HEAT TREATMENT AND HARDENING

OF

GREY IRON CASTINGS

THESIS FOR DEGREE OF M. E.

ZENAS EUGENE COLBY

1928

THESIS

Caution

Title

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approved June 6 1928

H B Dirks

THESIS

HEAT TREATMENT AND HARDENING OF GREY IRON CASTINGS

The object of this thesis is not intended to be a metallurgical research, but has for its sole object the advancement of the mechanical phase of and results which may be obtained through the heat treatment of grey iron castings. The accompanying chemical and metallurgical date being used only as a means to this end.

At the time the writer started this research, but very little data seemed to be available, in fact, I was unable to obtain any outside information, but of late a considerable amount of metallurgical research work has been done but still leaving the subject far from a thorough survey. In fact, present foundry practice has not as yet reached the stage where grey iron foundries producing a variety of work can maintain absolute control and which is absolutely essential for uniform results.

Late in 1923, the writer was confronted with the problem of producing a grade of cast iron rollers which would be much higher in hardness than would be possible to machine with the result that a large number of tests were run to determine a proper analysis and method to be pursued to properly harden yet toughen these rollers. Various methods were tried for quenching and drawing. These rollers were quenched in a salt brine solution also in oil and in water with a final result that the production method adopted was that of partially quenching in oil and finishing in water. The oil was kept at a constant temperature by means of a circulating system which circulated the oil through cooling vats and back to the tank again holding the oil at between 70 and 90 degrees F.

Our reason for finish quenching in water was not because of any definite reaction to the work being heat treated but because the one minute in the oil bath was sufficient to cool the work below the critical temperature and thus making it easier to maintain a satisfactorily low oil temperature without a too elaborate oil cooling system.

These rollers were heated in an electric furnace to a temperature of 1600 degrees F. and left in the furnace a sufficient length of time to produce a uniform temperature throughout the entire structure. These rollers were then with-

In drawing, care must be taken to see that the work is not left at this temperature a length of time sufficient to bring the work up to 1300 degrees as by so doing, the work will be, not only softened, but actually weakened. The result desired is simply to remove the internal stress produced by quenching.

A better method to strengthen the work after treating is to heat the work slowly but thoroughly to a much lower temperature, preferably between 700 degrees and 800 degrees F. and allowed to cool slowly.

We adopted the first method after considerable trials to determine the exact time to be left in the annealing furnace, simply as an aid to production and would not recommend this as a safe method where the work is not of a uniform size or character.

To show the effect of drawing at 1300 degrees, seven samples of exactly the same analysis were heat treated and drawn and curves plotted as shown on sheet marked Sample 4-11-H.

It will be noted from sheets 2-16-H and 2-20-O, also the microphotographic views of 2-10-O, 2-15-H, 2-16-H and 2-17-H that the physical change resulting from heat treatment is the raising of the combined carbon and the lowering of the graphitic carbon, also that the best hardening or quenching temperature for all analysis seems to be around 1600 degrees F. Also that the degree of hardness is also influenced by the amount of silicon. The higher degrees of hardness are obtained with low silicon.

It was found that the degree of hardness as well as toughness varied with the manganese and with the silicon, our best result was obtained by running our silicon about 1.65% to 1.70% with the manganese about .60% to .70%. This after hardening and drawing with this analysis produced a roller which was stronger against shock than was the original casting. However, before drawing, the roller would be quite brittle and would not stand the shock that the original roller before heat treatment would stand. It was also found that we could not reach as high a degree of hardness with the silicon about 2%.

The result obtained from these experiments convinced the writer that if the analysis of our metal could be held absolutely uniform and our quenching and drawing conditions absolutely uniform that we could produce a very uniform and satisfactory product and to determine, if possible, just what actually took place during these hardening and annealing processes, the writer ran a series of approximately 100 samples of standard test bars of 1/2 square inch cross section of area of which analysis was taken before hardening and analysis of the carbon contents taken after hardening also the tensile strength was determined as well as the degree of hardness and these results were plotted in a series of curves showing a hardness compared with the tensile strength. None of these samples, however, were annealed to show the effect on these test bars with the exception of sample 4-11-H, as our previous test in production had convinced the writer that the castings could be brought back to their original degree of hardness and that the strength could even be increased by a heat treatment process.

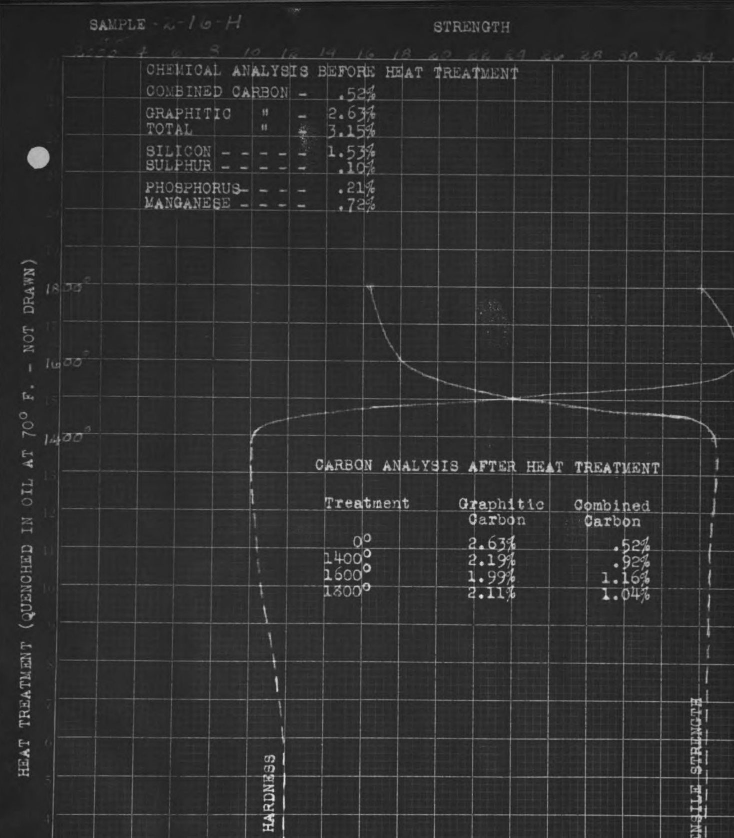
However, from the laboratory experiments, it is very evident that unless all conditions are kept absolutely uniform that very erratic results will be obtained. No heat treating was recorded at a lower than 1300 degrees F. as it was found that there was very little effect on the cast iron below this temperature, at least, as far as its hardening qualities were concerned.

The time for heating and quenching depends entirely upon the size and shape of the specimen, but in all cases the work should be left in the furnace sufficiently long to insure a uniform temperature throughout.

MECHANICAL APPLICATION

We have found through investigation, that it is frequently more economical when requiring large size drill bushings for jig work to use cast iron bushings cored nearly to size, machine nearly to size allowing grinding stock, heat to 1600 degrees F. quench in oil and finish grinding.

Tool bits can also be made from low silicon hardened cast iron which will be slightly better than carbon steel but its use for this purpose is not economical or justifiable except in special cases of emergency. The writer has used hardened cast iron tool bits simply to determine what actually could be done.

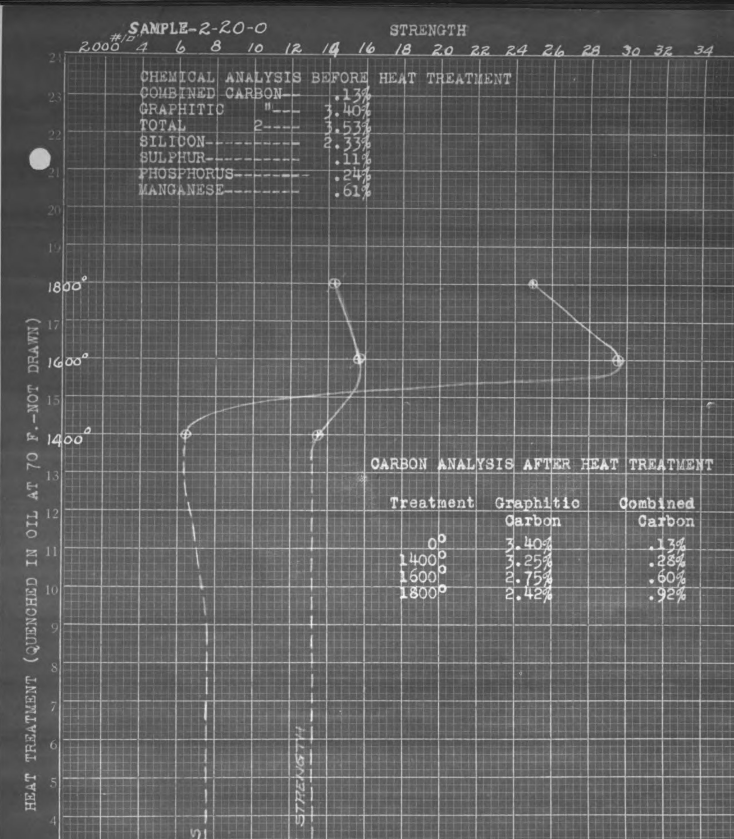


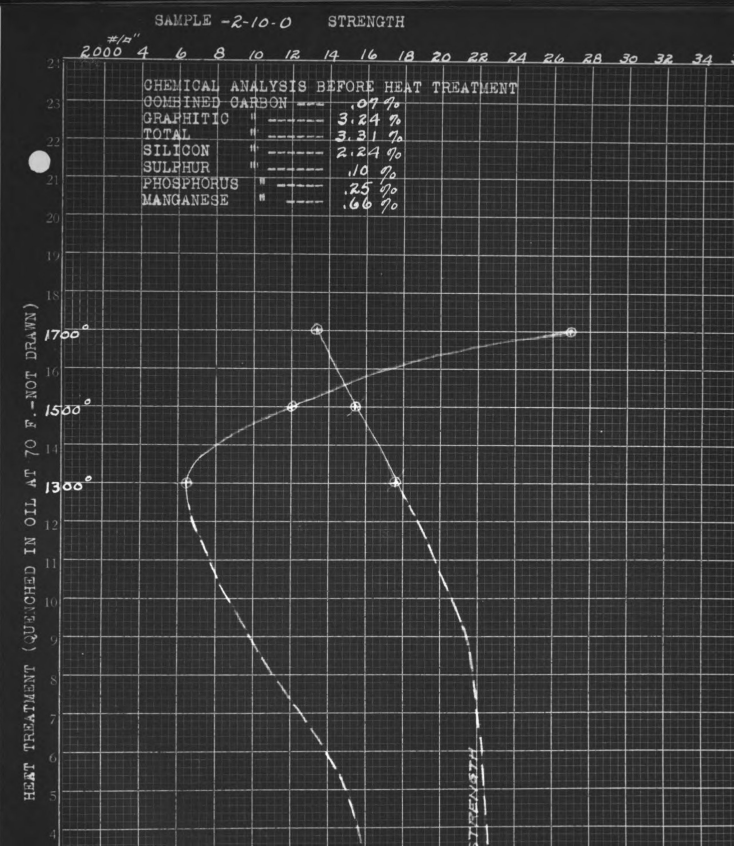
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT

COMBINED CARBON	-	.52%
GRAPHITIC "	-	2.63%
TOTAL "	-	3.15%
SILICON	- - - - -	1.53%
SULPHUR	- - - - -	.10%
PHOSPHORUS	- - -	.21%
MANGANESE	- - - -	.72%

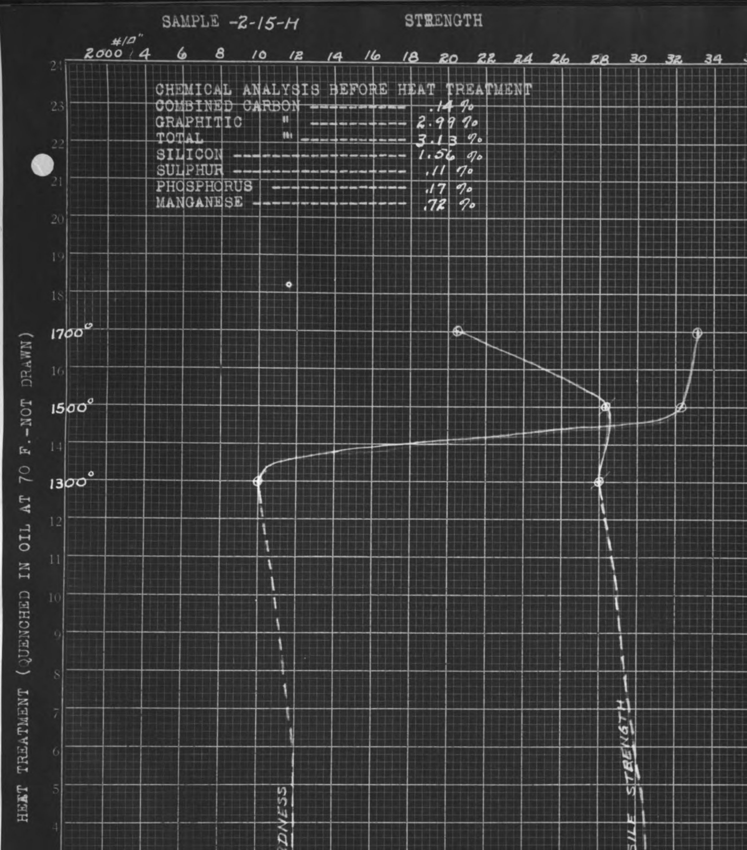
CARBON ANALYSIS AFTER HEAT TREATMENT

Treatment	Graphitic Carbon	Combined Carbon
0°	2.63%	.52%
1400°	2.19%	.92%
1600°	1.99%	1.16%
1800°	2.11%	1.04%


SAMPLE-2-20-0
STRENGTH
#1/□" 2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON-- .13%
GRAPHITIC "--- 3.40%
TOTAL "---- 3.53%
SILICON---------- 2.33%
SULPHUR---------- .11%
PHOSPHORUS--------- .24%
MANGANESE-------- .61%
1800°
1600°
1400°
HEAT TREATMENT (QUENCHED IN OIL AT 70 F.-NOT DRAWN)
CARBON ANALYSIS AFTER HEAT TREATMENT
Treatment Graphitic Carbon Combined Carbon
0° 3.40% .13%
1400° 3.25% .28%
1600° 2.75% .60%
1800° 2.42% .92%
STRENGTH

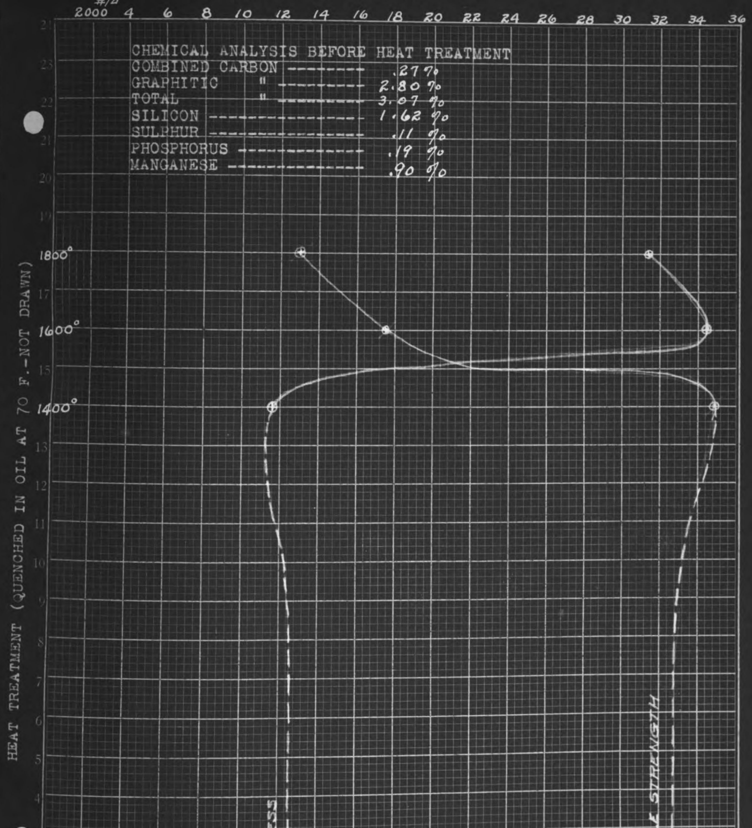


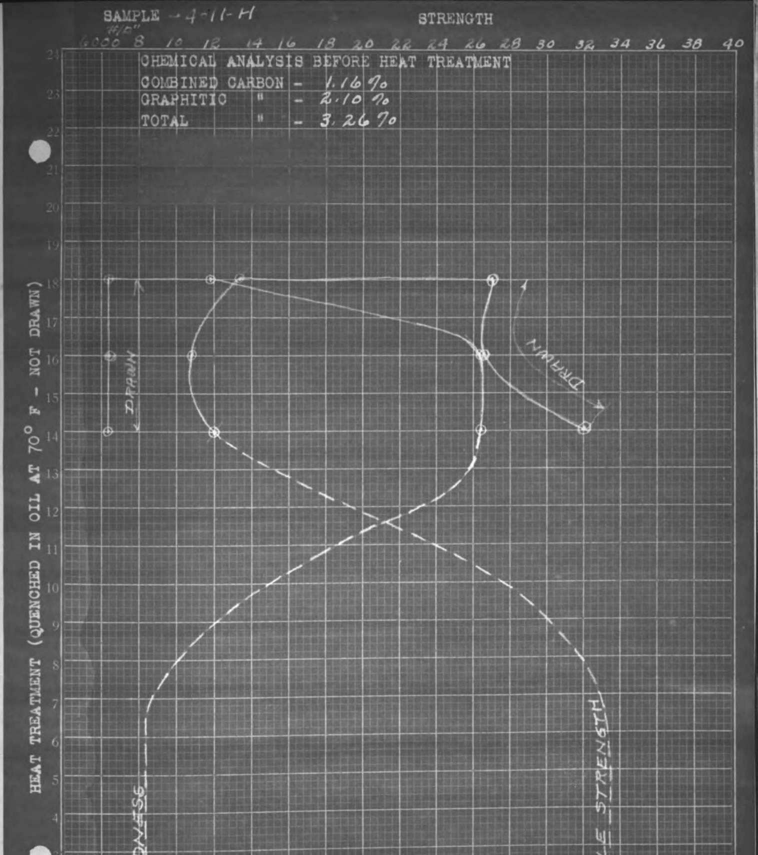
SAMPLE -2-10-0 STRENGTH
#/□"
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON --- .07 %
GRAPHITIC " ------ 3.24 %
TOTAL " ------ 3.31 %
SILICON " ------ 2.24 %
SULPHUR " ------ .10 %
PHOSPHORUS " ----- .25 %
MANGANESE " ---- .66 %
1700°
1500°
1300°
HEAT TREATMENT (QUENCHED IN OIL AT 70 F.-NOT DRAWN)
STRENGTH

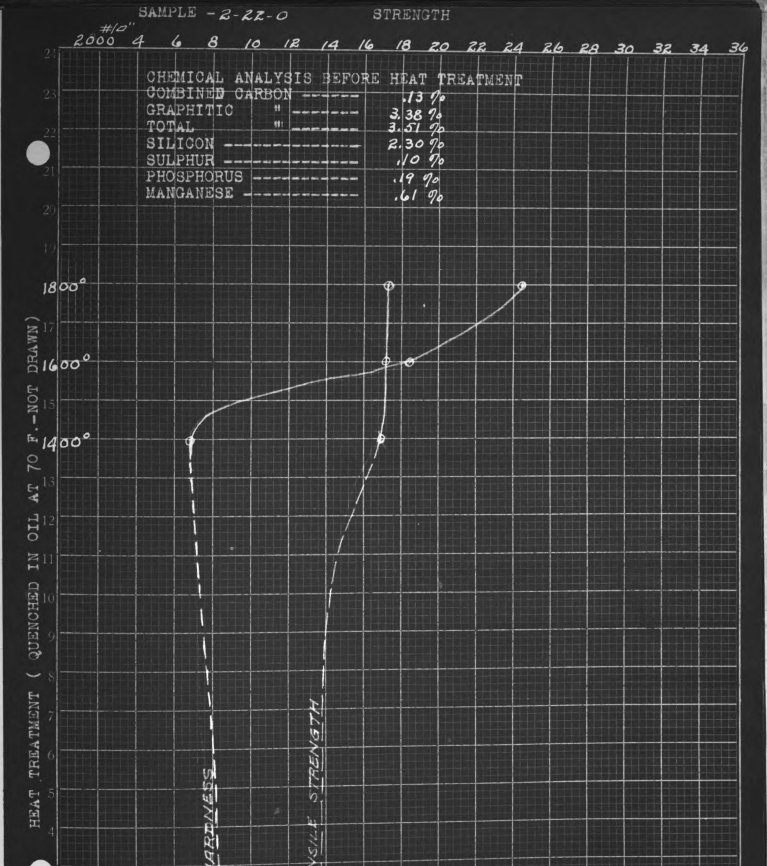


SAMPLE -2-15-H
STRENGTH
#10"
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON ---------- .14 %
GRAPHITIC " ---------- 2.99 %
TOTAL " ---------- 3.13 %
SILICON ------------------ 1.56 %
SULPHUR ------------------ .11 %
PHOSPHORUS ------------- .17 %
MANGANESE --------------- .72 %
HEAT TREATMENT (QUENCHED IN OIL AT 70 F.-NOT DRAWN)
1700°
1500°
1300°
RDNESS
SILE STRENGTH

SAMPLE- 2-17-H STRENGTH



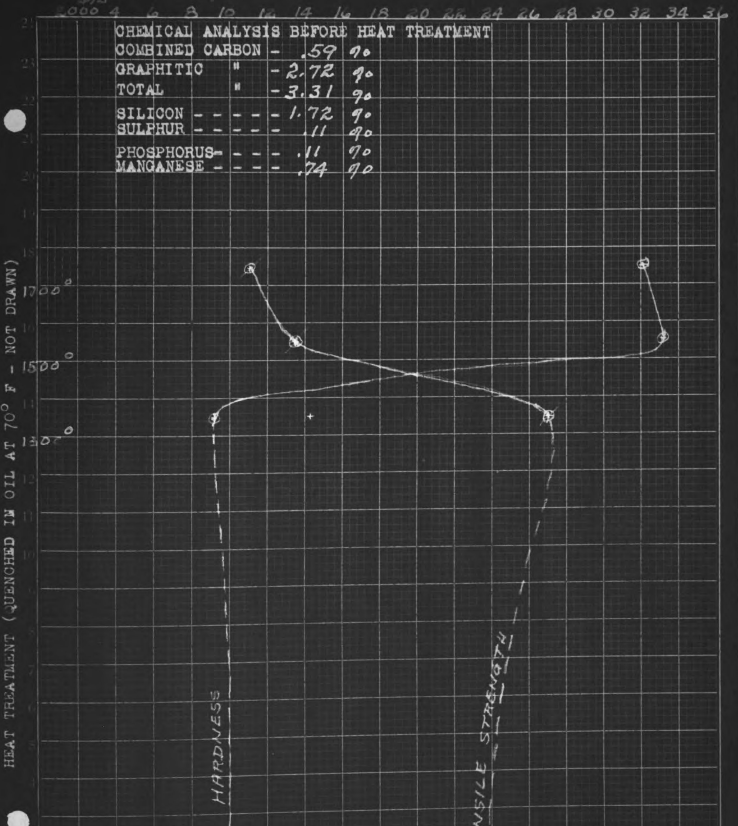

SAMPLE - 4-11-H
#10"
STRENGTH
6000 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON - 1.16 %
GRAPHITIC " - 2.10 %
TOTAL " - 3.26 %
DRAWN
DRAWN
HEAT TREATMENT (QUENCHED IN OIL AT 70° F - NOT DRAWN)
24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4


SAMPLE - 2-22-0
STRENGTH
#/□"
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON ------ .13 %
GRAPHITIC " ------- 3.38 %
TOTAL " ------- 3.51 %
SILICON -------------- 2.30 %
SULPHUR -------------- .10 %
PHOSPHORUS ----------- .19 %
MANGANESE ------------ .61 %
1800°
1600°
1400°
HEAT TREATMENT (QUENCHED IN OIL AT 70 F.-NOT DRAWN)
HARDNESS
TENSILE STRENGTH

SAMPLE -2-20-H STRENGTH

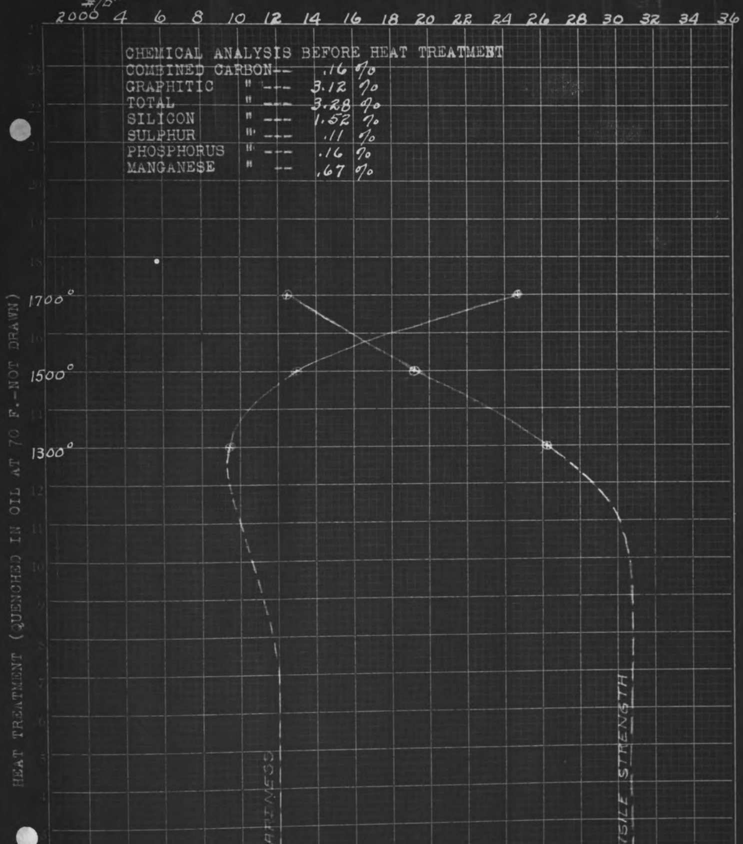
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT

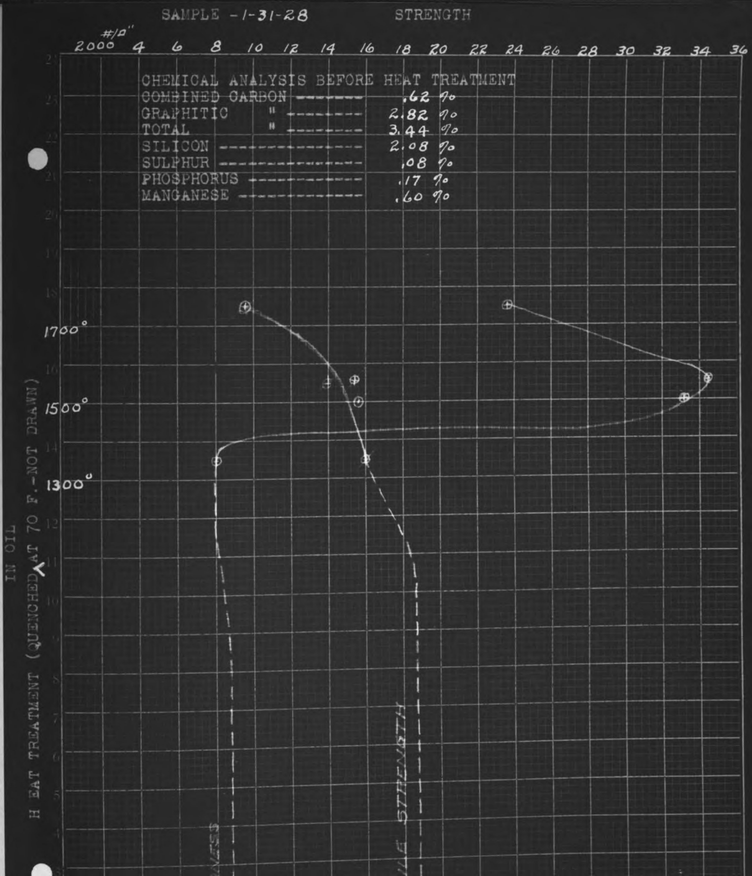
COMBINED CARBON	- .59	%
GRAPHITIC "	- 2.72	%
TOTAL "	- 3.31	%
SILICON - - - - -	- 1.72	%
SULPHUR - - - - -	.11	%
PHOSPHORUS - - - -	.11	%
MANGANESE - - - -	.74	%



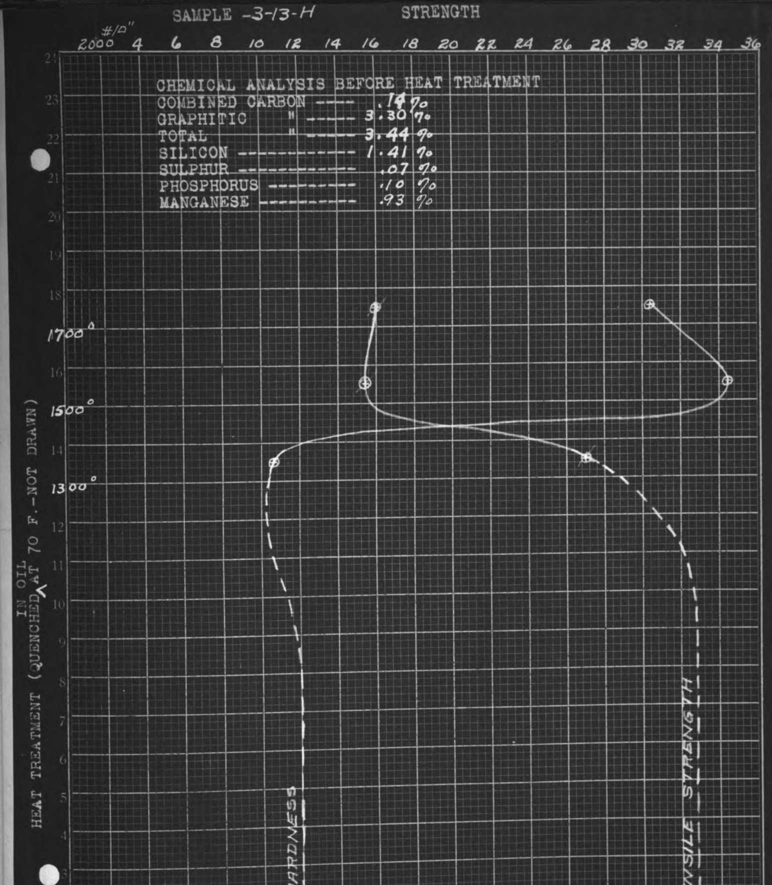
SAMPLE-2-21-H STRENGTH

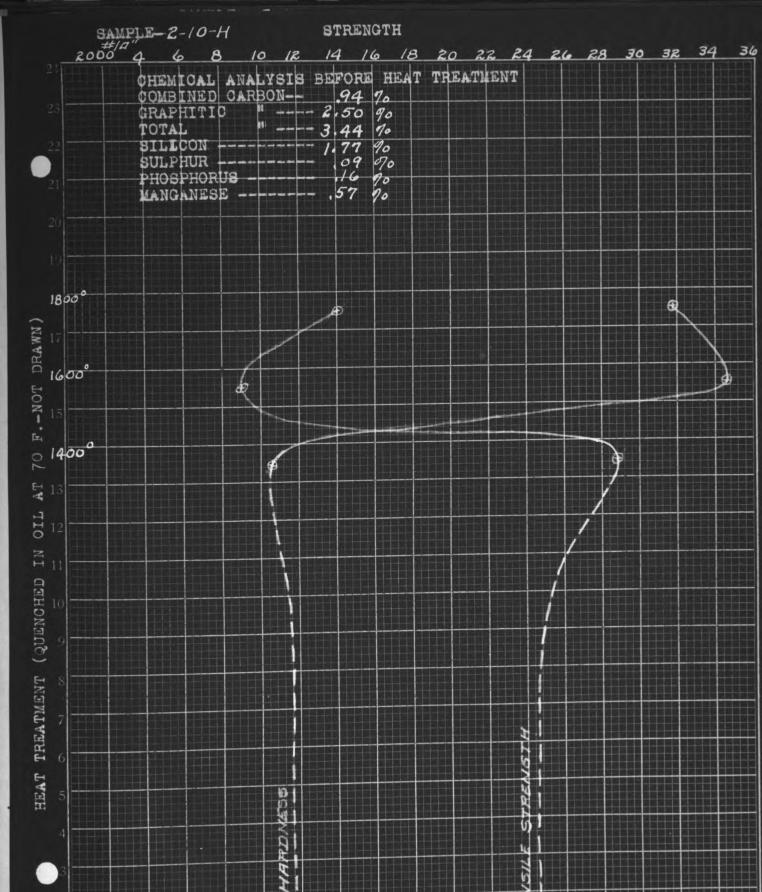
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON-- .16 %
GRAPHITIC " --- 3.12 %
TOTAL " --- 3.28 %
SILICON " --- 1.52 %
SULPHUR " --- .11 %
PHOSPHORUS " --- .16 %
MANGANESE " -- .67 %

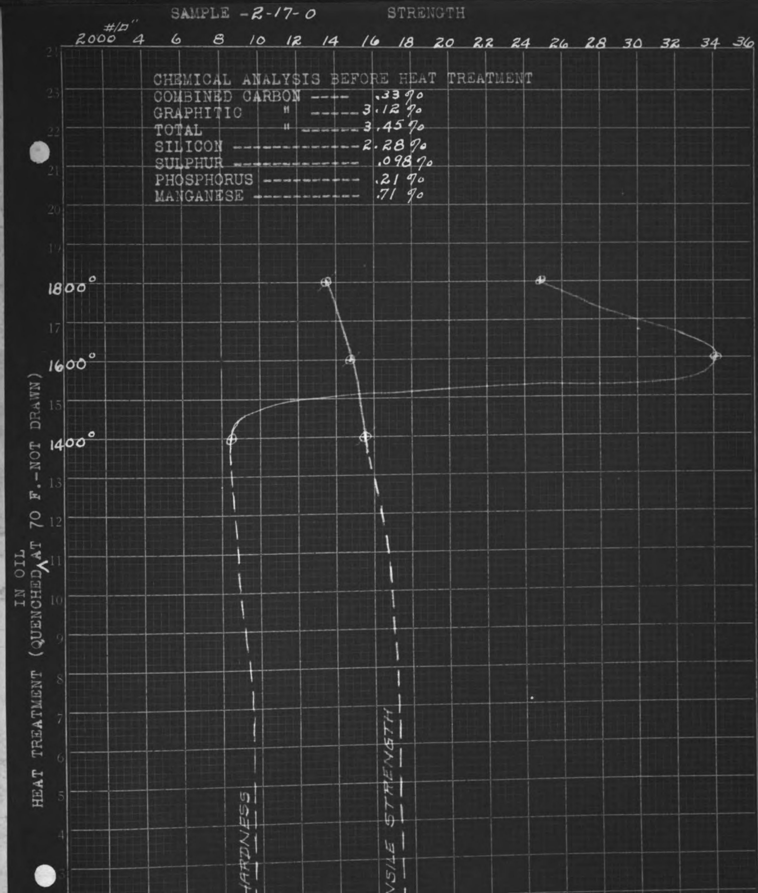




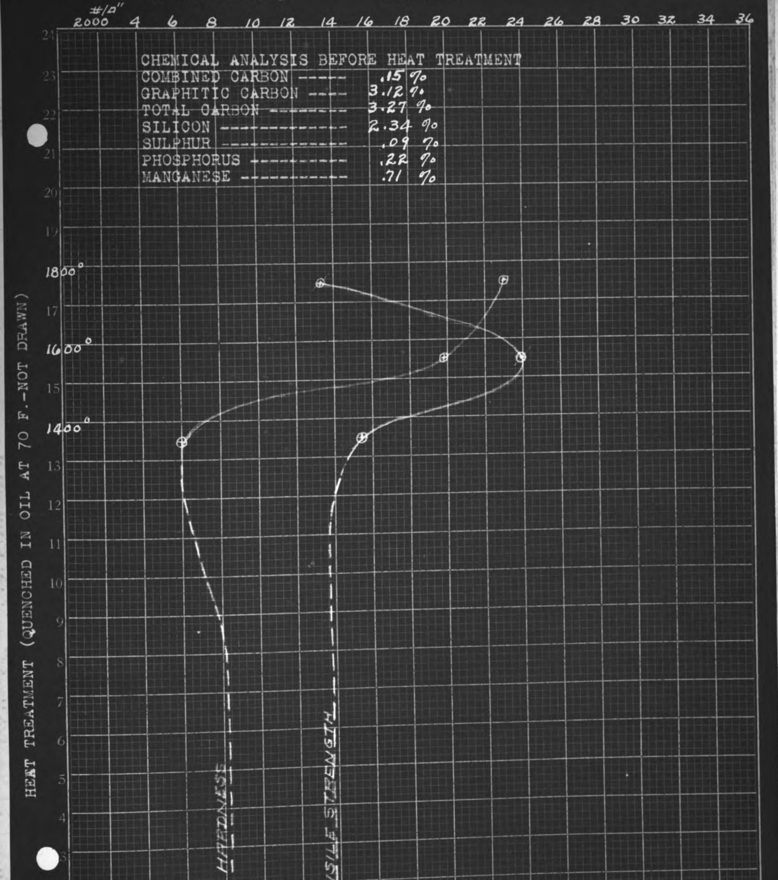
SAMPLE - 1-31-28
STRENGTH
#/□"
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON ------- .62 %
GRAPHITIC " -------- 2.82 %
TOTAL " -------- 3.44 %
SILICON -------------- 2.08 %
SULPHUR --------------- .08 %
PHOSPHORUS ------------ .17 %
MANGANESE ------------- .60 %
1700°
1500°
1300°
IN OIL
HEAT TREATMENT (QUENCHED AT 70 F.-NOT DRAWN)

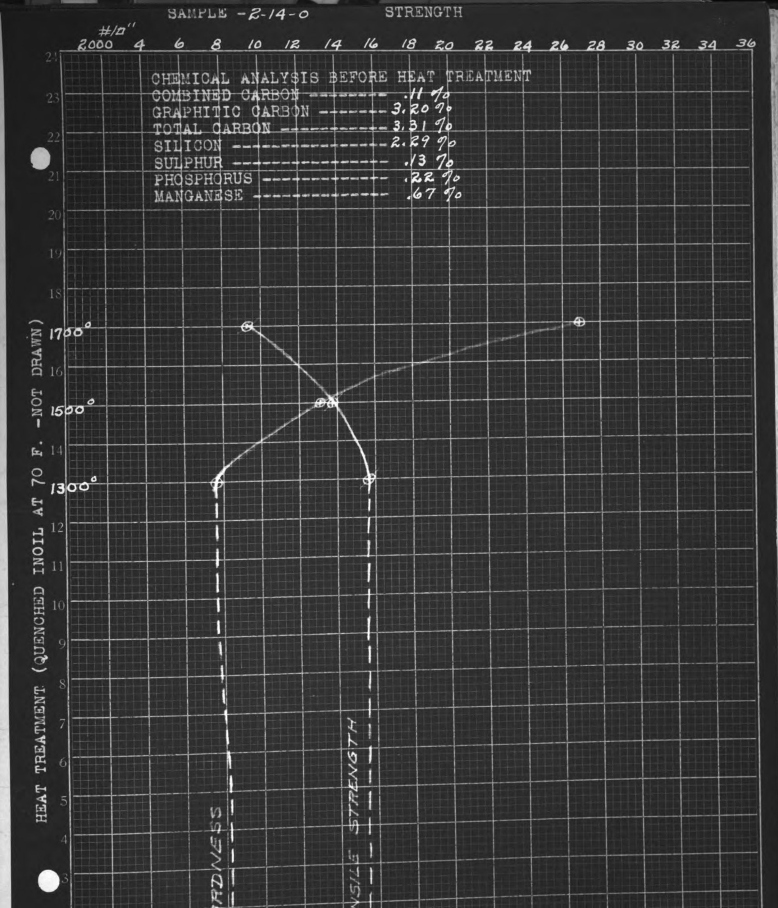

SAMPLE -3-13-H
STRENGTH
#/□"
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON ---- .14 %
GRAPHITIC " ----- 3.30 %
TOTAL " ----- 3.44 %
SILICON ----------- 1.41 %
SULPHUR ----------- .07 %
PHOSPHORUS --------- .10 %
MANGANESE --------- .93 %
1700°
1500°
1300°
HEAT TREATMENT (QUENCHED IN OIL AT 70 F.-NOT DRAWN)
HARDNESS
TENSILE STRENGTH


SAMPLE-2-10-H
#10"
STRENGTH
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON-- .94 %
GRAPHITIC " ---- 2.50 %
TOTAL " ---- 3.44 %
SILICON ---------- 1.77 %
SULPHUR ---------- .09 %
PHOSPHORUS -------- .16 %
MANGANESE -------- .57 %
1800°
1600°
1400°
HEAT TREATMENT (QUENCHED IN OIL AT 70 F.-NOT DRAWN)
HARDNESS
NSILE STRENGTH

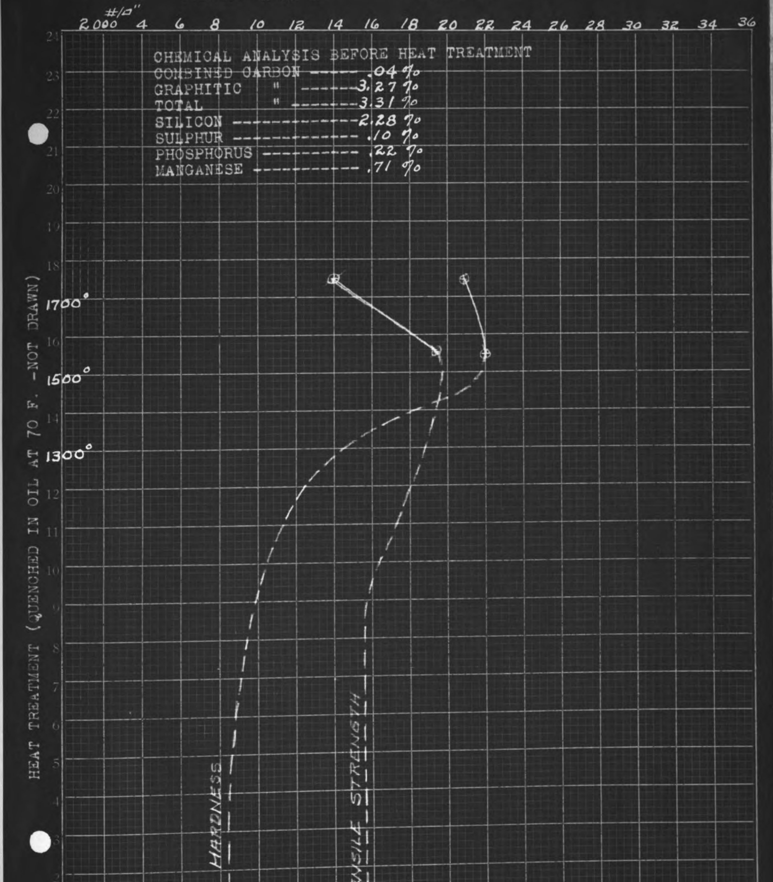

SAMPLE -2-17-0
STRENGTH
#/□"
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON ---- .33 %
GRAPHITIC " -----3.12 %
TOTAL " ------3.45 %
SILICON -------------2.28 %
SULPHUR ------------- .098 %
PHOSPHORUS ---------- .21 %
MANGANESE ----------- .71 %
1800°
1600°
1400°
HEAT TREATMENT (QUENCHED IN OIL AT 70 F.-NOT DRAWN)
HARDNESS
NSILE STRENGTH

SAMPLE -2-13-0 STRENGTH




SAMPLE -2-14-0
STRENGTH
#/□"
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON -------- .11 %
GRAPHITIC CARBON ------- 3.20 %
TOTAL CARBON ----------- 3.31 %
SILICON --------------- 2.29 %
SULPHUR --------------- .13 %
PHOSPHORUS ------------ .22 %
MANGANESE ------------- .67 %
1700°
1500°
1300°
HEAT TREATMENT (QUENCHED INOIL AT 70 F. -NOT DRAWN)
RDNESS
NSILE STRENGTH

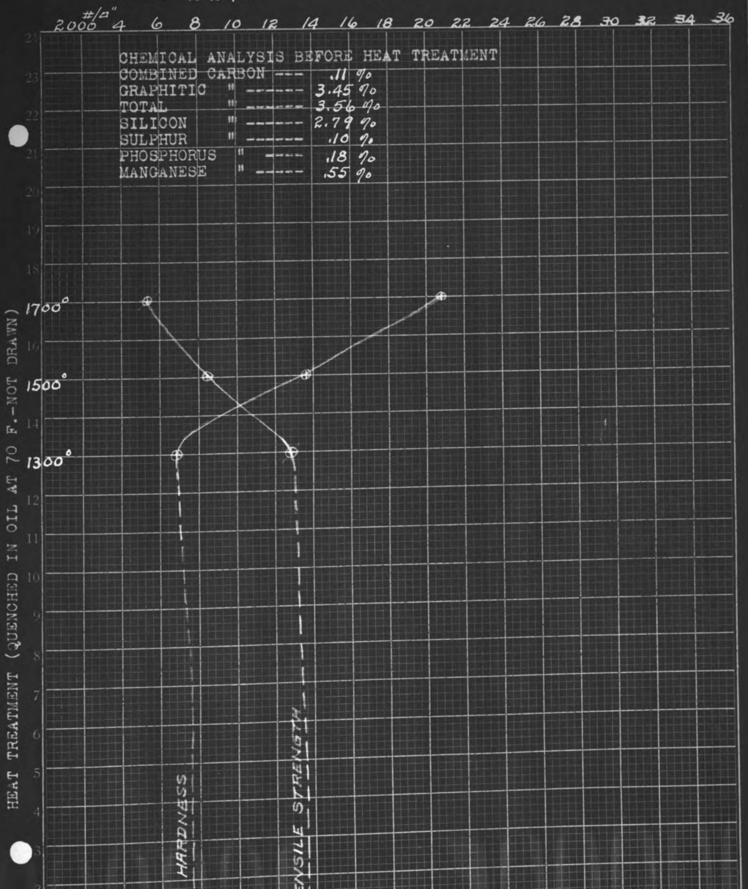
SAMPLE -2-15-0 STRENGTH

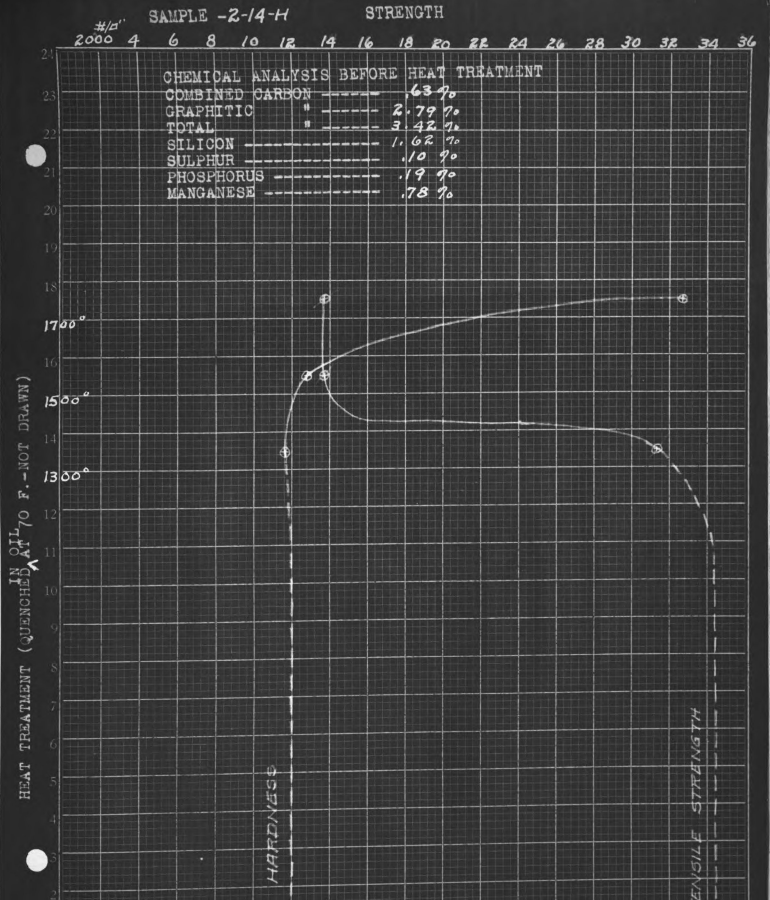


SAMPLE -2-24-0 STRENGTH

CHEMICAL ANALYSIS BEFORE HEAT TREATMENT

COMBINED CARBON	---	.11 %
GRAPHITIC "	------	3.45 %
TOTAL "	------	3.56 %
SILICON "	------	2.79 %
SULPHUR "	------	.10 %
PHOSPHORUS "	----	.18 %
MANGANESE "	-----	.55 %




SAMPLE -2-14-H
STRENGTH
#/□''
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON ------ .63 %
GRAPHITIC " ------ 2.79 %
TOTAL " ------ 3.42 %
SILICON -------------- 1.62 %
SULPHUR -------------- .10 %
PHOSPHORUS ----------- .19 %
MANGANESE ------------ .78 %
1700°
1500°
1300°
HEAT TREATMENT (QUENCHED IN OIL AT 70 F.-NOT DRAWN)
HARDNESS
ENSILE STRENGTH

SAMPLE -2-16-0 STRENGTH

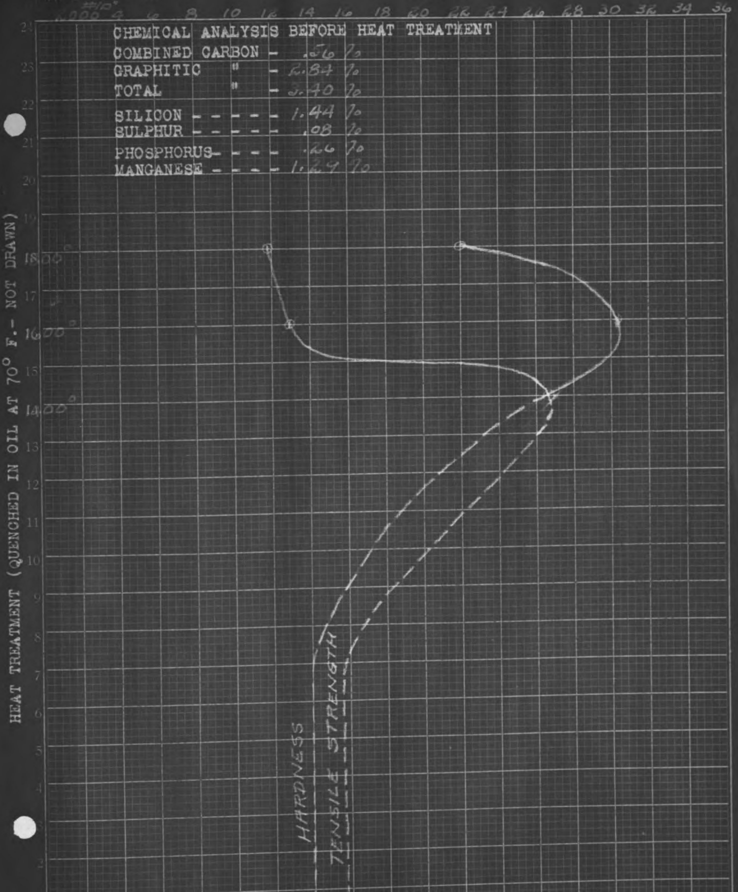
#/□" 2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36

CHEMICAL ANALYSIS BEFORE HEAT TREATMENT

COMBINED CARBON	----	.16 %
GRAPHITIC "	-----	2.94 %
TOTAL "	-----	3.10 %
SILICON "	-----	2.39 %
SULPHUR "	-----	.09 %
PHOSPHORUS "	-----	.23 %
MANGANESE "	-----	.68 %

SAMPLE -3-15-H

STRENGTH

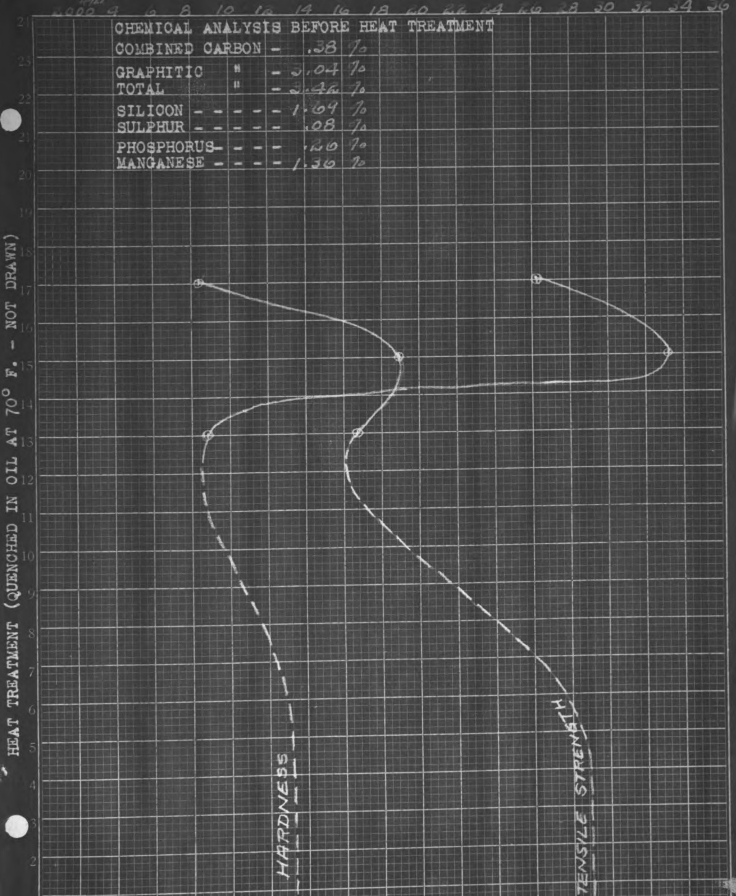


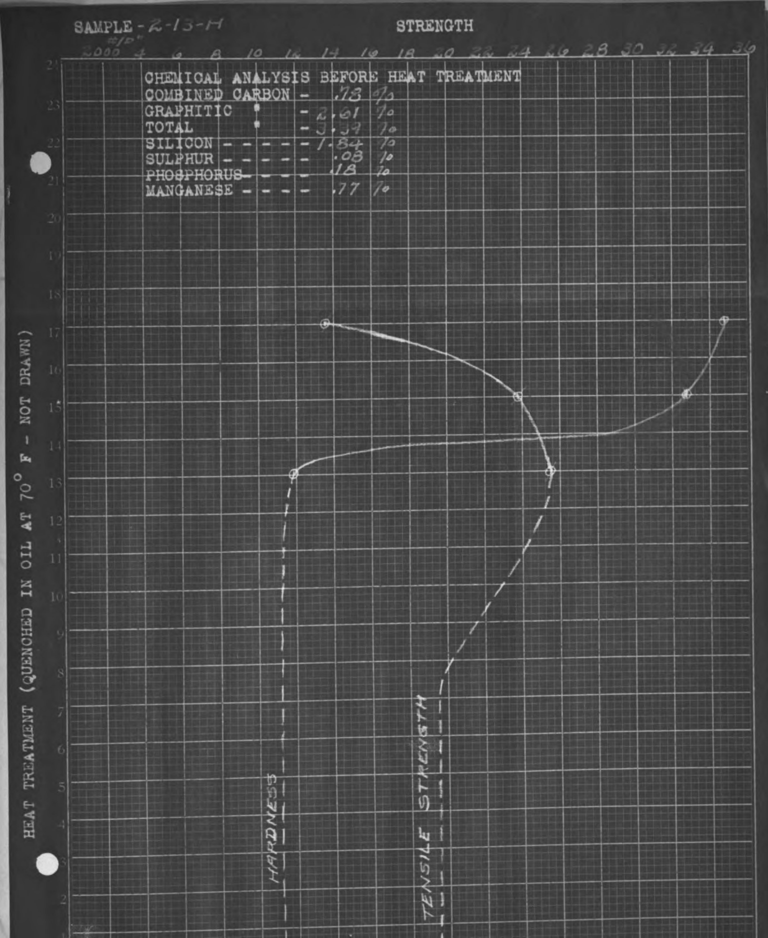
SAMPLE 3-14-H #10"

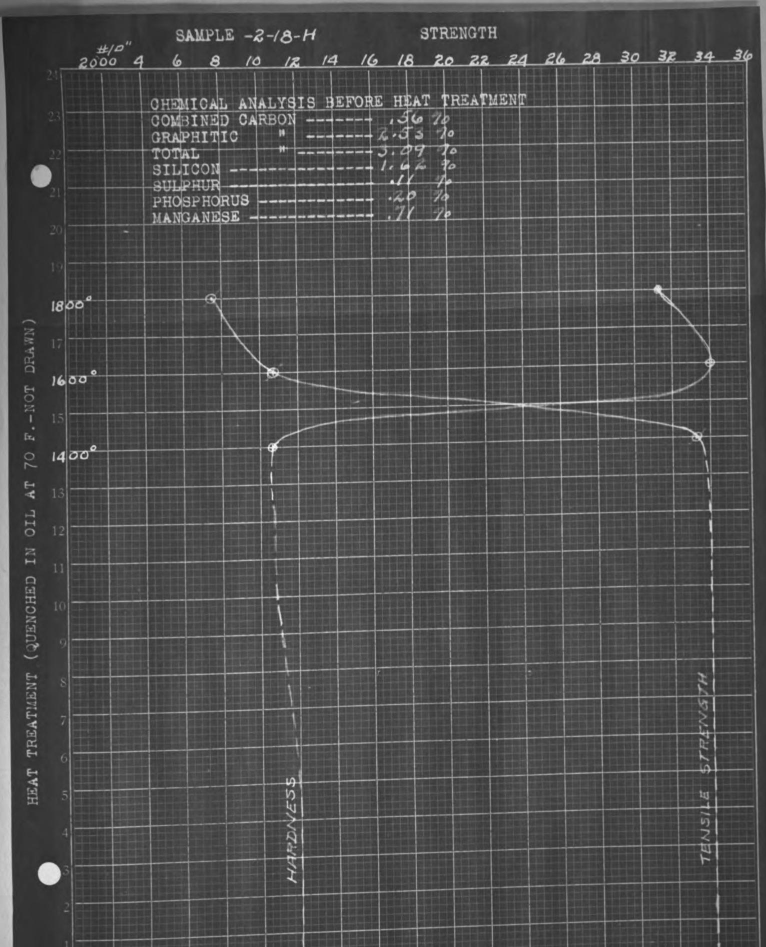
STRENGTH

CHEMICAL ANALYSIS BEFORE HEAT TREATMENT

COMBINED CARBON - .38 %
GRAPHITIC " - 3.04 %
TOTAL " - 3.42 %
SILICON - - - - - 1.69 %
SULPHUR - - - - - .08 %
PHOSPHORUS- - - - .26 %
MANGANESE - - - - 1.36 %




SAMPLE - 2-13-M
STRENGTH
#/D"
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON - .78 %
GRAPHITIC " - 2.61 %
TOTAL " - 3.39 %
SILICON - - - - - 1.84 %
SULPHUR - - - - - .08 %
PHOSPHORUS - - - - .18 %
MANGANESE - - - - - .77 %
HEAT TREATMENT (QUENCHED IN OIL AT 70° F - NOT DRAWN)
HARDNESS
TENSILE STRENGTH

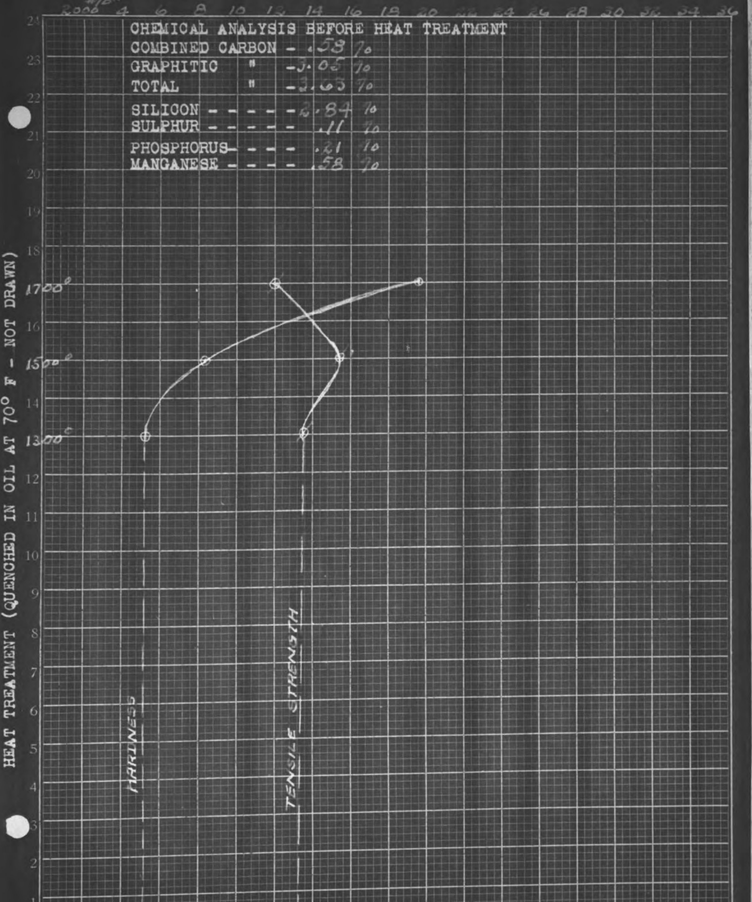

SAMPLE -2-18-H
STRENGTH
#/□"
2000 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT
COMBINED CARBON -------- .56 %
GRAPHITIC " -------- 2.53 %
TOTAL " --------- 3.09 %
SILICON --------------- 1.62 %
SULPHUR --------------- .11 %
PHOSPHORUS ------------ .20 %
MANGANESE ------------- .71 %
1800°
1600°
1400°
HEAT TREATMENT (QUENCHED IN OIL AT 70 F.-NOT DRAWN)
HARDNESS
TENSILE STRENGTH

SAMPLE - 2-23-H

STRENGTH

CHEMICAL ANALYSIS BEFORE HEAT TREATMENT

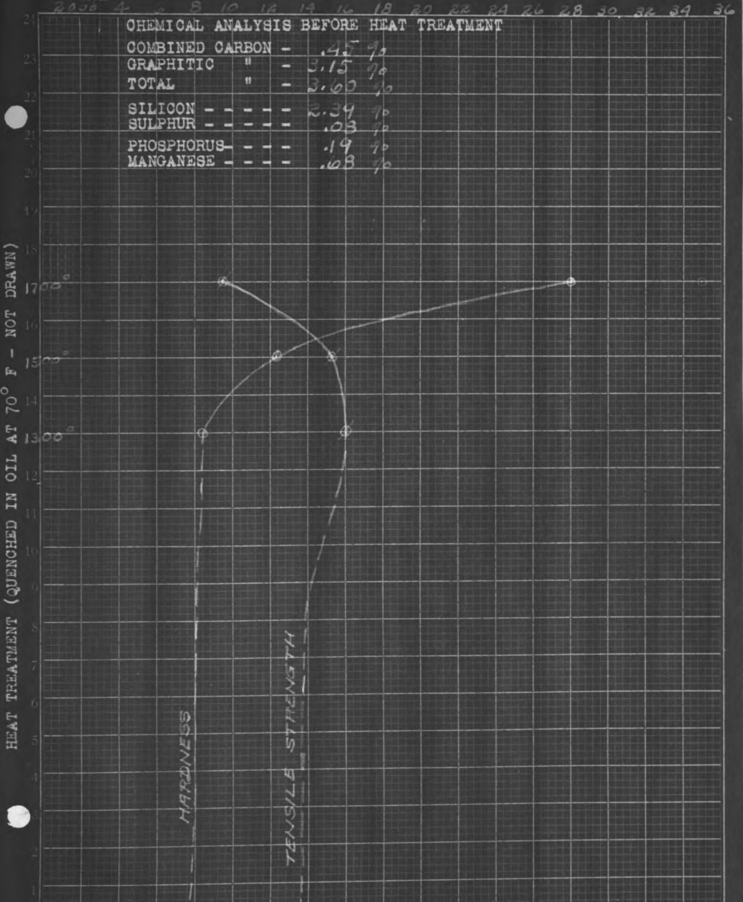
COMBINED CARBON - .58 %
GRAPHITIC " - 3.05 %
TOTAL " - 3.63 %
SILICON - - - - - 2.84 %
SULPHUR - - - - - .11 %
PHOSPHORUS - - - - .21 %
MANGANESE - - - - .58 %

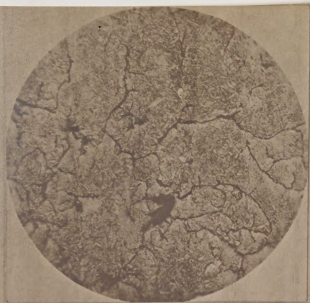


SAMPLE - 2-1-0 STRENGTH

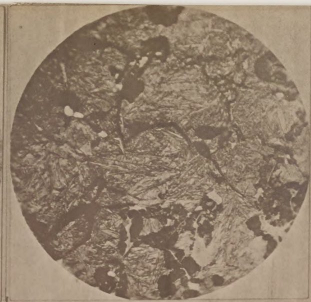
CHEMICAL ANALYSIS BEFORE HEAT TREATMENT

COMBINED CARBON	-	.45 %
GRAPHITIC "	-	3.15 %
TOTAL "	-	3.60 %
SILICON	- - - - -	2.34 %
SULPHUR	- - - - -	.03 %
PHOSPHORUS	- - - -	.19 %
MANGANESE	- - - -	.08 %



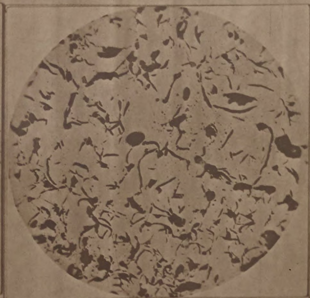


Etched, 1600° F,
Magnification - X400
Constituents - Graphite,
Martensite, Cementite

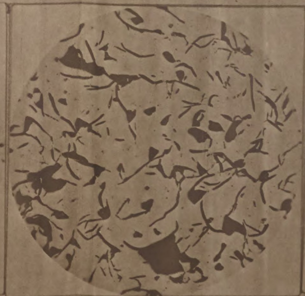


Etched - 1800° F
Magnification - X400
Constituents - Graphite,
Martensite, Cementite.

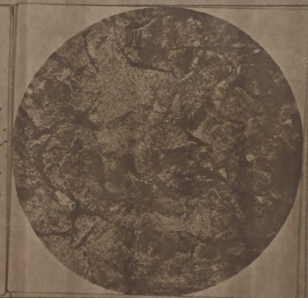
Unetched - 1400° F
Magnification - X100
Constituents - Graphite



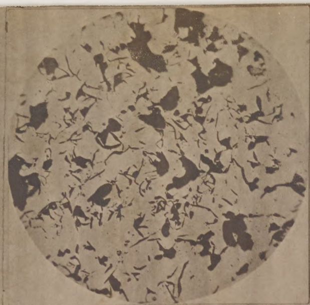
Unetched - 1600° F
Magnification - X100
Constituents - Graphite



Unetched - 1800° F,
Magnification - X100
Constituents - Graphite



Etched - 1400° F
Magnification - X400
Constituents -Graphite
Pearlite, Cementite



Unetched - Untreated
Magnification - X100
Constituents - Graphite

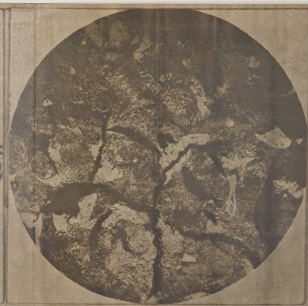
Unetched - 1800° F
Magnification - X100
Constituents - Graphite

Etched - Untreated,
Magnification - X400
Constituents - Graphite,
Pearlite,Cementite

Etched - 1800° F
Magnification - X400
Constituents - Graphite
Martensite,Cementite

Unetched-Untreated
Magnification - X100
Constituents - Graphite

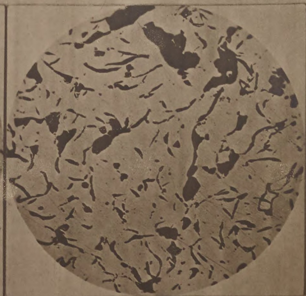
Unetched - 1700° F.
Magnification - X100
Constituents - Graphite



Etched - Untreated
Magnification - X400
Constituents - Graphite, Pearlite, Ferrite

Etched - 1700° F
Magnification - X400
Constituents - Graphite Martensite, Cementite

Unetched - Untreated
Magnification - X100
Constituents - Graphite



Unetched - 1700° F.
Magnification - X100
Constituents - Graphite

Etched - Untreated
Magnification - X400
Constituents - Graphite and Pearlite

Etched - 1700° F
Magnification -X400
Constituents -Graphite Martensite, Cementite