (1934), 289.
- (2) E. S. Davenport and E. C. Bain : Trans. ASM, 22 (1934), 879.
- (3) P. Schane : Trans. ASM, 22 (1934), 1038.
- (4) C. H. Herty, D. L. McBride and E. H. Hollenback : Trans. ASM, 25 (1937), 297.
- (5) R. F. Mehl : Trans. ASM, 29 (1941), 813.
- (6) T. Sato, K. Mano, S. Toya and K. Tomabeji : J. Japan Inst. Metals, 19 (1955), 177.
- (7) H. Borchers and G. Saur : Stahl u. Eisen, 78 (1958), 40.
- (8) S. A. Herres and C. H. Lorig : Trans. ASM, 40 (1948), 775.
- (9) D. K. Bullens : Steel and Its Heat Treatment, Vol. 1, 5th Ed. (1948) 373, 386.

750 to 1000°C.

In all cases, the austenitizing was performed in an electric vacuum furnace for 1 hr.

Fig. 1 Dimensions of test piece.

(ii) The effect of austenitizing time

The austenitizing time was varied in a range of 10 min to 10 hr in this experiment.

Austenitizing temperatures used for the torsion test pieces were 750, 800 and 900°C, and for the hardenability test pieces 900°C.

(iii) The effect of prior heat treatment

In the prior heat treatment, the test pieces were austenitized over the temperature range from 750 to 1100°C, and for final hardening, austenitized at a constant temperature of 800°C. In all cases, the austenitizing time was 1 hr.

Prior heat treatments applied to the torsion test pieces were as follows:

- (a) Annealing (750~1100°C)
- (b) Hardening (750~1100°C)
- (c) Hardening (750~1100°C) and Annealing (800°C)

For the hardenability test pieces, the prior heat treatment applied was annealing (750~1000°C).

(2) Torsion test

A torsion test was carried out on the test pieces of as-hardened state by the Amsler type torsion tester with capacity of 30 kg-cm.

Torsion strength τ_B and plastic torsion angle θ_p , as illustrated in Fig. 2, were measured. The Rockwell C hardness test was also carried out at the grips of the test pieces.

(3) Hardenability test

The Jominy test was employed in this experiment. The Rockwell C hardness test and a microscopic test were made in the axial direction of the side surface of the test pieces.

From these test results, the following values were determined to indicate hardenability.

Hardness of hardened zone; Hardness of quenched end, R_C

D_M ; Thickness of martensite, mm

D_{M+T} ; Thickness of martensite including primary

troostite, mm

J_{40} ; Distance from the quenched end to the position indicating R_C 40, mm

Fig. 2 Torque-torsion angle diagram.
 θ_p : plastic torsion angle.

Hardness of Normalized Zone; Hardness of air cooled end, R_C

(4) Measurement of austenitic grain size

(i) Torsion test piece

Vilella and Bain's method⁽¹⁰⁾ was used for hardened torsion test pieces.

(ii) Hardenability test piece

Mixed structure zone of martensite and primary troostite of the test pieces was used for the measurement of austenitic grain size.

III. Experimental Results

1. Torsion test results

The effects of austenitizing temperature on the austenitic grain size and mechanical properties of the hardened steel are illustrated in Fig. 3.

When the austenitizing temperature rises, the austenitic grain is coarsened, and the torsion strength and plastic torsion angle decrease remarkably after reaching their peaks at about 850°C. Above about 950°C plasticity is almost lost, and embrittlement occurs in these overheated steels.

Fig. 4 shows the effect of austenitizing time on the austenitic grain size and mechanical properties of the hardened steel, when austenitizing temperatures are held constant.

The torsion strength and plastic torsion angle are markedly affected by the austenitizing time, but the austenitic grain size is scarcely affected. Especially, when the austenitizing temperature is 900°C, it is observed that these mechanical properties decrease suddenly after attaining their peaks 1 hr later.

Fig. 5 shows the effect of the austenitizing temperature in the prior heat treatment on the austenitic grain size and mechanical properties of the steel finally

(10) E. C. Bain and J. R. Vilella: ASM Metals Handbook, (1948), 399.

hardened from 800°C.

This result indicates that the strength and plasticity are affected markedly by the austenitizing temperature

Fig. 3 The effect of austenitizing temperature on mechanical properties of hardened 0.80 % C steel.

Fig. 4 The effect of austenitizing time on the mechanical properties of hardened 0.80 % C steel.

in the prior heat treatment, even if the austenitic grain size attained by the final hardening is almost the same, and that such brittleness due to overheating cannot be eliminated by these simple subsequent heat treatments.

2. Hardenability test results

The effect of the austenitizing temperature on the austenitic grain size and hardenability is illustrated in Fig. 6, which shows the coarsening of the austenitic grain and the increase in hardenability as the austenitizing temperature rises.

Moreover, it is observed that the hardness of the normalized steel increases as the austenitizing temperature rises. This phenomenon is considered to be caused by the fact, that the A_{r1} transformation temperature falls as the austenitizing temperature rises, so that the

transformed product becomes finer and harder pearlite (the reduction in lamellae intervals and the thinner formation of ferrite and cementite).

Fig. 5 The effect of austenitizing temperature in prior heat treatment on the mechanical properties of 0.80 % C steel, austenitizing temperature in final hardening is 800°C.

Fig. 6 The effect of austenitizing temperature on hardenability of 0.85% C steel.
 D_M : Thickness of martensite zone.
 D_{M+T} : Thickness of martensite zone including troostite.
 J_{40} : Distance from quenched end to the position showing R_c 40.

This phenomenon indirectly proves that the hardenability increases according to the rise of the austenitizing temperature, in respect that a fall of A_{r1} transformation temperature causes the retardation of the pearlite nucleation in the austenite.

Fig. 7 shows the effect of the austenitizing time on

Fig. 7 The effect of austenitizing time on hardenability of 0.85 % C steel (austenitizing temperature : 900°C).

the austenitic grain size and hardenability when the austenitizing temperature is held at 900°C.

An abrupt increase of hardenability unrelated with the austenitic grain size is observed in test pieces held over 1 hr, and this phenomenon is in good agreement with the abrupt decrease in torsion strength and plastic torsion angle observed by varying austenitizing time, as shown in Fig. 4.

Fig. 8 shows the effect of the austenitizing temperature for the prior heat treatment on the austenitic grain size and hardenability. In this case, the prior heat treatment was annealing lasting for 1 hr over the temperature range from 750 to 1000°C, and the final end-quenching was performed from 800°C.

The effect of the austenitizing temperature for prior heat treatment on the hardenability is remarkable, the higher austenitizing temperature results in the increase of hardenability, but scarcely affects the austenitic grain size. This phenomenon is also consistent with the varying aspects in the strength and plasticity due to the prior heat treatment, as shown in Fig. 5.

IV. Discussion

In ordinary hardening, austenitic grain coarsening, toughness-decrease and hardenability-increase are observed in accordance with rising of the austenitizing temperature, as shown in Figs. 3 and 6. Judging

Fig. 8 The effect of austenitizing temperature in prior annealing on hardenability of 0.85 % C steel, austenitizing temperature in final quenching is 800°C.

merely from these results, it seems that toughness and hardenability depend entirely upon the austenitic grain size. However, as shown in Figs. 4 and 7, steels overheated in prior heat treatment and finally hardened from a definite low temperature are remarkable in toughness decrease and hardenability increase, in spite of their fine austenitic grains. Moreover, as shown in Figs. 4 and 7, hardened steels austenitized for a longer time show some changes in their properties independently of the austenitic grain size.

These phenomena suggest that toughness-decrease and hardenability-increase due to overheating may be attributed not only to the austenitic grain coarsening but also to some variation occurring in the austenite.

It is well known that the increase of the austenitizing temperature and time brings about an increase of the carbon content in the austenite due to the dissolving of the cementite or carbide in steel as well as homogenization of austenite, thus causing the decrease in toughness and the increase in hardenability^{(11)~(14)}.

According to Mehl⁽⁵⁾, for complete dissolving of cementite and homogenization of austenite in the 0.85 % C steel, time intervals of about 1 min and 30 min are required respectively at a temperature of 800°C, and about 18 sec and 4 min at 840°C.

However, the overheating process in this experiment was done at a temperature of 950°C or higher for 1 hr, so that the resulting toughness decrease and the hardenability increase should not be attributed to such causes.

As mentioned in the introduction, it is considered that the toughness-decrease due to overheating is caused by precipitation of impurities at the austenitic grain boundary.⁽⁸⁾⁽⁹⁾

Moreover, it is recognized that, in overheated steels, the toughness-decrease is brought about by heterogenizing of austenite or enrichment of precipitates of impurities due to plus or minus absorption⁽¹⁵⁾⁽¹⁶⁾ at the austenitic grain boundary.^{(17)~(20)}

The cause of hardenability increase upon overheating remains ambiguous, but it seems likely that such microstructural changes in the austenite affect hardenability as well as toughness to some extent.

This may also be considered by an example which demonstrated that the effect of boron additions to steels

retarded the pearlite nucleation owing to the high absorption austenitic grain boundaries.⁽¹⁾

V. Conclusion

The effects of austenitizing temperature, austenitizing time and austenitizing temperature in prior heat treatment on torsion strength, plastic torsion angle of hardened eutectoid carbon steel and its hardenability were investigated in relation to the austenitic grain size. The results obtained are as follows:

(1) According to a rise of the austenitizing temperature, phenomena such as toughness decrease, hardenability increase and austenitic grain coarsening in hardened steel were observed.

(2) A longer austenitizing time gives almost the same effect as a higher austenitizing temperature, but in some cases, an abrupt change in toughness and hardenability unrelated with the austenitic grain size was observed.

(3) Even when the austenitizing temperature in final hardening was held constant (800°C) and the austenitic grain sizes attained were almost the same, the toughness and hardenability were remarkably affected by the austenitizing temperature in prior heat treatment.

(4) The above results suggest that the toughness decrease and hardenability-increase upon overheating are attributed not only to the austenitic grain coarsening but also to some unknown changes in the austenite. It is not clear what changes are brought about by overheating, but heterogenization of austenite or enrichment of precipitates of impurities due to grain boundary absorption can be considered.

The author wishes to express his heartfelt appreciation to Dr. Ôwaku, former chief of Laboratory of Metals, Railway Technical Research Institute, Japanese National Railways, for his guidance in this study.

- (11) R. Yamada and K. Yokoyama: *J. Japan Inst. Metals*, **14** (1950), 42.
- (12) S. Ôwaku and K. Iijima: *J. Japan Inst. Metals*, **18** (1954), 362.
- (13) M. Tanaka: *J. Japan Inst. Metals*, **19** (1955), 509.
- (14) S. Hara, Y. Miura and M. Sugiyama: *J. Japan Inst. Metals*, **20** (1956), 1.
- (15) J. W. Spretnak and R. Speiser: *Trans. ASM*, **43** (1951), 734.
- (16) L. Colombier: *Metal Progress*, **67** (1955), 116.
- (17) A. Preece, A. Hartley, S. E. Mayer and J. Nutting: *J. Iron Steel Inst.*, **153** (1946), 237.
- (18) A. Preece, J. Nutting and A. Hartley: *J. Iron Steel Inst.*, **164** (1950), 37.
- (19) A. Preece and J. Nutting: *J. Iron Steel Inst.*, **164** (1950), 46.
- (20) T. Ko and D. Hanson: *J. Iron Steel Inst.*, **164** (1950), 51.
- (21) H. Imai: *J. Japan Inst. Metals*, **19** (1955), 106.