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

Earl Joesting McNely

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

BY

E.J. McNELLY

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 W. Mann

Associate Professor of Metallurgy.

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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 temper­
ature 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 with­
in.

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 1/4" 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 im-
possible 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" alumnum 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, 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 re-sorted 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, 5, 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°C and 890°C. In the second series, microphotographs page 17, this decrease in size does occur between 880°C 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.

<table>
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<tr>
<th>No.</th>
<th>Temp.</th>
<th>Time Up To Temp.</th>
<th>Size (Sy.m.m.)</th>
<th>No.</th>
<th>Temp.</th>
<th>Time Up To Temp.</th>
<th>Size (Sy.m.m.)</th>
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<td>2</td>
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<td>28'</td>
<td>0.000653</td>
<td>23</td>
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<td>5</td>
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<td>37'</td>
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<td>610</td>
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<td>63</td>
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<td>65</td>
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<td>0.000782</td>
<td>66</td>
<td>3 hrs. 20'</td>
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<td>53</td>
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-12-
<table>
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<th>Temp.</th>
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<td>900</td>
<td>52'</td>
</tr>
<tr>
<td></td>
<td>610</td>
<td>12'</td>
</tr>
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MICROPHOTOGRAPHS
Microphotographs Showing the Effect of Temperature on Crystal Size

Original, Size .0006

1, 600°C, 10', Size .000533

10, 770°C, 1 hr, 10', Size .00092

13, 870°C, 1 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

39. 900° C. 52'  
Size .00070

41. 880° C. 36'  
Size .00157
Microphotographs Showing the Effect of Length of Exposure to a Given Temperature on Crystal Size

52. 610°C. 1 hr. 10'
Size .000658

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

37. 500°C. 4 hrs. 26'  Size .00227
38. 800°C. 6 hrs. 10'  Size .00226

62. 800°C. 3 hrs.  Size .00185
Microphotographs Showing the Effect of Cooling Medium on Crystal Size at 610°C.

50. 12' Size .000418
Water Quenched

58. 12' Size .000374
Air Cooled

59. 12' 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. 1 hr. 33' Size .00149  
Water Quenched

14. 1 hr. 33' Size .00262  
Air Cooled

20. 1 hr. 33' Size .00384  
Furnace Cooled
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The Crystalline Structure of Iron and Steel. Dr. Stead.
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