1916

The effect of temperature upon the crystal size and physical properties of iron and steel

Earl Joesting McNely

THE EFFECT OF TEMPERATURE UPON THE CRYSTAL SIZE AND PHYSICAL PROPERTIES OF IRON AND STEEL

BY

E.J.McNELY

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

BACHELOR OF SCIENCE IN METALLURGY

Rolla, Mo.

1916

Approved by Horace T. Mann

Associate Professor of Metallurgy.

TABLE OF CONTENTS.

THE EFFECT OF TEMPERATURE UPON THE CRYSTAL SIZE AND PHYSICAL PROPERTIES OF IRON AND STEEL.

This investigation was deemed of sufficient merit to require the work of two terms. It naturally is divided into two parts, i.e., the effect that temperature has upon the crystal size; and the effect that temperature has upon the physical properties of iron and steel.

This part of the work deals with the effect that temperature has upon the crystal size of a .03 per cent carbon steel, the analysis of which is found within.

Chief among the investigators of this same subject are found Heyn, Stead, Sauveur, Joisten, and Howe. Inasmuch as this is not an original investigation, Professor Howe was closely followed.

The specimens were cut 5/8" long, from ½" steel bars, containing .03 per cent carbon, .002 per cent phosphorus, .04 per cent manganese, and .030 per cent sulphur. This makes it a very low carbon steel. The phosphorus, manganese, and sulphur were not in sufficient quantity to affect the results. The slugs were numbered consecutively, but it was impossible to take them from the furnace in order.

Pyrometer number two and millivoltmeter number two, which had been previously standardized, were used. The junction of the pyrometer was placed directly over the top of the specimens, which enabled the temperature to be controlled within 10° C. on either side of the desired points.

The electric furnace consisted of a 3"x 8" alumdum tube, closed at one end and wound with platinum wire. This in turn was incased in insulating material.

In order to note the effect on the crystal size that simply bringing the steel to a given temperature, specimens were placed in the furnace, brought up to 600° C. and taken out at temperature intervals of 20° C., except near the final transformation point until 900° C. had been reached. A duplicate series, taken out at temperature intervals of 40° C., was run. Owing to a defect in the furnace, it burned out at 850° C. It was again brought to 850° C., and the balance of the specimens up to 900° C. were run. The results are found in table number one, page 11.

In order that the effect on the crystal size of the cooling medium might be noted, specimens were heated to 600° C., 850° C., and 900° C., and at each temperature, one water quenched, air cooled, and furnace cooled. The results are found in table number three, page 13.

Two sets of specimens, one at 610° C. and the other at 800° C., taken out at hour intervals, were run in order to note the effect that length of exposure to heat at a given temperature has upon the crystal size. The results are found in table number two, page 12.

Microphotographs were made of a specimen of the original bar; of specimens number 1, 10, 13, 8, 9 of first series; of 19, 14, 41, 39 of second series; of 63, 62, 37, 68, 52, 56, 58, 59, 60, 40, 46, 20, 22, and of scale, all of which are found elsewhere.

The microphotographs were taken with a number 10 eyepiece and 4 m.m. lense. These, with the camera, gave a magnification of about 150 diameters.

All specimens were polished and etched in a solution of twelve parts water and one part nitric acid, from 5 to 45 seconds, to bring out the grain structure sufficiently to enable the crystals to be counted. When the microphotographs were taken, the specimens were etched electrolytically, with a dilute nitric acid solution for an electrolyte.

The Heyn's method of measuring crystals was resorted to. It depends upon the assumption that the intercepts of a straight line intersecting a number of crystals will be proportional to the square root of the areas of the crystals, or on the assumption that the crystals are squares. The vertical hair in a micrometer eyepiece was measured with a m.m. scale under a 4 and 16 m.m. lense. The 4 m.m. lense was used in most cases, but where the crystals were large, the 16 m.m. lense was used. Seventeen readings were taken across each specimen and the average taken. Dividing the length of the hair by the average, and squaring the result, gave the areas found in the tables.

Stead holds that low carbon steel coarsens progressively and without limit between 600° C. and 770° C. Professor Howe says that there is a decided growth of crystals in the same regions and increases rapidly as it approaches 770° C. An examination of specimens number 1, 6, 3, 2, 5, 7, 4 and 19, 31, 24, 23, and 16 of table number one, page 11, do not bear out these statements as to rapid growth between, say 600° C. and 740° C. As to rapid growth near 770° C., specimens number 10 and 32 do bear out this assumption. In order to be able to make a more definite statement as to rapidity of growth of crystals about 600° C., specimens number 52-57 of table number two, page 12, were made. As before stated, they were taken out at hour intervals. Using the fact that the time element does increase the size of the crystals, it would be expected that a decided increase in growth would be seen in number 56, heated six hours, provided a rapid growth did take place in this 600° region. But there is only a very slight growth. Professor Howe further states that a slow growth is to be expected above 770° C. Specimens number 12, 13,and 14, table number one; also specimens number 34, 14, and 20, of table number three, run at 850° C., quenched, air cooled, and furnace cooled indicate a decided growth. These results do not agree with Professor Howe.

In order to make a comparison of growth of crystals in region about 600° C. and 770° - 800° C. a set of specimens was run at 800° C. Between the first and last of the 52-56 series, table number two, page 12, microphotographs page 18, there is about a 1 per cent increase; or allowing for error in measuring, practically none. While in the case of the 63-68 series, table number two, microphotographs page 19, there is about a 200 per cent increase. These results bear out the assumption that time as well as temperature is a factor in grain growth. To further uphold this fact, specimens in table number three, page 13, were quenched, air cooled, and furnace cooled. The set at 610° C., microphotographs page 20, show apparently no difference in growth, which was to be expected from results in table number two. The set at 850° C., microphotographs page 22, shows a slight growth in the furnace cooled, while at 900° C., microphotographs page 21, the furnace cooled shows a decided growth which Professor Howe maintains would happen in the region above the critical point, provided a specimen is held there sufficiently long.

In table number one, page 11, in specimens 1-13, microphotographs page 15, there is a progressive growth, apparently negligible at first, then quite rapid until 900° C. is reached where a very great increase is noted. According to theory and experimental results, a reduction in size of crystals should have occurred at the critical point between 880° and 890° C. In the second series, microphotographs page 17, this decrease in size does occur between 880° and 890° C. and reaches almost the original size at 900° C. Just how to account for this difference might be explained by the fact that, refining or reduction in crystal size, although it may be very rapid, at times is slow. In table number one in the first set, the difference in the time between the temperature intervals is about three minutes while in the second set the time is about six minutes. The crystals in the first case failed to refine, and were carried over into the next region, consequently giving the growth noted in specimen 9. This is in accord with Professor Howe's theory.

Results at higher temperatures could not be obtained.

In conclusion, I wish to give credit to Professor C.Y.Clayton for his assistance and suggestions.

TABLES

TABLE No. 1.

No.	Temp.	Time up to Temp.	Size Sq.m.m.		No.	Time up to Temp.	Temp.	Size Sq.m.m.
1	600	10'	.000533		19	38'	600	.00065
6	620	17'	.000461		31	45'	640	.000572
3	660	21'	.000648		24	54'	680	.000675
2	680	28'	.000653		23	1hr.	700	.000841
5	700	37'	.000578		16	" 8'	730	.000569
7	740	47'	.000525		32	" 17'	770	.001860
4	740	47'	.000547		30	" 23'	810	.001161
10	770	1hr. 16'	.000902		14	" 33'	850	.002620
12	830	" 26'	.001616		41	36'	880	.001567
11	850	" 30'	.001600		44	41'	890	.001039
13	870	" 33'	.00220		39	52'	900	.00070
8	890	" 37'	.00262		X	52'	900	.00077
9	900	" 39'	.01022		21	1hr 33'	850	.005120
Original	—	—	.000600					

TABLE No. 2.

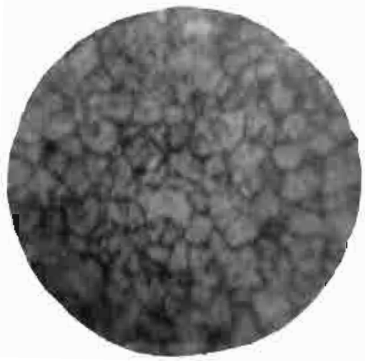
No.	TIME Including Heating Up.	TEMP.	SIZE Sq. m.m.		No.	TIME Including Heating Up.	TEMP.	SIZE Sq. m.m.
52	1hr: 10'	610	000618		63	1 hrs.	800	.000782
54	2hrs 10'	"	.000595		65	2 hrs.	"	.000920
57	3hrs 10'	"	.000435		62	3hrs.	"	.001850
53	4hrs. 10'	"	.000607		66	3hrs. 25'	"	.001361
55	5hrs. 10'	"	.000715		37	4hrs. 25'	"	.002270
56	6hrs. 10'	"	.000680		67	5hrs. 25'	"	.001837
					68	6hrs. 10'	"	.00236

TABLE No. 3

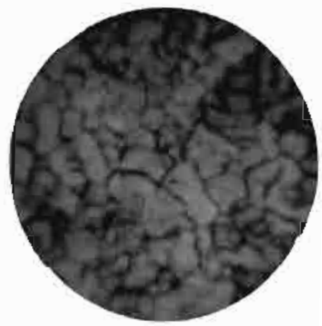
TEMP.	TIME UP TO TEMP.	SIZE - SQ. M.M.						
		No.	Quench-ed	No.	Air Cooled	No.	Furnace Cooled	
850	1hr. 33'	34	.001763	14	.00262	20	.00384	
"	"	22	.001490	21	.00512	28	.00226	
900	52'	40	.000750	39	.000700	46	.00826	
"	"	51	.000895	X	.000770	49	.00826	
610	12'	60	.000418	58	.000374	59	.000432	

MICROPHOTOGRAPHS

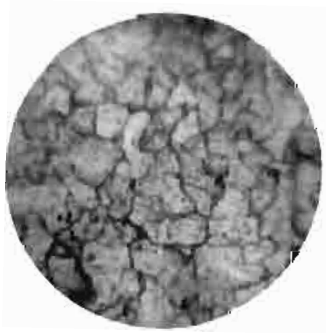
Microphotographs Showing the Effect of Temperature on Crystal Size



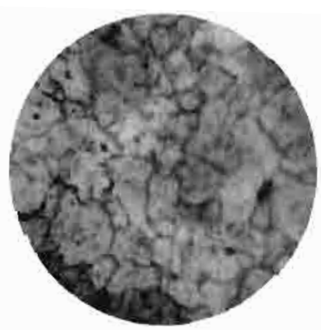
Original. Size .0006



I. 600°C. IO'
Size .000533

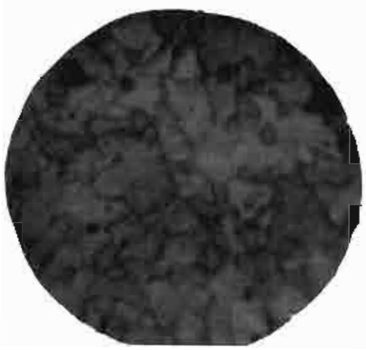


IO. 770°C. I hr. IO'
Size .00092



I3. 870°C. I hr. 33'
Size .0022

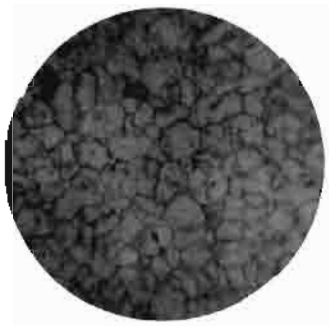
Microphotographs Showing the Effect of Temperature on Crystal Size



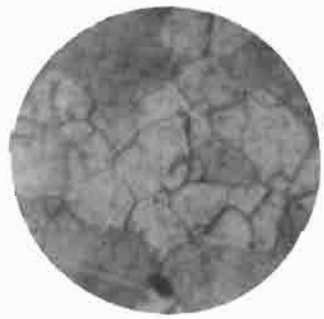
8. 890°C. I hr. 37'
Size .00262

9. 900°C. I hr. 39'
Size .01022

Microphotographs Showing the Effect of Temperature
on Crystal Size



19. 600° C. 38'
Size .00065

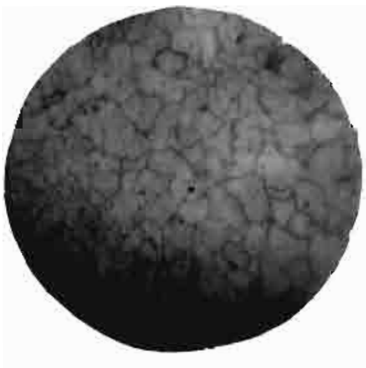


14. 850° C. 33'
Size .00262

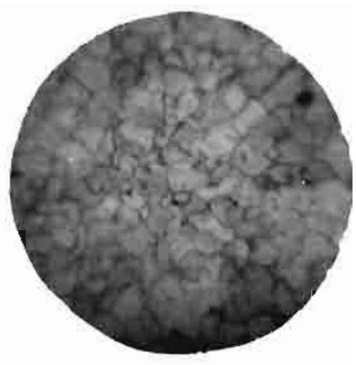
41. 880° C. 36'
Size .00157

39. 900° C. 52'
Size . 00070

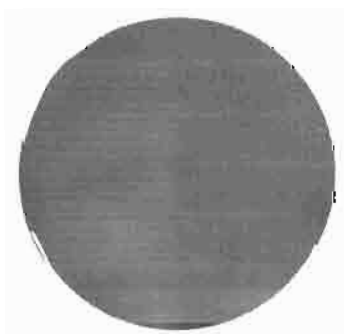
Microphotographs Showing the Effect of Length of
Exposure to a Given Temperature
on Crystal Size



52. 610° C. 1hr. 10'
Size .000518

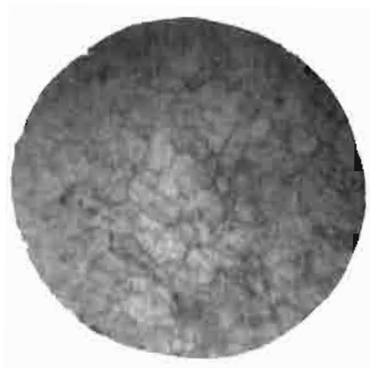


56. 610° C. 6 hrs. 10'
Size .00068

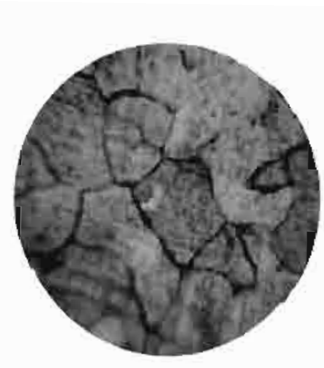


SCALE--Each division equals .01 m.m. Magnification is equal to about one hundred and fifty diameters.

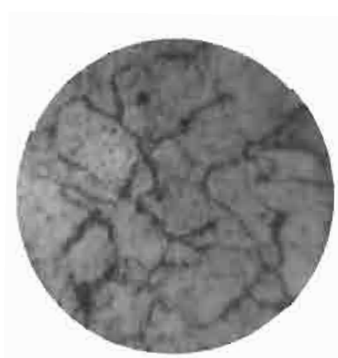
Microphotographs Showing the Effect of Length of
Exposure to a Given Temperature
on Crystal Size



65. 800 C. 1 hr.
Size .00078



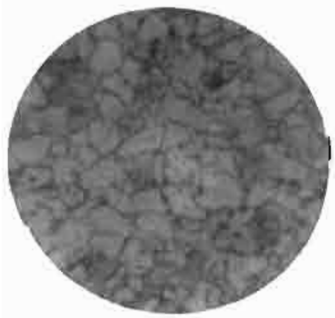
62. 800°C. 3 hrs.
Size .00185



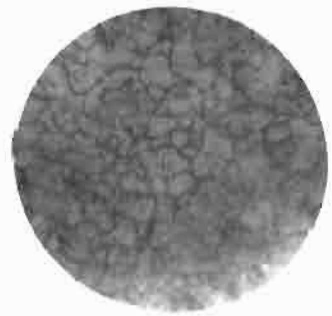
37. 800°C. 4 hrs. 25'
Size .00227

68. 800°C. 6hrs. 10'
Size .00226

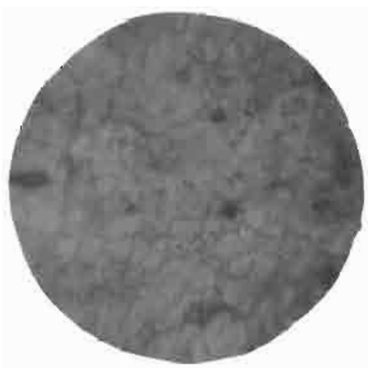
Microphotographs Showing the Effect of Cooling
Medium on Crystal Size at 610°C.



50. I2' Size .000418
Water Quenched



58. I2' Size .000374
Air Cooled



59. I2' Size .000432
Furnace Cooled

Microphotographs Showing the Effect of Cooling
Medium on Crystal Size at 900°C.

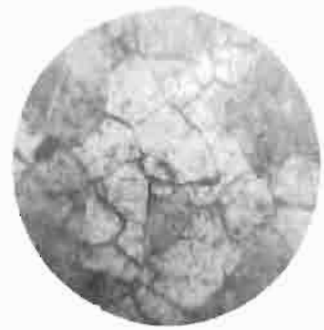
40. 52' Size .00075
Water Quenched

39. 52' Size .0007
Air Cooled

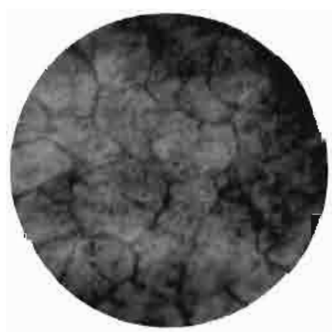
46. 52' Size .00826
Furnace Cooled

Microphotographs Showing the Effect of Cooling
Medium on Crystal Size at 850°C.

22. I hr. 33' Size .00I49
Water Quenched



I4. I hr. 33' Size .00262
Air Cooled



20. I hr. 33' Size .00384
Furnace Cooled

BIBLIOGRAPHY.

Microscopic Analysis of Metals. F.Osmond, J.E.Stead.

Life History of Net Work and Ferrite Grains in Carbon Steel. H.M.Howe. Am. Soc. of Testing Materials, v.11,1911, p.262-386.

The Crystalline Structure of Iron and Steel. Dr.Stead. Journal Iron and Steel Institute, v.1, 1898, p.145-189.

The Metallography and Heat Treatment of Iron and Steel. A.Sauveur, p.86-207.

INDEX.