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On the permanent growth of grey iron

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ON THE PERMANENT GROWTH OF GREY IRON

By

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- TABLE OF CONTENTS -

- LIST OF ILLUSTRATIONS -

- REVIEW OF PUBLISHED WORK -

After making a survey of the available information on the subject of permanent growth in grey iron castings,it was found that very little definite information is available and such as is available does not seem to satisfy all conditions. As is perhaps generally known, grey iron castings withstand a growth in volume upon repeated heating and cooling, which growth is a permanent deformation and is not a function of the temperature co-efficient. In the case of ingot molds, Diesel engine pistons, carburizing boxes, continuous-furnace parts, grate bars, stoker links and all such castings which are subjected repeatedly to high and low temperatures, the phenomenon of growth presents a very vital problem. Ingot molds distort and produce cracks which result in seams or laps, which appear as defects in the finished steel product. The head of Diesel pistons frequently fail by cracking in a stellar shape. This is attributed usually to the result of permanent growth. Distortion and change of dimension of furnace parts, as would be expected, frequently renders them entirely unusable. In chain grate stokers, mechanical difficulties have

frequently been encountered due to the growth of the links causing binding which does not permit the chain to lie horizontally as it passes into the combustion chamber. Under proper operation these links should never attain a temperature sufficiently high to start growth, but in the case of an incompetent fireman chain grates are frequently stopped in a hot setting permitting the chain to attain an exceptionally high temperature. The problem is of sufficient importance then to warrant further consideration.

The most outstanding published work upon the subject is that of Carpenter and Rugan, Journal of Iron and Steel Institute, 1909, No. 11; the work of Andrews and Hyman, Iron and Steel Institute, May, 1924, and the work of Carpenter, Journal of Iron and Steel Institute, 1911, No. 1. Further work has been done upon the subject in the Mechanical Engineering Laboratories of Washington University but has not been published as yet.

The work of Andrews and Hyman was performed for the following reasons: No. 1, to determine the effect of silicon in promoting growth. No. 2, to ascertain the change in the graphite, and No. 3, to determine the effect of certain alloying elements such as chromium and vanadium. In this work, test-bars of various compositions were subjected to fifty heats of fifteen minutes

duration each, at 900 degrees Centigrade. The results of their efforts are as follows: No. 1, hard white irons do not grow, nor do carbonless silicon irons. No. 2, no growth was exhibited by chromium, molybdenum or vanadium alloy irons, and No. 3, silicon and nickel increase the growth. The effect of nickel is to increase the rate of growth beyond that of every other element tried. The theory offered by these two investigators was that the growth was due to the oxidation of a silico-ferrite, the graphite flakes serving as channels and entries for the deeper penetration of oxygen below the surface of the metal. It was the formation of this supposed oxide of silico-ferrite which expanded the metal internally and resulted in an extended external dimension, the volume of the oxide being greater than that of the metal from which it was formed. In their work, complete carbon elimination was never effected; even after a series of fifty heats at 900 degrees Centigrade, carbon as high as 0.05% was found to remain. From analytical results, it appears that not until an appreciable amount of oxide is formed, does carbon begin to oxidize and become less in quantity. Their results for the alloys show as follows: Chromium, Molybdenum and Vanadium irons show practically no growth. Aluminum tends to promote growth as does nickel. The promotion

of growth caused by the nickel and aluminum is explained by their coarsening effect on graphite which produces wider channels, resulting in better penetration of the oxygen. They believe that growth takes place in two stages; first, oxidation of the ferrite with but slight burning away of the carbon - second, when sufficient metallic oxide has been formed, carbon becomes oxidized, causing the entire channels previously occupied by graphite to become filled with oxide, which serves to expand them. Andrews and Hyman say - "The penetration of oxygen to the inner core of the bar is slow and is accomplished by the oxide near the surface increasing in oxygen content to the higher oxide of iron serving to further oxidize the unaffected portions more internally." In the case of the alloy cast irons, those alloys which tend to eliminate growth are in all cases too expensive to be used in manufacturing heat-resisting cast irons with the exception, perhaps, of chromium which produces cast iron in such a hardened condition as to render it non-machinable. Quoting the paper of Andrews and Hyman appearing in Foundry January 15, 1927 - "After fifty heats, a central core of more or less unoxidized material still remained." Table 2 shows iron No. 4 to be of the following analysis before heating:-

T.C.	3.26
C.C.	3.26
Si.	1.37
Mn.	0.56
Cr.	1.19

The same iron after fifty heats gave a total carbon analysis of 0.05 in the outer ring and 3.08 inside of the annular area.

To quote briefly from the work of Rugan and Carpenter:- "Because of such small quantities of sulphur present in grey iron, say 0.20%, and the tendency it has to keep the carbon in the combined form, it is certain that this element does not add appreciably to the growth; if anything, it is possible to cause contraction. When silicon does not exceed 0.70%, manganese does not contribute to the growth but dimishes it, - the lower the silicon the greater the diminution. Manganese is regarded as a retarding factor in all cases, and in the majority of cases causes an actual diminution. For irons containing phosphorus present as a phosphide eutectic (Steadite) a diminution as well as a growth is possible, but in no cases is it a deciding factor." This leaves silicon and total carbon as the influencing elements in determining the amount of growth with the condition of the carbon, combined or graphitic, recognized as a factor.

There has been a "Gas Theory" advanced which in brief attributes the permanent growth of grey iron to the expansion of occluded gas pockets upon heating. The

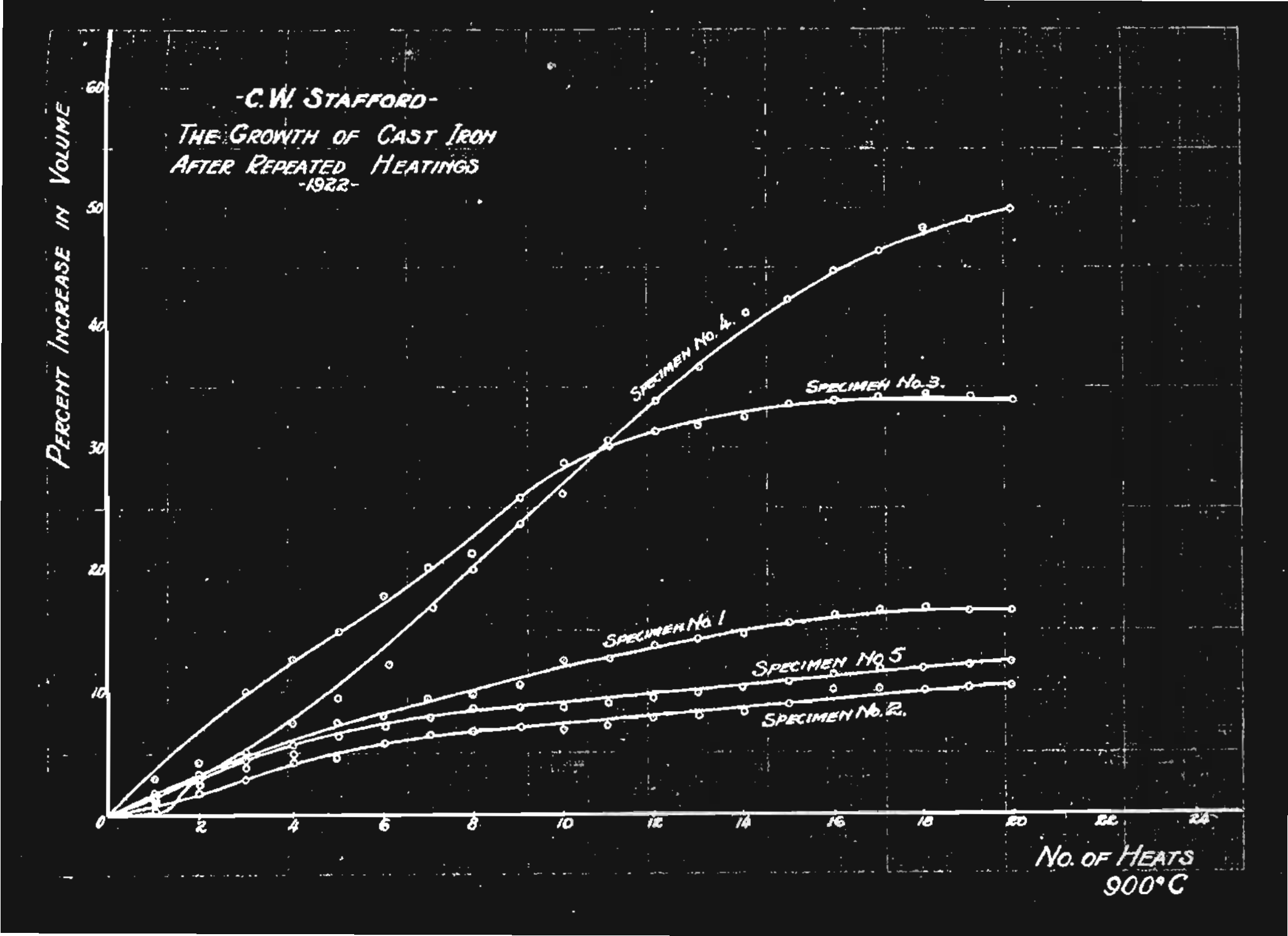
fact that high aluminum cast irons in which the opportunity of being gaseous is very slight, due to the scavenging effect of the aluminum, it is found that growth continues to take place very rapidly.

- WORK DONE AT WASHINGTON UNIVERSITY -

To review the work carried on at Washington University, we must go back to a thesis of C. W. Stafford, 1922. He used irons of various compositions giving a gradation of the degree of "greyness" of the iron. Iron of five different compositions was obtained and these compositions are listed in the following table:

No.	T.C.	G.C.	Si.	Mn.	S.	P.
1	3.97	3.33	0.89	0.55	0.073	0.416
2	2.45	-	1.07	0.25	0.057	0.197
3	3.96	3.26	2.09	0.48	0.077	0.316
4	3.10	-	3.05	0.50	0.058	0.830
5	4.21	2.59	0.60	0.68	-	0.322

These irons were selected with their silicon content in view. Test-bars were subjected to twenty heats of three hours duration each and at a temperature of approximately 900 degrees Centigrade. The test-bars were sealed by fire clay in a cast-iron box and according to the report no oxidation of the specimens existed. Curves plotted from Stafford's results are shown in Figure No. 1. It will be noted that Sample No. 4 with 3.05% silicon showed a maximum growth of 50% increase in volume with a decrease in growth accompanying a lessening in silicon content. These were all commercial irons obtained from regular heats in St. Louis foundries. A 2.02% increase in weight accompanied the maximum growth. All pieces were heated


-C.W. STAFFORD-
THE GROWTH OF CAST IRON
AFTER REPEATED HEATINGS
-1922-
PERCENT INCREASE IN VOLUME
0
10
20
30
40
50
60
2
4
6
8
10
12
14
16
18
20
22
24
SPECIMEN No. 4.
SPECIMEN No. 3.
SPECIMEN No. 1
SPECIMEN No. 5
SPECIMEN No. 2.
No. OF HEATS
900°C

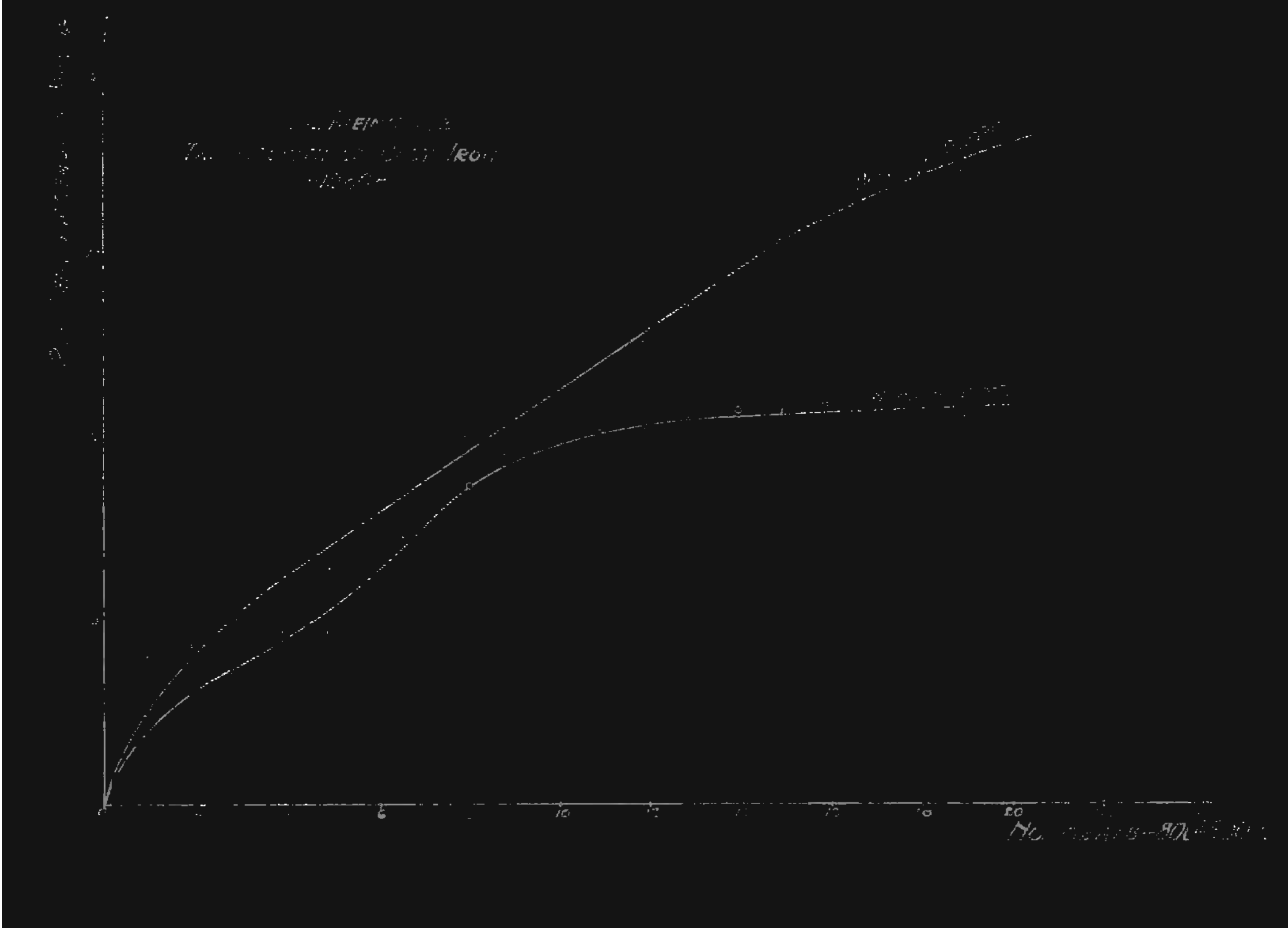
in a neutral atmosphere and permitted to cool down with the furnace.

Meinholtz, 1926, continued under the direction of the writer upon the same subject. Commercial iron of approximately the same analysis as that which showed greatest growth in the previous work was obtained, namely, 2.75% silicon. This was subjected to various treatments in order to determine - first, the effects of repeated heatings in a medium, free from oxygen, at 800 degrees Centigrade, and at 900 degrees Centigrade, and second, the comparative effects in different heating media of prolonged heatings at 800 degrees Centigrade, 900 degrees Centigrade and 1000 degrees Centigrade. The tabulated results are as follows:

No. of Heats	Held at	For	Growth in Volume	Medium
20	800 deg.C	½ hr.	1.05%	Salt bath
20	900 "	"	1.80%	" "
1	900 "	7½ hrs.	.94%	" "
1	900 "	7½ "	1.62%	Closed box
1	900 "	7½ "	1.90% (Approximately)	Open furnace
1	800 "	7½ "	.27%	Salt bath
1	800 "	7½ "	.89%	Closed box
1	1000 "	7½ "	2.00%	Closed box

Plotted results are shown in Figure No. 2.

In the last six tabulated heats the change in weight was negligible. Neither the salt bath nor the open furnace heats could be obtained at 1000 degrees



Centigrade because of the decomposition and volatilization of the former and the excessive oxidation in the case of the latter. The salt bath used was Houghton's Liquid Heat and all specimens from the repeated heating tests were cooled in the atmosphere. Meinholtz determined a transformation point for this material at 796 degrees Centigrade. He also obtained a slight increase in physical properties in the test bars of the 900 degrees series after the first several repeated heatings. This would be expected since the microscope showed more combined carbon after the air cool than was revealed in the original test-bars.

Fisher and McBurney, 1924, determined the effect of highly superheated steam on cast iron. This work was done to investigate the effect both upon grey and malleable irons such as would be used in valves and turbine fittings. Steam with a temperature as high as 1100 degrees Fahrenheit was used but no growth was found at these temperatures. They also ran some heats in an open furnace in which their coolings and conditions of atmosphere were not recorded. The results were as follows:

Held at	For	Growth
1200 deg. F.	2 hrs.	None
1300 " "	2 "	0.3%
1420 " "	2 "	1.6%

This work is of little importance because not much

accurate information is available.

- FURTHER WORK -

After collecting all available information upon the subject the writer decided to make various determinations in the laboratory to fill in some of the gaps in the work which had been left undone; therefore, it was decided upon to run a series of heats at the same maximum temperature as had been used in the past, holding at this temperature a different length of time, namely one and one-half hours, and varying the rate of cool for the various specimens. Also an atmosphere free from oxygen was to be maintained in the furnace throughout the heating and holding period. The various rates of cool selected were cooling down with the furnace, an "air rate", and a quench in a light oil. The heating rate remained constant for all heatings. This rate is shown in Figure No. 3. The furnace used was a Standard Fuel Engineering Company high-speed steel furnace, heated with fuel gas, and manually controlled. The test pieces were enclosed in a cast iron box into which the thermo-couple was inserted. This box was practically gas tight. A small gas flame was kept burning at the opening on the top of the furnace. Also several pieces of incandescent coke were kept inside of the furnace door to consume any small

amounts of oxygen which might filter into the crevices; however, during the cooling period, since the gas was turned off and the coke gradually lost its power of consuming the infiltering air, the oxygen gradually penetrated into the furnace chamber and some even permeated the box atmosphere, - however, no great amount of oxidation was present within the box, as shown by the clean condition of the test-bars after twenty heats. Some, however, was known to enter the box since the carbon content of the furnace-cooled specimen was decreased very considerably. The "air-rate" was carried out by placing the test-bar in a very thin sheet metal container across the mouth of which oily waste was maintained burning. The burning of the waste, filling the container with a dense black smoke and flame, also proved to be a non-oxidizing condition. The sheet metal container as well as the cast-iron box used in the furnace are shown, together with the furnace itself, in Figure No. 4. The oil quench was carried out by immersing the piece directly from the furnace into a container of circulating oil. The oil was a mixture of gas engine and transformer oil of the following physical properties: Flash 256 degrees Fahrenheit and Fire 276 degrees Fahrenheit by the Cleveland Open Cup

and Viscosity by the Universal Standard Viscosimeter, 71 at 100 degrees Fahrenheit, 38 at 210 degrees Fahrenheit. The cooling rates for furnace cool, the "air cool" and for the oil quench are shown in Figures No. 5, No. 6 and No. 7, respectively. The "air rate" was used to obtain a cooling condition which would approximate an "air rate" and yet have the very undesirable conditions of oxidation eliminated. The furnace conditions upon chemical analysis by the Orsat Apparatus were as follows: CO_2 - 13.4%, O_2 - 0.6%, CO - 0.4%. Approximately the same period of time was permitted to elapse between succeeding heatings. After each heating period the bars were measured at six different diameters with a micrometer and the length was also determined with a micrometer. From time to time the bars were weighed as the work progressed. These weighings were not considered worthy of record because the oil quench specimen was thoroughly saturated with oil and both of the other test-bars were coated with a film of oil to prevent rusting. However, at the completion of the work the test-bars were heated in a small electrical muffle to a temperature of about 325 degrees Centigrade

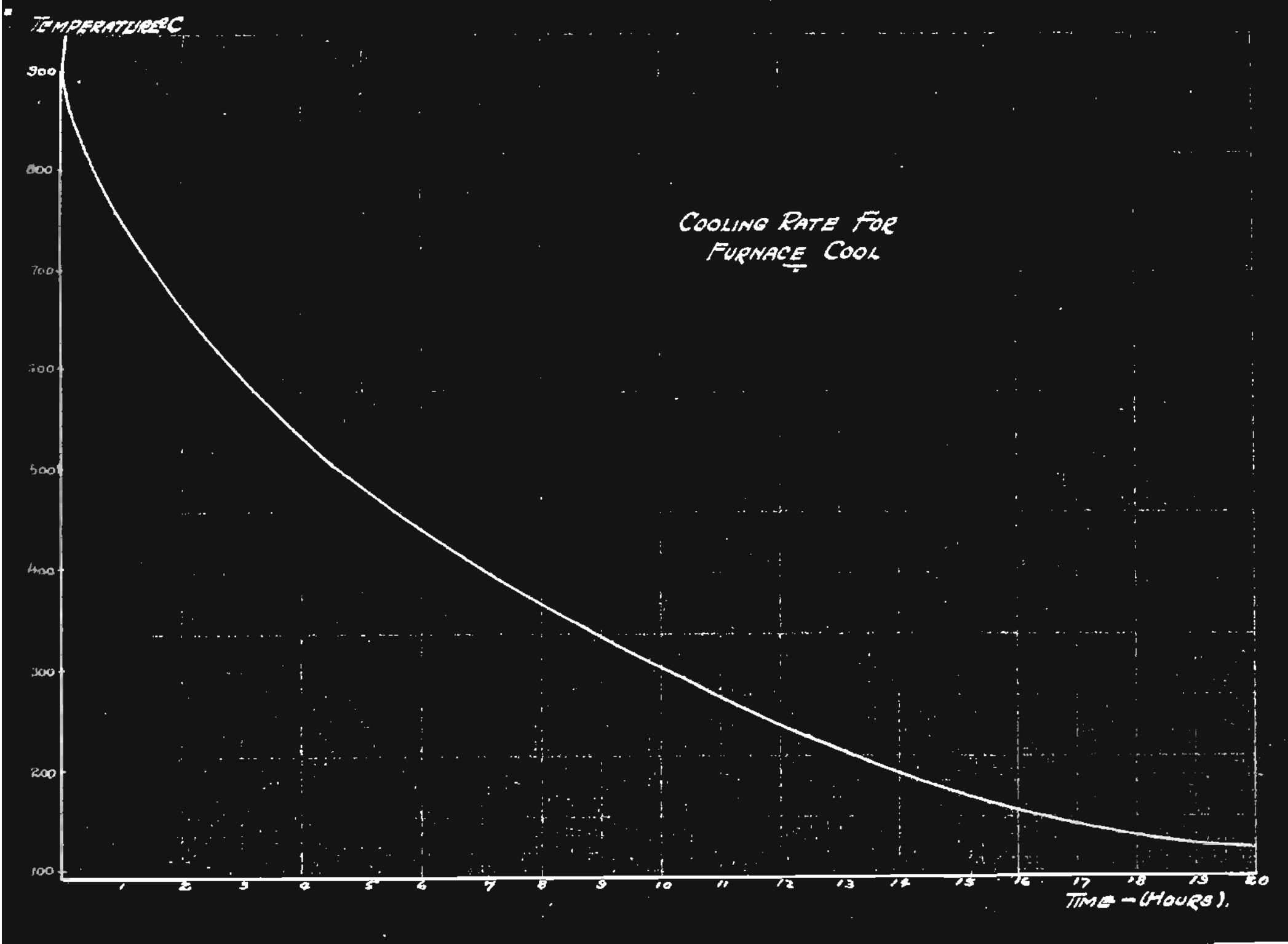
Figure No. 4. - Furnaces and Boxes.

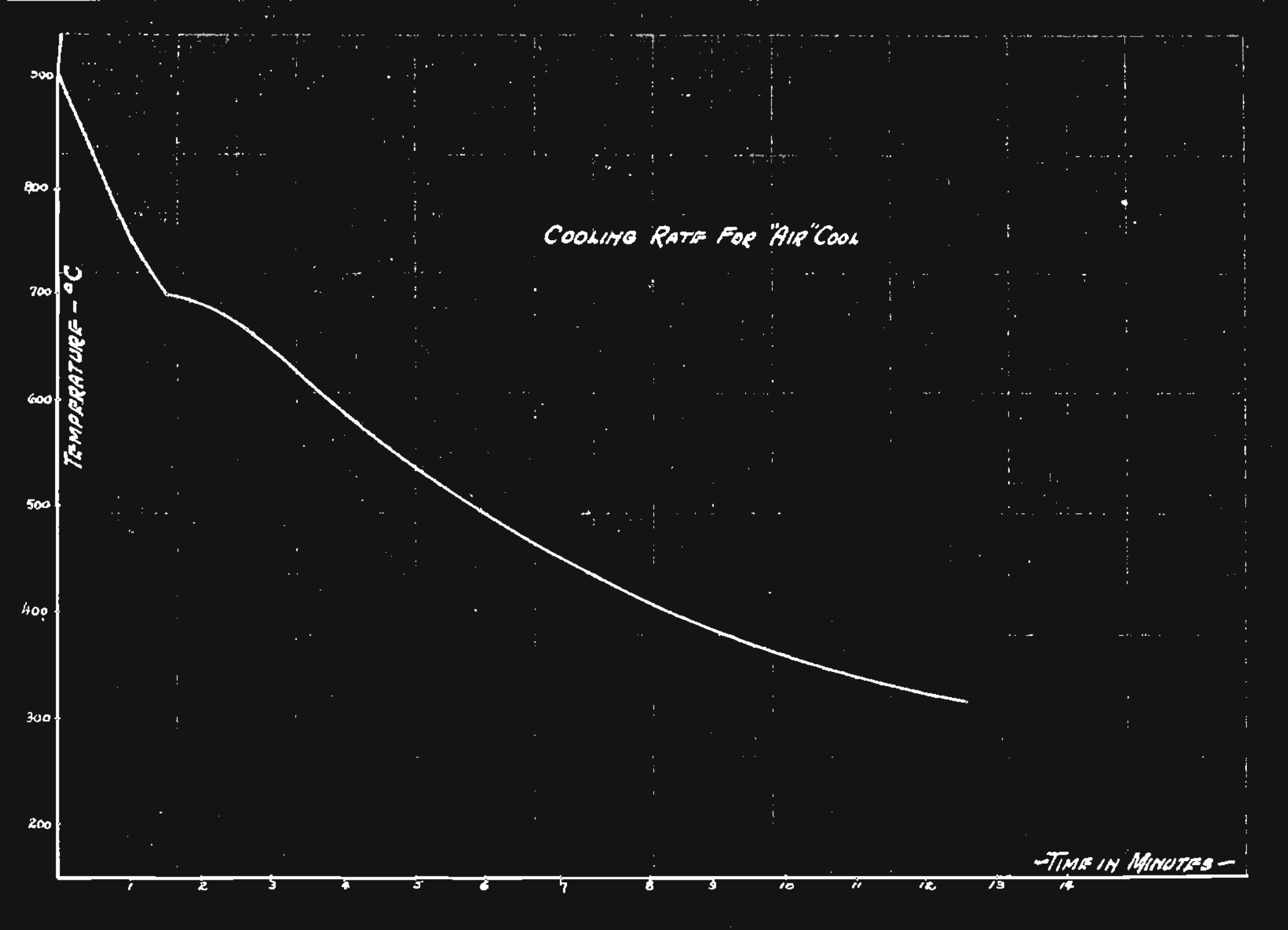
which was deemed adequate for the complete driving off of all remaining oil and the bars were then weighed.

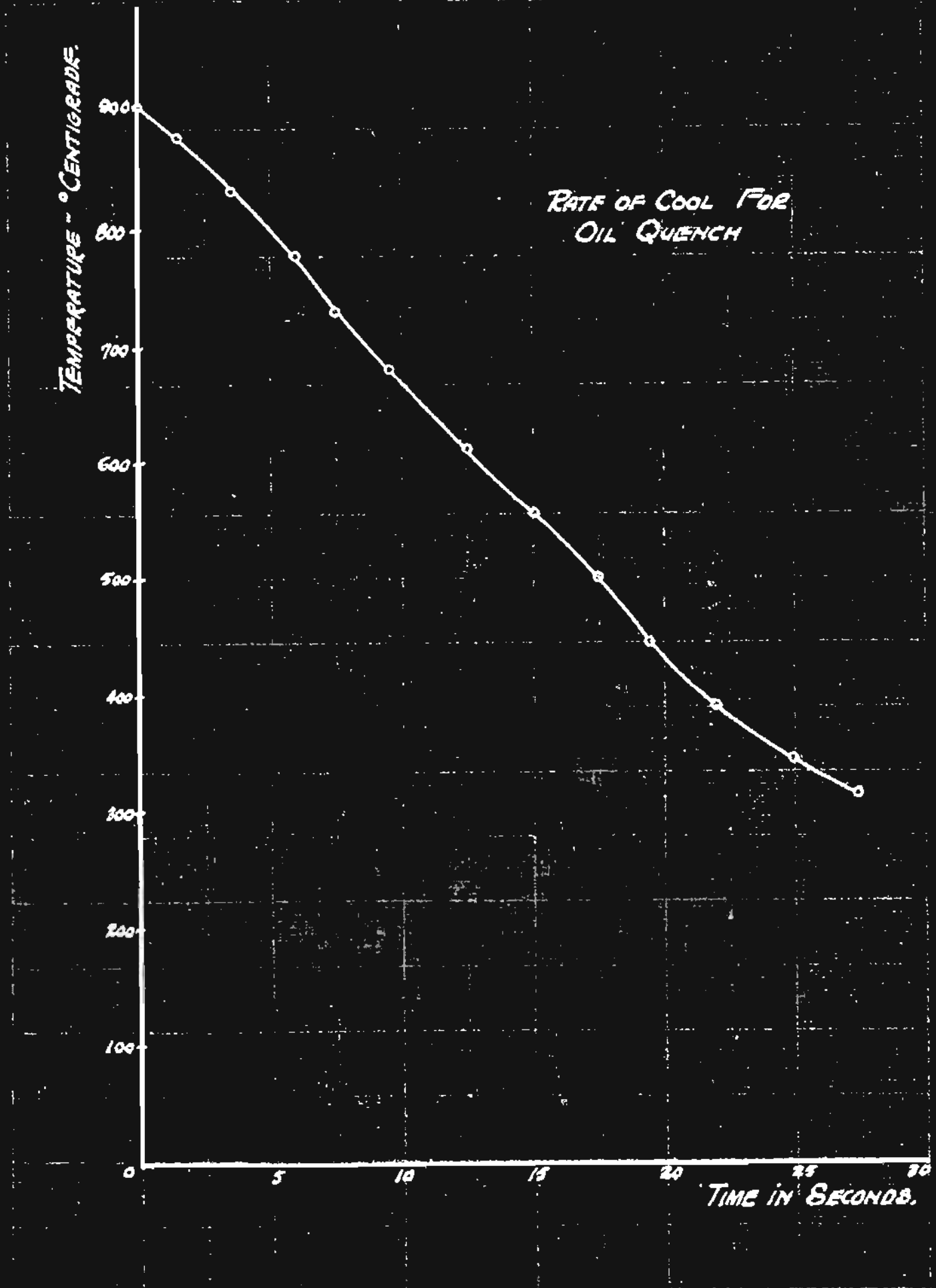
The test-bars were cast from the same ladle of iron, being a commercial heat in one of the St. Louis foundries. The bars were then turned down to a five-eighths inch diameter and a six inch length before heating. The original test bars gave the following analysis: T.C.-3.26; C.C.-0.09; P.-0.45; S.-0.05; Mn.- 0.55; Si.- 2.75. To be sure that there would be no appreciable differences in carbon content, each bar was analyzed separately for total carbon, giving the following:-

	T.C.
Furnace cool	3.26
"Air cool"	3.23
Oil quench	3.20

This iron was used because it was believed it would give


Temperature °C
900
800
700
600
500
400
300
200
100
Cooling Rate For
Furnace Cool
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time - (Hours).


COOLING RATE FOR "AIR" COOL
TEMPERATURE — °C
900
800
700
600
500
400
300
200
— TIME IN MINUTES —
1
2
3
4
5
6
7
8
9
10
11
12
13
14


Rate of Cool For
Oil Quench
Temperature - °Centigrade.
900
800
700
600
500
400
300
200
100
0
5
10
15
20
25
30
Time in Seconds.

a very decided growth. After the twenty-five alternate heatings and coolings the bars gave the following chemical analysis:-

	T.C.	C.C.	P.	S.	Mn.	Si.
Furnace cool	0.13	0.08	0.479	.049	.58	2.67
"Air rate"	3.19	0.25	0.483	.078	.31	2.67
Oil Quench	2.02	0.19	0.478	.083	.29	2.67

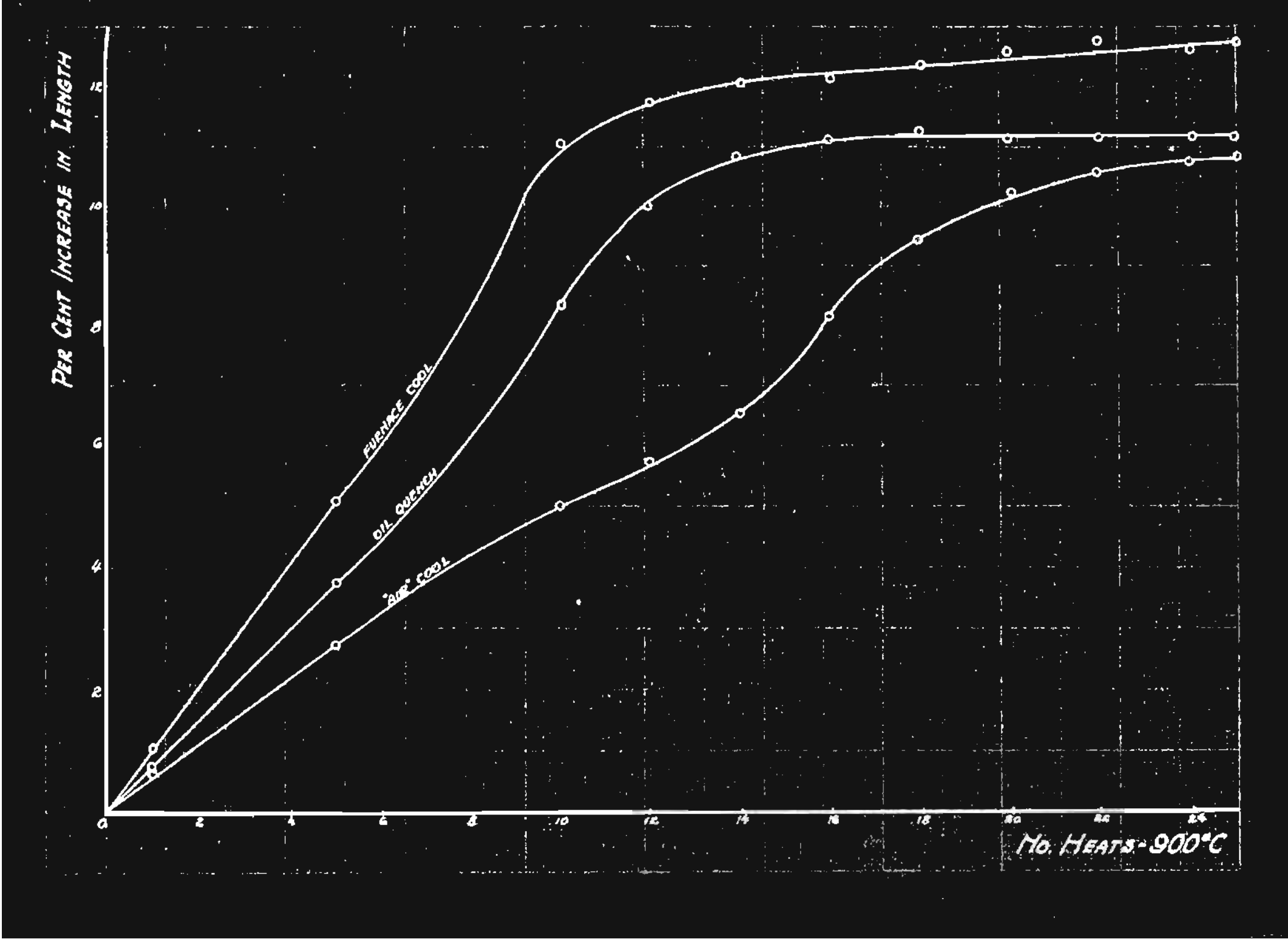
The increase in volume due to the increase in weight calculated in terms of cubic inches of Fe_2O_3 amounted to only a very small amount. The loss of carbon was considered as being replaced by oxygen and no allowance was made for the porosity of the cast iron which we know is always present in soft grey varieties to a more or lesser degree. In other words, giving all the benefits of things,which might be questioned, to the oxygen, the increase in volume due to the added weight,gave the following:-

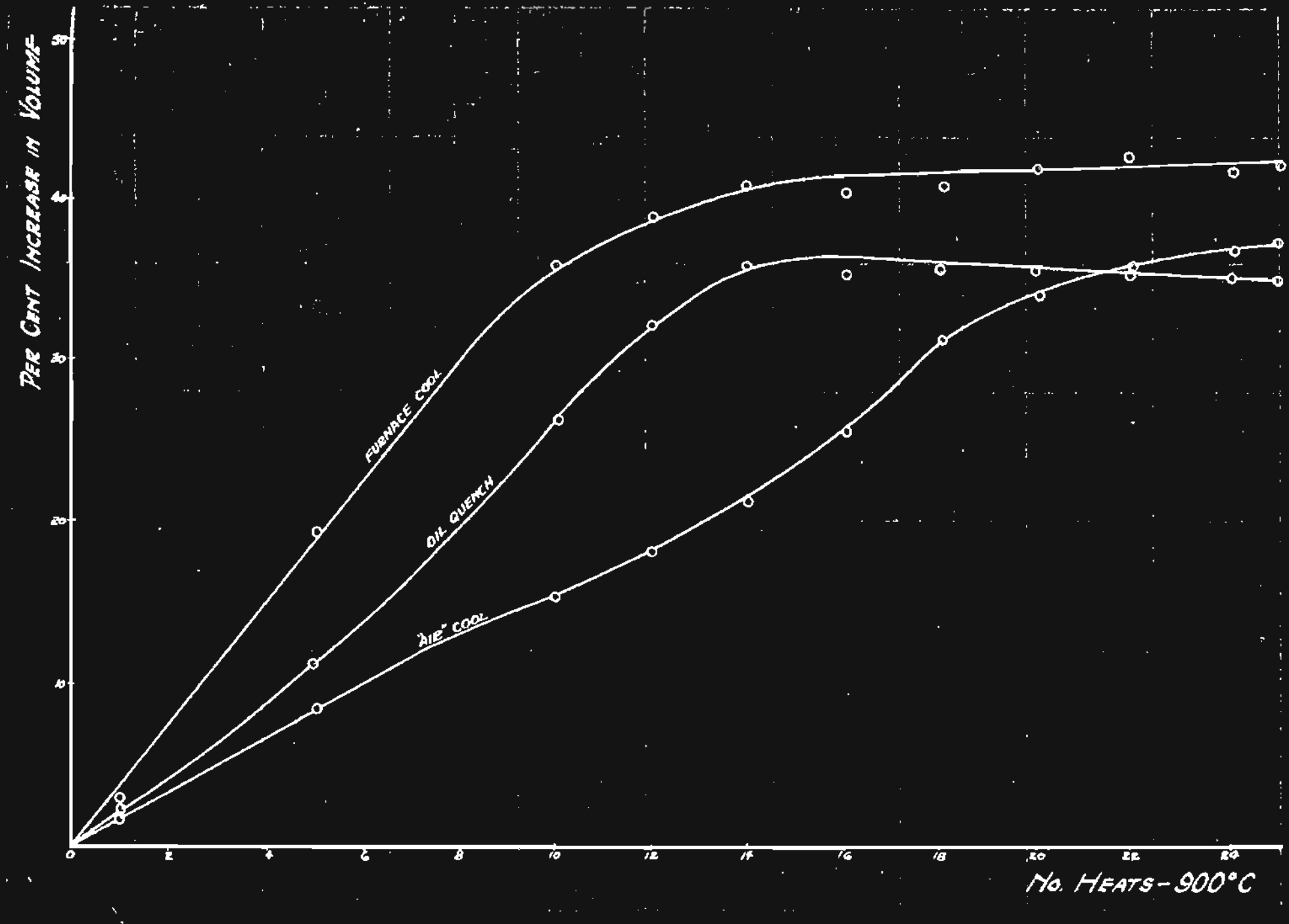
Furnace cool - 0.58% increase in volume
"Air cool" - 3.2 % increase in volume
Oil quench - 7.5 % increase in volume

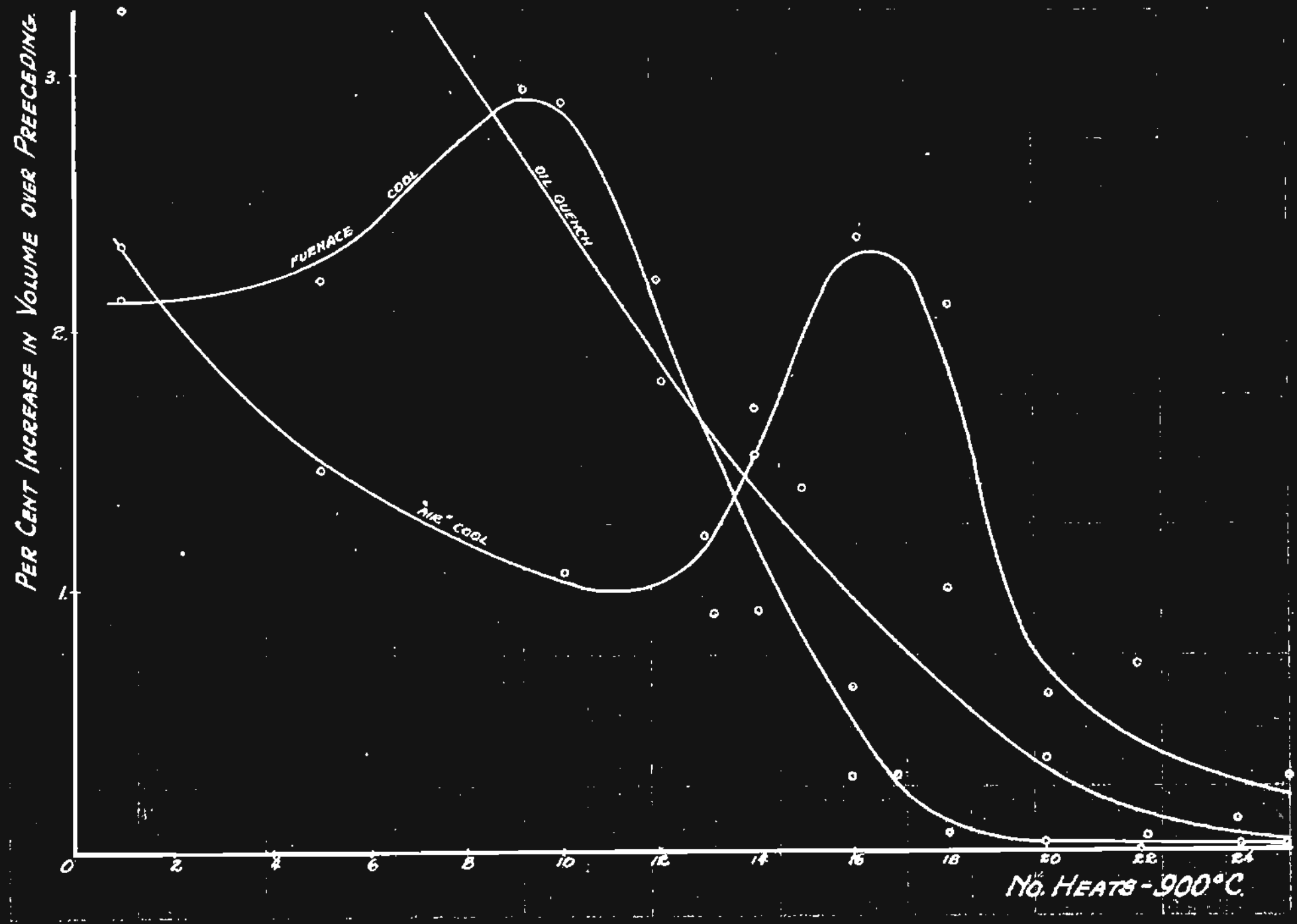
In view of the actually measured growth, these percentages are convincing that some other explanation must be offered.

- THEORY AND CONCLUSIONS -

In the opinion of the writer, the fact that the oil quench as well as the "air cool" showed a growth approximately the same as that of the furnace cool without any appreciable elimination of carbon is, in itself, sufficient evidence to eliminate the explanation of growth as offered by investigators in previously published papers. From Figures No. 8 and No. 9, it is seen that, independent of the rate of cool, all the bars increase in dimension about the same amount, but at a different rate of increase. When this amount has been reached, further heating and cooling changes the dimensions of the piece only an infinitesimal amount. This limiting growth amounts to approximately twelve percent increase in length for this material. A series of curves was plotted (Figure No. 10), in which the percent increase of volume in terms of percent of the preceding volume, is plotted against the number of heats. In other words, this curve is a plot of the rate of growth rather than the growth itself. From these curves it is seen that two very definite humps appear both in the case of the furnace cool and more especially in the case of the "air cool". These are not thought to be included under the heading of experimental error since not one or a few points assume


PER CENT INCREASE IN LENGTH
FURNACE COOL
OIL QUENCH
"AIR" COOL
0
2
4
6
8
10
12
14
16
18
20
22
24
No. HEATS - 900°C


PER CENT INCREASE IN VOLUME
FURNACE COOL
OIL QUENCH
"AIR" COOL
0
2
4
6
8
10
12
14
16
18
20
22
24
No. HEATS - 900°C


PER CENT INCREASE IN VOLUME OVER PRECEDING.
3.
2.
1.
0
FURNACE COOL
OIL QUENCH
AIR " COOL
2
4
6
8
10
12
14
16
18
20
22
24
No. HEATS - 900° C.

this shape, but all of the points lie approximately along this line. No attempt will be made to explain this change of rate.

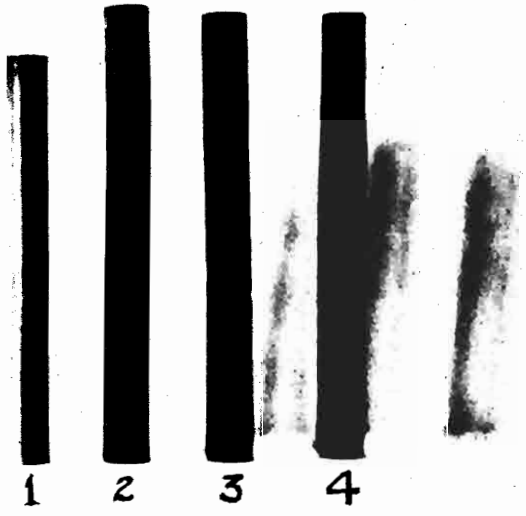


Figure No. 11. Heated Test-bars.

Figure No. 11 shows the test-bars after completion of twenty-five heats in order as follows: No. 1, Original bar. No. 2, Furnace cool. No. 3, "Air cool." No. 4, Oil quench. Figure No. 12 shows the original specimen in the unetched condition at 200 diameters. Figure No. 13 is the same piece in the etched condition, the combined carbon appearing as pearlite in the dark areas not shown

Figure No. 12. Original Test-bar, unetched.

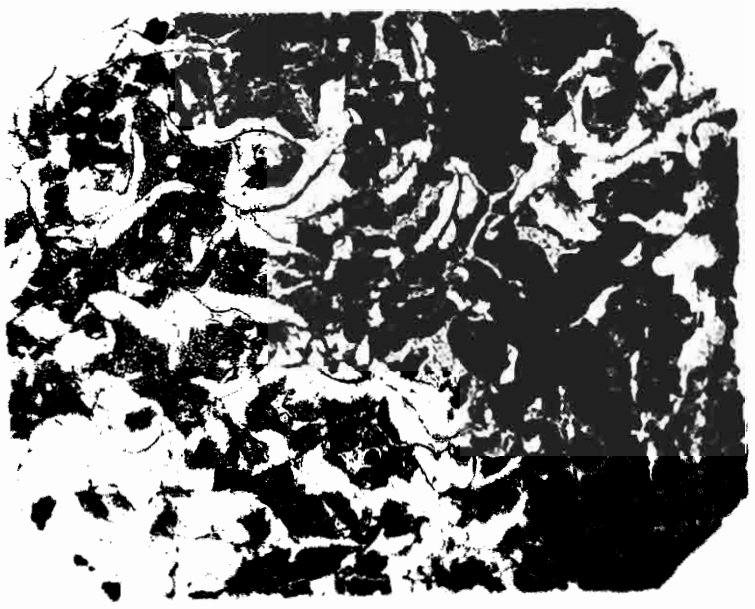


Figure No. 13. Original Test-bar, etched with ten percent Nitric Acid in Amyl Alcohol.

on the unetched sample. Figures No. 14, No. 15 and No. 16 represent the conditions in the unetched pieces after exposure to repeated heatings and coolings. What formerly appeared as graphite flakes has now the appearance of a very voluminous ragged network of voids, the slower cools being slightly coarser, believed to be due to the opportunity presented for that time element necessary for the coalescence of the carbon into a larger graphite area. This period of time was not permitted to elapse at a sufficiently high temperature in the case of the other two cools to permit this coarse structure to be formed. The growth is believed by the writer to take place in the following manner: upon heating and holding the test-bar at the elevated temperatures, some of the graphite which was present, was taken into solution through the general process of cementation. Upon cooling this carbon which had been absorbed, was again thrown out as graphite flakes; but since the graphite flakes cannot be formed in the void which was left, as a result of cementation, the new graphite flakes would be born in a volume of previously solid metal. This graphitization would correspond to that of a cast iron in which the proeutectoid cementite breaks down into graphite and iron. This cycle would continue until a certain condition of sponginess was

Figure No. 14. Test-bar, unetched, Furnace Cool after repeated heatings.

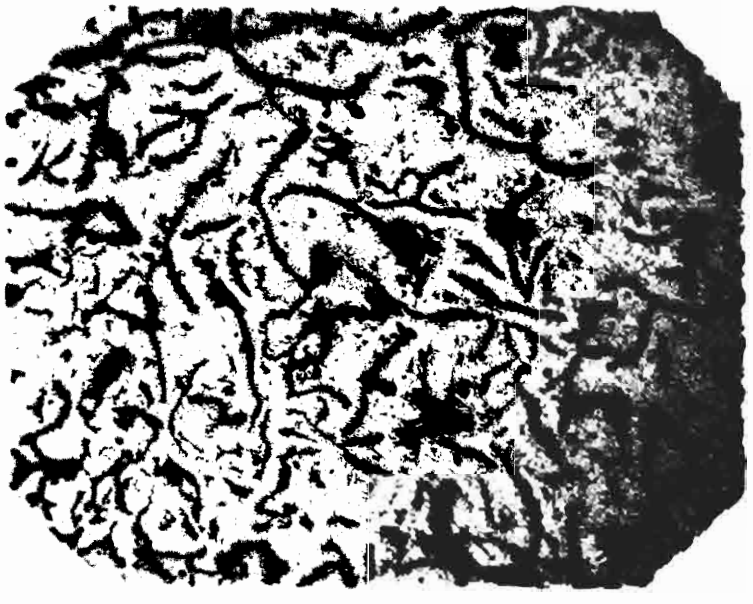


Figure No. 15. Test-bar, unetched, "Air cool" after repeated heatings.

Figure No. 16. Test-bar, unetched, Oil quench after repeated heatings.

attained, after which any reprecipitation of graphite in virgin areas would be taken care of by the internal distortion of the spongy skeleton work. The higher the silicon the greater would be the tendency for reprecipitation, all other things being equal.

- SUMMARY -

The higher the silicon the greater would be the growth because precipitation of graphite upon cooling would be greater. The maximum growth would be dependent upon the impurities present which would be the influencing factors in determining the ductility of the ferrite-pearlite constituent of the cast iron. The rate of cool does not determine the maximum growth but merely the rate of growth, the slower the cool the more conducive are conditions for graphitization, therefore a faster rate of growth. The length of time at the maximum temperature would determine the amount of carbon absorbed up to a point which might be termed the saturation point for any given temperature. The effect of temperature, although not having been determined experimentally, would be expected to be the customary in all temperature-time relations: that is, by going to a higher temperature the rate of cementation is more rapid and the saturation point would be reached in a shorter period; a lower temperature having the opposite effect, that of increasing the length of time necessary for the saturation point to be reached in the heated specimen. A very slight growth which continues in the case of the furnace cool may be

due to oxidation. This growth would have to be accomplished by the oxide formed, choking up the voids after the carbon has been eliminated, and tending to overcome the spongy condition which would exist, had not the voids been filled. In no case can the writer imagine the oxygen penetrating along the flakes of incandescent graphite and oxidizing a silico-ferrite in preference to burning out the incandescent graphite adjacent to it. Such would be contrary to the general basic principles of chemistry.

However, the recommendation for using a white iron or a low-silicon mottled iron, if machine work is necessary, for all parts which are exposed to alternate conditions of heating and cooling would agree with the recommendations of others who have worked on the subject.

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