แกรนออสเทนไนท์ในระหว่างการกระทำทางความร้อนต่าง ๆ กันของเหล็กกล้าคาร์บอนต่ำ

e Austenite Grain Size during Various Heat Treatment of Plain Low-Carbon Steels

ผู้ช่วยศาสตราจารย์ ดร.กัณฑ์วริชญ์ พลูปราชญ์
Asst.Prof.Ing.Ganwarich Pluphrach , PhD.
Email: pganwarich@yahoo.com

e prior mean austenite grain size of two plain low-carbon steels were investigated using
al Standard (ISO643) with determination of grain size by comparing to the standard charts
ation to the index G equation. The grain size of austenite was evaluated after heating at
°C for 1-6 h and water quenching. The steels were killed with aluminium and therefore
herently fine grained, and can be successfully heat treated at higher temperature and hold
eriod of time without the danger of abnormal grain growth. It was found that the Vickers
timated had good correlation to grain size.

Austenite grain size, Carbon steels, ISO643, Grain growth

ฉลี่ยขนาดเกรนออสเทนไนท์เดิม ของเหล็กกล้าคาร์บอนต่ำสองกลุ่มได้ถูกสำรวจโดยการใช้
จรฐานไอเอสโอ643 เพื่อเทียบขนาดเกรนต่อสมการ G ขนาดเกรนออสเทนไนท์ถูก
ภายหลังการให้ความร้อนที่อุณหภูมิ 1000-1200°C สำหรับ 1-6 ชั่วโมง และจุ่มลงน้ำ
ร์บอนต่ำถูกกระทำด้วยธาตุผสมอลูมิเนียม ดังนั้นจึงมีเกรนละเอียดตั้งแต่ต้น และสามารถ
วยการกระทำทางความร้อน ณ อุณหภูมิสูงเป็นเวลานาน โดยปราศจากอันตรายจากการ
รนที่ผิดปกติ การวิจัยพบว่าค่าความแข็ง Vickers มีความเป็นสหสัมพันธ์ที่ดีต่อขนาดเกรน

---

1. Introduction

Plain lo
i.e. sheet or stri
final temper rol
invariably displa
alloying additio
minimum residu

The Initial Auste

The aus
austenite grains a
the pearlite disap
growth theory, th

where N is the nu
the free energy ba
can be obtained.

Grain Size Control

The room
cementite/martensi
just before the tran
necessary to chan
necessary to heat t
is unstable at lowe
heated above the l
working, or combi

1. Introduction

Plain low-carbon steels are predominantly produced in the form of flat rolled steel products, i.e. sheet or strip. Usually they are produced in the cold rolled and annealed condition with often a final temper rolling treatment to remove the discontinuous yield phenomenon which these steels invariably display. The compositions of these steels invariably are low carbon with less than 1% total alloying additions. Low carbon is essential for the cold-formability requirements, as also is a minimum residual alloy content [6].

The Initial Austenite Grain Size

The austenite without significant grain refiners added [18] forms by the nucleation of austenite grains at various locations and their growth. Eventually they begin to impinge, and finally the pearlite disappears. At this stage the steel has its initial austenite grain size. From nucleation and growth theory, the number of grains per unit area N_i in a planar cut through a sample is given by [4] :

$$N_i = 1.01\,(N/G)^{1/2} \tag{1}$$

Therefore $$N = K\exp(\Delta G_C/RT)\exp(-\Delta G_b/RT) \tag{2}$$

and $$G = K(\Delta g_V)\exp(-\Delta G_b/RT) \tag{3}$$

where N is the nucleation rate, G is the growth rate, ΔG_C is the critical free energy change, ΔG_b is the free energy barrier change and Δg_V is the free energy change per volume. From N_i the grain size can be obtained.

Grain Size Control

The room temperature microstructure of plain low-carbon steel is principally ferrite plus cementite/martensite. These phases have formed from the grains of austenite that existed in the steel just before the transformation. If the size of ferrite, cementite and martensitic grains want to alter, it is necessary to change the size of the austenite grains before transformation. For this purpose it is necessary to heat the steel and make the austenitic grains to reappear in the structure. Since austenite is unstable at lower temperatures, austenitic grains can be made to reappear only when the steel is heated above the lower critical temperature. Heat treatment at lower temperature, cold mechanical working, or combinations of these may alter and distort the microstructure of steel, so that its

grain size can no longer be revealed by any ordinary method, but they cannot actually
s grain size.

uring slow reheating of steel, austenite begins to form at the interfaces between ferrite and
:rystals when the temperature reaches lower critical temperature. At this temperature a very
er of austenitic grains appear and they are at their minimum size. The size of the austenitic
ease with increase in temperature and time of heating. In many heat treatments, it is
dissolve ferrite or cementite by heating above the upper critical temperature. By doing so,
ening of austenitic grains take place, but it is not appreciable and can be tolerated for
id steels. Above this temperature, the increase in size of austenitic grains is rapid and
ith increasing temperature and holding time.

best method of controlling the grain size of steel is by addition of certain alloying
ring the manufacturing process. For example, addition of aluminium results in inherently
steels which can be successfully heat treated without the danger of grain coarsening [3].

n of Grain Size

International Standard (ISO643) specifies a micrographic method of determining
tenite grain size in plain low-carbon steels. It describes the methods of revealing grain
nd of estimating the mean grain size of specimens with unimodal size distribution. The
ied on the screen (or on a photomicrograph) is compared with a series of standard charts
he standard charts at a magnification of x 100 are numbered from 00 to 10 so that their
qual to the index G. Where the magnification g of the image on the screen or
aph is not x 100, the index G shall be equal to the number M of the closest standard
d as a function of the ratio of the magnifications [10] :

$$G = M + (6.64 \log g/100) \qquad (4)$$

tal Procedure

low-carbon steels were studied to optimize the influence of carbon content and single
ons on the austenite grain size. The composition (wt%) of these steels used in this study
le 1. The samples were austenitized at 1000, 1100, and 1200°C for 1, 3, and 6 h.

Table 1. Chemic

The aust
photomicrographs
specially etched in
had to be adjusted
filler eyepiece.

The austen
the grain so that sm
that the picture m
microstructures of
brittleness, resilienc
to deformation or in

3. Result and Discu

Since the a
necessary to compar
prior austenite grain
size. Table 2 shows
eighteen samples. Sir
size (μm) is reported

Table 1. Chemical composition of experimental carbon steels, wt%

Element	Steel 27 Mn4	Steel 16 Mn4
C	0.27	0.16
Mn	1.01	1.08
Si	0.38	0.41
P	0.018	0.018
S	0.010	0.011
V	-	-
Ti	-	-
Al	0.04	0.03

The austenite grain size microstructures of all the relevant samples representative photomicrographs were taken. In order to determine the austenite grain size, the samples were specially etched in a saturated picric acid solution at about 80°C [1]. The concentration of the acid had to be adjusted for different samples. The austenite grain size was then measured at x 25 using a filler eyepiece.

The austenite grain size determination should be done in a magnification suited to the size of the grain so that small grains may not be lost. The degree of magnification will be limited by the fact that the picture must include a sufficient number of grains [21]. The all austenite grain size microstructures of the sample steels are shown in Fig 1. Hardness may denote strength, stiffness, brittleness, resilience, toughness, or combination of these properties. It usually implies the resistance to deformation or indentation [3].

3. Result and Discussion

Since the austenite grain size of plain low-carbon steels is an important factor, it was necessary to compare the grain size between the different temperatures and times of the steels. The prior austenite grain boundaries were revealed by etching the specimens for evaluated the mean grain size. Table 2 shows the evaluated mean austenite grain size characteristics, and Vickers hardness of eighteen samples. Similarly, the relation of the austenitizing temperature (°C) and time (h) with grain size (μm) is reported in Fig. 2 & 3.

The evaluation mean austenite grain size of plain low-carbon steels were showed a primary
response. There are usually carbide and are often present in steel that have also been
ned by precipitation and solid solution strengthening. The kinetics solution of second phase
gly temperature and time dependent, so varying results can be obtained with steel depending
nperature history. The mean grain size of austenite in many samples are similarly, because
ratures were high, so that aluminium results in inherently fine-grained steels which can be
lly heat treated, and had major effect on retarding recrystallization. When steel is heated at a
mperature or for an extremly long period of time, it results in overheating. During
ng, grain growth occurs, and consequently a coarse grain structure is obtained. Such a coarse
ructure will have poor mechanical properties, such as low toughness, ductility and impact

sions

he following conclusions may be drawn from the results presented in this paper :

The tendency of low carbon steel toward grain growth increases with decreasing carbon

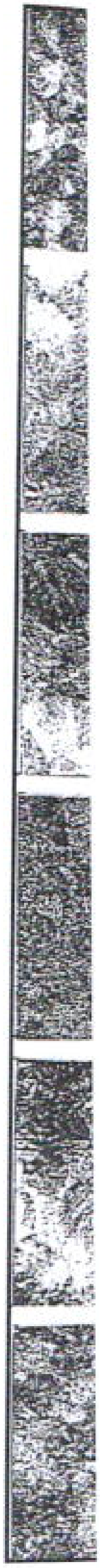
Plain low-carbon steels, killed with additionally aluminium result in inherently fine
eels, and can be successfully austenitized at higher temperature (up to 1000°C) and hold
eriod of time (up to 6 h for steel 27 Mn4) without the danger of abnormal grain growth.

Grain size of steel has a marked effect on its mechanical properties. A coarse-grained steel
ower hardness as compared to fine-grained steel.

There is good correlation in the Vickers hardness estimated according to mean grain size.

lgements

Pluphrach would like to thank very much to Prof.Ing.Karel Macek, DrSc., Faculty of
Engineering, Czech Technical University in Prague, Czech Republic for his help in this
rk.



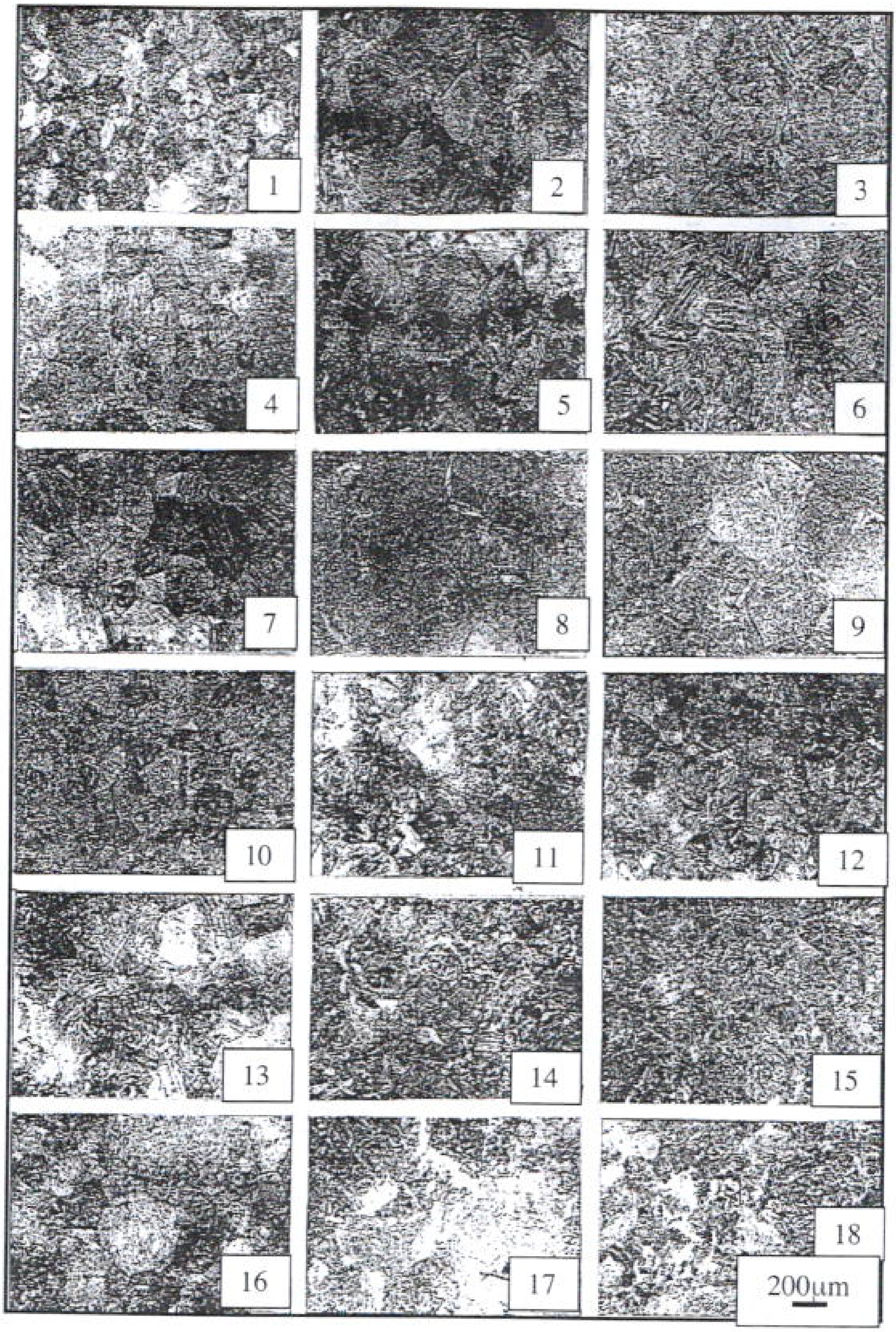
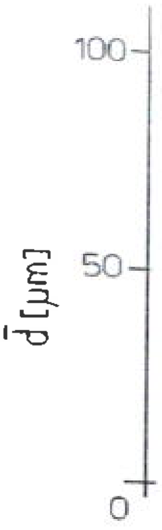


Fig.1 Optical austenite microstructure of the eighteen samples (in the same magnification)

. Evaluated mean austenite grain size characteristics according to International Standard (ISO643), and Vickers hardness of carbon steels [10]

1	2	3	4	5	6	7
(°C) (h)	closest standard chart	Equivalent index of grain	Estimated grain size	Mean diameter	Mean intersected	Vickers hardness
) ; 1	7	3	7	31.2	28.3	503
) ; 3	6	2	6	44.2	40	414
) ; 6	6.5	2.5	6.5	37.7	34.2	452
; 1	6.5	2.5	6.5	37.7	34.2	440
; 3	5	1	5	62.5	56.6	350
; 6	5	1	5	62.5	56.6	357
; 1	5	1	5	62.5	56.6	357
; 3	4	0	4	88.4	80	283
; 6	4.5	0.5	4.5	75.5	68.3	332
; 1	7.5	3.5	7.5	26.7	24.2	528
; 3	5.5	1.5	5.5	53.4	48.3	382
; 6	4.5	0.5	4.5	75.5	68.3	332
; 1	5.5	1.5	5.5	53.4	48.3	382
; 3	4	0	4	88.4	80	298
; 6	3.5	-0.5	3.5	106.7	96.5	239
; 1	5	1	5	62.5	56.6	353
; 3	3	-1	3	125	113	222
6	3	-1	3	125	113	217



Fig

Fig. 3 The r

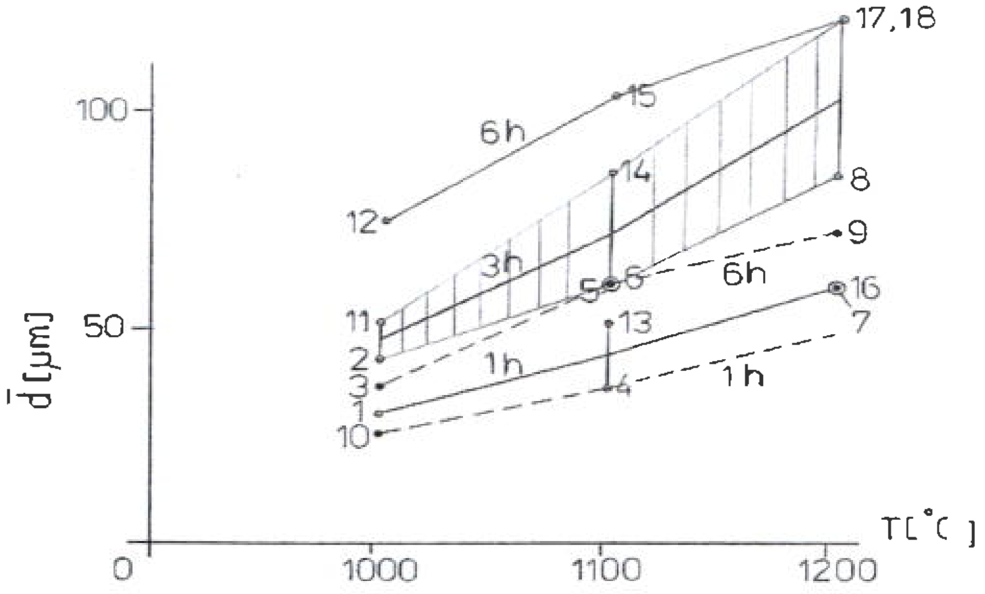


Fig. 2 The relation between grain size and temperature in eighteen samples

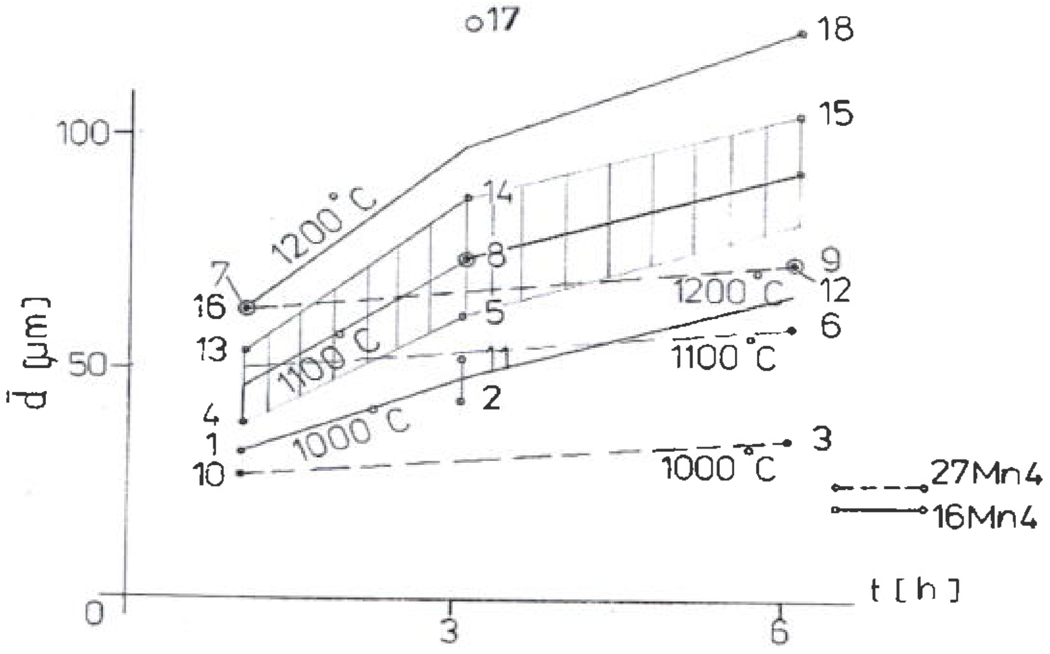


Fig. 3 The relation between grain size and time in eighteen samples as different temperature

:es

:lwazri, E.Essadiqi and S.Yue:ISIJ International, *v.44* , no.1, pp. 162-170, 2004.

ɔh, Mater. Sci.Technol., *6*, 1139, 1990.

.grawal, "Introduction to Engineering Materials," Tata McGraw-Hill, New Delhi, 1989.

rooks, "Principles of the Austenitization of Steels," Elsevier Applied Science, Essex, 1992.

ɜkeland, "The Science and Engineering of Materials," 3rd SI. Ed., Chapman & Hall, London, 1996.

ckering, "Physical Metallurgy and the Design of Steels," Applied Science Publishers, Ltd., 1978.

'ickering, "Materials Science and Technology," 7 ed. by R.W.Cahn, P.Haasen and mer, VCH, Weinheim, 1992.

ndrade, M.G.Akben and J.J. Jonas:Metall. Trans. A, *14A*, 1967, 1983.

ani, F.Terasaki and T.Kunitake : Trans. ISIJ, *12*, 118, 1972.

ational Standard (ISO643), "Steels-Micrographic determination of the apparent grain size,")03.

ɜrman, B.Donnay and V.Leroy, "ISIJ Inter," *32*, 779, 1992.

ıg and T.N.Baker, "ISIJ Inter," *43*, 2015, 2003.

en and G.S.Ansell, "Alloy and Microstructural Design," Academic Press, New York, 1976.

:urzydlowski and B.Ralph, "The Quantitative Description of the Microstructure of " CRC Press, Boca Raton, 1995.

t, "Neural Network Modelling of Hot Deformation of Austenite," Wolfson College, The of Cambridge, Cambridge, 2001.

eminezhad and A.K.Taheri, Mater. Sci.Technol., *20*, 106, 2004.

ɜhby and D.R.H.Jones, "Engineering Materials," Pergamon Press, Oxford, 1980.

ınnerz and de Kazinczy, Journal of the Iron and Steel Institute, *208,* 475, 1970.

ɜrill and P.R.Mould, "Recrystallization and Grain Growth in Metals," Surrey University lon, 1976.

. Honeycombe and H.K.D.H. Bhadeshia, "Steels Microstructure and Properties," Edward ndon, 1995.

Hoff and F.N.Rhines, "Quantitative Microscopy," McGraw-Hill, New York, 1968.

ɜslie, "The Physical Metallurgy of Steels," McGraw-Hill International Book Company, 2.

Suppl

[1]ภาควิ

[2]ภาควิชาสถิติ

งานวิจัยนี้มีจุดมุ่
ไทย โดยใช้พื้น
โครงสร้างของก
ไหลของสินค้า
ปัจจุบันจะนำมาสู
วิเคราะห์สภาพปั
อุปทาน

This research aim
industry in Thai
Samutsakhon, in
information flow
study in AS-IS m
supply chain man
analysis.

คำสำคัญ (Keywo
Shrimp Industry