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**EFFECT OF HIGH TEMPERATURE "CONDITIONING" TREATMENT
ON THE HARDNESS, MICROSTRUCTURE, AND GRAPHITIC CARBON
OF WHEEL IRON**

by

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A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science.

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Date: June 22, 1951.

ACKNOWLEDGMENTS

I have great pleasure in acknowledging with a deep sense of gratitude, the help, which Professor Clark B. Carpenter, Head of the Department of Metallurgy, Colorado School of Mines, rendered in the investigation of this problem. The subject itself was suggested by the learned professor. But for the keen interest he took in this work and the suggestions and guidance he gave, this subject would not have seen the light of day.

I am also indebted to D. C. Card, C. O. Penney and R. H. Muench of the C. F. Card Iron Works, Denver for all the help they rendered in connection with the making of the molds, casting and 'conditioning' of the specimens.

I am thankful to Professor M. C. Smith, Dr. L. B. Gulbranson, and W. M. Mueller of the Department of Metallurgy, Colorado School of Mines, for their kind help and suggestions and also for making available to me the facilities of their respective laboratories.

My thanks are due to Mr. Matson and Mr. Pierce of the Experimental Plant, Colorado School of Mines, for allowing me to use the facilities at the Plant in connection with the preparation of the samples and their analysis.

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INTRODUCTION

Cast irons of like composition and method of manufacture show considerable variations in their properties and behavior. This has stimulated much investigation, leading to a better understanding, of the material and of the methods of improving its properties. It has been long realized, that the properties of gray cast iron depend on the type and distribution of the graphite flakes as well as the nature of its matrix.

In a very recent investigation undertaken at the University of Michigan to determine the Time-Temperature-Transformation characteristics of Ni Hard Grain Roll Iron, it was found that the isothermal transformation characteristics of Ni Hard Iron were greatly affected by a High temperature 'Conditioning' treatment of the material above its critical temperature.¹² It was found, that a 'conditioning' treatment such as "cooling the specimen at a rate of 60 to 70°F per hour from about 1700°F to the isothermal transformation temperature" or "holding the specimen at 1400°F for two hours before cooling down to the transformation temperature" resulted in an increase in hardness over that of the specimens which were cooled in air to the isothermal transformation temperature.^{12, 13, 16}

Realizing the possibilities of improving the hard-

ness and other properties of "wheel iron" by this 'conditioning' treatment this subject was suggested by Professor Carpenter, and the author undertook its investigation.

This paper gives an account of the procedure followed to find whether the hardness of "wheel iron" increases with a conditioning treatment for two hours at temperatures of 1600°F, 1400°F, 1200°F and 1000°F, and attempts at a possible explanation of the difference in properties, particularly hardness, between the 'conditioned' and 'unconditioned' samples. In this attempt the nature of the graphite flakes formed, the nature of the matrix, the determination of the combined and graphitic carbon of the samples and an X-ray diffraction study were undertaken.

Suggestion for further work in the line are given towards the end of the paper.

EXPERIMENTAL PROCEDURE

Casting of the Test Specimens:

All specimens were cast at the C. S. Card Iron Works, Denver. A wedge specimen of the size shown in Fig. 1 was preferred to other shapes, as it would enable the study on different section thicknesses of the sample. The particular dimensions were chosen, so that the specimen could be easily introduced into an electric furnace, available at the C. S. Card Iron Works.

Wheel Iron charge, melted in the cupola of the Card Iron Works was tapped into a large ladle. The temperature of the metal at the mouth of the spout of the cupola was around 2700°F. From the large ladle about fifty pounds of metal was poured into another small ladle. The surface of the metal was then cleaned of all floating impurities and then it was poured into green sand molds. Two specimens were cast from the same metal in separate flasks, one of which was subjected to the 'conditioning treatment' while the other was allowed to cool in the mold to room temperature.

'Conditioning' Treatment:

The metal was allowed to solidify in the mold and about five minutes after pouring, one of the samples was

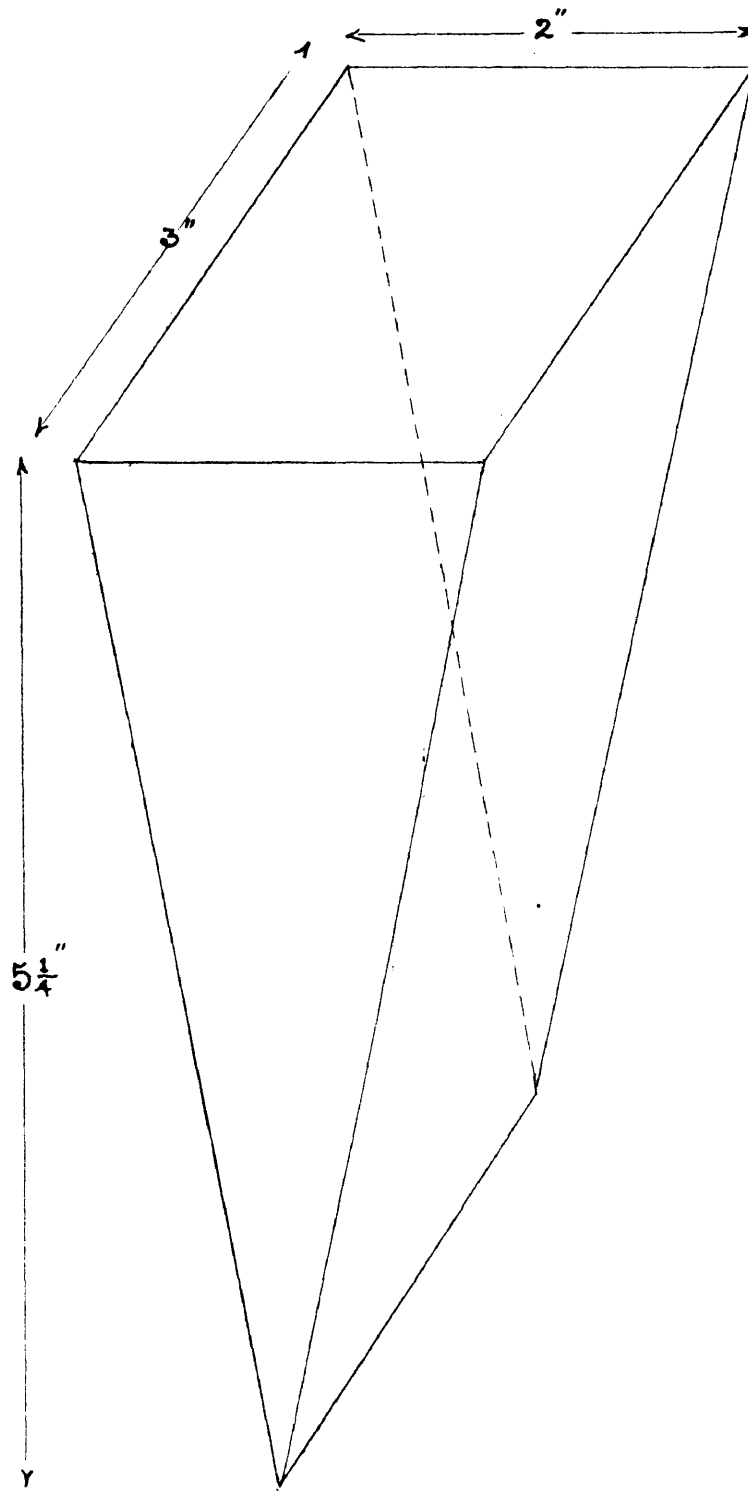


Fig. 1 Dimensions of the Test Specimen

shaken out of the mold and the runner head broken off with a hammer. The specimen was then immediately put into an electric furnace kept at the desired temperature. Due to the heat in the specimen the furnace temperature often went up a little above the desired level; this was controlled by keeping the door of the furnace open a little for a few minutes, during which time the temperature came down to the desired level. This was later accomplished by keeping the temperature of the furnace a few degrees below the desired temperature so that when the sample was introduced into the furnace it would come up to the desired level. The temperature of the furnace was noted by means of a thermocouple and it was controlled within $\pm 5^{\circ}\text{F}$.

After keeping the sample at the chosen temperature for two hours it was taken out and allowed to cool to room temperature in air.

Examination of the Hardness:

Both specimens were cleaned and the surface ground off. It was then cut through the middle into two halves as shown by the dotted lines in Fig. 2. The cut surface of one of the pieces was then ground flat and polished on the emery belt. The Brinell Hardness of the specimen was then taken along a central line of the section from the base to the apex of the wedge, at nine or ten approximately equi-

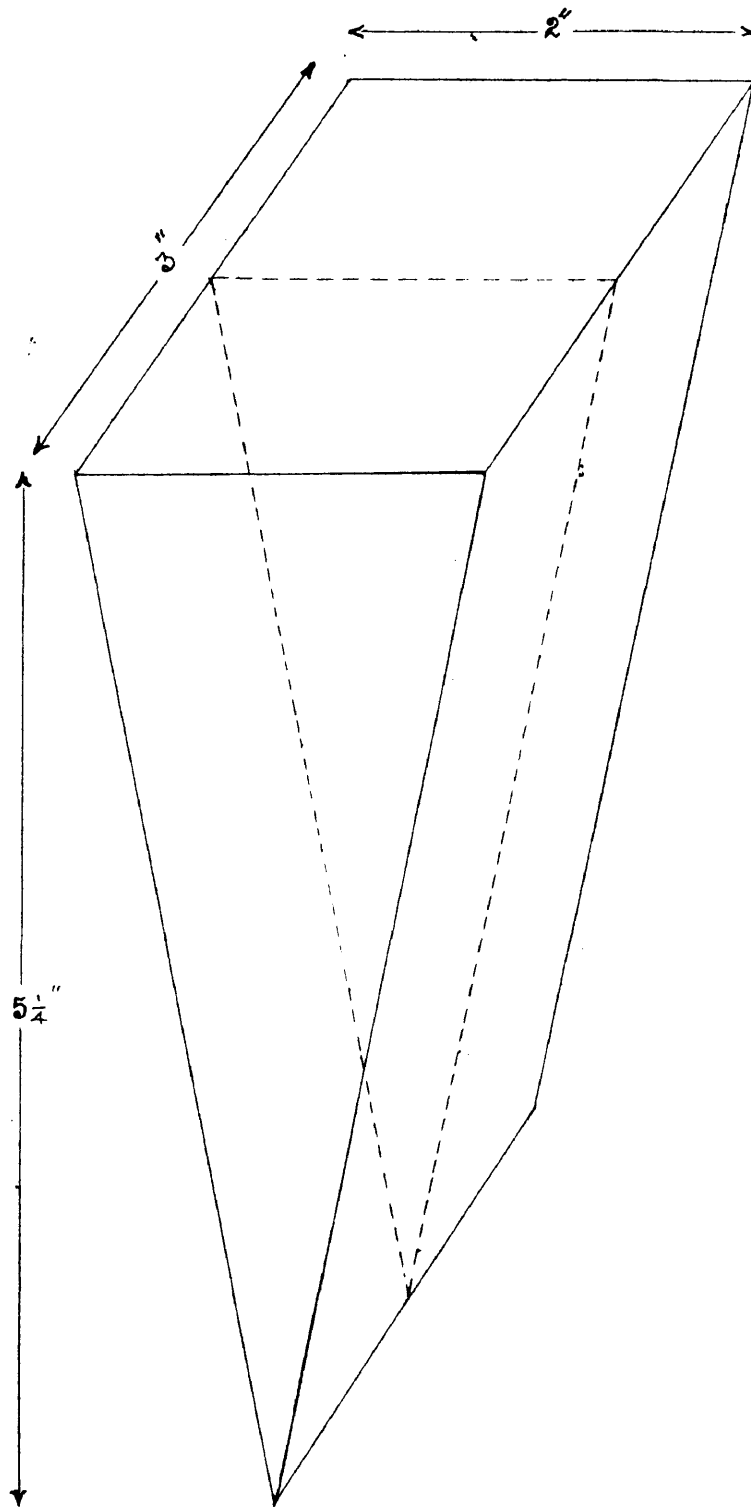


Fig. 2

distant points. These points are numbered starting from the base towards the apex. The hardness values of the 'unconditioned' samples and of samples 'conditioned' at the different temperatures are shown in Table No. 1 to Table No. 4. These results are also plotted in Figure 3 to Figure 6, which also shows the size of the section and the central line of the section along which the hardness measurements were taken.

The Brinell Hardness value was preferred to Rockwell C values as the former is thought to be more reliable for gray iron. The Rockwell machine may register a lower or higher hardness value if the diamond point should indent a flake of graphite or a mass of cementite respectively.

Table I

Hardness values of the sample 'conditioned' at 1600°F and
the corresponding 'unconditioned' sample

Point No.	Brinell Hardness Number		Difference in B. H. Number
	'Unconditioned'	'Conditioned'	
1	196	207	11
2	187	207	20
3	196	217	21
4	192	217	25
5	196	217	21
6	202	228	26
7	212	248	36
8	228	255	27
9	269	end broken off	--

Table II

Hardness values of the sample 'conditioned' at 1400°F and
the corresponding 'unconditioned' sample

Point No.	Brinell Hardness Number		Difference in B. H. Number
	'Unconditioned'	'Conditioned'	
1	192	196	4
2	187	192	5
3	183	196	13
4	183	196	13
5	192	207	15
6	196	210	14
7	202	212	10
8	212	217	5
9	241	235	-6
10	293	cracked	-

Table III

Hardness values of the sample 'conditioned' at 1200°F and those of the corresponding 'unconditioned' sample.

Point No.	Brinell Hardness Number		Difference in B. H. Number
	'Unconditioned'	'Conditioned'	
1	202	187	-15
2	196	179	-17
3	192	179	-13
4	196	179	-17
5	202	187	-15
6	207	187	-20
7	217	196	-21
8	223	217	-6
9	255	248	-7

Table IV

Hardness values of the sample 'conditioned' at 1000°F and those of the corresponding 'unconditioned' sample

Point No.	Brinell Hardness Number		Difference in B. H. Number
	'Unconditioned'	'Conditioned'	
1	196	196	0
2	187	187	0
3	187	187	0
4	192	192	0
5	196	196	0
6	196	202	6
7	202	207	5
8	207	217	10
9	223	235	12

Brinell Hardness

280

260

240

220

200

180

0

1

2

3

4

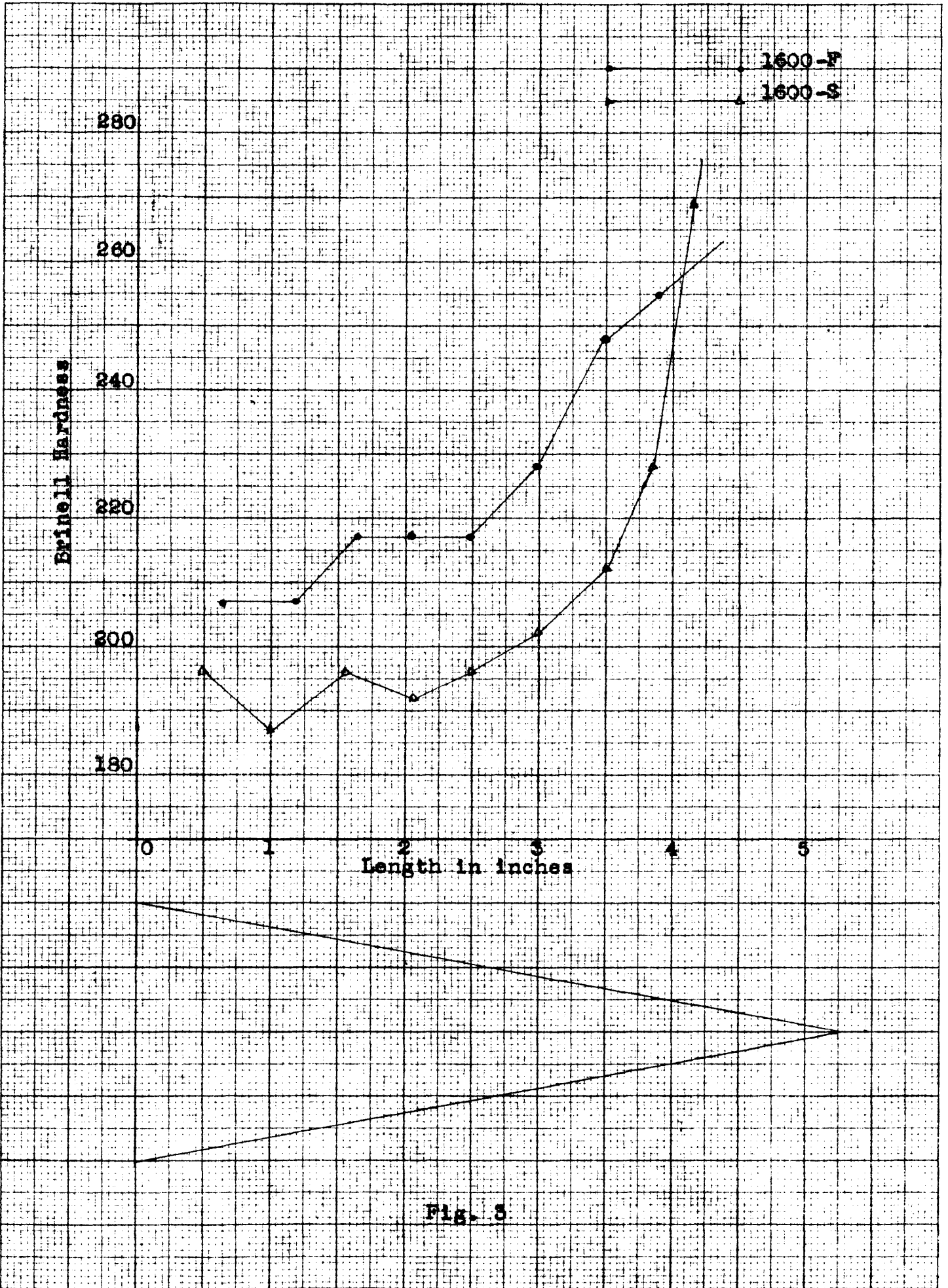
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Length in inches

1600-F

1600-S

Fig. 3



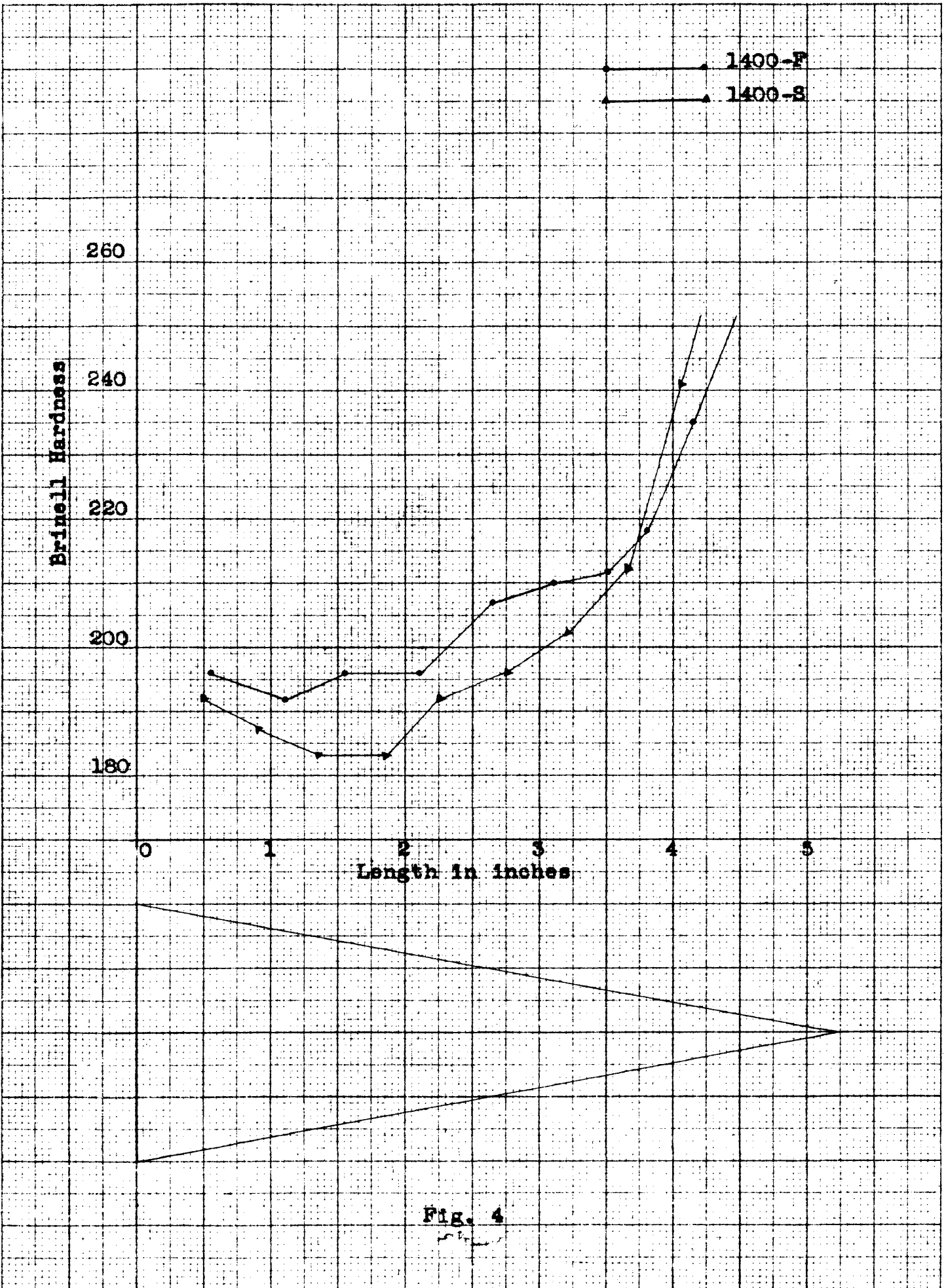


Fig. 4

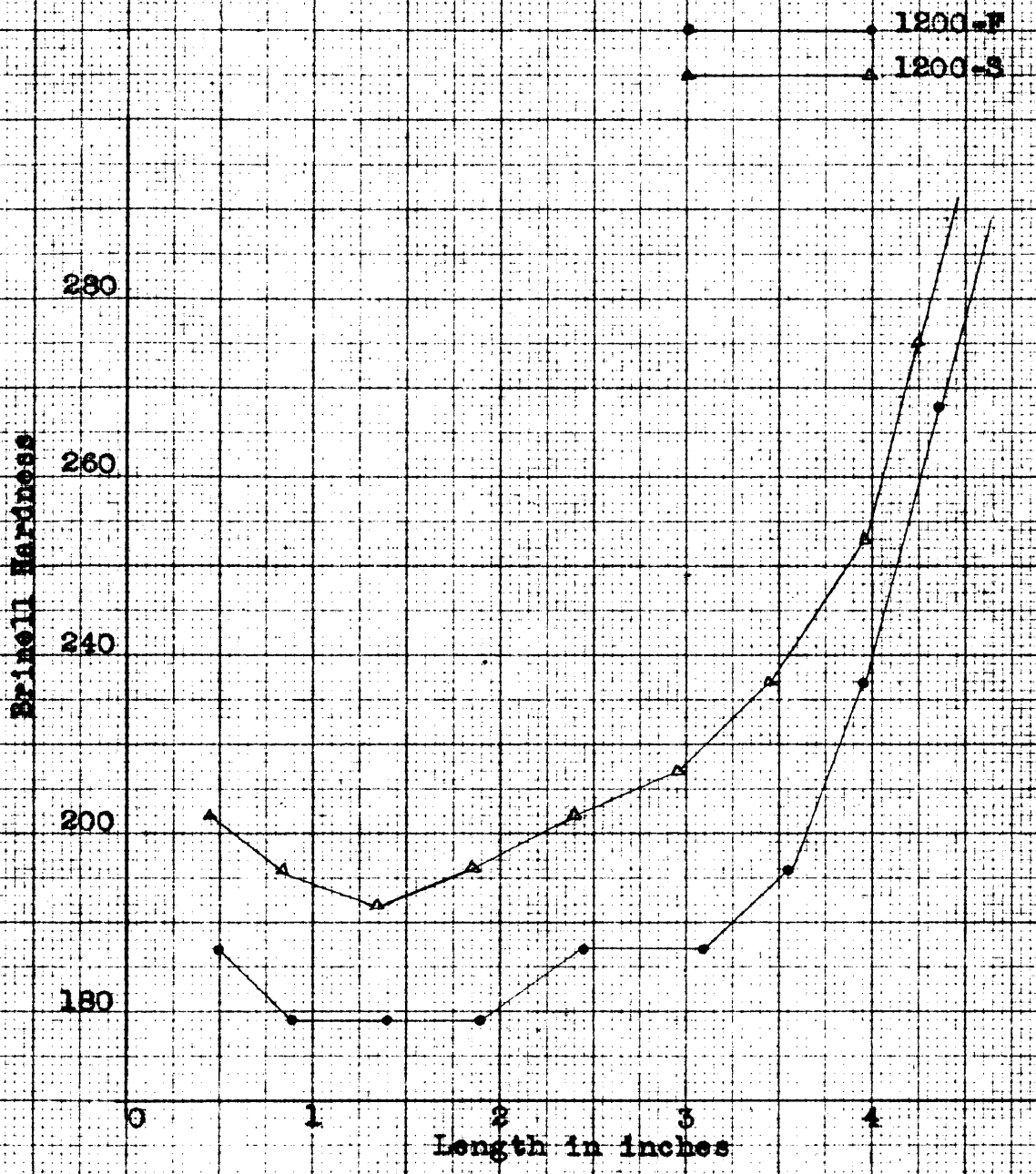


Fig. 5

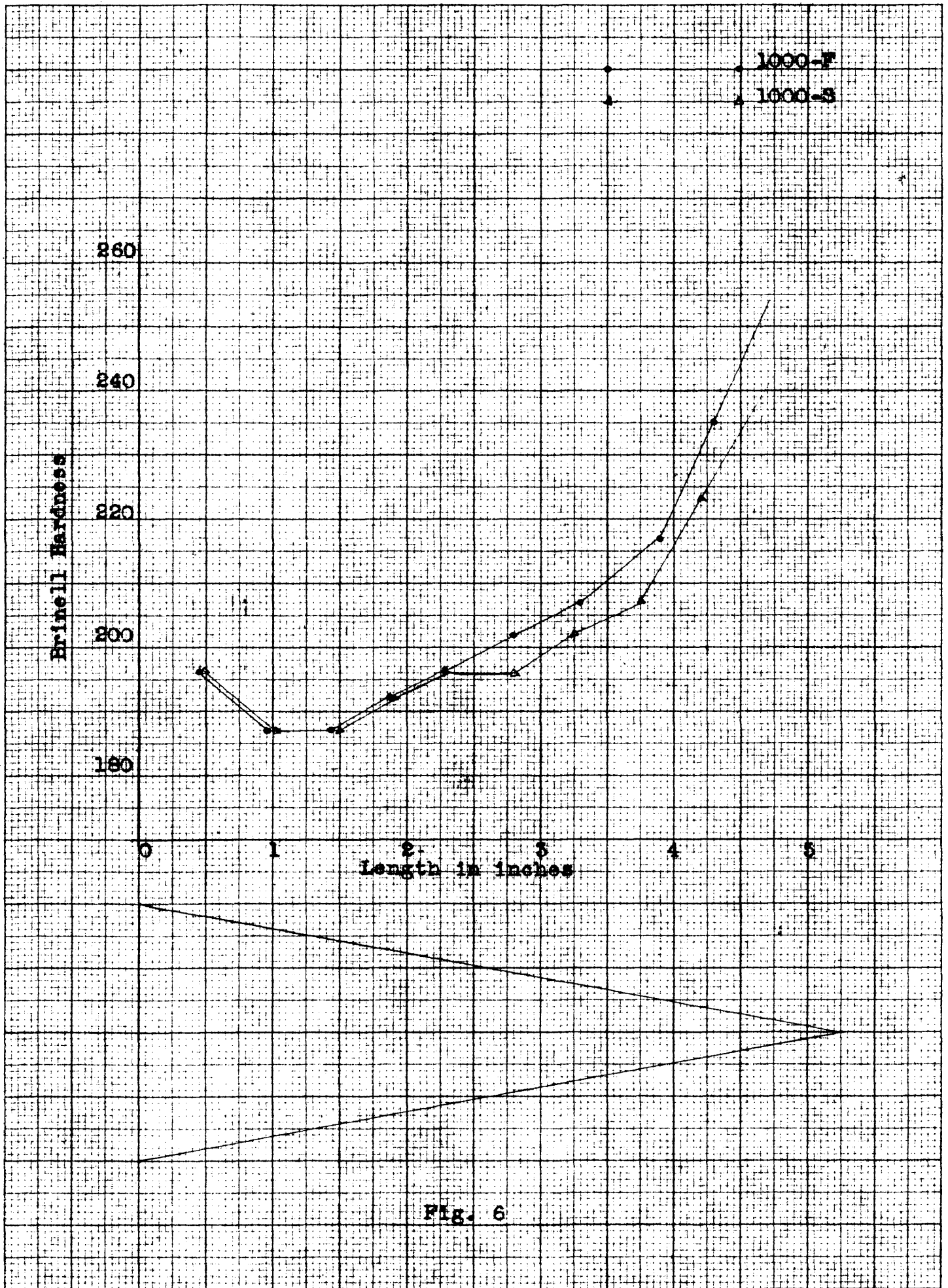


Fig. 6

From the above tables and graphs, it is seen that 'conditioning' of the samples at temperatures of 1600° F and 1400° F does increase the hardness all along the specimen. The maximum increase in hardness is observed at a section thickness of about one-half inch in the case of the sample conditioned at 1600° F and at a section thickness of about one inch in the one conditioned at 1400° F.

In the case of the samples conditioned at 1200° F, there is a decrease in hardness all along the length of the specimen. The maximum decrease in hardness is observed at a section thickness of about one inch and the hardness difference from there towards the base is approximately constant.

'Conditioning' at 1000° F has no effect on the hardness of the specimen from about a section thickness of about one and one-eighth inch down to the base of the wedge. However, towards the apex an increase in hardness is noted.

Microscopic Examination:

One of the half-sections from each specimen was sectioned at five places so that each piece would have a thickness of about one inch. These sections were then polished and examined under the microscope.

A word about the polishing of cast iron pieces, as in this investigation, does not seem to be out of place

here. Cast iron must be polished very carefully so as to retain the graphitic flakes without being torn out and to prevent the formation of pits on the polished surface which might be mistaken for nodules of graphite. In fact the polishing operation took much time and after much careful work it was found that doing a fine polishing on '0000' paper and straightway going to the final polishing wheel gave the required results.

Examination of the Graphitic Structure:

The polished sections were examined under the microscope 'unetched' and then photographed. These photographs of the sample 'conditioned' at 1600°F and the corresponding 'unconditioned' one, which are typical of the other three sets as well, are shown in Plates No. 1 to 10.

The sections are numbered from 1 to 5 starting from near the base and progressing towards the apex, as for example section 1600-F-1 means the first section nearest the base of the sample 'conditioned' at 1600°F.

Section No. 1 has the coarsest and longest graphitic flakes and there is a gradual decrease in the size of flakes from this section to section No. 5 which has therefore the finest flake formation. It may be said here that the section No. 1 was gray and section No. 5 mottled in fracture.



Plate No.1, 1600-S-5.
100 X.



Plate No.2, 1600-F-5.
100 X.



Plate No.3, 1600-S-4.
100 X.



Plate No. 4, 1600-F-4.
100 X.

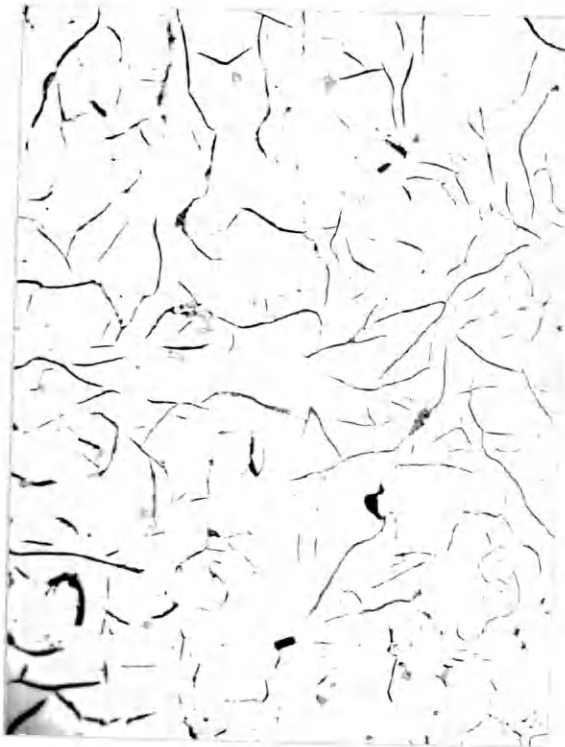


Plate No. 5, 1600-S-3.
100 X

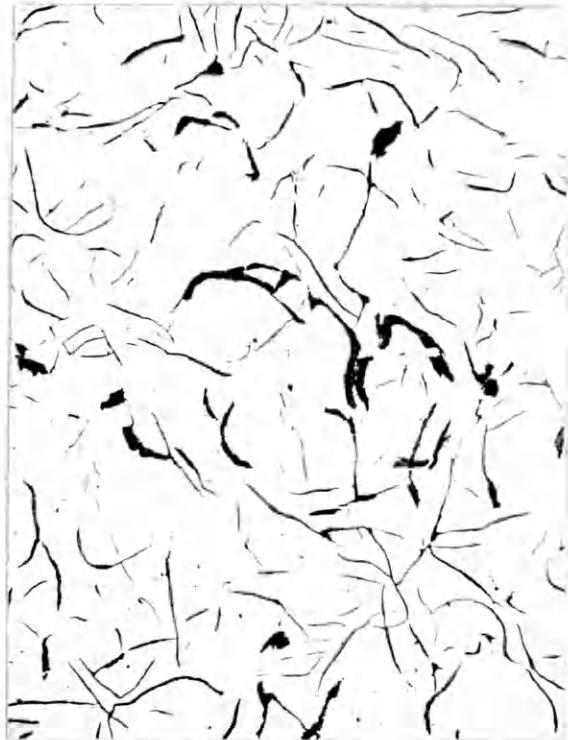


Plate No. 6, 1600-F-3.
100 X

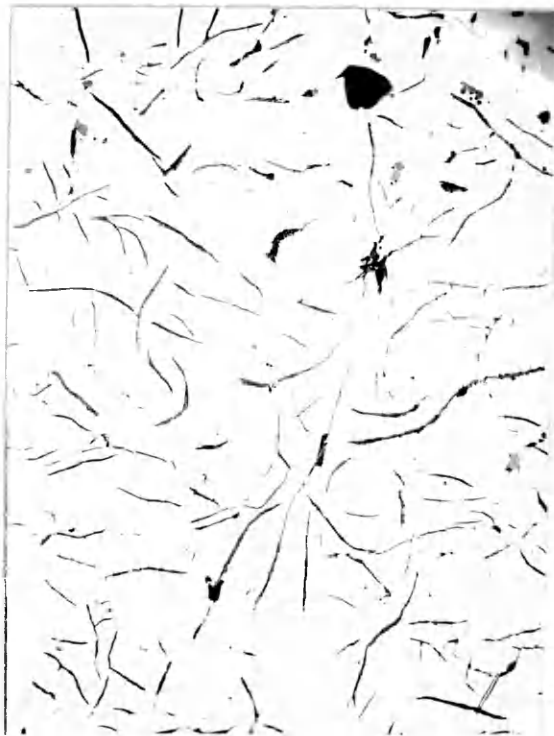


Plate No. 7, 1600-S-2.
100 X



Plate No. 8, 1600-F-2.
100 X



Plate No.9, 1600-S-1.
100 X



Plate No.10, 1600-F-1.
100X

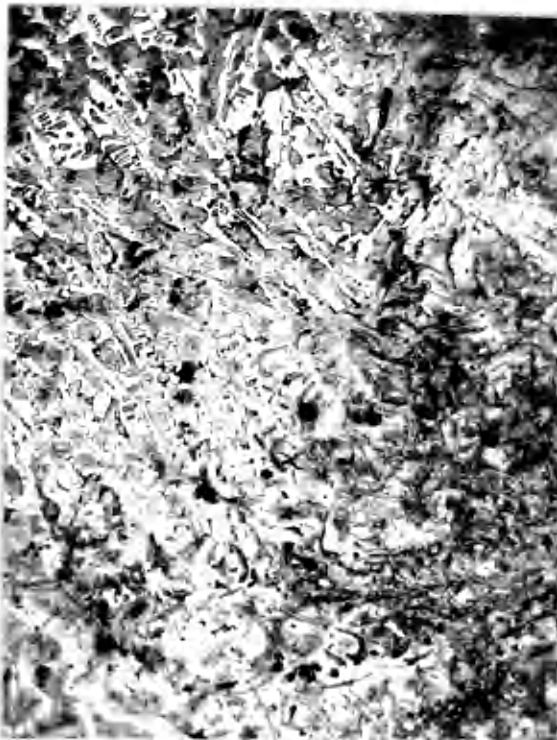


Plate No.11, 1600-S-5.
100X



Plate No.12, 1600-F-5.
100 X

No appreciable difference in the mode of graphite formation was noted in any one section of the 'conditioned' sample from that of the corresponding section of the 'unconditioned' sample, although in certain samples sections could not be cut off at exactly one inch from each other. For example section No. 5 could not always be cut at exactly one inch from the apex as it was too hard for the hacksaw to cut at this point. This naturally would give a corresponding difference in the size of the graphitic flakes.

Examination of the matrix:

Nital Etch. The polished sections were etched with 2% nital and examined under the microscope and their photographs taken. These photographs are shown in Plate No. 11 to Plate No. 34.

(a) 'Conditioned' at 1600°F: (denoted as 1600-F) and the corresponding 'unconditioned' sample (denoted as 1600-S). Sections of these samples are numbered as 1600-F-1, 1600-F-2, 1600-F-3, 1600-F-4 and 1600-F-5 for the 'conditioned' specimen and as 1600-S-1, 1600-S-2, 1600-S-3, 1600-S-4 and 1600-S-5, for the corresponding 'unconditioned' sample starting from near the base of the wedge in both cases.



Plate No.13, 1600-S-4.
100 X



Plate No.14, 1600-F-4.
100 X



Plate No.15, 1600-S-3.
100 X

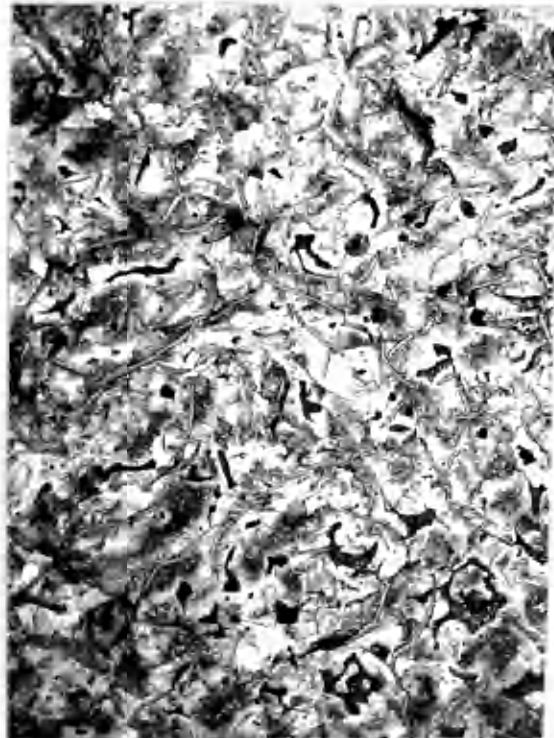


Plate No.16, 1600-F-3.
100 X



Plate No.17, 1600-S-2.
100 X



Plate No.18, 1600-F-2.
100 X

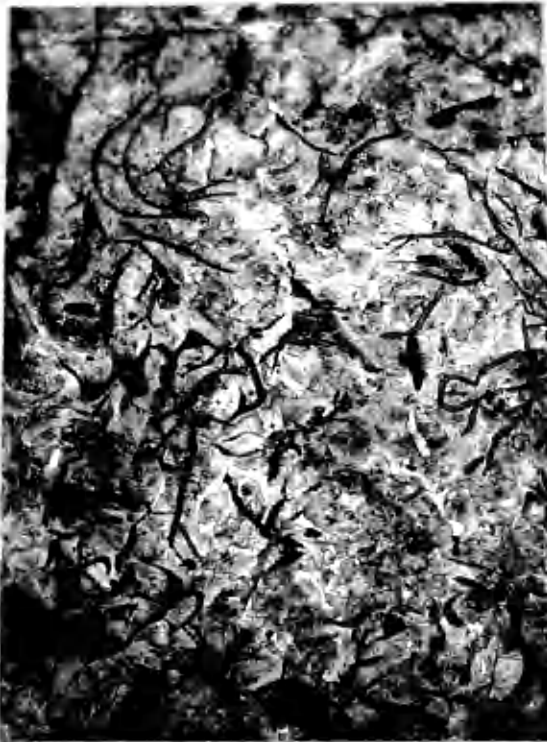


Plate No.19, 1600-S-1.
100 X

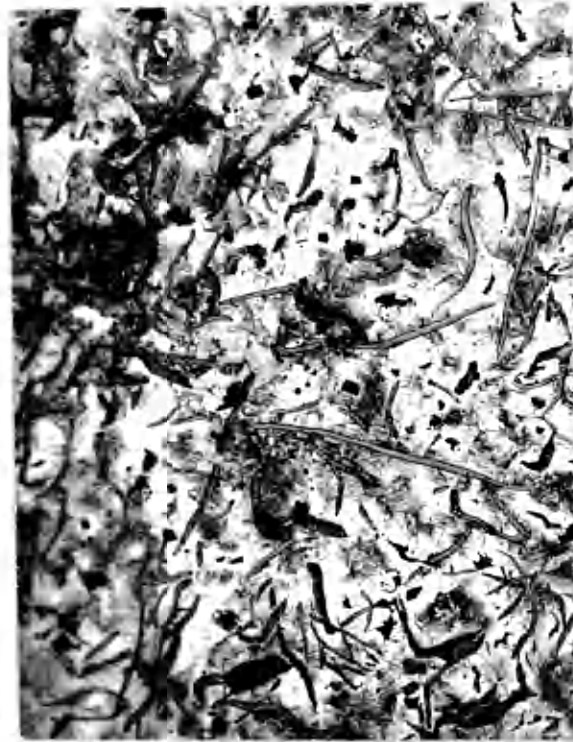


Plate No.20, 1600-F-1.
100 X

1. In sections of both 1600-F and 1600-S, the microstructure consists of pearlite, steadite and graphite towards the base sections. In sections 1600-S-5 and 1600-F-5 dendritic white iron structure (cementite, steadite and transformed ledeburite), is seen, though in 1600-F-5 the dendritic structure is less noticeable.

2. In all the 1600-S sections there is a network of steadite with its characteristic microstructure very clearly seen at higher magnification. This network of steadite is completely absent in the 1600-F sections. The difference between the 'conditioned' and the 'unconditioned' samples is more pronounced in the wider sections than towards the apex. In section 1600-S-5 the dendritic structure is still seen. In section 1600-F-5, there is appreciable amount of homogenization but not to the same extent as is the case with sections towards the base of the wedge. The difference in the steadite formation is clear from the photographs of the 1600-F-1 and 1600-S-1 sections shown at a higher magnification in Plate No. 21 and Plate No. 22 respectively.

3. More of the so-called "Primary Ferrite"¹⁶ is seen in sections of 1600-F than in 1600-S. The formation of this "primary ferrite" is more pronounced on the edges and towards the apex of the 'conditioned' wedge especially

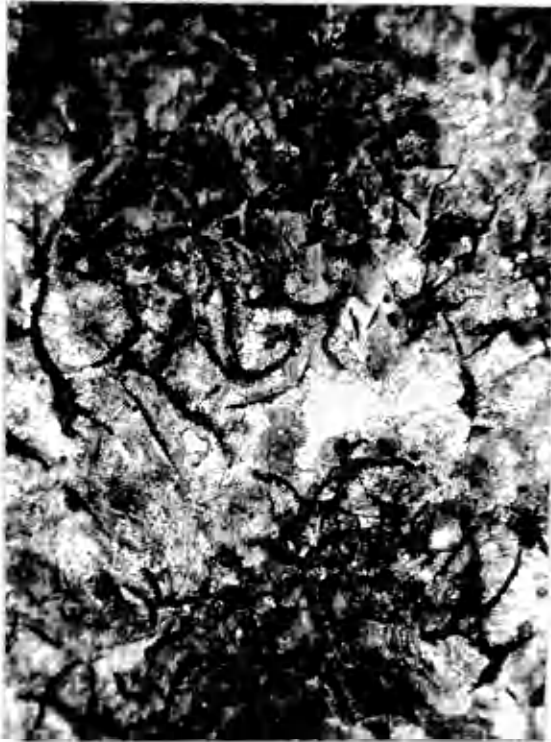


Plate No.21, 1600-S-1.
250 X



Plate No. 22, 1600-F-1
250 X



Plate No.23, 1600-S-3.
75 X

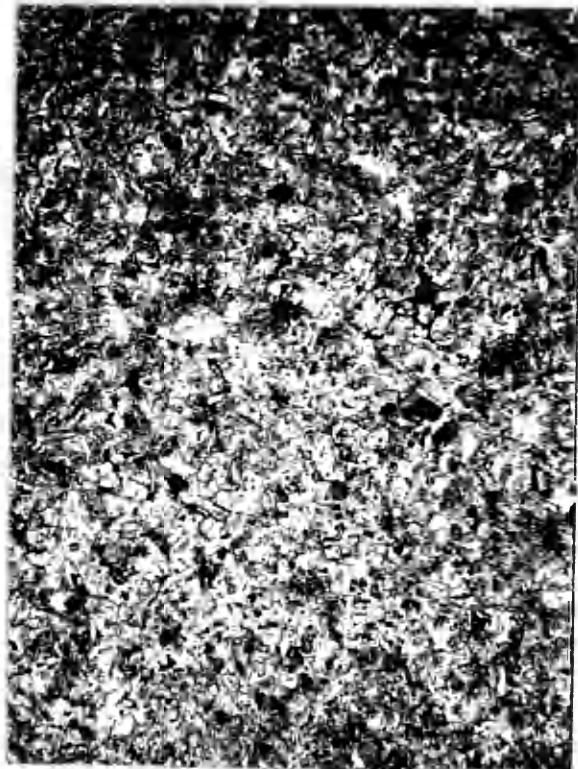


Plate No.24, 1600-F-3.
75 X

at places where fine graphite or graphite rosettes are seen. In the middle sections there is no appreciable difference in the formation of the "primary ferrite". The "primary ferrite" formation in 1600-S-5 and 1600-F-5 sections are shown at a higher magnification in Plate No. 25 and Plate No. 26.

4. In all the 1600-F sections there seems to be an appreciable increase in the grain size. This is only natural due to the longer sojourn of the specimen at an elevated temperature much above the critical temperature. In the last section, namely 1600-F-5, there seems to have occurred some destruction of the dendritic structure due to slight annealing.

Because of the absence of the steadite or cementite network it was not very easy to find out the grain size in sections of the conditioned specimen, though it was possible because of a lighter etching around the grain boundaries.

To show a contrast in the homogenization which the 'conditioned' specimens have undergone and the consequent effect on the grain size, section 1600-F-3 and 1600-S-3 are shown at a lower magnification in Plate No. 23 and Plate No. 24.

(b) 'Conditioned' at 1400°F (denoted as 1400-F) and the corresponding 'unconditioned' sample (denoted as



Plate No.25, 1600-S-5
250 X



Plate No.26, 1600-F-5.
250 X



Plate No.27, 1200-S-3.
100 X



Plate No.28, 1200-F-3.
100 X

1400-S). Sections are denoted as 1400-F-1 to 1400-F-5 and 1400-S-1 to 1400-S-5 respectively, as in the previous case.

1. The microstructure consisted of the same constituents (pearlite, steadite, cementite and graphite) with no free cementite in the wider sections and the white iron structure towards the apex of the wedge.

2. The disappearance of the steadite network, especially in the wider sections, as a result of conditioning was noticeable in this case as well, though perhaps the homogenization and absorption of the phosphide has not taken place to the same extent in 1400-F samples as with 1600-F sections.

3. Primary ferrite is seen in the 1400-F sections just as in the case of 1600-F sections especially associated with places of undercooling and fine graphite formation.

4. There is no appreciable increase in grain size in the 1400-F sections over that of the 1400-S sections.

(c) 'Conditioned' at 1200°F (denoted as 1200-F) and the corresponding 'unconditioned' sample (denoted as 1200-S). Sections are denoted as before, namely 1200-F-1 to 1200-F-5 and 1200-S-1 to 1200-S-5, respectively.

1. The matrix is exactly similar in both cases and consists of the same constituents as in the previous samples, with dendritic white iron structure towards the apex,

partially destroyed in the 1200-F-5 sample.

2. In this case the steadite formation around the grain boundaries has not disappeared on 'conditioning' at this temperature. Steadite network is seen in all 'conditioned' and 'unconditioned' samples with primary cementite of the white iron formation towards the apex of the wedge.

3. Slight increase in the "primary ferrite" formation is seen associated with fine graphite at the supercooled areas towards the apex. This is shown in Plates No. 31 and No. 32 taken at a higher magnification.

4. One difference noted between the 'conditioned' and 'unconditioned' samples is that in the 'conditioned' ones there is a distinct tendency for the spheroidization of the pearlite lamellae. This is more evident in Plates No. 33 and No. 34 taken at a higher magnification.

(d) 'Conditioned' at 1000°F (denoted as 1000-F) and the corresponding 'unconditioned' sample (denoted as 1000-S).

Sections are noted as before, as 1000-F-1 to 1000-F-5 and 1000-S-1 to 1000-S-5 respectively.

No difference is noted in the microstructures of the corresponding sections of these specimens. Steadite network is present in both of the specimens and in both specimens the microstructure changes from the white iron structure near the apex to that of gray iron without any



Plate No.29, 1000-S-4.
100 X



Plate No.30, 1000-F-4.
100X



Plate No.31, 1200-S-5
250 X



Plate No.32, 1200-F-5.
250 X



Plate No.33, 1200-S-1.
250 X



Plate No.34, 1200-F-1.
250 X

free cementite along the grain boundaries towards the base sections.

Alkaline Sodium Picrate etch:

Samples were then repolished and boiled in a freshly made sodium picrate etching reagent for about eight minutes and then examined under the microscope. As the structures seen were a bit confusing these samples were then etched with nital and examined microscopically. The observations were in close conformity with those stated in the previous sections; the cementite towards the apex was colored, the pearlite was darkened due to nital etch and the steadite and "primary ferrite" (the latter on the sides of the graphite rosettes) remained white. The steadite had the characteristic dotted structure due to nital etch. No steadite network was seen in samples conditioned at 1600°F and 1400°F.

Chemical Analysis:

(a) Determination of Phosphorus:

As it was found that the effect of 'conditioning' is primarily a question of homogenization and absorption the steadite network, the four samples of iron were analysed for their phosphorus contents, by the gravimetric method as follows:

Procedure: 1 gm. of the sample of cast iron was

dissolved in 30 ml. of dilute nitric acid (sp. gr. 1.2). The graphite was filtered off and the filtrate collected in a 250 ml. conical flask. To this 10 ml. of KMnO_4 solution (2.5%) was added to oxidize the phosphate formed completely to the ortho form, and also to oxidize the organic matter. This was then boiled for a minute or two and the precipitate of MnO_2 formed was dissolved by careful dropwise addition of a saturated solution of Na_2SO_3 and then it was boiled to expel the oxides of nitrogen. This was then neutralized with ammonia and 3 to 4 ml. of nitric acid and 10 gms of ammonium nitrate were added. The solution, which should not be more than 50 ml. at this stage, was heated to about 75°C and to it 50 ml. of ammonium molybdate solution was added. The flask was then stoppered and shaken vigorously for ten minutes. The precipitate of ammonium phosphomolybdate was then allowed to stand for about two hours and filtered in a fine-pored Gooch crucible, washed with cold dilute HNO_3 (2:100) and five times with KNO_3 solution (1%), dried and weighed. From the weight of the ammoniumphosphomolybdate thus obtained the percentage of phosphorus was calculated. The following table shows the results of the analysis:

Table V
Determination of Phosphorus in the Samples

Sample No.	% P
1. 1600-F & 1600-S	0.29
2. 1400-F & 1400-S	0.30
3. 1200-F & 1200-S	0.28
4. 1000-F & 1000-S	0.25

(b) Determination of Combined Carbon and Graphitic Carbon:⁶

To study the effect of 'conditioning' upon the combined and graphitic carbon contents the specimens were analysed for total carbon and graphitic carbon by the direct combustion method; the combined carbon was found by their difference.

1. Total Carbon: The principle of the method is that a clean and representative sample of the specimen is completely burned in a stream of oxygen free of interfering gases; the carbon is completely oxidized to CO₂ which is then separated from other products of combustion and excess oxygen and accurately measured.

The apparatus therefore consisted of an oxygen source, an oxygen purifying train, a combustion furnace, a

purifying train for combustion products and an absorption unit for CO_2 .

Procedure: After setting up the apparatus and testing it for leaks, etc., the blank on the system was determined.

A suitable factor weight (1.3636 gm.) of the sample (in the form of hacksaw cuttings), was weighed out and spread out as a thin uniform layer on the alundum bedding. About 0.2 gm of tin was then sprinkled on top of it to act as an accelerator and then a thin layer of alundum was placed over it. The boat was then pushed into the hottest part of the combustion tube, which was kept at about 1000°C , and the tube was immediately closed. A steady current of oxygen was then passed through it for twelve minutes. The absorption tower containing soda asbestos ("ascarite"), as the CO_2 absorber, was then disconnected, opened momentarily to equalize the pressure inside to that of the atmosphere and weighed. The increase in weight due to the absorption of CO_2 was noted from which the percentage of total carbon was calculated.

A mean value of four determinations per sample was taken as the total carbon content of the sample. This is shown in Table VI given on the following page:

Table VI

Determination of Total Carbon

Sample No.	Experimental values %	Mean value %
1600-F & 1600-S	3.164, 3.382, 3.400, 3.376	3.331
1400-F & 1400-S	3.380, 3.450, 3.448, 3.462	3.435
1200-F & 1200-S	3.342, 3.270, 3.330, 3.354	3.324
1000-F & 1000-S	3.376, 3.340, 3.386, 3.382	3.371

2. Graphitic carbon:

Procedure: The same factor weight of sample (1.3636 gm.) was dissolved in 50 ml. of HNO_3 (sp. gr. 1.2) and heated very gently on the hot plate. The solution was allowed to come down to a low volume to assure that the action had gone to completion. The graphite residue (with any separated silicic acid) was collected by suction on prepared asbestos contained in a Gooch crucible. This was then washed with hot water, then with a hot solution of KOH (sp. gr. 1.10), hot water, then with dilute HCl (1:20) and finally with hot water. The suction applied left just enough moisture to prevent any oxidation of the graphite and so without any further drying, the graphite particles together with the asbestos fibre was taken out of the Gooch crucible, placed over the alundum bedding of the nickel boat, and inserted into the combustion tube of the furnace kept above 900°C . The carbon content was found out just as in the

case of the total carbon estimation, taking care to close the combustion tube immediately after inserting the sample.

A mean value of two determinations was taken as the graphitic carbon content of the sample.

For the determination of graphitic carbon, the sample should be preferably in the form of drillings or small cuttings and not in the form of fine hacksaw cuttings. Experiments with hacksaw cuttings gave very low value of graphitic carbon and so all experiments were repeated with small solid cuttings from the samples. The cuttings were taken from corresponding points from all samples on the widest section.

The combined carbon was found as the difference between the total and graphitic carbons.

The results of the experiments are shown in Table VII.

Table VII

Determination of graphitic carbon

Sample No.	Experimental values %	Mean value %
1600-F	2.690, 2.702	2.696
1600-S	2.664, 2.680	2.672
1400-F	2.890, 2.548	2.719
1400-S	2.656, 2.708	2.682
1200-F	2.799, 2.662	2.730
1200-S	2.640, 2.652	2.646
1000-F	2.774, 2.866	2.820
1000-S	2.764, 2.796	2.780

Table VIII gives the complete results of analysis.

Table VIII

Effect of 'Conditioning' on graphitic (or combined) carbon

Sample No.	Total carbon %	Graphitic carbon %	Combined carbon %	Increase in graphitic carbon %
1600-S & 1600-F	3.331	2.672 2.696	0.659)) 0.635)	0.024
1400-S & 1400-F	3.435	2.682 2.719	0.753)) 0.716)	0.037
1200-S & 1200-F	3.324	2.646 2.730	0.678)) 0.594)	0.084
1000-S & 1000-F	3.371	2.780 2.2820	0.591)) 0.551)	0.040

The above table shows very slight increase in graphitic carbon contents on conditioning. Within limits of experimental errors nothing much could be attributed to such low values; all that can be said is that graphitization, if any, is only very slight. This is also in accordance with the photomicrographs of the unetched samples. The slight increase in graphitic carbon contents may be accounted for by the slight increase in the 'primary ferrite' formation on 'conditioning'.

Examination of the X-ray diffraction patterns:

It was postulated that conditioning might give smaller amounts of retained austenite in the samples on cooling to room temperature, because of the following facts:

After solidification in the mold, when cast iron cools down to room temperature, factors such as graphitization and change of phase of iron—namely from face-centered-cubic γ iron (austenite) into body-centered-cubic α iron (ferrite) tend to increase the volume of the casting. But the outside of the casting is cooling at a faster rate than the inside, with the result that differential thermal shrinkage occurs between the inside and outside of the casting. Thus we have a situation where we have a shrinking outside with the inside trying to expand. This may develop high pressures within the casting and inhibit not only graphitization but the change of the austenite into pearlite as well. This may thus give some retained austenite in the casting on cooling to room temperature.

On conditioning at the elevated temperature, particularly above the critical temperature, the metal remains plastic for a longer time which thus may reduce the internal stresses produced, giving less retained austenite in the sample on cooling to room temperature. Thus it was

postulated that 'conditioning' may give less retained austenite, which might also partly account for the increase in hardness.

To see whether this could be studied by X-ray diffraction methods, 'Back Reflection Patterns' of the 'conditioned' as well as the 'unconditioned' specimens were taken. 1600-F and 1600-S samples were used for this purpose, after polishing and etching off the surface to remove any residual stresses left on the surface layer due to polishing.

With Cu-radiation there was so much fluorescence even with a Ni-filter that no rings could be discerned.

With Mo-radiation a few very faint rings were obtained using a ZrO filter, after an exposure of 12 hours.

The diameters of the rings thus found were measured. They are shown below in table IX.

Table IX

Data obtained on X-ray analysis

Target: Molybdenum

Filter: Zirconium Oxide

Sample	Diameters of rings found
1600-F	11.28 cms., 6.0 cms., 4.73 cms.
1600-S	11.28 cms., 6.0 cms., 5.17 cms.

The 'd' values of the planes causing the reflections were calculated as shown in Table X.

Table X
Calculation of the 'd' values

No.	Diameter of ring	'd'
1.	11.28 cms.	0.38806 A.
2.	6.0 cms.	0.37309 A.
3.	5.17 cms.	0.36420 A.
4.	4.73 cms.	0.36270 A.

Apparently 'reflections' No. 3 and 4 are caused by the same constituent in the metal and the slight change in the 'd' values may therefore be taken as the result of 'conditioning'. This may be due to retained austenite or may be due to the solution of the phosphide of the steadite in the iron. Further work in this line is necessary to say anything definite about it.

DISCUSSION OF RESULTS

The results obtained by conditioning wedge specimens of wheel iron at 1600° F, 1400° F, 1200° F, and 1000° F are given in the foregoing pages. In this section of this paper a discussion of the results will be attempted, with a probable explanation of the increase or decrease in hardness of the samples treated at the above temperatures as compared with that of the corresponding one cooled in the mold.

Hardness measurements of the samples have shown that:

1. 'Conditioning' at 1600° F for two hours increases the hardness of the specimen all along the length of the wedge, the maximum increase in hardness observed being towards the middle of the wedge.
2. 'Conditioning' at 1400° F for two hours also increases the hardness of the specimen, the maximum increase in hardness in this case too being observed towards the middle.

'Conditioning' at 1600° F gives higher hardness than at 1400° F.

3. Treating the specimen at 1200° F for two hours gives a decrease in hardness all along the specimen.
4. Holding the specimen at 1000° F for two hours has no appreciable effect on the hardness except

towards the apex of the wedge where it shows a slight increase.

The properties of cast iron to a great extent depend upon the size, shape, and distribution of the graphitic flakes. As was shown, 'conditioning' of wheel iron at the above temperatures for two hours has little effect on the formation of the graphitic flakes which therefore cannot account for the increase or decrease in hardness.

Bolton, writing on "Phosphorus in Cast Iron", writes thus:⁸

The existence of the ternary formation in white iron is established clearly. During the graphitization reaction, occurring in the formation of gray irons the carbide of the ternary eutectic diffuses out and under suitable cooling conditions and with suitable compositions only the binary formations are left. However, if cooling is too rapid to permit complete diffusion of carbon (carbide) from the ternary formation some of this remains in the steadite. If cooling is slow and phosphorus well under .5% the steadite may appear structureless. If the iron is annealed at 1600° F or above the steadite is broken down, the Fe₃P slowly going into solid solution in the ferrite.

This is what may have happened during the 'conditioning' of the wheel iron samples at temperatures of 1600° F and 1400° F. Though Bolton says that breakdown of the steadite and the solution of Fe₃P in the ferrite happens at temperatures of 1600° F or above, these

experiments show that in the case of wheel iron it may happen even at 1400° F. The Fe₃P going into solid solution in ferrite of the pearlite may largely account for the increase in hardness of the iron.

The question of 'conditioning' in these experiments at 1600° F and 1400° F is therefore apparently one of homogenization and breakdown of the steadite and solution of the Fe₃P in the ferrite. At the higher temperature of 1600° F these effects are more pronounced than at 1400° F; hence the increased hardness at the higher temperature.

The so-called "primary ferrite"⁴ formation has been associated with a certain rate of cooling, some degree of supercooling, and the presence of fine graphitic formation. The combination of these facts probably gave more "primary ferrite" formation towards either end of the wedge giving the maximum hardness difference towards the middle of the wedge. This may also be due to partial annealing of the dendritic formation towards the apex.

In samples treated at 1200° F and 1000° F there is apparently little homogenization and breakdown of the steadite network. Consequently they register no increase in hardness.

In the sample treated at 1200° F the decrease in hardness could be accounted for by the tendency of the pearlite lamellae to spheroidize and a slight difference in the amounts of the "primary ferrite formation".

CONCLUSION

This work on the 'conditioning' of wheel iron for two hours at elevated temperatures has shown the following:

1. 'Conditioning' above the critical temperature definitely increases its hardness. No increase in hardness is observed after 'conditioning' below the critical range.
2. 'Conditioning' for two hours has no appreciable effect on the amount and nature of the graphitic flake formation, although a slight increase in the formation of the so-called 'primary ferrite' indicates that there must be a slight increase in the amount of graphitic carbon.
3. The effect of conditioning at 1600° F and 1400° F for two hours apparently results from homogenization and breakdown of the steadite, the Fe₃P entering into solid solution in the ferrite.
4. Whether this treatment has any effect on the amounts of residual austenite has not been fully studied. This may better be done with alloyed irons with and without carbide stabilizers. Even small amounts of residual austenite

can be estimated by means of a focusing camera which is not available in our X-ray laboratory.

Another way of investigating the subject is by quenching the samples from different 'conditioning' temperatures after different duration of 'conditioning' treatments.

Though it is true that increase in metallurgical knowledge has explained many of the mystifying behaviours of cast iron, yet it is equally true that there remains before us a great and little explored territory, the careful mapping of which will add greatly to our knowledge and concurrently to improvements.

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