PART I

THE EFFECT OF HYDROGEN AND HELIUM ON PLAIN CARBON STEEL

PART II

SOME PHYSICAL PROPERTIES OF CARBURIZED STEELS

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Eldon H. Shotwell

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SOME PHYSICAL PROPERTIES OF CARBURIZED STEELS

By

ELDON H. SHOTWELL

A THESIS

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A C K N O W L E D G M E N T S

The author wishes to express his gratitude for the cooperation and guidance received from the late Professor H. E. Publow.

He also wishes to express his thanks to Professor R. L. Sweet under whose guidance the work was continued.

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TABLE OF CONTENTS

Part I

Part II

Part I

The Effect of Hydrogen and Helium on Plain Carbon Steel

INTRODUCTION

The primary purpose of this experiment was to design and construct an electric furnace capable of heat-treating metals under controlled conditions of atmosphere. Plain carbon steel was to be the subject of study, using atmospheres of helium and hydrogen.

Particular attention was to be paid to the macroscopic appearance of the surface scale and the microscopic appearance of the heat-treated specimens. At the outset it was hoped that an atmosphere could be obtained which would be inert to the metallic surfaces. This, however, proved to be an impossibility with the experimental methods used. Possible causes for this failure will be discussed later.

"Bright annealing" is a term used in industry for annealing in relatively inert gases. However, it should be noted here that most of the successful "bright annealing" is at present carried on with metals or alloys whose recrystallization temperatures are in a relatively low range. Metals and alloys, such as aluminum, copper, brass, etc., are annealed at temperatures usually not exceeding 1100°F. and are fairly aptable to a "bright annealing" treatment. Steel, however, recrystallizes at temperatures ranging from 1340°F. to 1650°F., thereby presenting a more difficult problem. The only advantage seen in "bright annealing" steel or ferrous alloys at the present time is to reduce the scale formation to a minimum and thereby shorten the pickling, sanding, or cleaning operation. It might also be pointed out at this time that metals having heavy cross-sections would require prolonged time for annealing, thus introducing a problem of greater scope in the so-called "bright annealing" process. In this problem a time of five hours was selected and a temperature of 1700°F., which is well above the recrystallization range of all hypo-eutectoid steels. The samples were all placed in the furnace before the temperature was raised, and were removed from the furnace at room temperature.

EXPERIMENTAL WORK AND RESULTS

The first problem to be confronted was the construction of the furnace. It was desired to have a furnace that would heat to a maximum temperature of 1800°F. in one hour. Actual tests proved that the furnace would heat to 1700°F. in one hour.

It was decided to construct a simple electric resistance furnace using Chromel "A" wire for the heating element. The wire was "close wound" on to the center section of a silica furnace tube. The winding was about 10 inches in overall length. Asbestos sheet was wrapped around the tube between the winding and the furnace tube. Silica was chosen for the furnace tube because of its high refractory properties and its relative imperviousness to gases, as compared to other refractory materials. A round tube was chosen having an inside diameter of 1-7/8 inches, a length of 24 inches, and a wall thickness of 3/16 inch. The tube was open at both ends for purposes of adapting fittings for control purposes. The furnace tube and winding were supported between two asbestos board supports. The furnace body or frame was a cylindrical sheet steel cylinder 10 inches in diameter and 10 inches long. The body, which was packed with asbestos and fire brick insulation material, was supported between the two upright asbestos board ends. The description of the furnace may be clarified by observing its construction in figure 1.

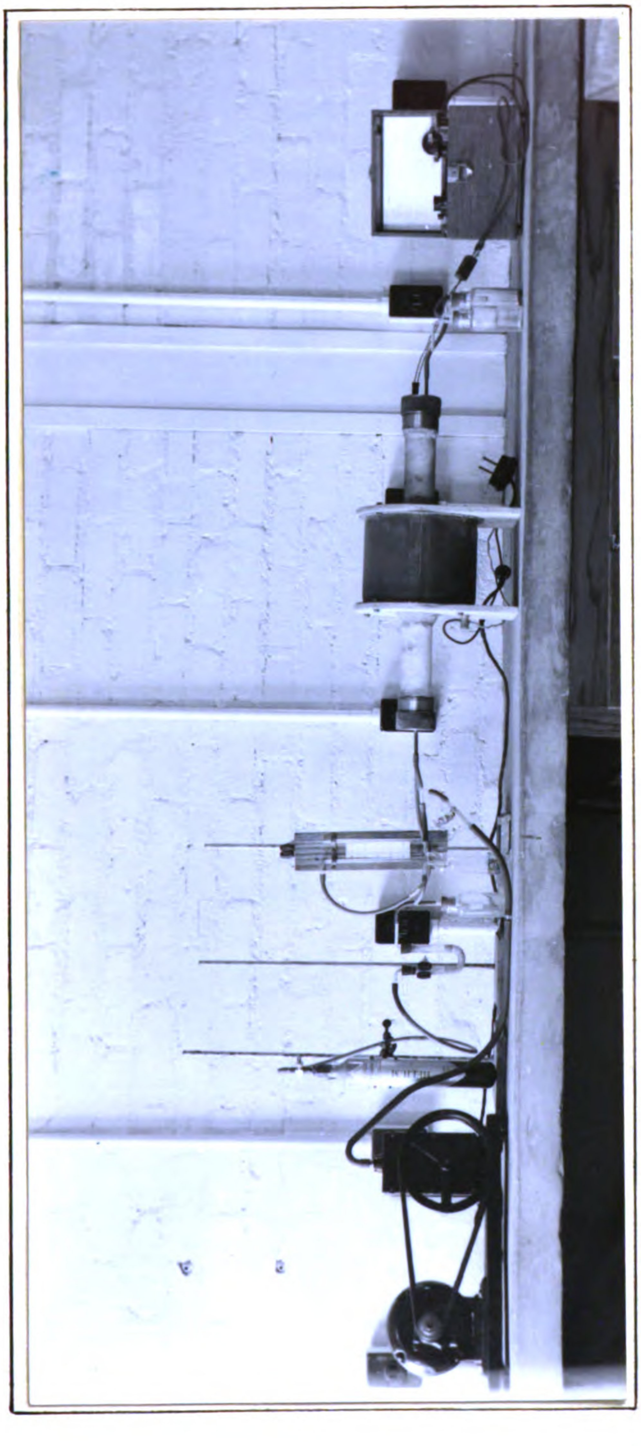


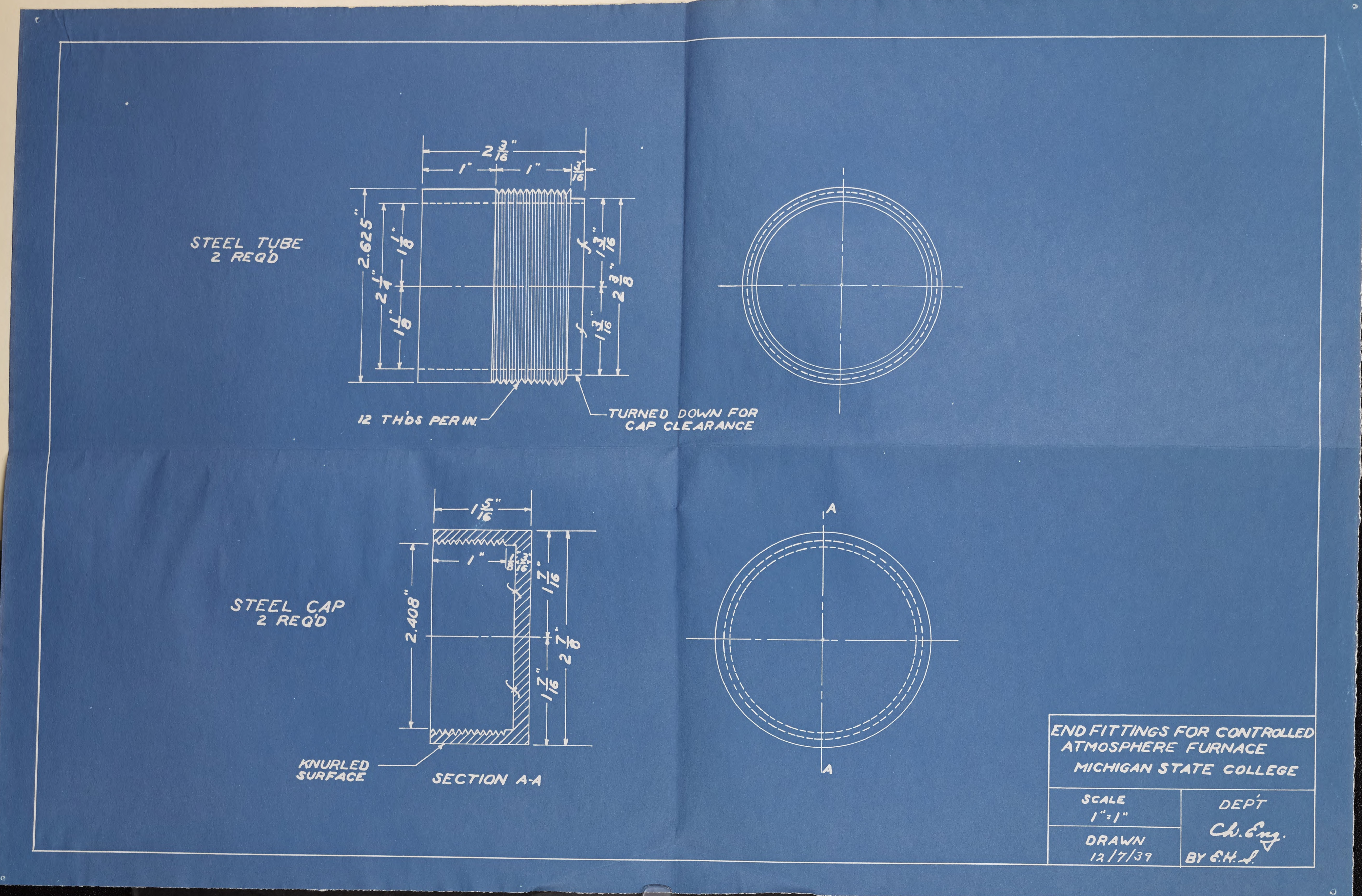
Figure 1

Apparatus used for controlled atmosphere annealing.

As stated before, the ends of the furnace tube were both open. A threaded steel tube with a cap to fit was designed to fit over each of the ends. The caps were made removable to allow for the introduction of the samples, thermocouple replacements, adjustments of various sorts, and cleaning. Three holes were drilled in each cap, into which copper tubes one inch in length and 1/4 inch in diameter were inserted and soldered into position. The purpose of the tubes was to serve as an inlet for the thermocouple wires and as an inlet and exhaust for the gases. A manometer and a vacuum pump were connected to these tubes as well. Figure 2 is a blueprint of the designed threaded tube and cap.

The means of fastening the steel tube onto the silica tube afforded a serious problem. Furnace cement was first tried with little success. It was found that the cement after being subjected to the heat conducted down the silica tube soon lost its coherent properties and crumbled with the slightest torque placed on the tube. This in turn broke the air-tight seal of the furnace. A "steam fitters" cement was then tried. The cement was composed of litharge (PbO) in a glycerine base. It is essential that the PbO be in the yellow form. It was obtained in this form by heating the red Pb_3O_4 to a temperature of 1350°F. for 30 minutes. Enough glycerine was added to the litharge to make a pasty mass. After thorough mixing it was quickly applied to the tube joint and allowed to "set." This joint had excellent strength and did not crumble throughout the entire experiment.

Hydrogen was used first as an atmosphere for the furnace. The generator first selected was a Hoffman electrolysis unit. Connected in series with the generator in the order named were: (1) An ascarite


STEEL TUBE
2 REQ'D
12 TH'DS PER IN.
TURNED DOWN FOR
CAP CLEARANCE
STEEL CAP
2 REQ'D
KNURLED
SURFACE
SECTION A-A
A
A
END FITTINGS FOR CONTROLLED
ATMOSPHERE FURNACE
MICHIGAN STATE COLLEGE
SCALE
1" = 1"
DRAWN
12/7/39
DEP'T
Ch. Eng.
BY E.H.S.

tube; (2) an overflow bottle; (3) Sulfuric acid desiccator bottle; (4) an overflow bottle; (5) the furnace; (6) an overflow bottle; (7) an exhaust regulator. Also connected to the furnace was a vacuum pump, thermocouple leads, and a manometer. Reference to figure 1 may serve to clarify this description. The purpose of the ascarite was to remove any traces of CO_2. Sulfuric acid served as a desiccant to remove any water vapor present. The exhaust regulator served as a pressure regulator, keeping the gas pressure within the furnace at the desired conditions. The thermocouple leads led, of course, to a potentiometer which was of the portable Leeds and Northrup manually operated type.

After several blank trials were made using the Hoffman generator, it was found that that type of generator did not supply a large enough capacity for successful operation of the furnace. It was consequently discarded. Several leaks were also noticed in the apparatus.

The gaskets originally used in the furnace were asbestos. These gaskets were placed between the end of the steel tube and the inside head of the cap. It was believed that the gaskets were too porous in nature and were a source of leaks. Lead gaskets were next tried, but it was found that a snug fitting was impossible with such a gasket. Hard rubber gaskets were next used and were found to be quite successful. It was necessary, however, that a heavy coating of grease be applied on the threads of the cap.

With these final adjustments made, it was found that the furnace was capable of holding gage pressures of four to five inches of water. Along with these improvements, it was also decided that a method must be devised to evacuate the air present in the furnace before admitting the gas. This was possible by use of the vacuum pump. Absolute pressures in the neighborhood of one cm of mercury were obtained.

Instead of using the electrolysis apparatus as a generator, small tanks of gas were used. This was done to avoid the method of infinite dilution for filling the furnace. Small tanks of Hydrogen and Helium were purchased from the Fisher Scientific Company. The analysis of the gas was reported as follows:

Hydrogen

Hydrogen	99.8%
Moisture	.2%
	100.0%

Helium

Helium	98.2%
Nitrogen and impurities	1.8%
	100.0%

It was found that these cylinders of gas provided enough gas for one or two experimental tests.

The general procedure of the test was to first evacuate the system to about 1 cm of Hg absolute pressure, then admit the gas into the furnace to atmospheric pressure. The system was then evacuated again and refilled to a gage pressure of 2 inches of water. Gas was then admitted slowly to the system so that the exhaust regulator bubbled about 4 bubbles per minute.

The polished steel samples were placed in the furnace in a nickel boat resting on alundum sand, the sand preventing fusion between the nickel boat and the furnace tube. The samples, of course, were placed in the furnace before it was evacuated.

All of the tests were made at 1700°F. for a total time of 5 hours, including one hour for the preheat of the furnace. The samples were allowed to cool in the furnace. It was necessary to admit the gas at a faster rate during the cooling period to allow for the contraction of the cooled gases. The samples were removed at or near room temperature.

The samples used were obtained from S.A.E. 1010, 1020, and 1040 hot rolled rounds. Photomicrographs of these steels as received may be seen in figures 3, 4 and 5. Figures 6, 7 and 8 are photomicrographs of the same steels after a five hour anneal at 1700°F. in an atmosphere of air. The grain size should be somewhat comparable to those samples annealed in Helium and Hydrogen atmospheres for the same length of time.

The surfaces of the "air annealed" samples were noted to have a heavy flaky oxide deposit. The oxide usually formed in air atmospheres is magnetite (Fe_3O_4).

Figure 9 shows the condition of the 1010 steel in the "as received" condition as 2000X. Figure 10 shows the same steel after a 5 hour "air anneal" at 1700°F. It may be stated here that the depth of decarburization, although noticeable, did not occur to any great extent.

Figure 11 is a photomicrograph of the 1020 steel in the "as received" condition magnified at 2000X. Figure 12 shows the "air annealed" condition of the S.A.E. 1020 steel at 2000X. Likewise with this steel the extent of decarburization was not appreciable.

Figure 13 is a continuous photomicrograph of S.A.E. 1040 steel annealed for 5 hours at 1700°F. in a hydrogen atmosphere. The resulting

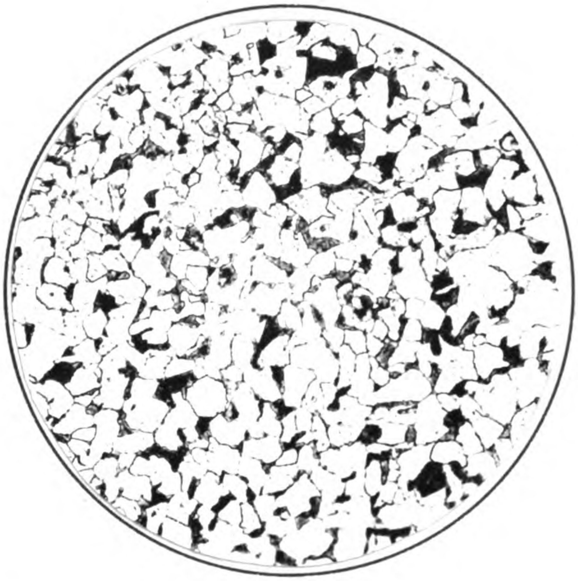


Figure 3
S.A.E. 1010 Steel
"As Received"
Mag. 200X

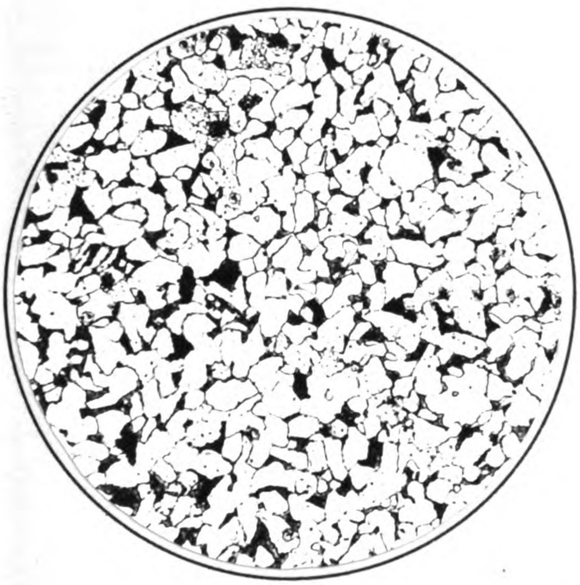


Figure 4
S.A.E. 1020 Steel
"As Received"
Mag. 200X

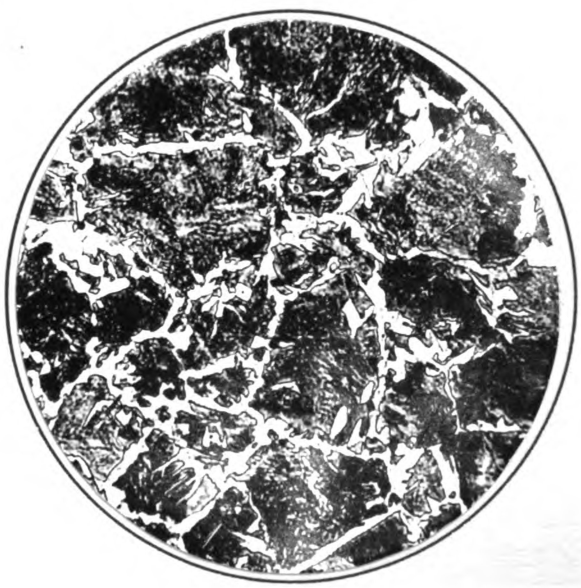


Figure 5
S.A.E. 1040 Steel
"As Received"
Mag. 200X

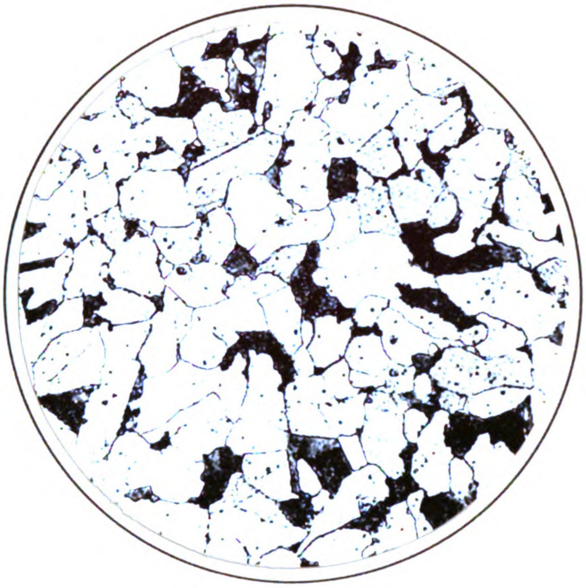


Figure 6
S.A.E. 1010 Steel
"Air Annealed" 5 Hrs.
at 1700°F.
Mag. 200X

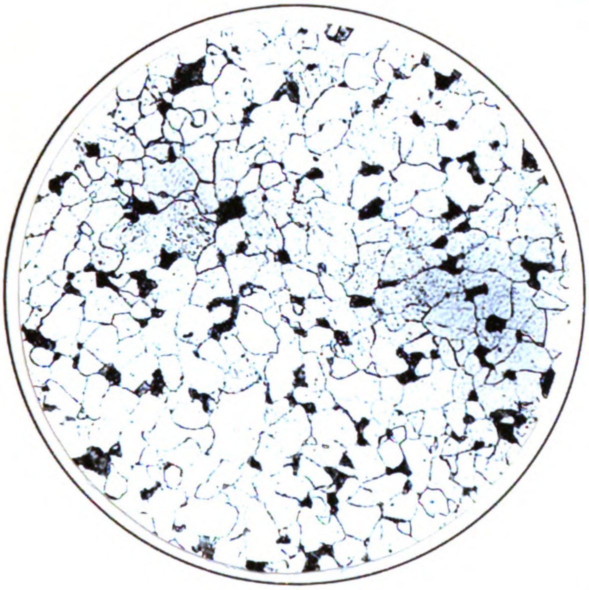


Figure 7
S.A.E. 1020 Steel
"Air Annealed" 5 Hrs.
at 1700°F.
Mag. 200X

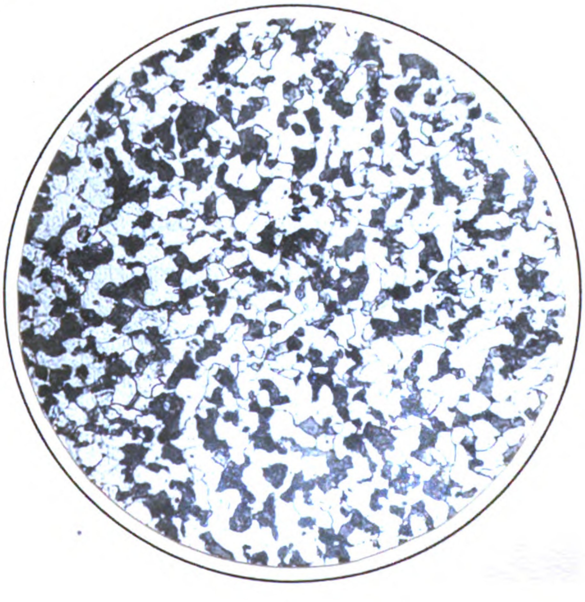


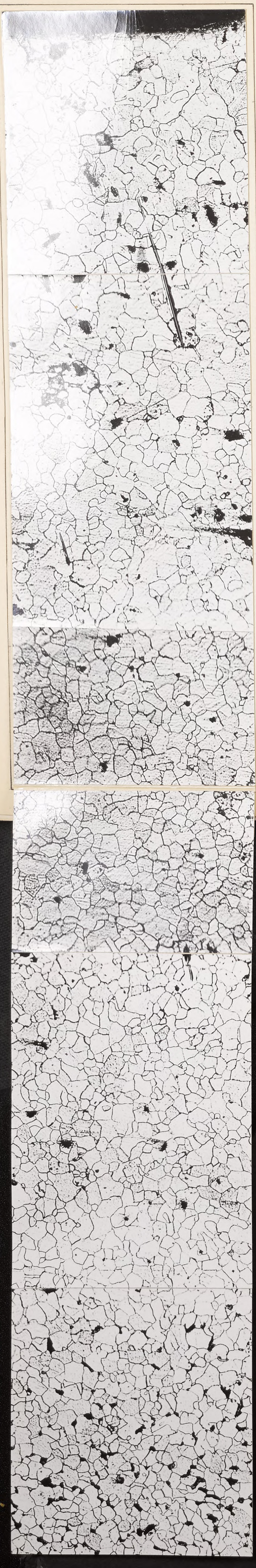
Figure 8
S.A.E. 1040 Steel
"Air Annealed" 5 Hrs.
at 1700°F.
Mag. 200X

Figure 9
S.A.E. 1010 Steel
"As Received"
Mag. 2000X

Figure 10
S.A.E. 1010 Steel
"Air Annealed" 5 Hrs.
at 1700°F.
Mag. 2000X

Figure 11
S.A.E. 1020 Steel
"As Received"
Mag. 2000X

Figure 12
S.A.E. 1020 Steel
"Air Annealed" 5 Hrs.
at 1700^{o}F.
Mag. 2000X



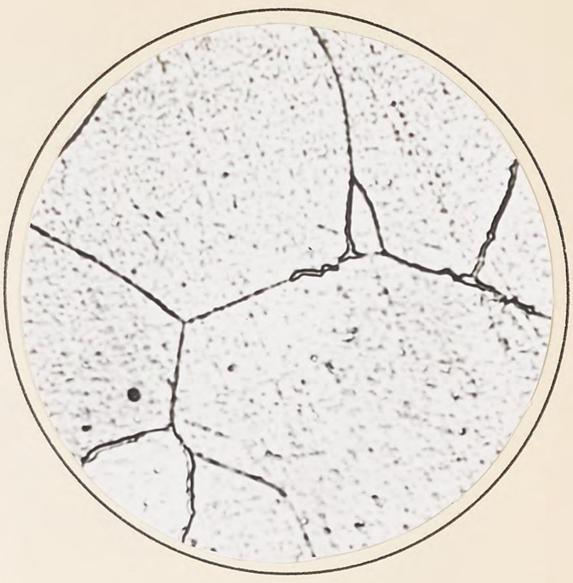


Figure 14

Decarburized Zone of S.A.E. 1020 Steel Annealed at 1700°F. in Hydrogen for 5 Hrs.
Mag. 2000X

Figure 13

Continuous Photomicrograph of S.A.E. 1020 Steel Annealed in Hydrogen Atmosphere at 1700°F. for 5 Hrs. Depth of Decarburization from Edge is shown.
Mag. 200X

decarburization is appreciable as may be seen. The series of photomicrographs are taken at 200X. Decarburization depth on the prints is 16 inches which when converted to actual depth on the metal is equivalent to .08 inches. Pits may also be seen in the series, which were probably due to the decarburization reaction. They might also be due to original inclusions in the metal which were "broken up" by the hydrogen gas at the elevated temperature. Figure 14 is a photomicrograph of the same steel at 2000X. Apparently only pure ferrite is left. No impurities may be detected as being present in the grain boundries.

It was noticed when hydrogen was used that the scale formed on the surface of the metal was relatively thin and of an adherent nature, as contrasted to the thick flaky scale formed in an atmosphere of air.

Figures 15, 16 and 17 show respectively the condition of the S.A.E. 1010, 1020 and 1040 steels after a 5 hour anneal at 1700^{o}F. in a Helium atmosphere. The micrographs are taken at 200X near the edges of the samples. Figure 18 is a continuous series of photomicrographs taken of S.A.E. 1040 steel annealed in Helium, showing the depth of decarburization. This depth may be contrasted to the depth in figure 13, incurred in a hydrogen atmosphere. The depth in the Helium atmosphere measured only .02 inches, which was one-fourth of the decarburization occurring in the Hydrogen atmosphere.

Figures 19 and 20 are micrographs of S.A.E. 1020 and 1040 steel respectively, annealed in a Helium atmosphere. The magnification is 2000X. Nothing is apparently revealed by their structures to indicate any impurities or abnormalities.

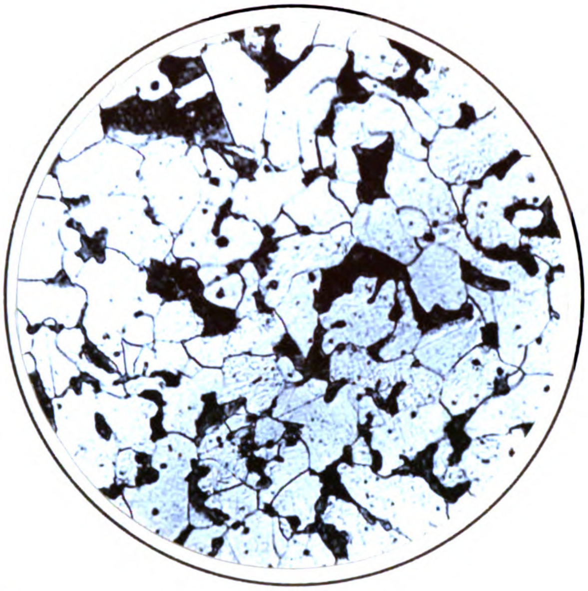


Figure 15
S.A.E. 1010 Steel
Annealed in Helium
5 Hours at 1700°F.
Mag. 200X

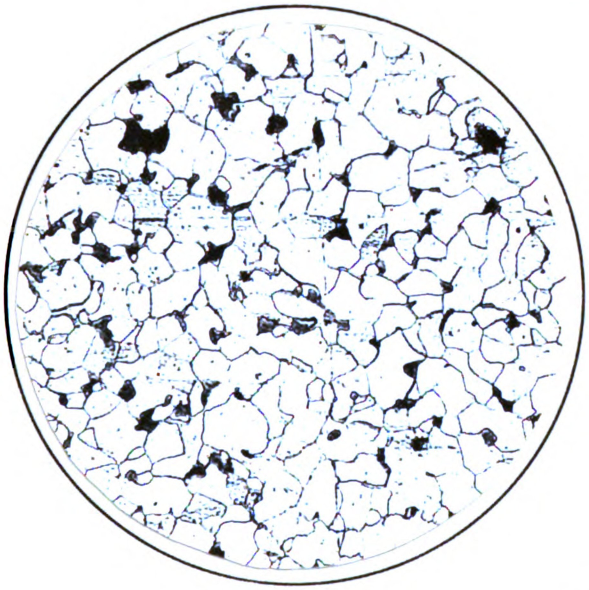


Figure 16
S.A.E. 1020 Steel
Annealed in Helium
5 Hours at 1700°F.
Mag. 200X

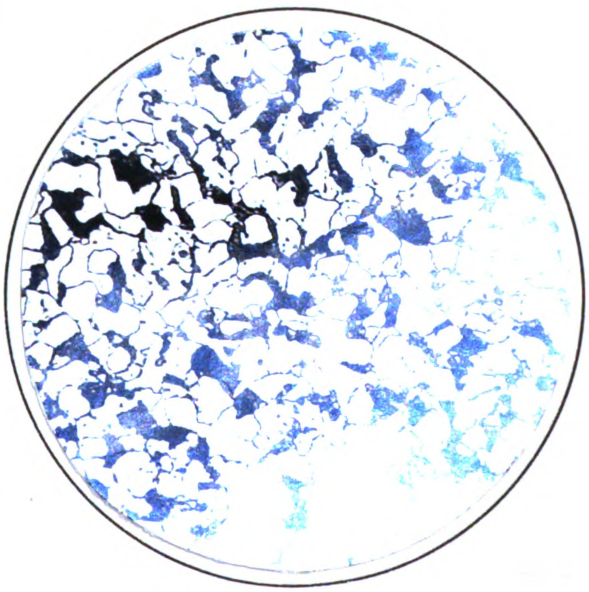


Figure 17
S.A.E. 1040 Steel
Annealed in Helium
5 Hours at 1700°F.
Mag. 200X

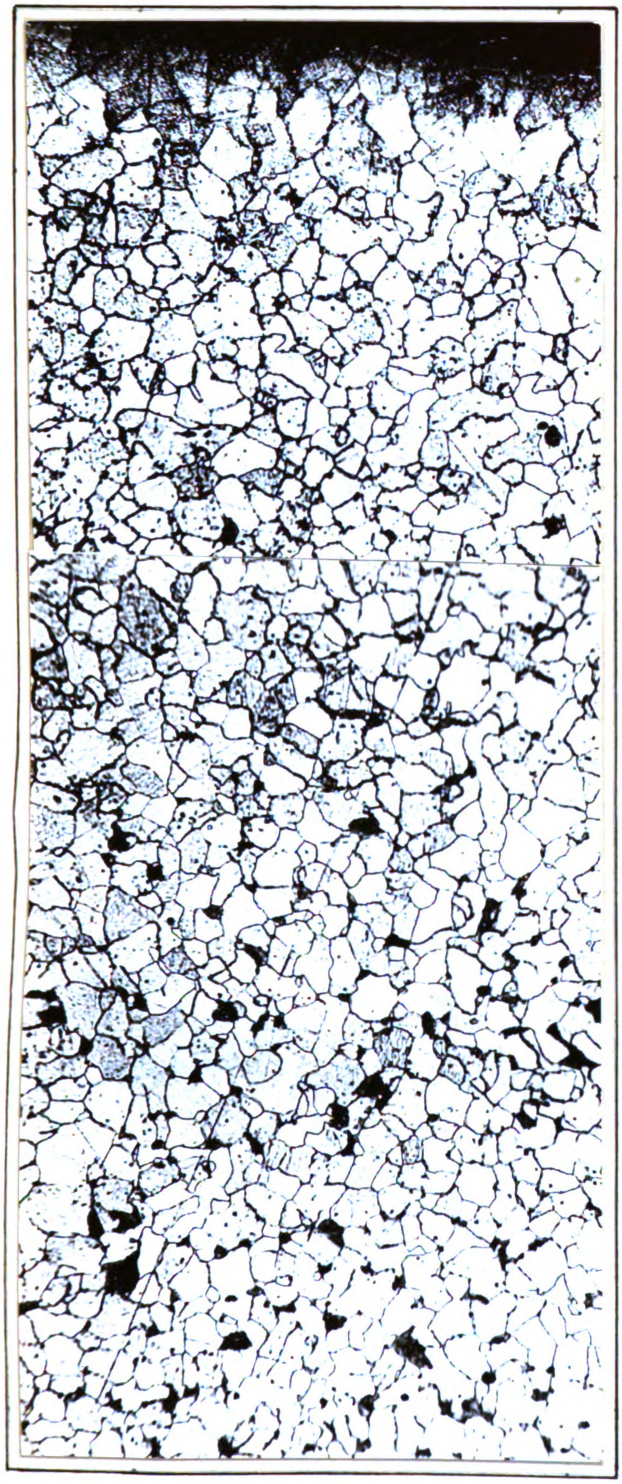


Figure 18
Continuous Photomicrograph of S.A.E. 1020 Steel Annealed in Helium for 5 Hours at 1700°F. Shows Depth of Decarburization.
Mag. 200X

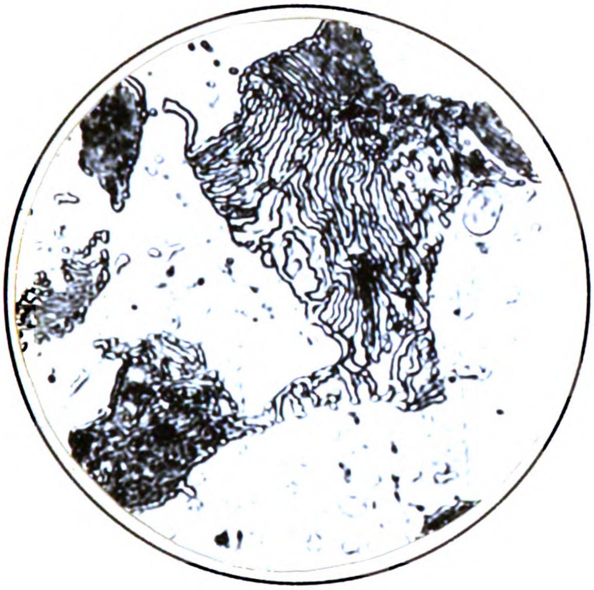


Figure 19
S.A.E. 1020 Steel
Annealed in Helium
Atmosphere 5 Hours
at 1700°F.
Mag. 2000X

Figure 20
S.A.E. 1040 Steel
Annealed in Helium
Atmosphere 5 Hours
at 1700°F.
Mag. 2000X

The outer surface conditions of the steels annealed in the Helium atmospheres were of an interesting character. Macroscopic examination revealed that it was crystalline in nature and extremely adherent to the metal. A low magnification photo of this granular coating may be seen in figure 21.

The nature of the scale was at first unknown. It was thought possible that it might be due to fusion with the alundum sand, or possibly with the Nickel boat. To ascertain this a spectrographic powder analysis was made on a sample of the scale. It was found, however, that only the iron showed up in the analysis. The analysis was made by the usual qualitative arc method, using a recessed carbon arc. No metallic impurities of any sort were found to be present.

It was next thought that the scale could be identified by X-Ray analysis. This was done through the assistance of Professor J. C. Clark of the Physics Department.

A finely powdered sample was prepared and mounted on a cardboard disc. The sample, which was about the size of a pinhead, was rotated during the exposure to obtain random orientation of the crystals.

The X-Ray light source was capable of emitting wave lengths of light equal to .712 Angstrom units. Exposures were made on Eastman Blue Line strip film with a fluorescent screen backing. The current through the X-Ray tube was kept at 22 milliamperes. Nineteen hours was required for correct exposure.

A reproduction of the pattern obtained may be seen in figure 22.

From Bragg's Law, the compound could be identified by determining d_n. The statement of Bragg's Law is:

Figure 21
Photomicrograph of Scale Formed on Steel Annealed in Helium Atmosphere
Mag. 30X

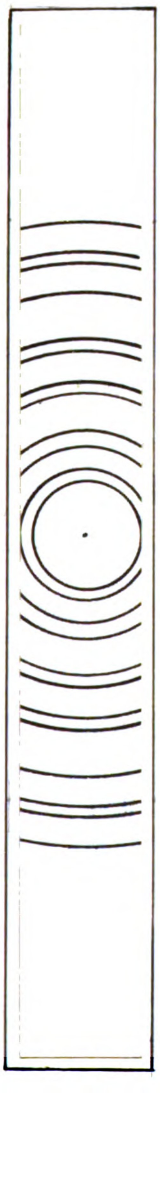


Figure 22
Replica of X-Ray Pattern Obtained from Scale Analysis of Samples Annealed in Helium Atmospheres.

$$n\lambda = 2d \sin \theta$$

where: n = order of reflection

d = distance between two successive planes of atoms

λ = wave length of light used

θ = angle of reflection from the atom planes

It can be shown that this relationship becomes

$$n\lambda = 2d \sin \frac{\mathrm{Tan}^{-1} \frac{S}{R}}{2}$$

where: S = distance from center beam on the film to the pattern lines

R = distance from the sample to the film

The resulting lines from the X-Ray pattern were measured accurately on a comparator and the respective d_n values for each was determined.

The resulting d_n values obtained from the calculations were plotted on a graph, as shown in figure 23, for comparison purposes. The d_n values for the oxides of iron FeO, Fe_2O_3 and Fe_3O_4 were plotted directly opposite them. These values were obtained from tables published by the Dow Chemical Company. The ordinate units plotted on the graph are in terms of relative intensity which were also available in the tables. Intensity values for the sample, however, were estimated.

It may be seen from these graphs that the scale formed is undoubtedly FeO. There are also indications of other impurities present. These, however, cannot be determined. No reason for the formation of the FeO can be given, except to say that the oxygen might have passed by diffusion from the steel impurities. Possibly some of the impurities in the gas might have been oxygen. Oxygen from leaks in the apparatus

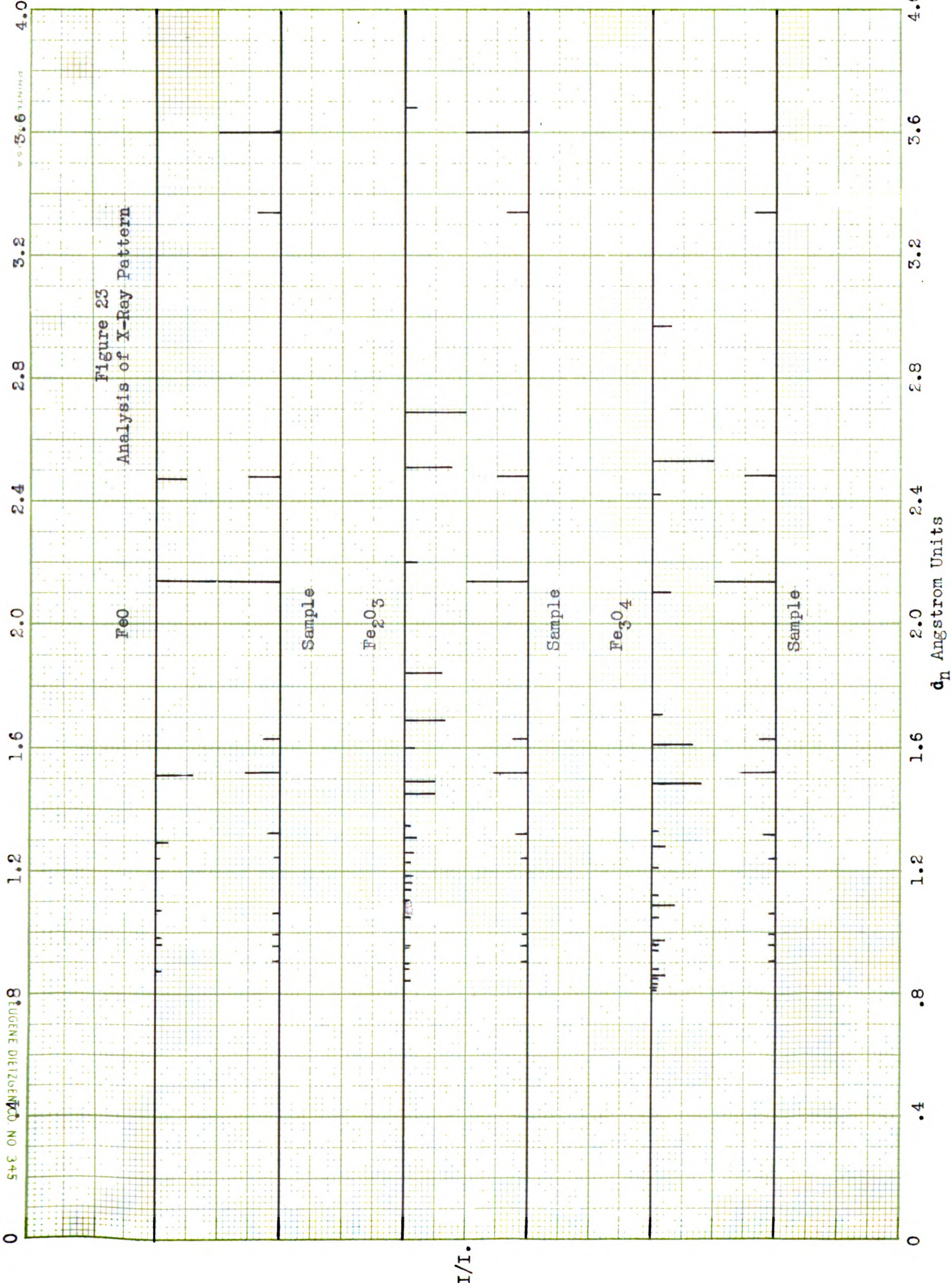


Figure 23
Analysis of X-Ray Pattern

is hardly feasible, due to the fact that the pressure in the furnace was at all times greater than atmospheric pressure. Incomplete evacuation could have been another source of the oxygen. In atmospheres of excessive oxygen Fe_3O_4 is formed.

CONCLUSIONS

1. Prolonged annealing at elevated temperatures (1700°F.) in reducing and neutral atmospheres is practically impossible without some slight scale formation.

2. The nature and depth of the oxides formed in the non-oxidizing atmospheres is different than those scales formed in oxidizing atmospheres. Usually a thinner and more crystalline scale is formed in the non-oxidizing atmospheres.

3. Decarburization occurs to a much greater extent in a reducing atmosphere than in either an oxidizing or neutral atmosphere. The ratio being 4 to 1 in comparing reducing and neutral atmospheres.

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Part II

Some Physical Properties of Carburized Steel

INTRODUCTION

Case Carburizing is a process of introducing carbon into the surface of steels to form a eutectoid or hypereutectoid surface. When quenched from the austenitic range a hardened condition will result due to the incomplete transformation incurred during the sudden temperature change. Case carburizing is carried out only when it is desired to have a hardened abrasive resistant surface, and yet retain a tough, shock resistant core. Such is the case desired in many gears, bearings, etc.

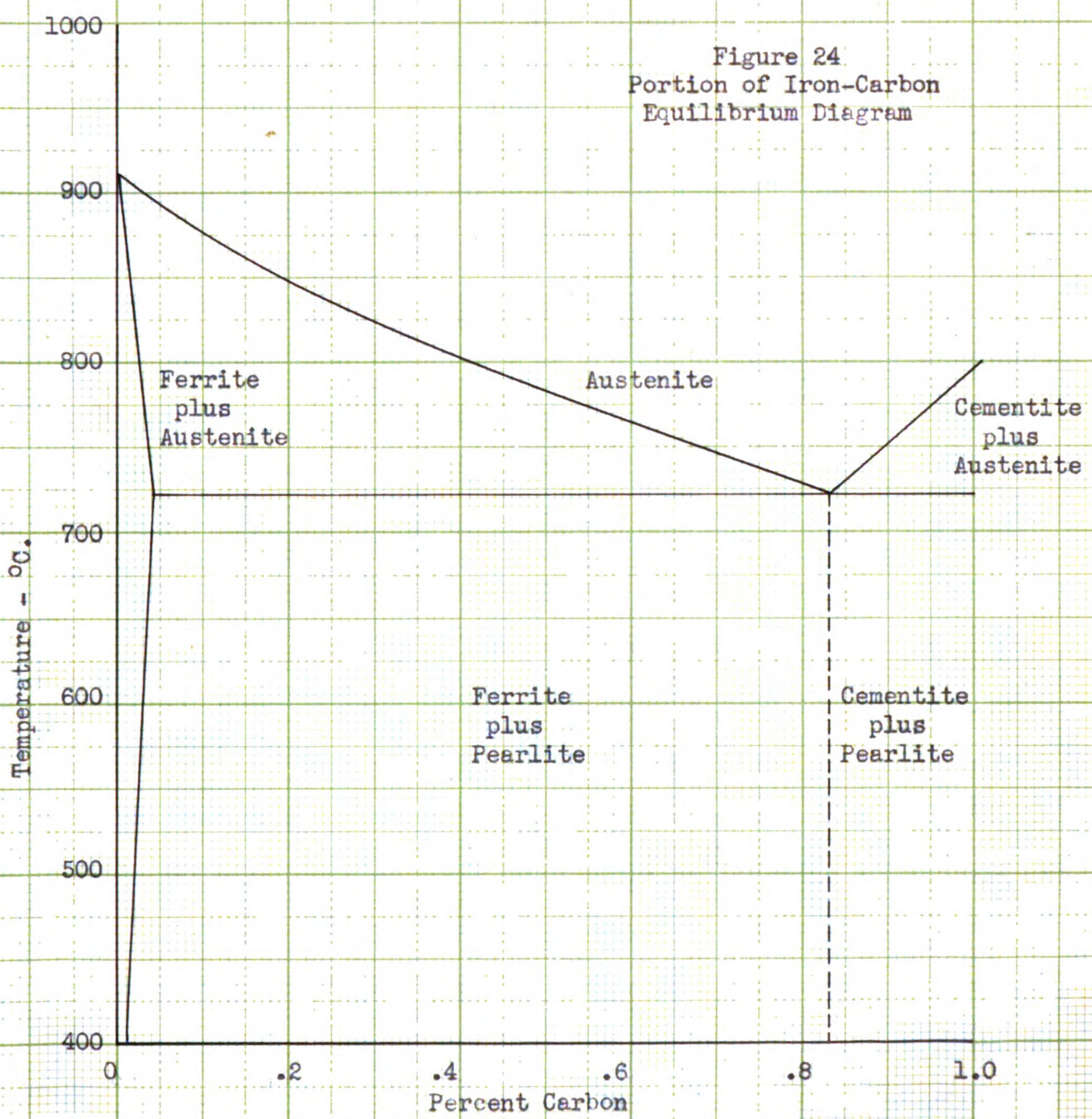
This paper, however, will not deal with the hardened conditions derived from quenching. It is merely desired here to determine the effects of carburizing for varied lengths of time, using a constant carburizing temperature and a furnace cool. Special emphasis will be paid toward the depth of carburization and the effects of the case depth on the transformations occurring as observed by the Chevenard Dilatometer.

For future reference it is desired to construct an iron-carbon equilibrium diagram which is shown in figure 24. This diagram is reproduced from the "Metals Handbook."

EXPERIMENTAL WORK AND RESULTS

The steel chosen for this experiment was an S.A.E. 1020 plain carbon steel. As stated before, the carburization was carried out at 1700°F. for times varying from one to eight hours. A pack carburizer was used having the following composition.

$BaCO_3$	10-12%
$CaCO_3$	2--3%
Na_2CO_3	2--3%
Coke	25-30%
Hardwood charcoal	Balance



EUGENE DIETZGEN CO NO 345

The reactions generally assumed as occurring during a carburization process are as follows:

$$2\ CO \rightleftarrows CO_2 + C$$

$$C + 3\ Fe \rightleftarrows Fe_3C$$

$$2\ CO + 3\ Fe \rightleftarrows Fe_3C + CO_2$$

It may be seen that the reactions are all reversible and therefore require "energizers" to keep the equilibrium shifted toward the formation of the Fe_3C. Common energizers used for this purpose are $BaCO_3$ and Na_2CO_3.

The samples which were cut to 55 millimeter lengths were then tested on the dilatometer for thermal effects due to different depths of carburization. The dilatometer used for this experiment is shown in figure 25.

The first sample tested on the instrument was an S.A.E. 1020 steel to find the normal thermal changes occurring when no carburization had taken place. Results of this test may be seen in figure 26. It may be noticed when comparing the critical temperatures obtained to the iron-carbon equilibrium diagram in figure 24 that the steel reacts normally. A general expansion is experienced from room temperature up to 730°C., which is the Ac_1 point. At this temperature the pearlite transformed to austenite and the ferrite gradually dissolved in this austenite until the Ac_3 temperature was reached. In the case of the S.A.E. 1020 steel, Ac_3 point is 830°C., which again checks with the equilibrium diagram very well. It may be noticed that a general contraction occurs through the austenite-ferrite zone. Upon reaching Ac_3 an expansion again occurs. When the alloy is cooled, the reverse effects are encountered. The upper and lower criticals being termed Ar_3 and Ar_1 respectively. It may also

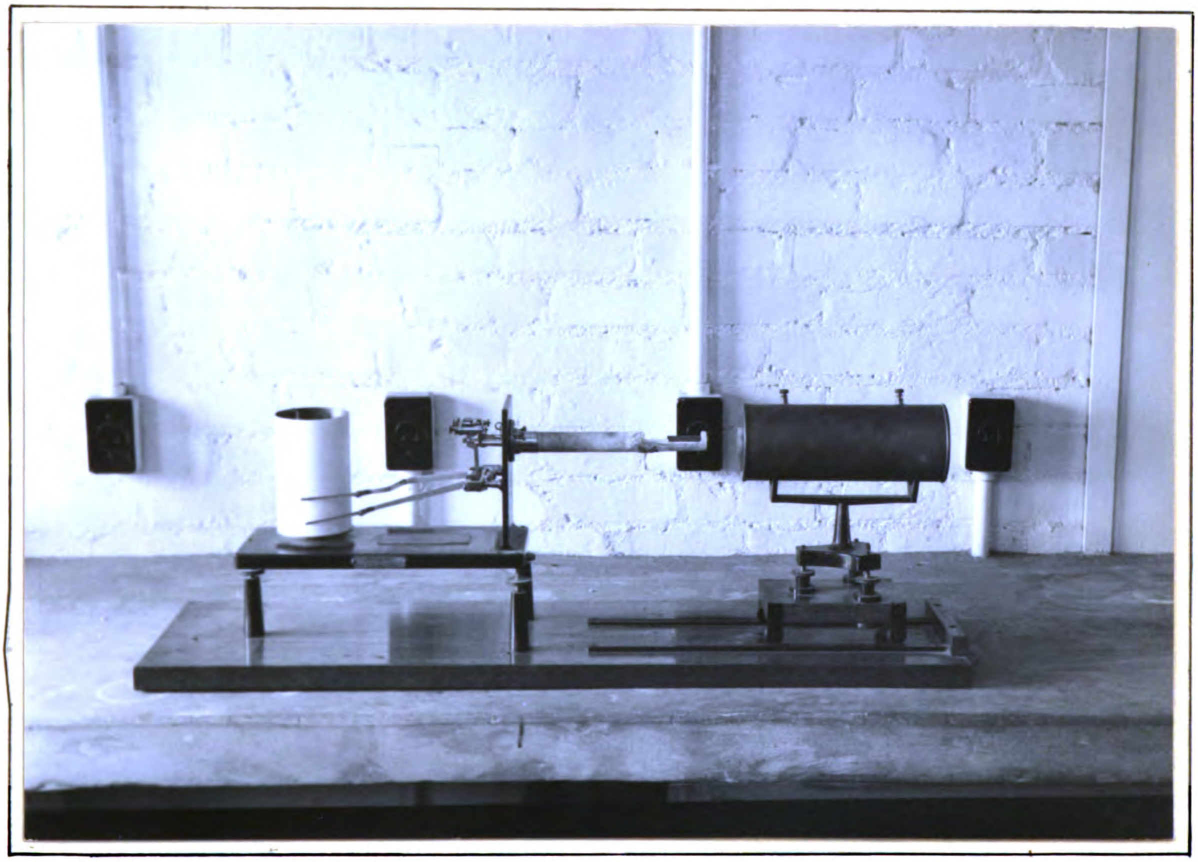


Figure 25
Photograph of Chevenard Dilatometer

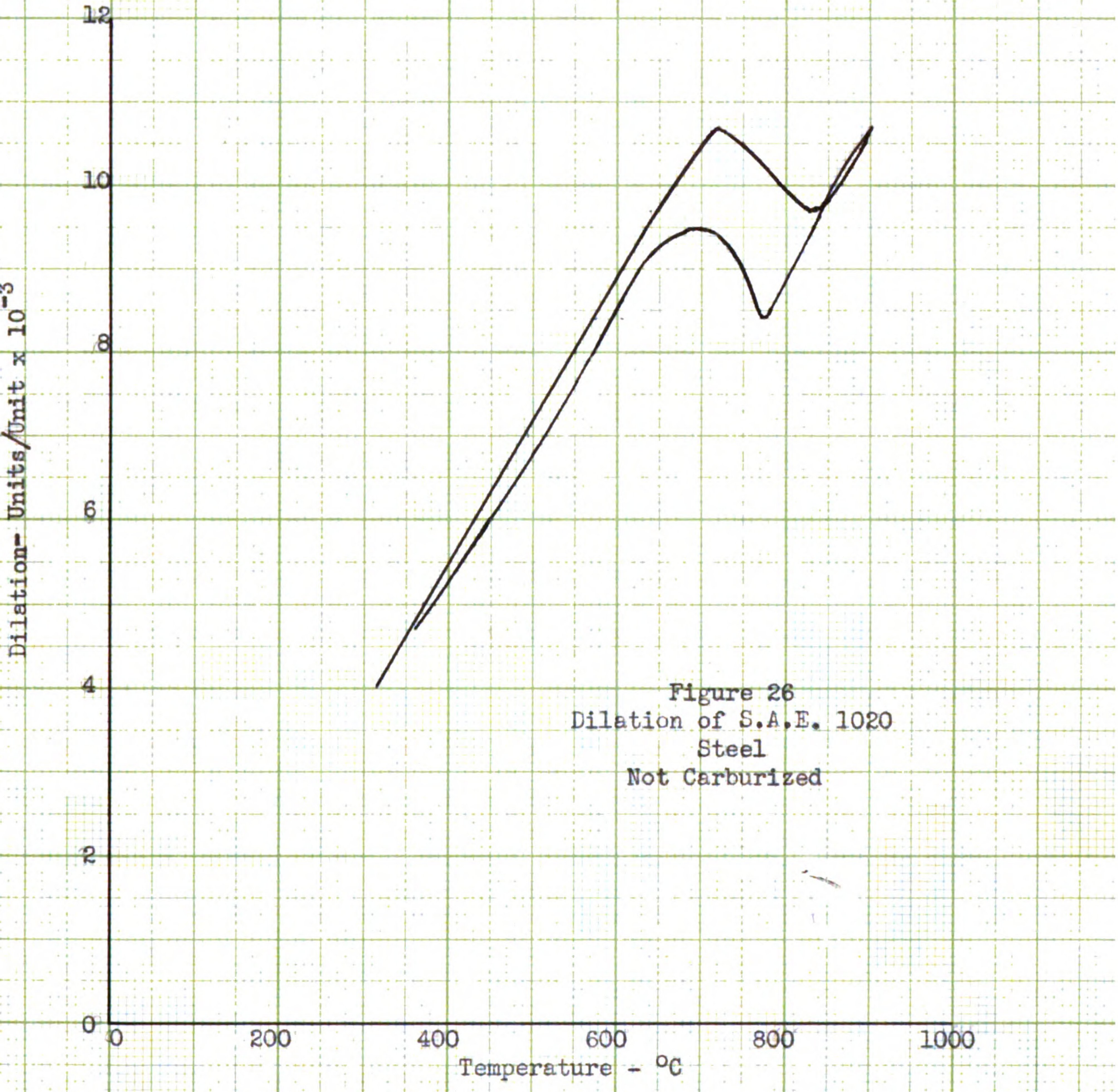


Figure 26
Dilation of S.A.E. 1020
Steel
Not Carburized

be noticed that the Ar_3 point was depressed to 775°C. and the Ar_1 point to 700°C.

In figure 27 we may see the reactions occurring in a sample carburized for 1 hour. It may be seen that the shape of the normal dilation curve has been altered extensively. The Ar_1 point is found to be raised slightly to 740°C. However, the austenite-ferrite transformation line has changed its slope considerably. This is thought to be due to the fact that the sample has undergone complete transformation according to zones in the steel. That is, the case being of eutectoid composition has undergone its complete transformation at one temperature, the Ar_1 point. Due to the fact that there is no excess ferrite or cementite to be dissolved in this newly formed austenite, the case again tends to expand with an increase in temperature. The core, however, being of hypoeutectoid composition has not undergone complete austenite-ferrite transformation and will continue to contract through this zone. This will set up an internal shear within the zones and the resulting expansion or contraction will be a resultant of the forces set up within the zones. Two zones were selected for descriptive purposes, but in reality there would be many zones of decreasing carbon content extending from the case to well within the core. The same is true for the hypereutectoid zones which extend in the other direction (toward the surface). The Ac_3 point, for the reason given above, is very difficult to define. Apparently from the curve the Ac_3 point is about 810°C., which is a depression of some 20°C. when compared to the non-carburized sample. The cooling criticals are apparently 805°C. and 660°C. for the Ar_3 and Ar_1 respectively. The occurrence of the change at 805°C. is not obvious at

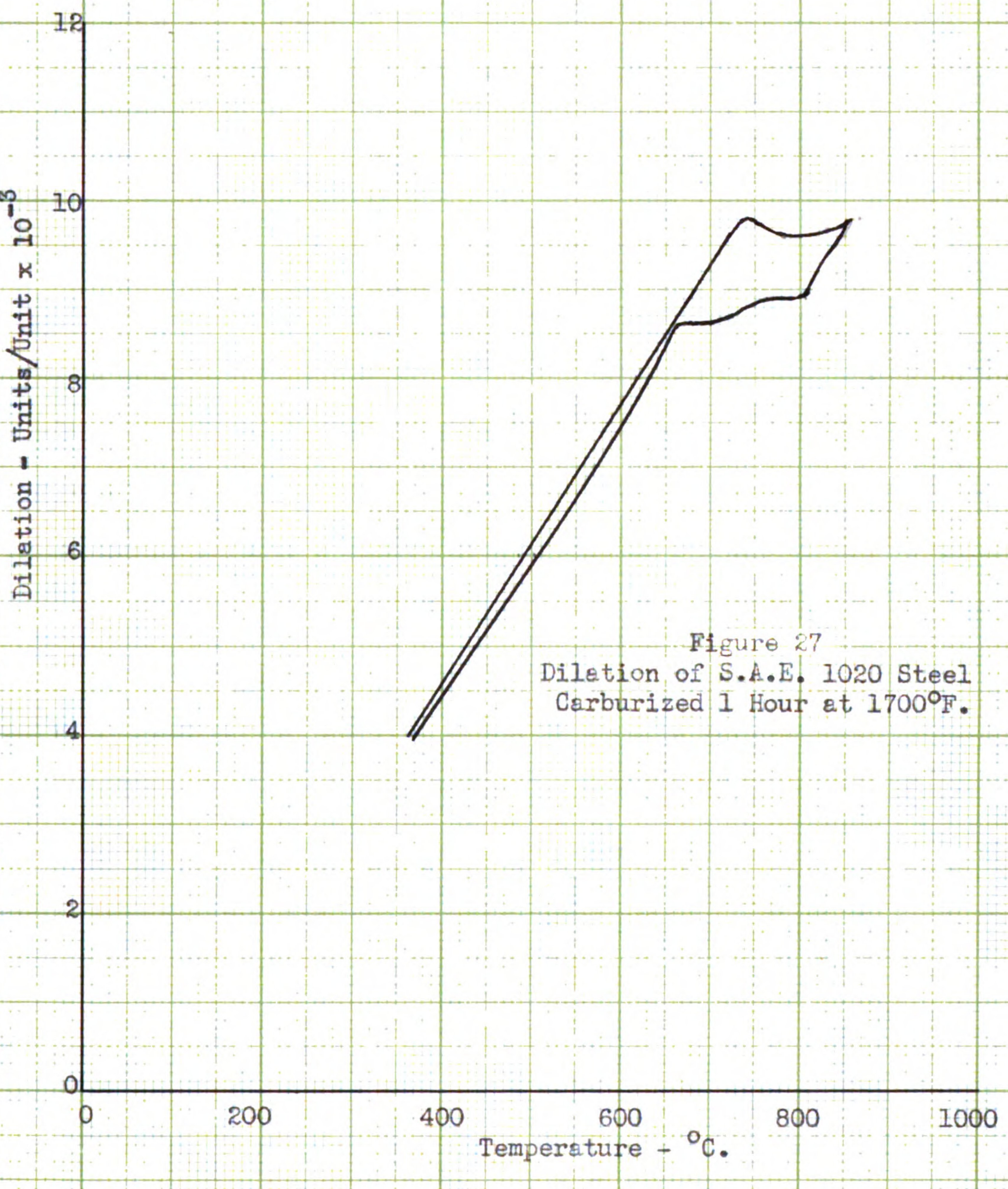


Figure 27
Dilation of S.A.E. 1020 Steel
Carburized 1 Hour at 1700°F.

present. It is apparently higher than the Ar_3 point for the 1020 steel. The Ar_1 point was depressed to 665°C. and occurs in the same relative position for all of the carburized samples. It is quite logical, however, that the Ar_1 point will vary that much over the range of compositions resulting from carburization. The slope of the austenite-ferrite transformation line may be seen to be quite different than in the non-carburized sample. The same explanation may be given here that was given for the transformation during heating.

Figures 28 to 34 inclusive are dilation curves derived from samples carburized from 2 to 8 hours. The same general effects in the critical zone may be noticed in all of these samples as was noticed in the samples carburized for 1 hour. The tendency is, however, for the case of approximately eutectoid composition to become the predominating zone in the transformations as shown by dilation. This is quite logical, however, due to the increase in the depth of case with a longer carburizing time. In the samples carburized five hours or more it will be noticed that the apparent transformation zone is narrowed down to some 30°C. which is further indication of the predominating character of the eutectoid or slightly hypereutectoid case.

Continuous photomicrographs were taken of each of the carburized samples. They may be seen in figures 35 to 42 inclusive. The increase in carburization depth may be noticed with the increase in time. These results may be more plainly seen from the graph in figure 43. The depth of the case in each photomicrograph was measured to the zone containing about an S.A.E. 1040 composition. It may be seen that the carburization rate decreases after about a 6 hour period. The cause for fluctuation

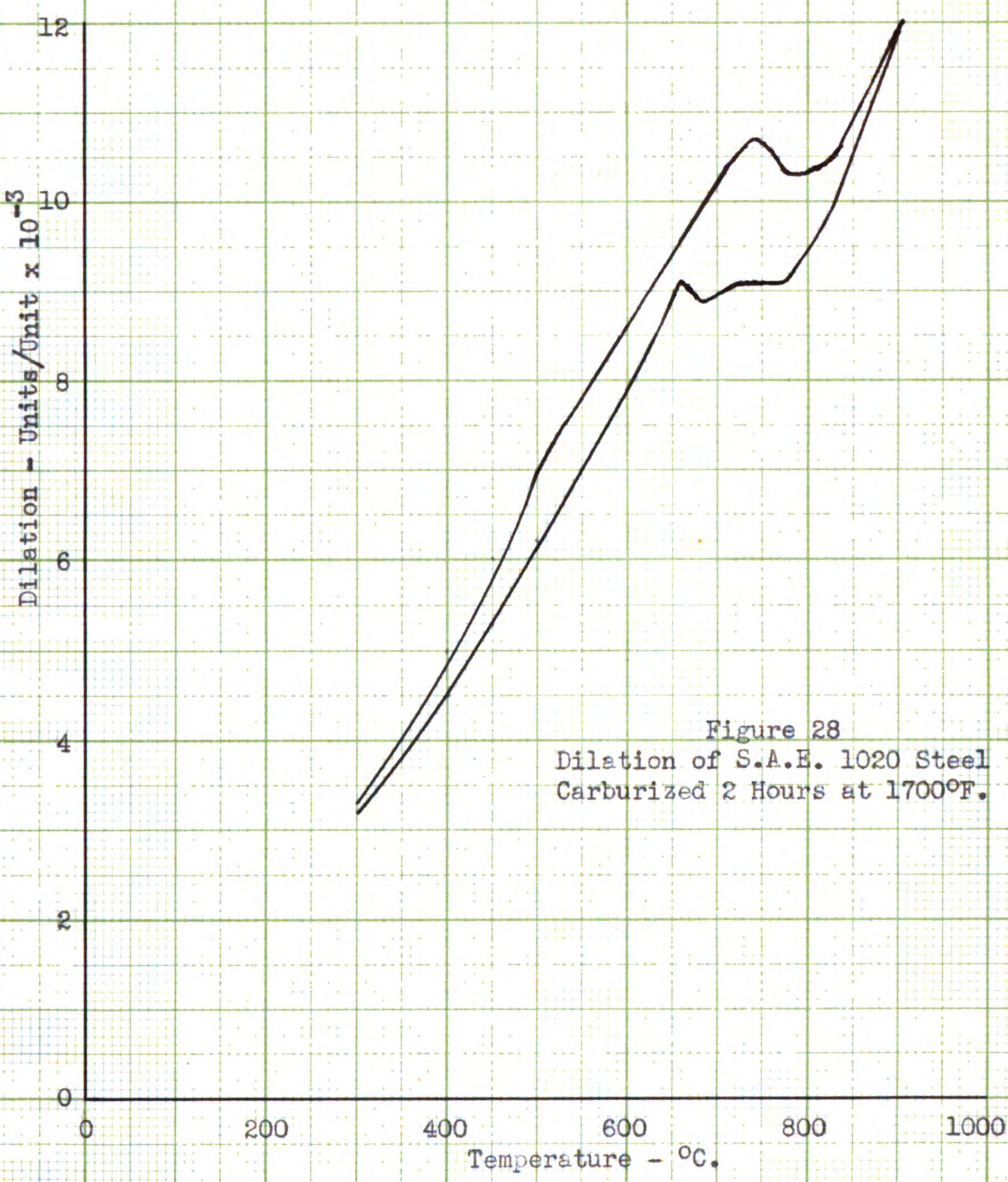
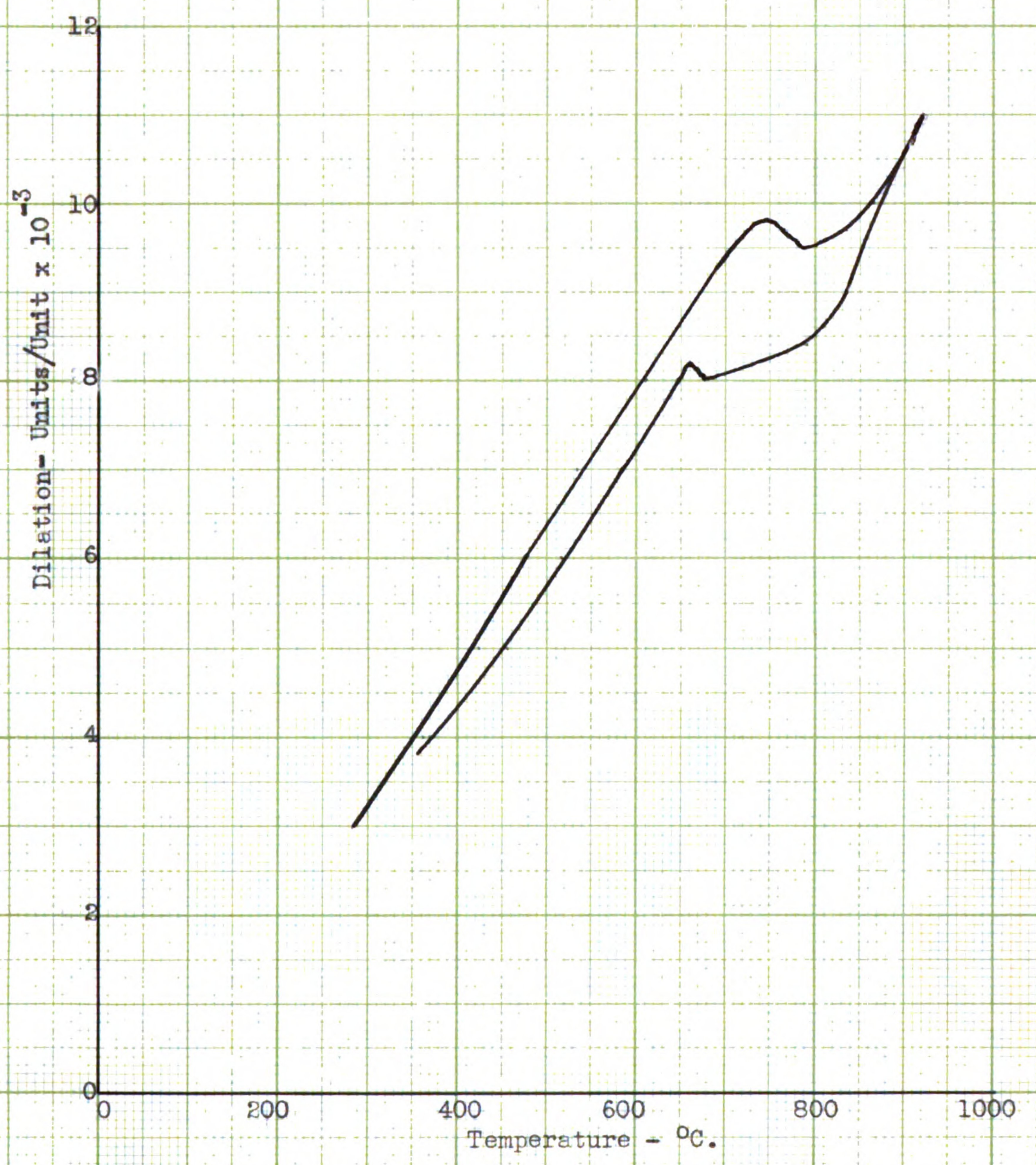


Figure 28
Dilation of S.A.E. 1020 Steel
Carburized 2 Hours at 1700°F.


Dilation- Units/Unit x 10^{-3}
12
10
8
6
4
2
0
0
200
400
600
800
1000
Temperature - ^{o}C.

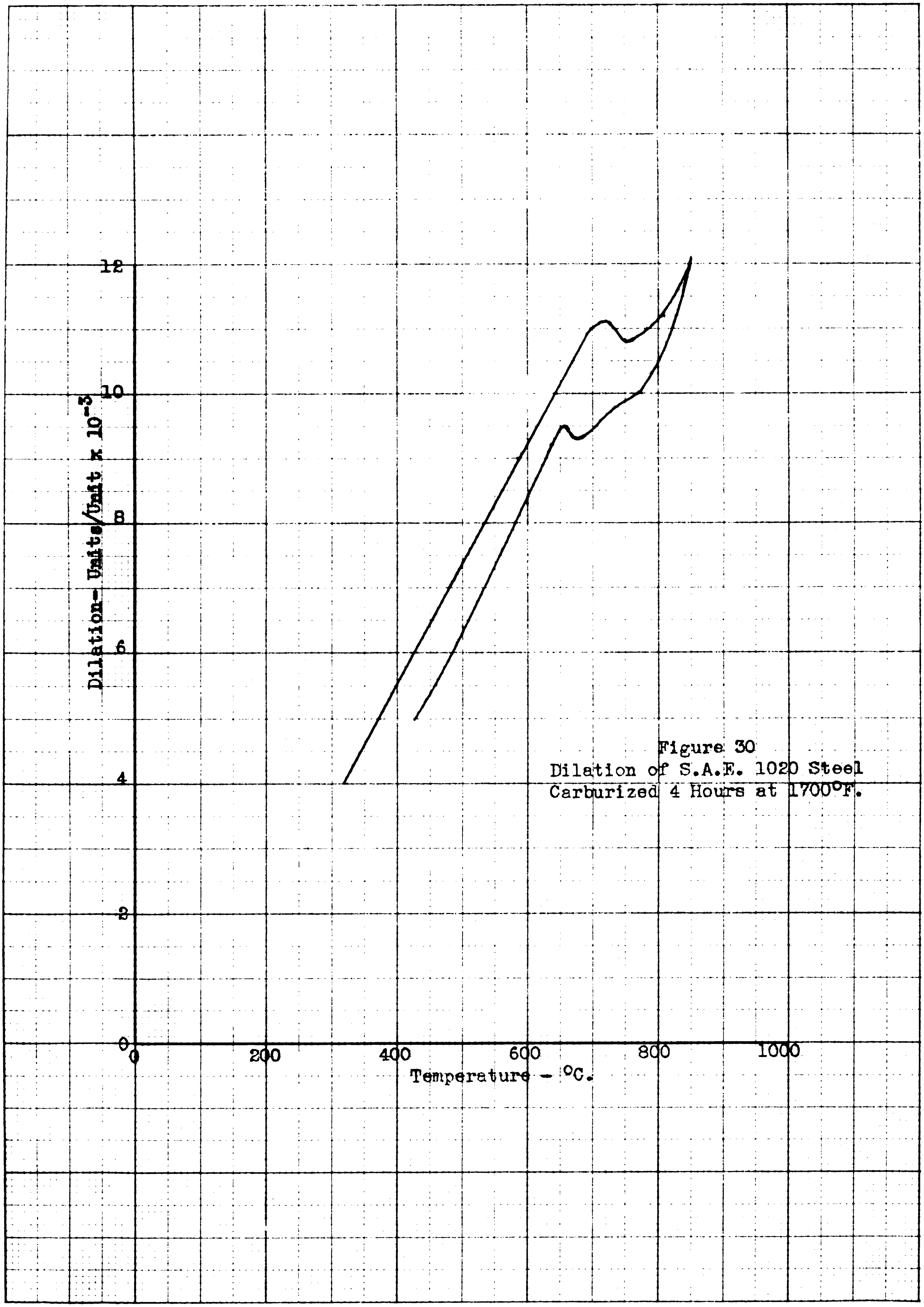


Figure 30
Dilation of S.A.E. 1020 Steel
Carburized 4 Hours at 1700°F.

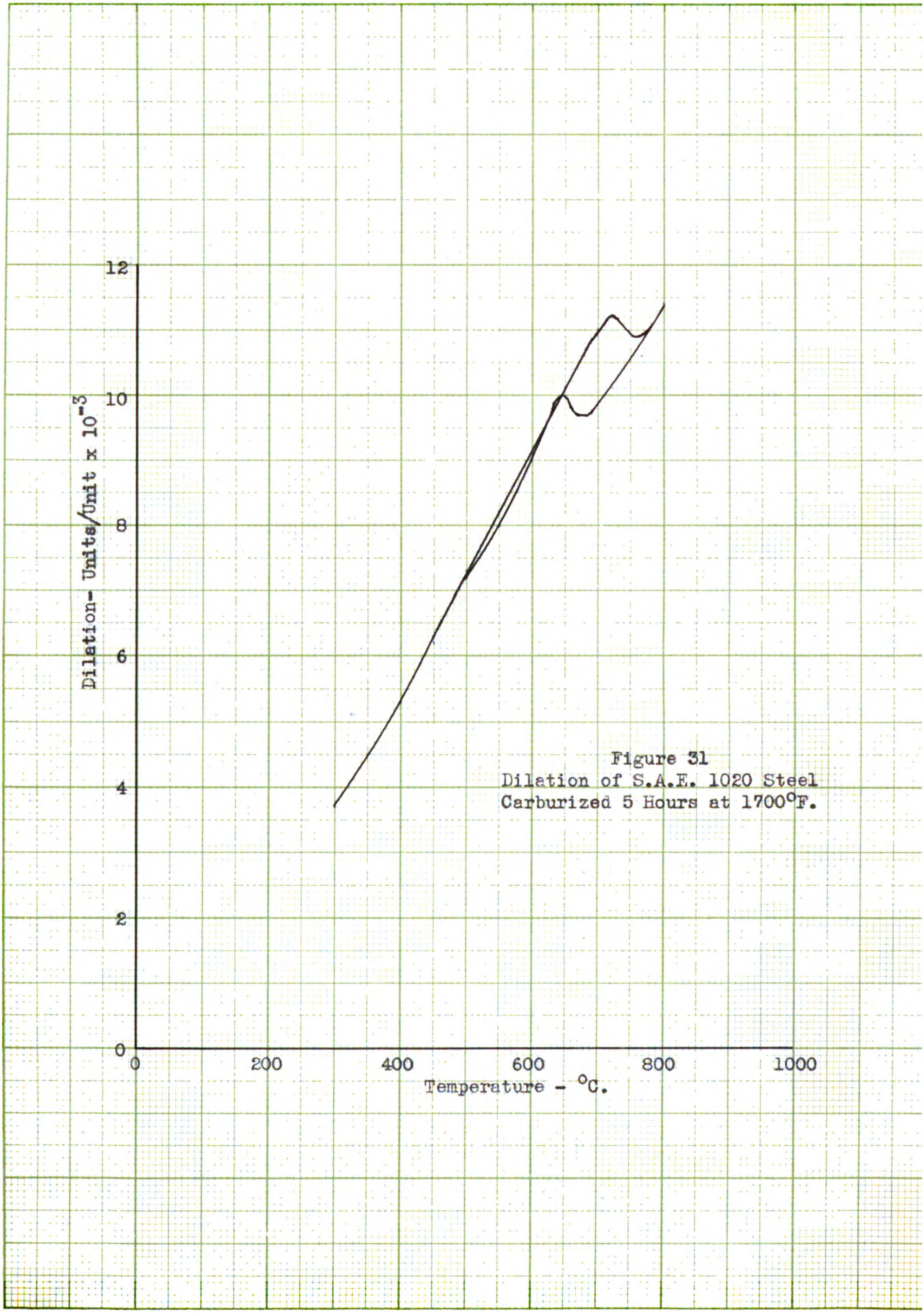


Figure 31
Dilation of S.A.E. 1020 Steel
Carburized 5 Hours at 1700°F.

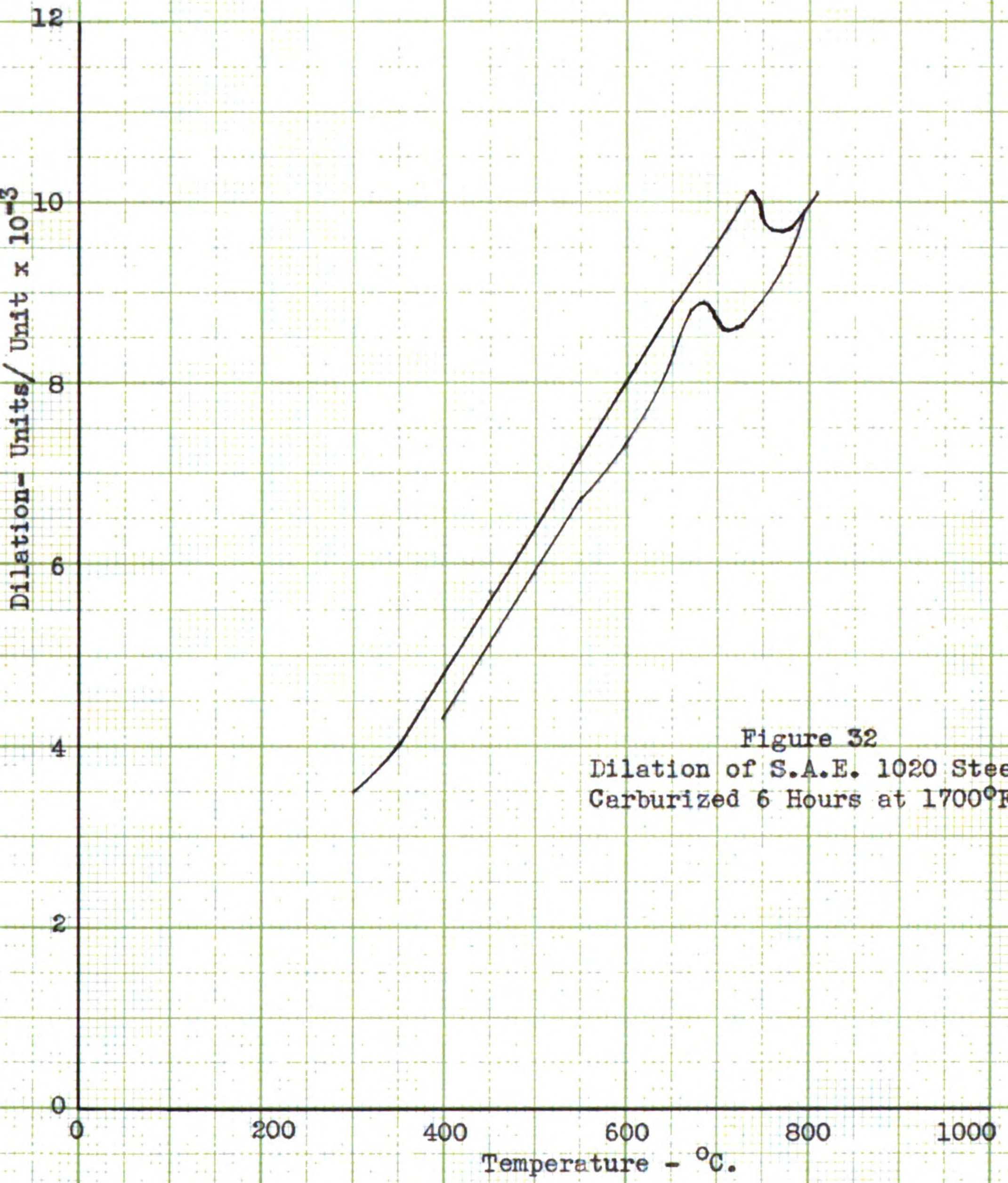


Figure 32
Dilation of S.A.E. 1020 Steel
Carburized 6 Hours at 1700°F.

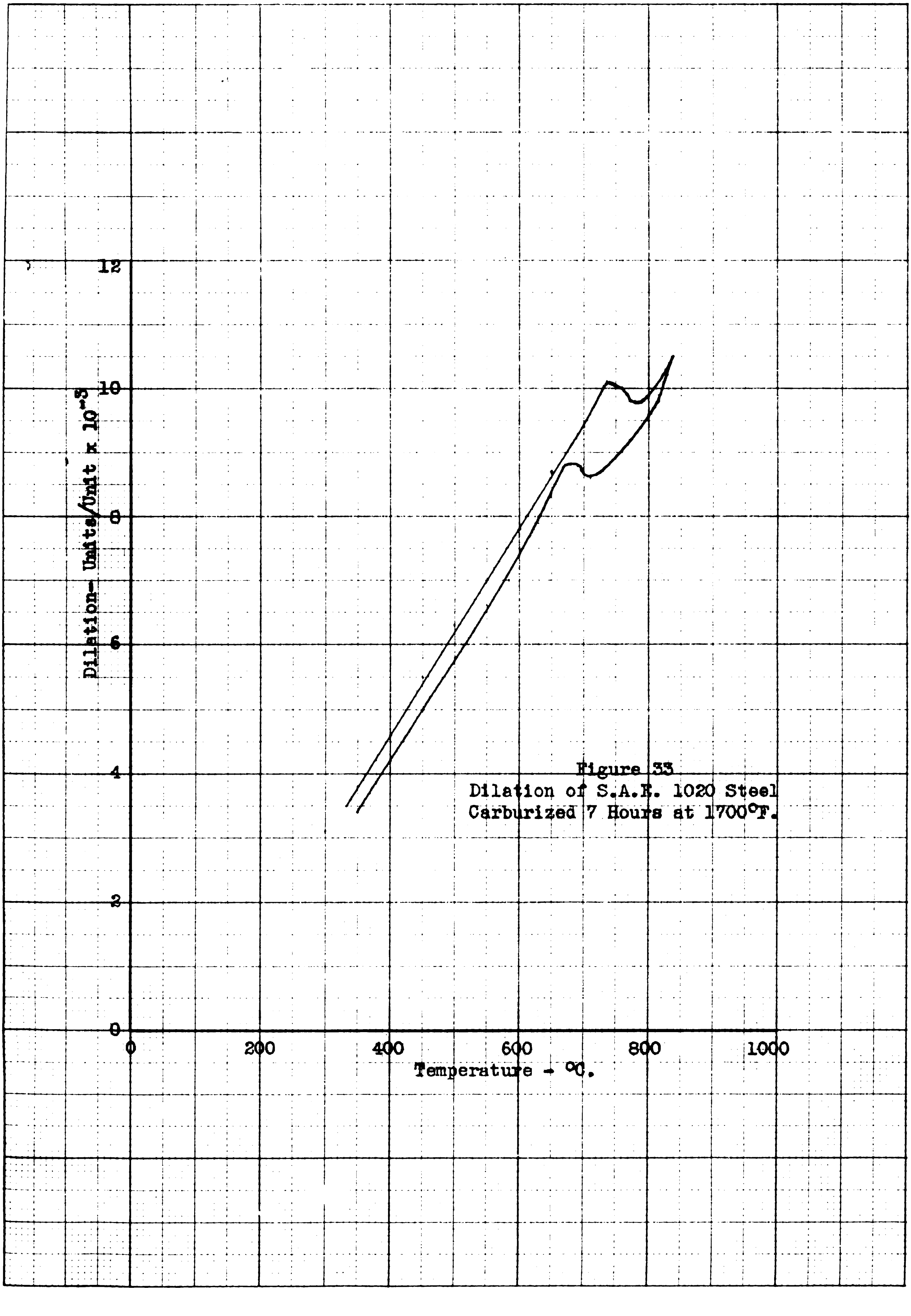


Figure 33
Dilation of S.A.E. 1020 Steel
Carburized 7 Hours at 1700°F.

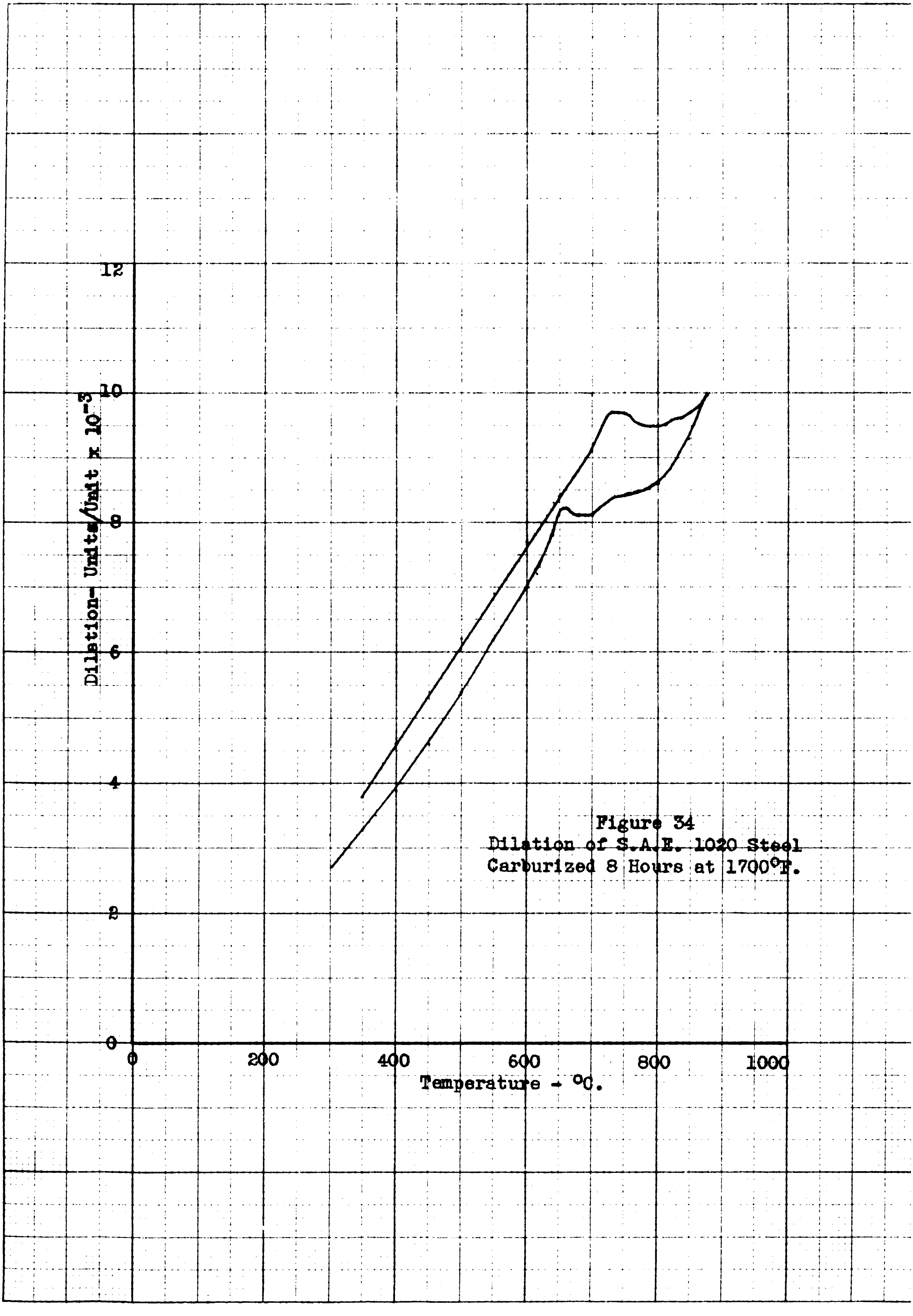


Figure 34
Dilation of S.A.E. 1020 Steel
Carburized 8 Hours at 1700°F.

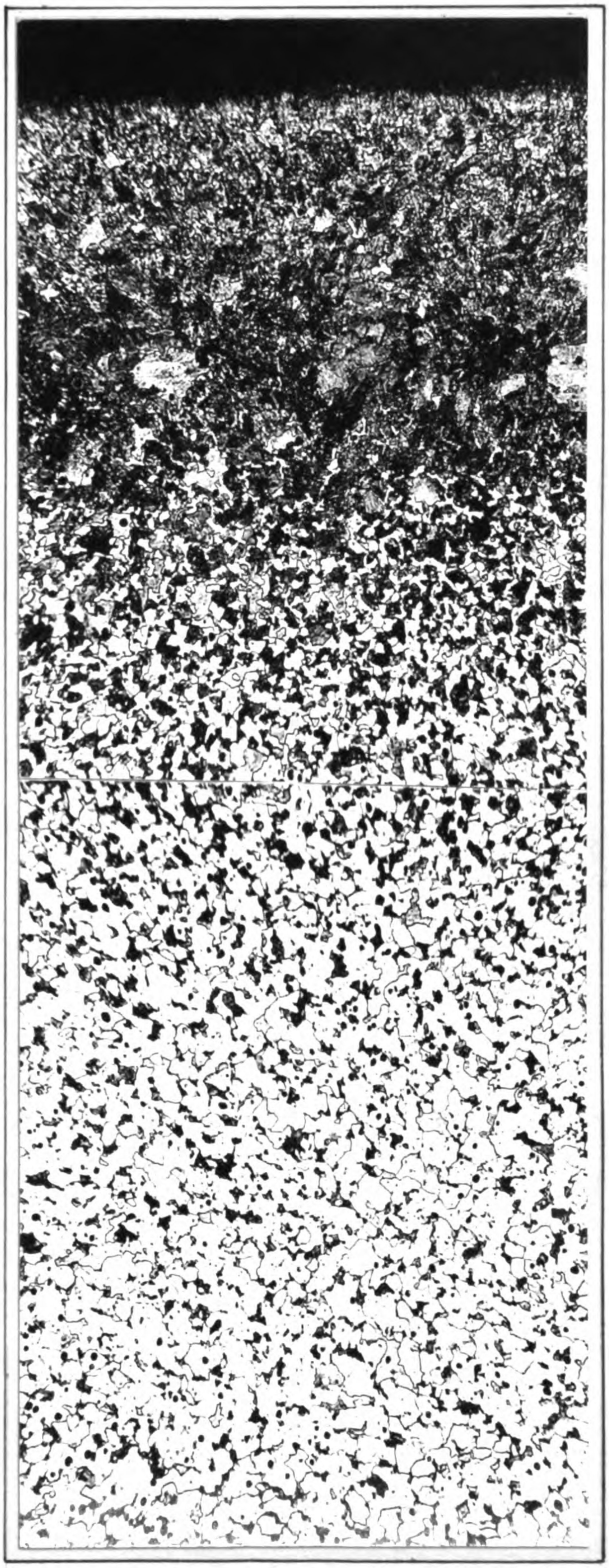


Figure 35
S.A.E. 1020 Steel
Carburized 1 Hour at 1700°F.
from Edge of Sample.
Mag. 160X

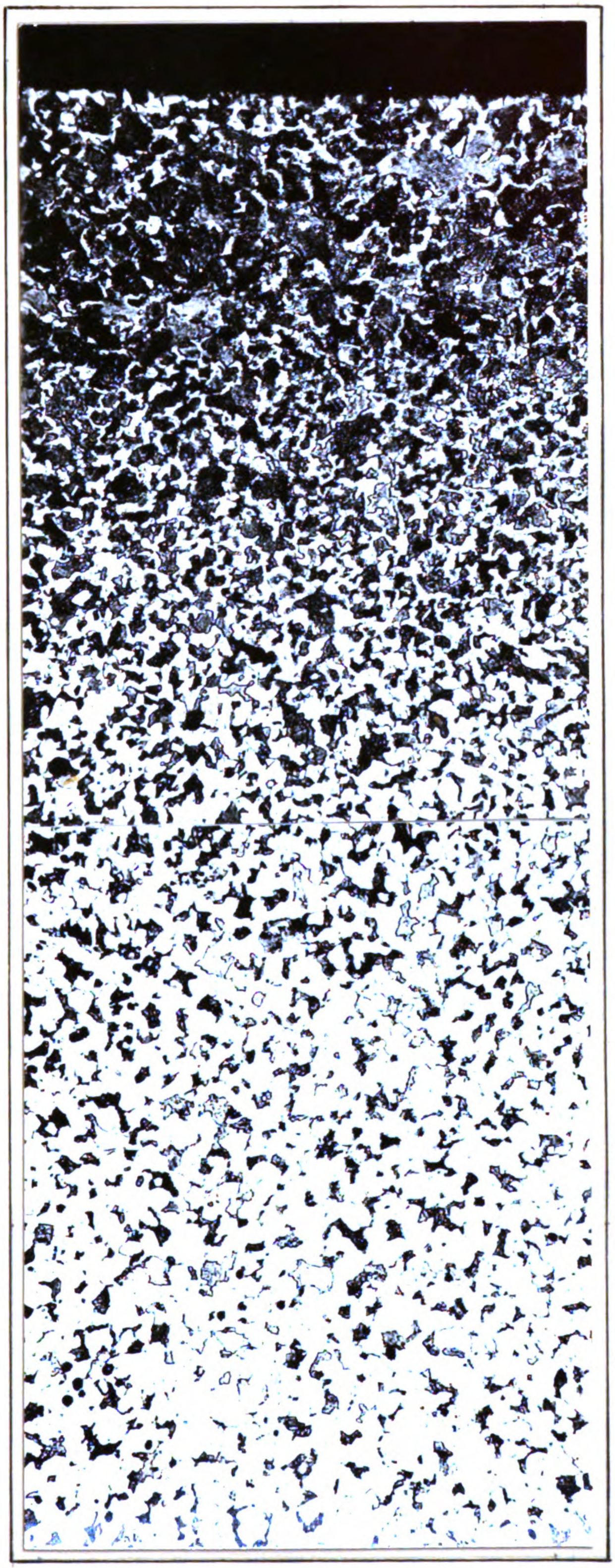


Figure 36
S.A.E. 1020 Steel
Carburized 2 Hours at 1700°F.
Continuous Photomicrograph
from Edge of Sample.
Mag. 160X

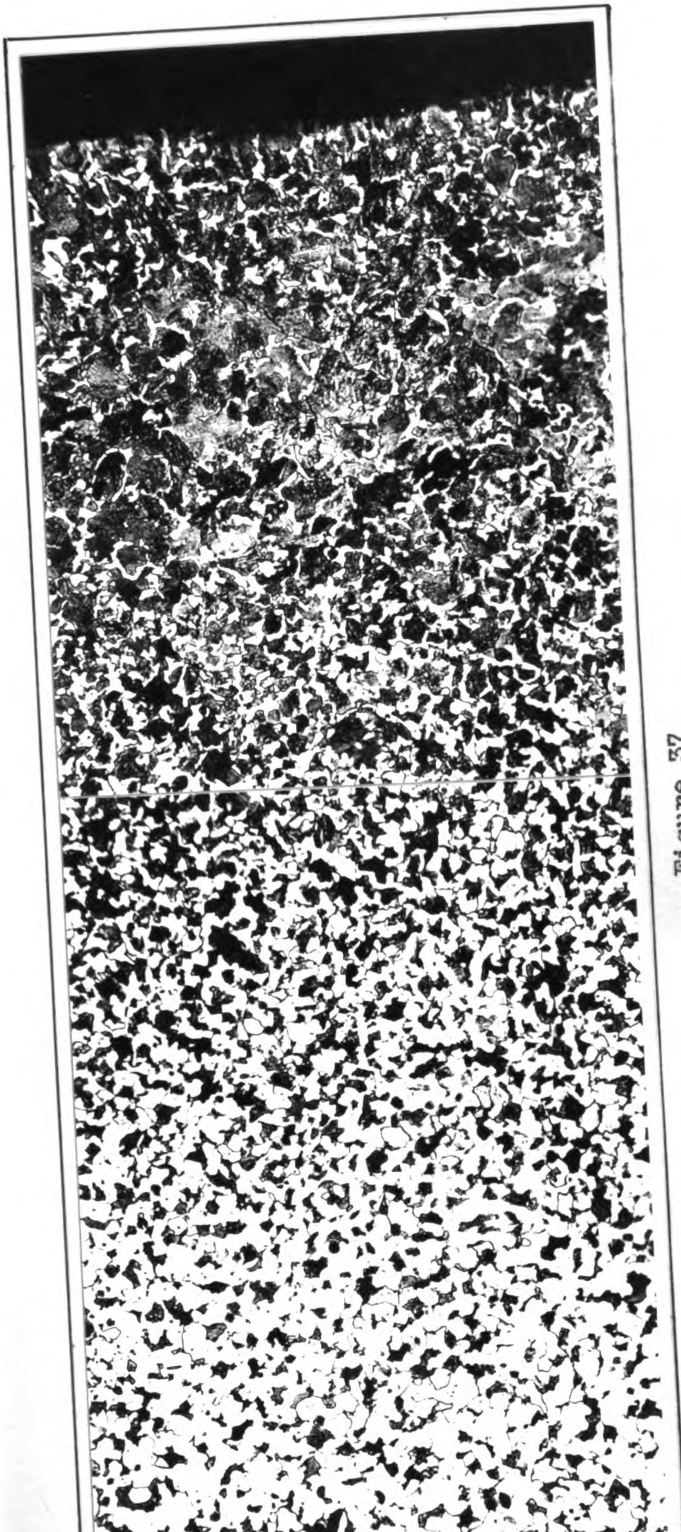


Figure 37
S.A.E. 1020 Steel
Carburized 3 Hours at 1700°F.
Continuous Photomicrograph
from Edge of Sample.
Mag. 160X

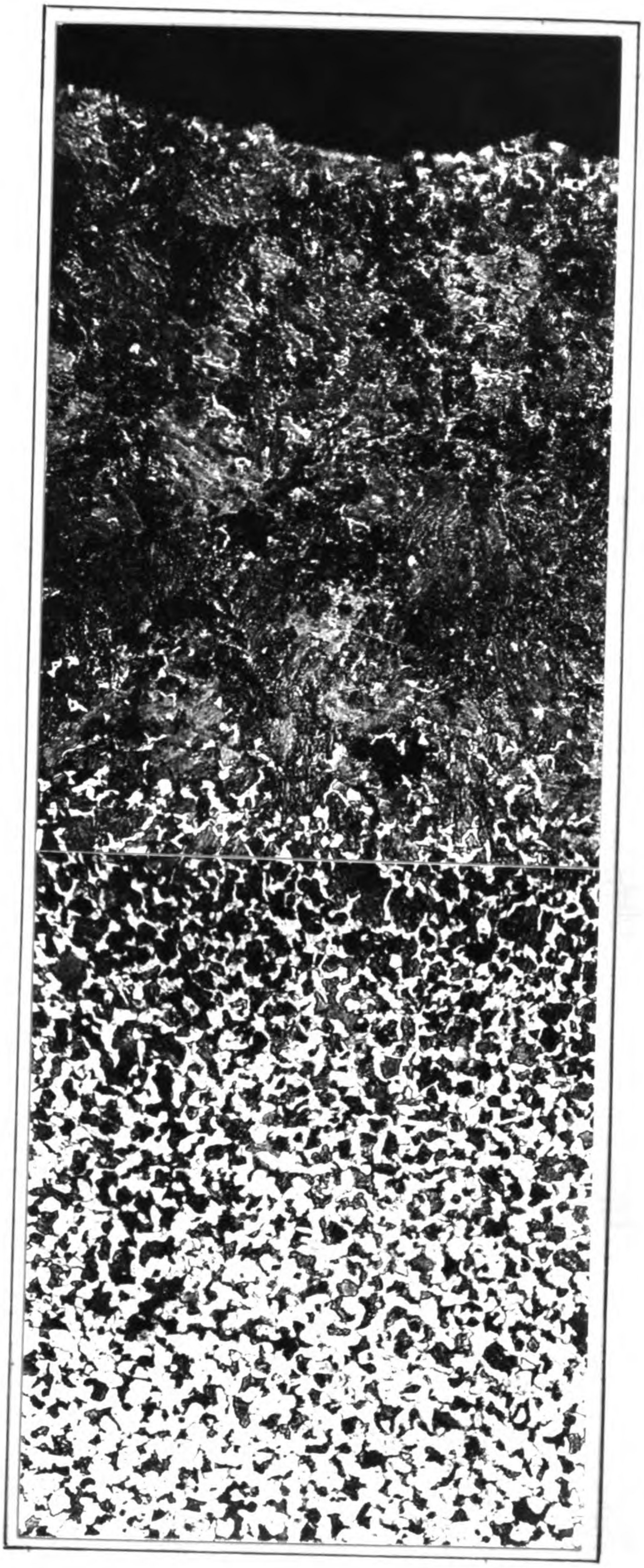


Figure 38
S.A.E. 1020 Steel
Carburized 4 Hours at 1700°F.
Continuous Photomicrograph
from Edge of Sample.
Mag. 160X

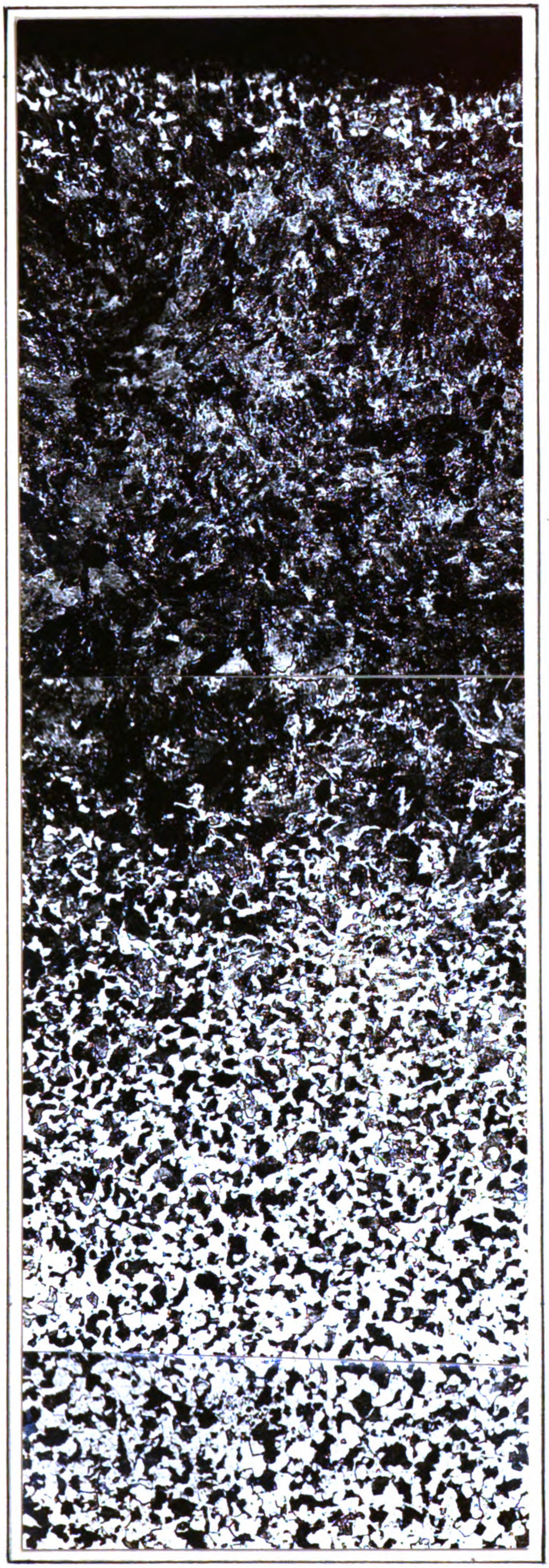


Figure 39
S.A.E. 1020 Steel
Carburized 5 Hours at 1700°F.
Continuous Photomicrograph
from Edge of Sample.
Mag. 160X

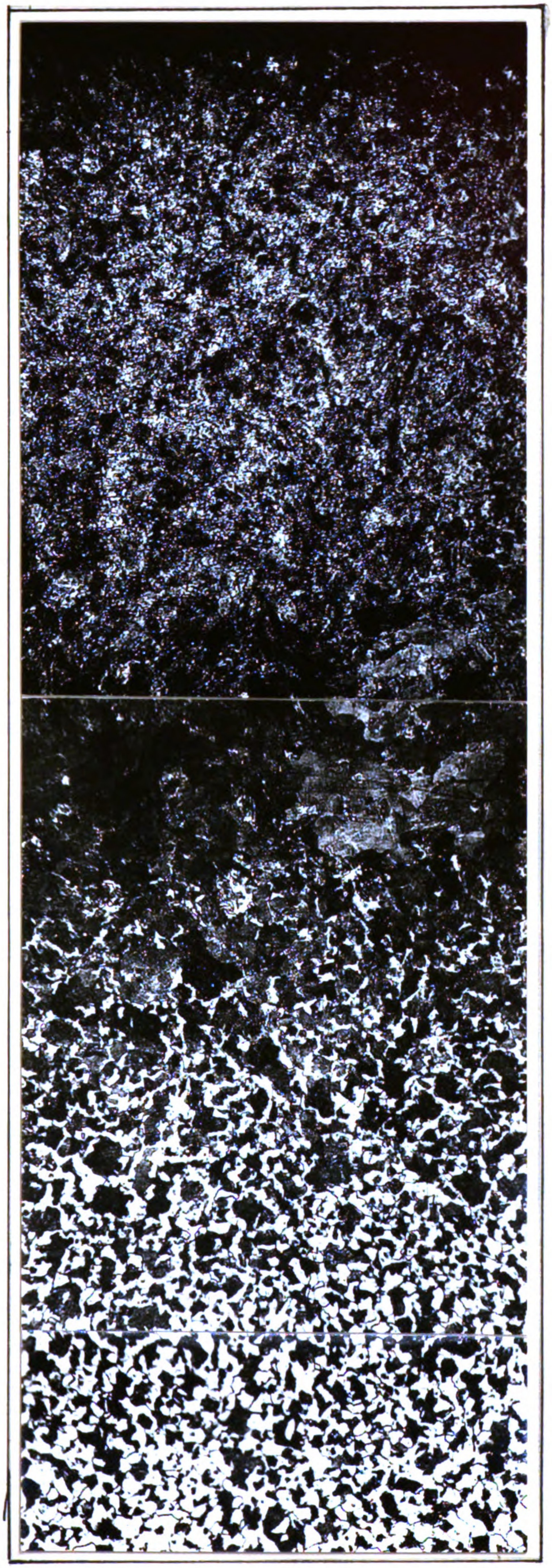


Figure 40
S.A.E. 1020 Steel
Carburized 6 Hours at 1700°F.
Continuous Photomicrograph
from Edge of Sample.
Mag. 160X

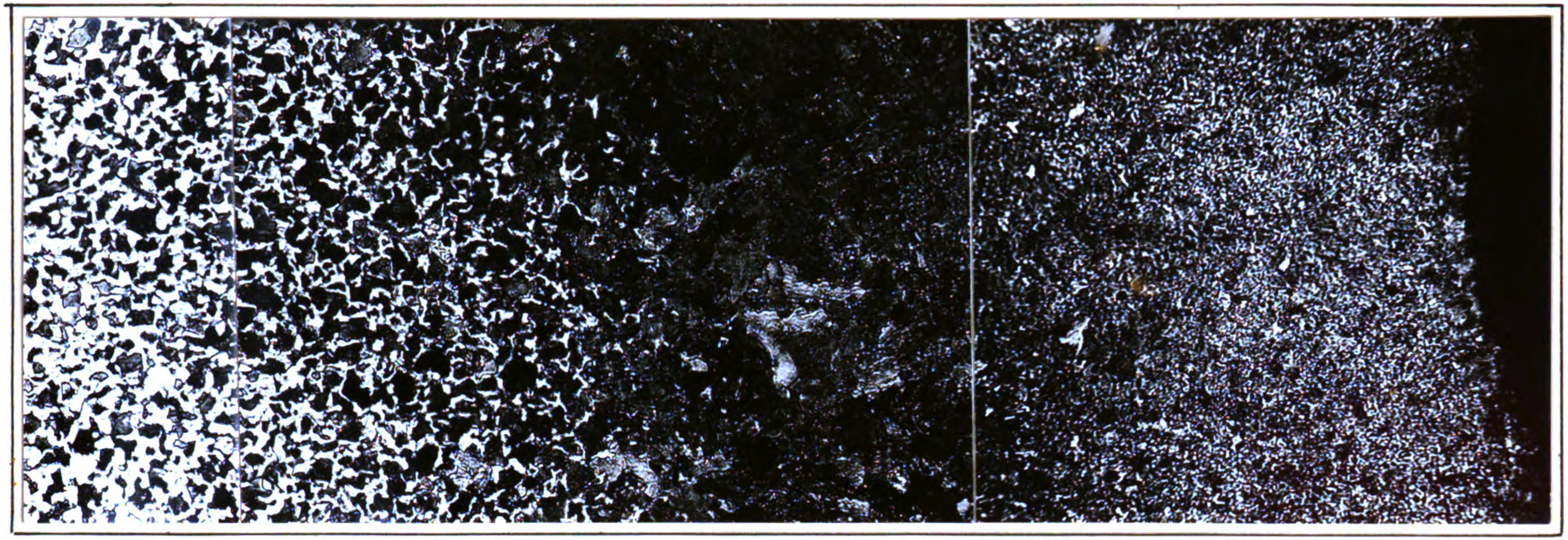


Figure 41
S.A.E. 1020 Steel
Carburized 7 Hours at 1700°F.
Continuous Photomicrograph
from Edge of Sample.
Mag. 160X

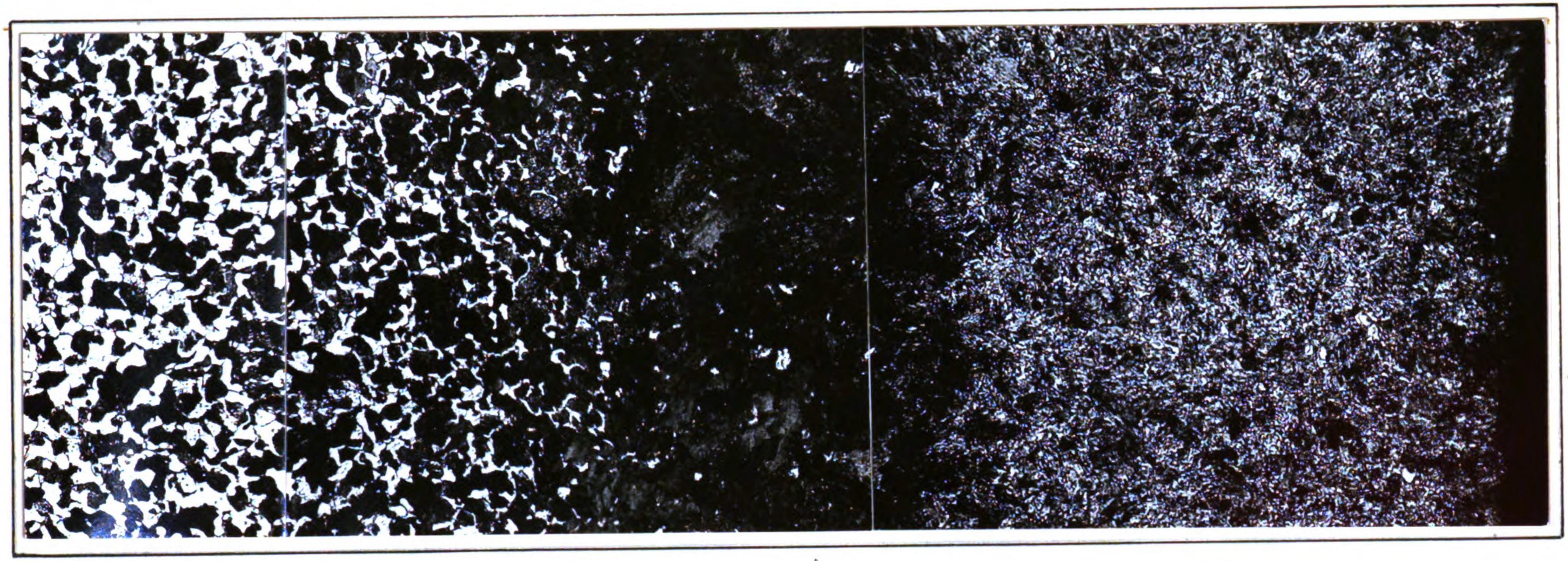


Figure 42
S.A.E. 1020 Steel
Carburized 8 Hours at 1700°F.
Continuous Photomicrograph
from Edge of Sample.
Mag. 160X

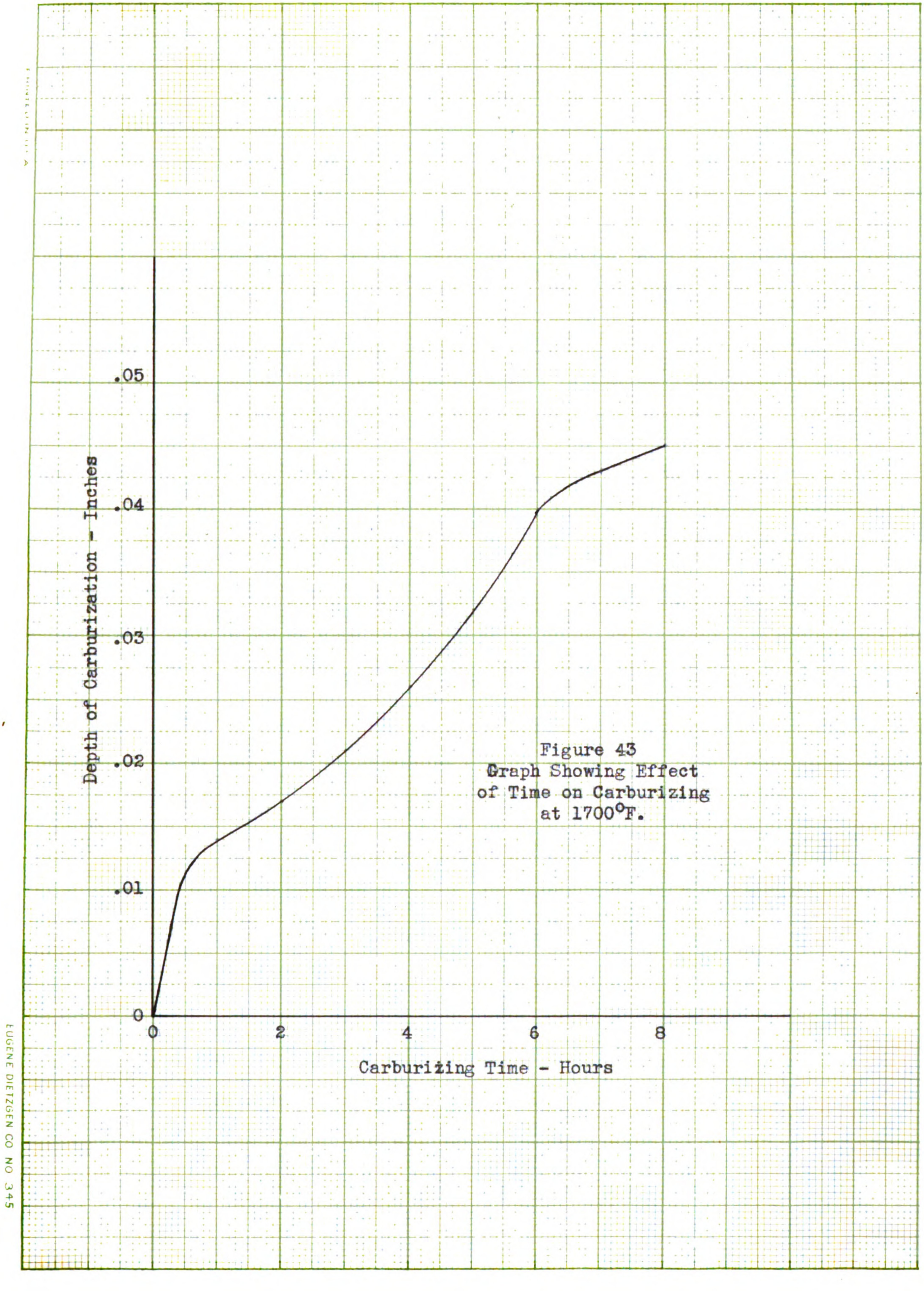


Figure 43
Graph Showing Effect
of Time on Carburizing
at 1700°F.

in the shorter carburization periods may be explained by the fact that the carbon did not diffuse at an even rate. In some instances the carbon content reached full eutectoid composition before any further appreciable diffusion would occur. This may be noticed especially in the sample carburized for a one hour period. Very little diffusion has occurred past the eutectoid zone. In the sample carburized for two hours, it will be noticed that the diffusion depth is greater, yet the carbon concentration in the case is much lower. This may be due somewhat to the nature of the carburizer, the quantity of carburizer in the bomb, or to the surface conditions of the steel.

Figures 44, 45 and 46 show the hyper eutectoid, eutectoid and hypo eutectoid compositions of the sample carburized for eight hours. The excess cementite can be seen in the grain boundaries of the hypereutectoid zone very plainly at this higher magnification used. This is not apparent in the photomicrographs taken at 160X. The pearlite may also be seen to be a distinct lamellar aggregate of ferrite and cementite. The pearlite in the hypo-eutectoid photo, however, shows that the pearlite is tending more toward the sorbitic form. Figures 47 and 48 show the eutectoid and hypo-eutectoid structure of the sample carburized for 3 hours. These photomicrographs are likewise taken at a magnification of 1000X. The pearlite is again well defined in the eutectoid zone, but is in more of a sorbitic nature in the hypo-eutectoid zone. Figure 49 is a photomicrograph taken at 1500X of the sample carburized for 1 hour. In this case the pearlite tends toward a sorbitic form.

Figure 44
Hyper-Eutectoid Zone
Case Carburized 8 Hours
at 1700°F.
Mag. 1000X

Figure 45
Eutectoid Zone
Case Carburized 8 Hours
at 1700°F.
Mag. 1000X

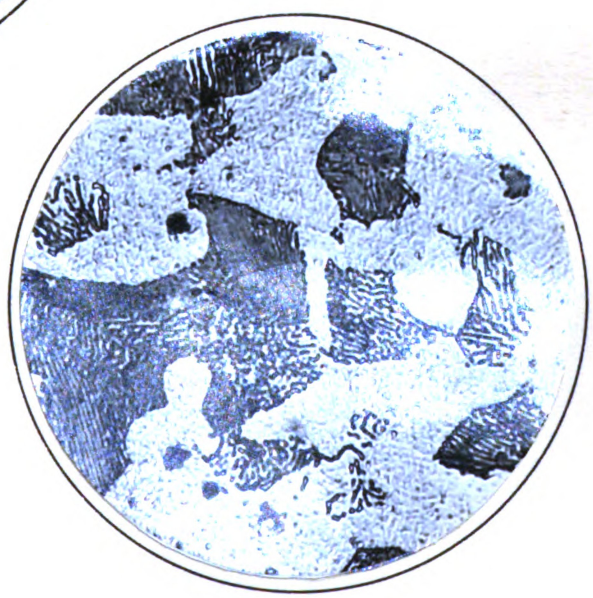


Figure 46
Hypo-Eutectoid Zone
Case Carburized 8 Hours
at 1700°F.
Mag. 1000X

Figure 47
Eutectoid Zone
Carburized 3 Hours at 1700°F.
Mag. 1000X

Figure 48
Hypo-Eutectoid Zone
Carburized 3 Hours at 1700°F.
Mag. 1000X

Figure 49
Eutectoid Zone
Carburized 1 Hour at 1700°F.
Mag. 1500X

CONCLUSIONS

1. The effect of carburization on the critical thermal range as measured with a dilatometer, is a resultant dilation effected from the zones present. The greater the depth of case, the greater is the tendency toward a single eutectoid type transformation. Carburization periods of 6, 7 and 8 hours reduce the transformation range to a minimum of 30°C. The normal range for the non-carburized sample being 100°C. (S.A.E. 1020).

2. The rate of carburization is retarded appreciably after a 6 hour period.

3. Non-uniformity in carbon content of steels may cause erroneous critical point measurements when measured with the dilatometer.

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