AN INVESTIGATION OF THE EFFECT OF ISOTHERMAL QUENCHING OF UNALLOYED COMMERCIAL CAST IRON

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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 Metallurgical Engineering.

Signed

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Date May 23, , 1947

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ACKNOWLEDGEMENT

The Author wishes to express his appreciation and indebtedness to Professor Clark B. Carpenter, under whose direction this investigation was pursued. The problem was undertaken at his suggestion. His supervision and interest in the work has been invaluable.

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ABSTRACT

Cast iron has been made and used for several centuries. Biringuccio reports on the use of cast iron cannon balls and the manufacture as early as 1540. Progress was slow until the last few decades. Then developments were made in control apparatus, raw materials, alloy addition agents and heat treatment.

About 1930 E. C. Bain and E. S. Davenport developed the austempering of steels. Later, E. L. Bartholomew applied the principles of isothermal transformation to cast iron. The structure was chiefly bainite in retained austenite. A marked increase in hardness and wearing properties was found.

Milliker and Cohen then worked out the transformation curves for two cast irons, one an unalloyed and the other a nickel cast iron.

It was the desire of the author to see what the physical properties would be if an unalloyed cast iron was heated to 1480° F., isothermally quenched to 350°, 400°, and 450° F. and held for five minutes, air cooled to room temperature, and then tempered at 600°, 800°, and 1000° F. for a period of one hour.

It was found that a structure like that of Bartholomew's was obtained upon quenching. The isothermal quench increased the hardness and tensile strength. After quenching, then tempering at a given temperature for one hour, all samples showed the same hardness irrespective of the initial quenching temperature.

INTRODUCTION

Cast iron indeed is a material which has been in use for a great number of centuries. Biringuccio[1] refers to its use for cannon balls as early as the fifteenth century. The method of manufacture has changed some but basically it is the same principle as has been used for centuries.

The major improvements have been in the control apparatus, and in the last few decades the developments have been in the selection of raw materials, alloy addition agents, and heat treatment. It is rather difficult to say who has contributed most to the cast iron industry. In very recent years great strides have been made in the physical properties of cast iron. For example, the increase in tensile strength of 15,000 or 20,000 pounds per square inch to a value which now exceeds 60,000 pounds per square inch as cast and in special heat treatment, values of 100,000 pounds per square inch have been obtained.[2]

The principle methods of manufacture of cast iron are the cupola, electric and air furnaces. Each has advantages and disadvantages of its own. These depend primarily upon the type of iron made and the specifications to be met.

All cast irons are eutectiferrous alloys and may be classified as:

Pig iron
White cast iron
Malleable cast iron
Gray cast iron

Gray cast iron either alloyed or unalloyed is produced in large quantities. The developments in the steel industry usually influence research and developments in the cast iron industry. This is natural since cast iron is a competitor of steel.

The work done by E. C. Bain and E. S. Davenport[3] on the austempering of steel stimulated E. L. Bartholomew[4] in the development of the isothermal quenching of cast iron.

Cast irons of the following analysis (in percent) were used.

Table I

	No. 53	Molybdenum Iron
Total carbon	3.35	3.25
Silicon	1.30-1.40	1.75
Manganese	0.50-0.80	0.80
Sulphur	0.13-0.15	0.10
Phosphorous	0.30 max.	0.30 max.
Nickel	2.00	----
Molybdenum	----	0.50
Chromium	----	----

These irons were heat treated as follows:

(1) Heat to 1550° F., hold at heat 15 minutes.
(2) Quench to 510° F., hold at heat 15 minutes.
(3) Air cool to room temperature.

This treatment gave the following results:

Table II

	No. 53	MI
Brinell Hardness "As Cast"	220	223
Brinell Hardness After Hot Quenching	388	341
Tensile Strength "As Cast"		47,500
Tensile Strength After Hot Quenching		75,500
AB Impact Strength* "As Cast"		44
AB Impact Strength* After Hot Quenching		61

*Impact tests were made on a Charpy type machine using a section of an unnotched arbitration test bar 1.125 inch in diameter broken on 6-inch center.

The structure of the metal was bainite in retained austinite. The austinite broke down into martinsite when cold worked. The bainite has a needle like structure and varies from the martinsitic structure. The austinite remains white when etched with Nital.

Bartholomew's work was followed by the research of Hilliker and Cohen[5]. These men worked out the isothermal transformation curves for an unalloyed cast iron and a nickel cast iron of the following analysis:

Table III

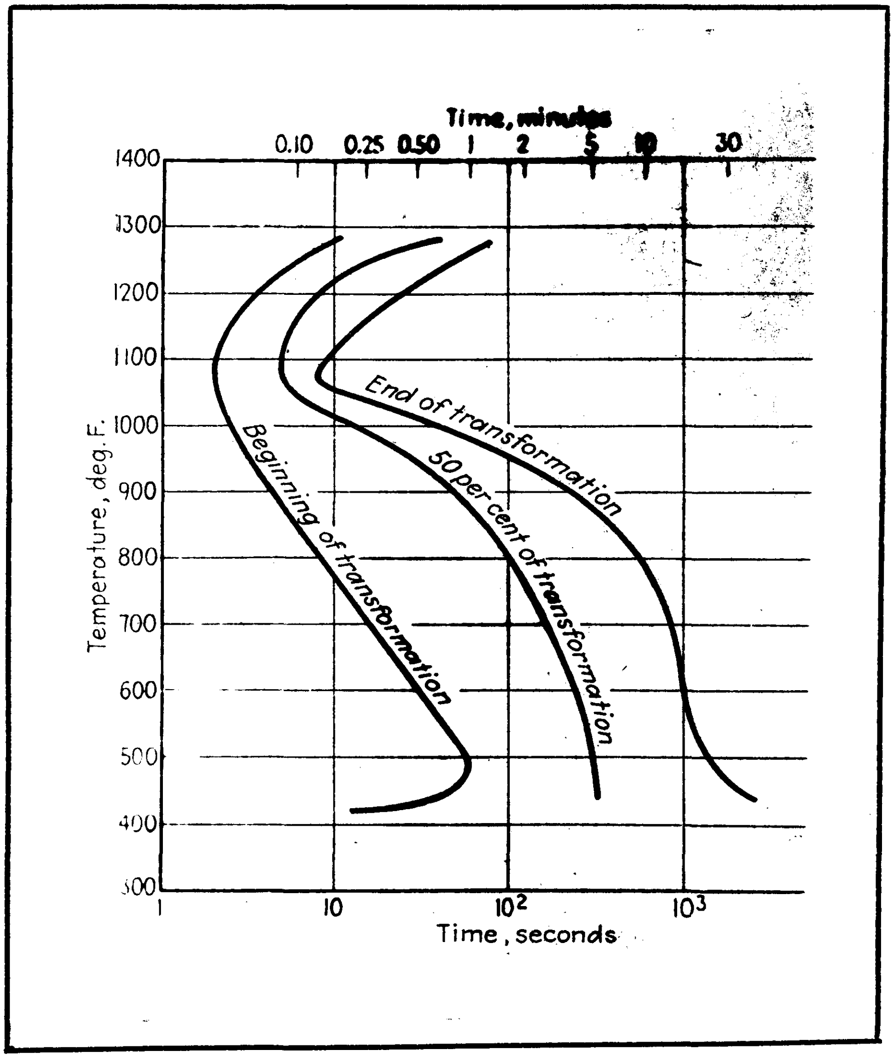
	Unalloyed C. I.	Nickel C. I.
Total carbon	3.63	3.68
Graphitic carbon	2.92	2.56
Combined carbon	0.71	1.12
Silicon	1.75	1.20
Manganese	0.53	0.37
Sulfur	0.10	0.11
Phosphorous	0.56	0.28
Nickel	--	2.03

The results are shown in Figures 1 and 2. The hardness values at the end of transformation are plotted as a function of transformation temperature as shown in Figure 3.

The dip in hardness just below the nose of the transformation curves corresponds to "acicular ferrite" found by E. S. Davenport[6] and H. Jolivet[7] in alloy steels. Further investigation by X-ray diffraction confirmed this ferritic nature. These findings lend considerable weight to R. F. Mehl's postulation that the "upper bainite" structures are nucleated by ferrite, unlike the pearlitic structures which are nucleated by cementite.

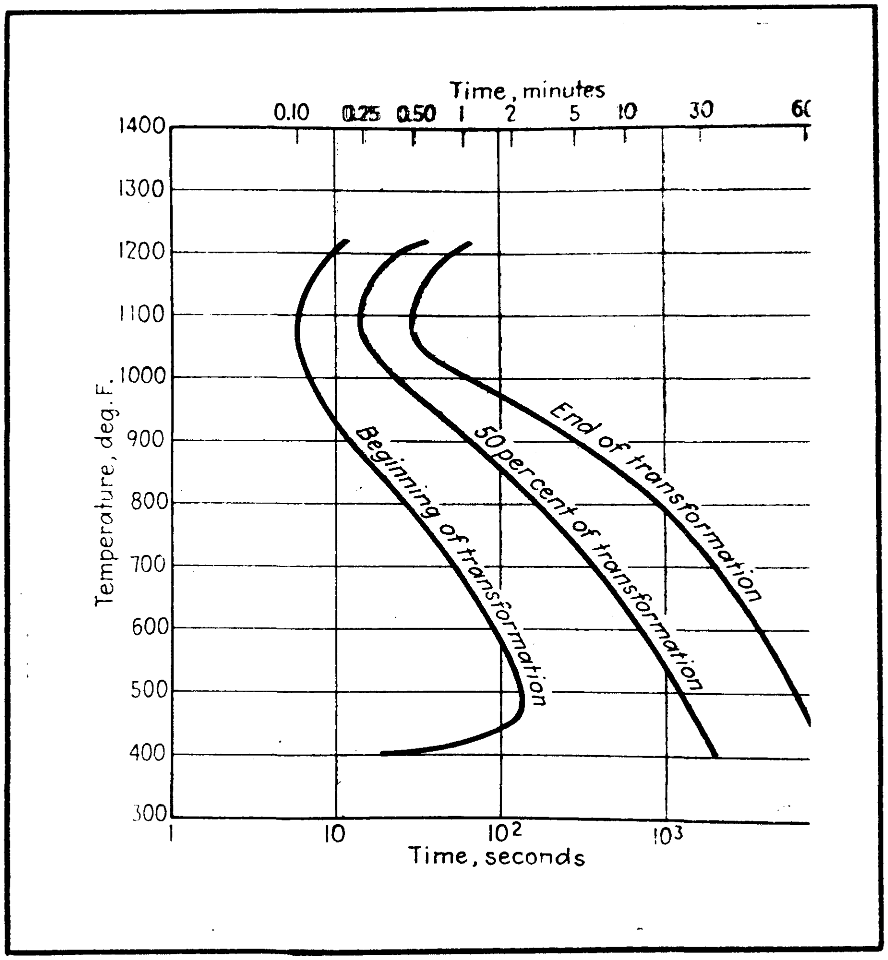
C. R. Austin[8] reports an increase in toughness or resistance to shock with a slight increase in tensile

Figure 1



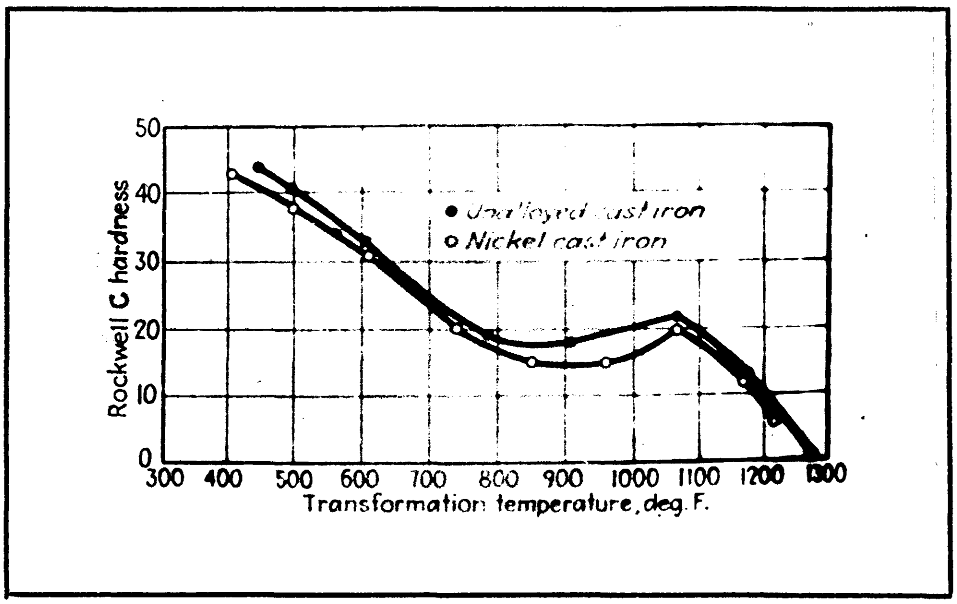
Isothermal transformation curves for an unalloyed cast iron.[5]

Figure 2



Isothermal transformation curves for a nickel cast iron.[5]

Figure 3



Effect of isothermal transformation temperature on the hardness of the unalloyed and nickel cast irons after virtually complete transformation.[5]

strength if cast iron is quenched at 850° F. and a marked increase in tensile strength and hardness without loss in toughness if quenched at 750° F. This applies to castings of relative small size. Castings can be quenched isothermally where a water or oil quench might result in warpage or fracture.

From the work done it has been shown that an isothermal, interrupted or hot quench can increase the tensile strength, hardness, toughness and tend to eliminate distortion[9, 10, 11, 12]. The product formed during quenching is bainite. Some prefer to call it an intermediate product[5].

SCOPE OF EXPERIMENTAL WORK

There has been some work done on the isothermal quenching of cast iron, namely, that done by Bartholomew, Hilliker and Cohen. Their results have been shown in the introduction.

The purpose of this investigation is to determine the physical properties, namely, hardness and tensile strength after quenching to predetermined temperatures (350°, 400°, and 450° F.) and holding at temperature for a period of five minutes, cooling to room temperature, then tempering for one hour at 600°, 800° and 1000° F.

EXPERIMENTAL WORK

Equipment

The principal pieces of equipment used in this investigation were the electric hump furnace, oil tempering bath and research metallograph.

The electric hump furnace was automatically regulated by a Leeds Northrup recording thermostatic control. The hump furnace and Leeds Northrup recorder are shown in Figure 4

The quenching equipment was a General Electric Oil Tempering Bath, twelve gallon capacity . This was heated by two two-kilowat heating elements submerged in the oil. These were automatically controlled by a Bristol's Thermometer Controller. Houghton's Mar Temp oil with a flash point of 550° F. was used as the quenching medium. This equipment is shown in Figure 5.

A Bausch and Lomb research metallograph was used to take all microphotographs .

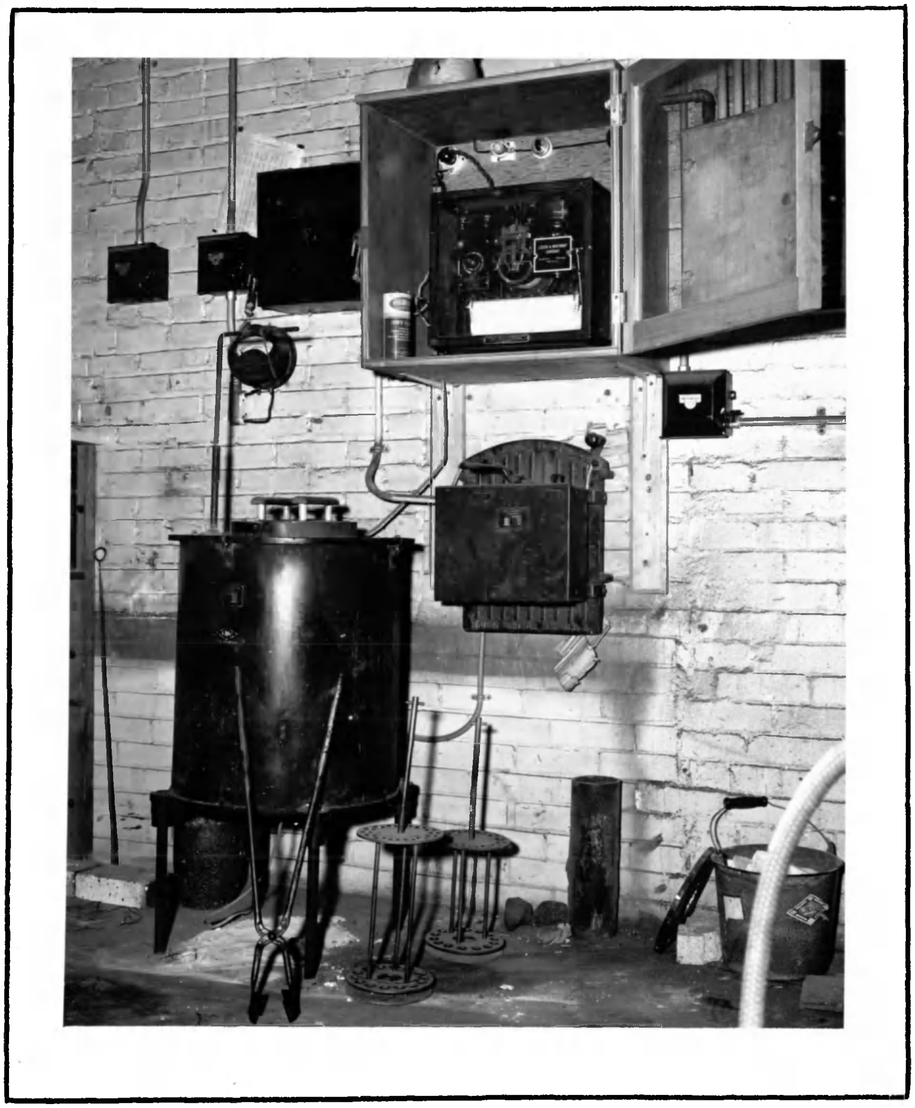
Specimens

Twenty-four standard test bars, 1 .20 inches in diameter and 21 inches long were obtained from a foundry in Denver, Colorado. These test bars were cut in half to provide a greater number of specimens. A chemical analysis was run and the results reported in the following table.

Table IV

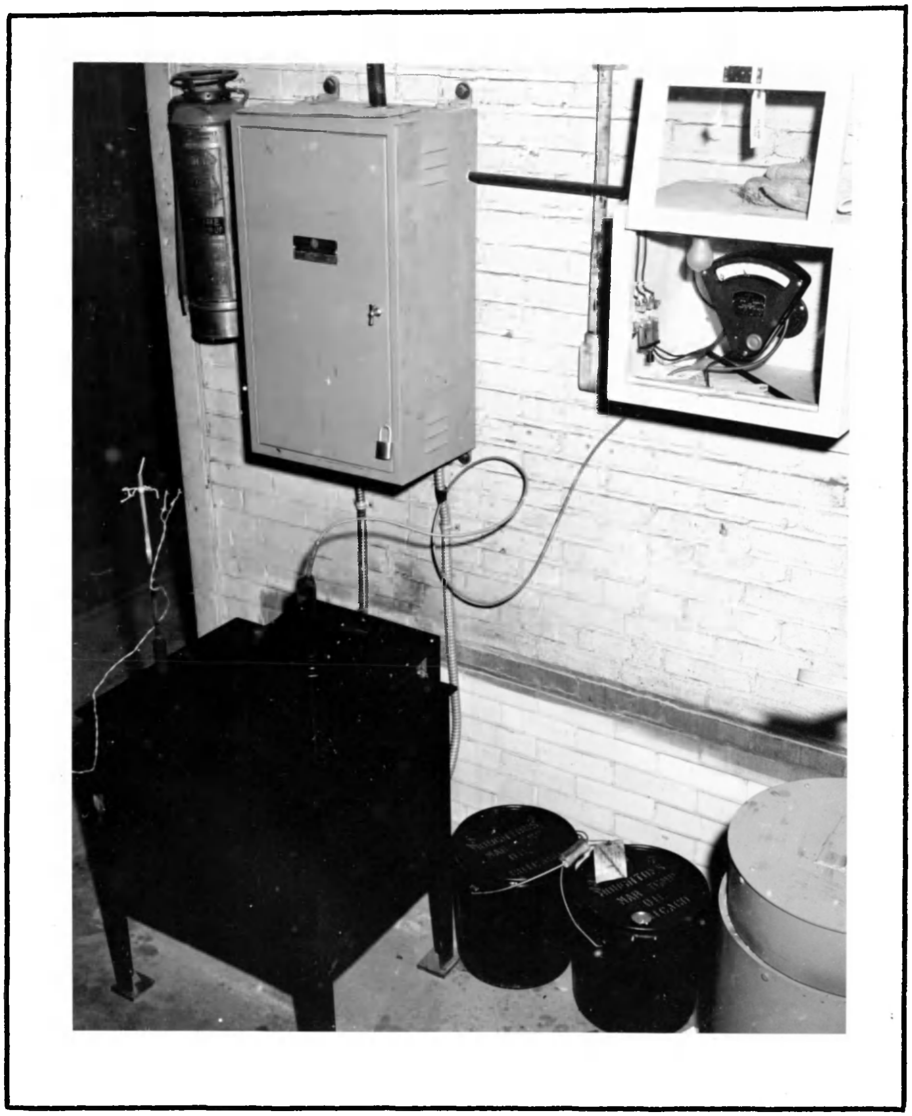
Total Carbon	3.56	Sulfur	0.11
Graphitic Carbon	2.85	Chromium	0.06
Combined Carbon	0.71	Copper	0.16
Silicon	1.52	Molybdenum	None
Manganese	0.85	Nickel	None
Phosphorous	0.58		

Figure 4



Hump furnace and control.

Figure 5



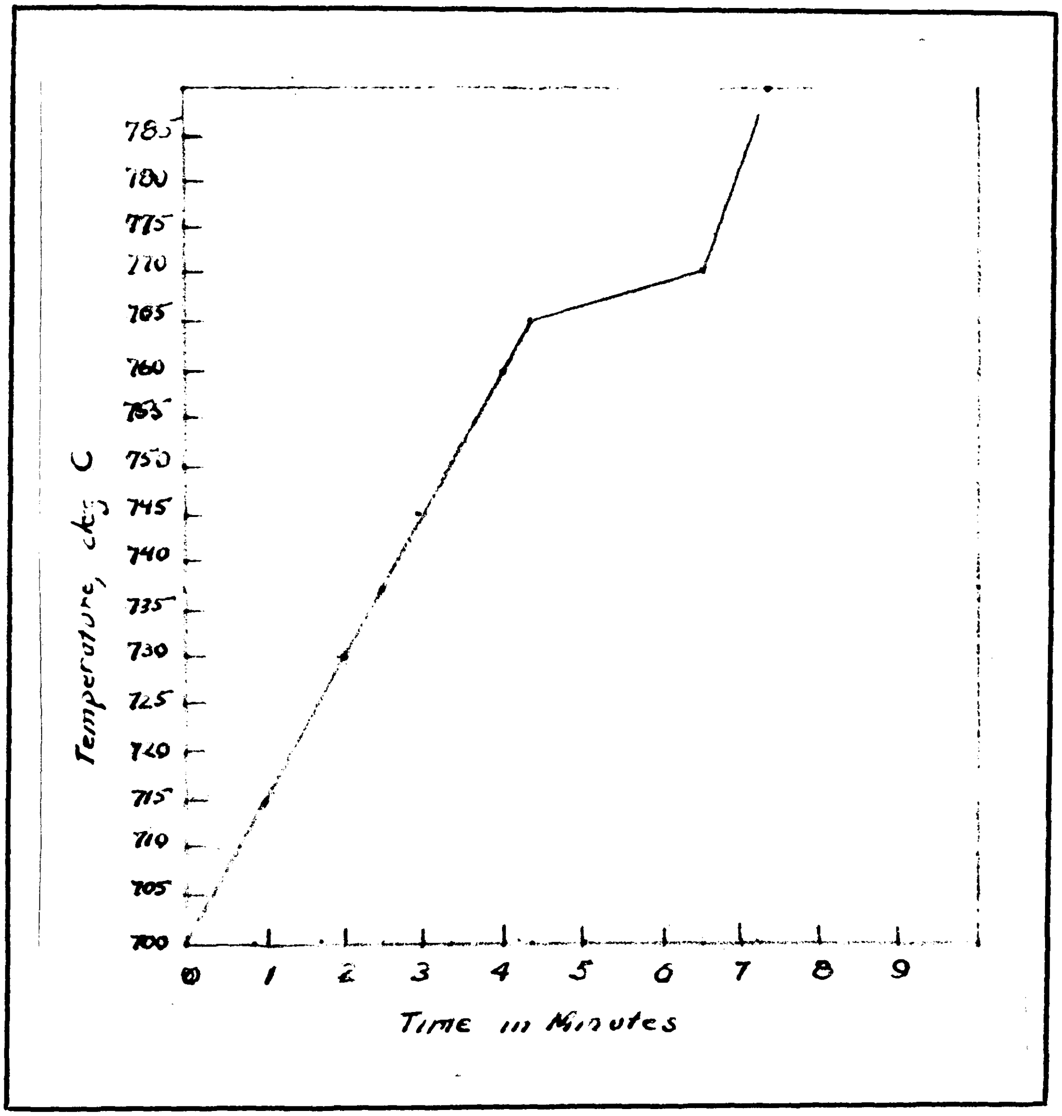
General Electric oil tempering bath
and Bristol thermometer control.

PROCEDURE

The first point to be established was the temperature at which the cast iron underwent the allotropic change. This was done by taking a sample of the cast iron, drilling a hole in the center, inserting a thermocouple, and measuring the temperature rise in 5° Centigrade increments. The temperature was plotted against the time required for the given rise and the results are shown in Figure 6. The critical temperature was found to be between 765° and 770° C. or 1409° and 1418° F.

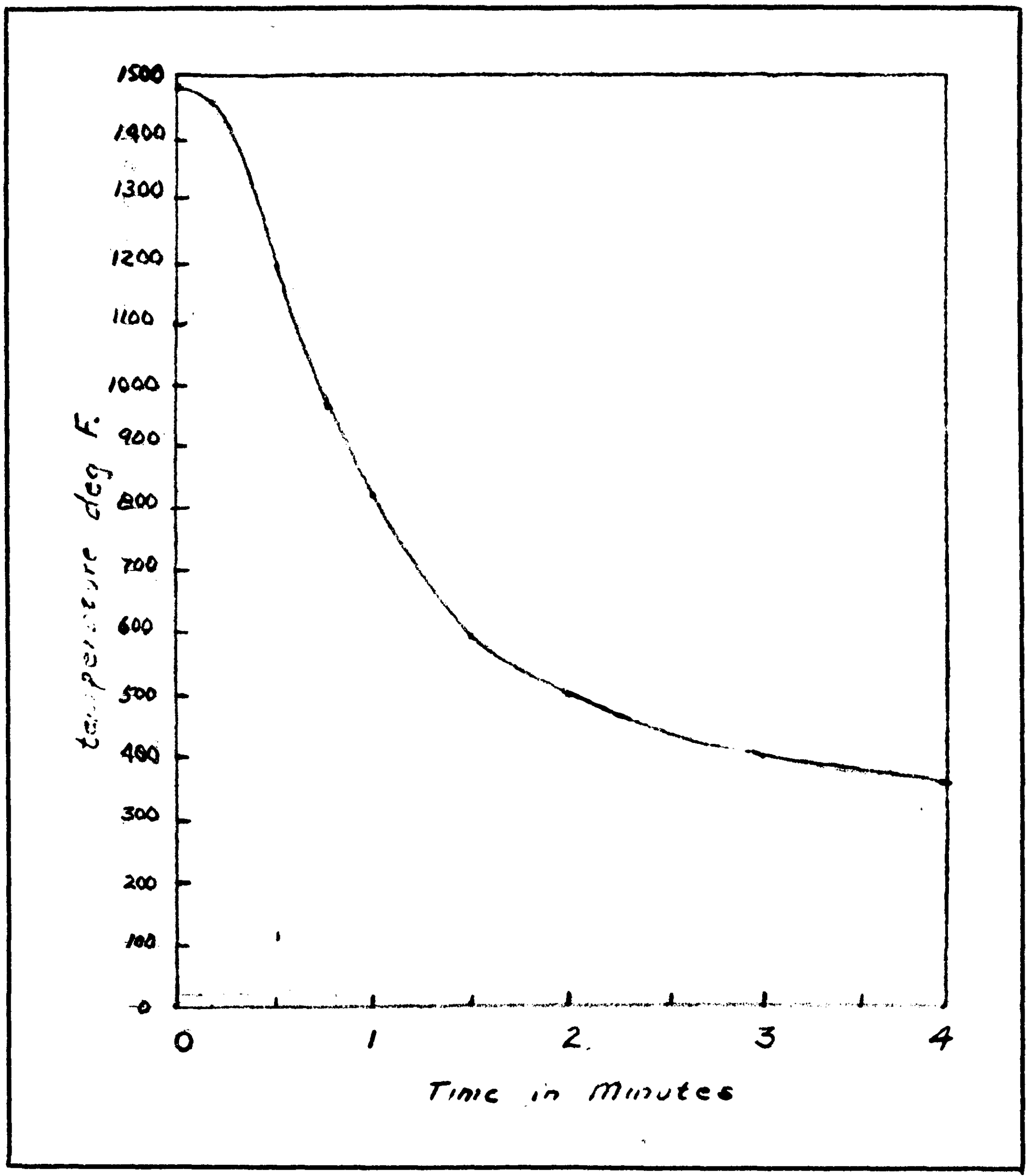
The next step was to determine the cooling rate of the center of a specimen when quenched. This was accomplished by taking a specimen of cast iron, drilling a hole in the center, inserting a threaded iron pipe and welding the junction. A Chromel-Alumel thermocouple and Brown Electrical Pyrometer were used to determine the cooling rate. The temperature was plotted against time. The results are reported in Figure 7.

Figure 6



Determination of the critical temperature.

Figuro 7



Cooling curve on quenching.

TREATMENT OF SPECIMENS

The specimens were brought to 1480° F., held at temperature from twenty to thirty minutes, quenched individually at the predetermined temperature (350°, 400°, or 450° F.) then allowed to cool to room temperature while resting on a board. After all were quenched and cooled, duplicate pairs were then tempered in the hump furnace which had reached equilibrium at the desired temperature of 600°, 800°, and 1000° F. At the end of one hour the specimens were removed and allowed to air cool to room temperature.

Tensile test specimens were turned from the heat treated specimens. These were then tested until fracture occurred. Then the ends farthest removed from the point of fracture were cut, polished and photographed. After photographs were made, Brinell Hardness readings were taken.

EXPERIMENTAL RESULTS

The experimental results are reported in the following table.

Table V

	BHN	Tensile Strength Lbs. per Sq. In.
As Cast	217	30,560
Quenched at 350° F. for 9 min.	418	39,125
Tempered for 1 hr. at 600° F.	387	36,400
Tempered for 1 hr. at 800° F.	286	36,330
Tempered for 1 hr. at 1000° F.	228	37,500
Quenched at 400° F. for 8 min.	418	33,000
Tempered for 1 hr. at 600° F.	387	42,800
Tempered for 1 hr. at 800° F.	286	37,430
Tempered for 1 hr. at 1000° F.	255	36,120
Quenched at 450° F. for 7½ min.	418	35,370
Tempered for 1 hr. at 600° F.	387	39,340
Tempered for 1 hr. at 800° F.	286	35,370
Tempered for 1 hr. at 1000° F.	255	37,300

DISCUSSION OF EXPERIMENTAL WORK

All specimens were studied by means of the microscope and the metallograph in the unetched condition, then studied after an etch with a 5% Nital solution and photographed at a magnification of 500 diameters.

Figure 8 shows the microstructure of the cast iron as cast. It was a normal structure. The Brinell hardness was 217.

Specimen numbers 2, 3, 4, and 5 were heated to 1480° F., quenched at 350° F. for a period of 9 minutes, then allowed to cool to room temperature. These were then tempered at 600°, 800°, and 1000° F., respectively.

Specimen number 2 is shown in Figure 9. The structure is somewhat acicular. It resembles very closely that which Hilliker and Cohen[5] obtained. This is claimed by these men to be bainite. Figures 10, 11, and 12 show the specimen after tempering for one hour at 600°, 800°, and 1000° F. The principal item to note here is the acicular or needle-like structure. There is some carbon diffusion in the sample tempered at 1000° F. Brinell hardness readings were 321, 367, 286, and 228, respectively.

Specimens 6, 7, 8, and 9 were heated to 1480° F. in the hump furnace then quenched at 400° F. for 8 minutes. Figures 13, 14, 15, and 16 show the microphotographs. These show the quenched structure and the structures when tempered at 600°, 800°, and 1000° F., respectively.

Figure 13 shows the same acicular structure that

Bartholomew[4] obtained when quenching at 510° F. This he called bainite. Figures 14, 15, and 16 are very similar to each other and to Figures 10, 11, and 12. Here is the same needle-like structure and growth of graphite when tempered at 1000° F. Brinell hardness readings were 418, 387, 286, and 255. It is interesting to note here that the BHN values for the tempered specimens are the same for both those quenched at 350° and 400° F. The value at 1000° F. is slightly different. This can be accounted for because the furnace went up to 1050° F. for a short period. The increase in temperature would cause a corresponding decrease in hardness.

Specimens 10, 11, 12, and 13 were heated to 1480° F. and quenched to 450° F. for 7½ minutes. Figures 17, 18, 19, and 20 show the specimens as quenched and tempered for one hour at 600°, 800°, and 1000° F., respectively. In the as quenched condition it resembles the quenched structure at 350° and 400° F. Again the tempered structures give the same general appearance. Brinell Hardness readings were 418, 387, 286, and 255 which correspond exactly to the values of the group quenched at 400° F.

It is significant to note that the hardness after tempering is the same for all groups irrespective of quenching temperature.

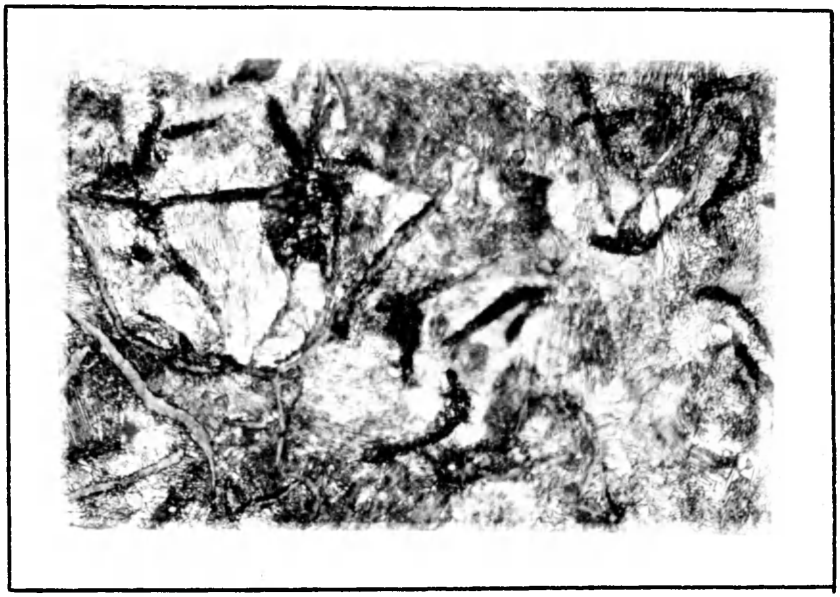
Before sections were cut from the heat treated specimens, tensile test specimens were turned. These were tested until fracture occurred. The section in the grips farthest removed from the fracture were used for microexamination.

The tensile strength tests are not conclusive although the values obtained show increased values of 10% to 40%. All but two of the tensile test specimens broke at the base of the radius of curvature. To overcome this type of fracture several things were tried. These included the changing of grips in the testing machine, using a different testing machine, changing the radius of curvature, and changing the diameter of the central portion of the test piece. Figure 21 shows four types of radii and test sections. Only two specimens failed to break at the base of curvature, one broke in the grips and the other is shown in Figure 21. Other samples of this type broke at the base of the radius.

It is believed by the author that if the standard screw grips as specified by A. S. T. M. could have been used more accurate values of the tensile strength would have been obtained.

Different rates of loading made no apparent change in the values of tensile strengths obtained.

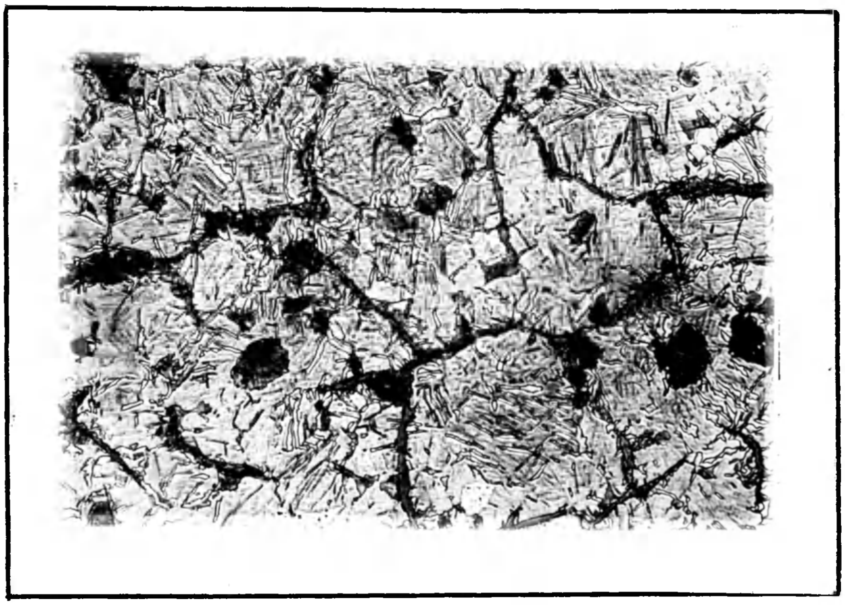
Figure 8



Mag. 500 X

As Cast.

Figure 9



Mag 500 X

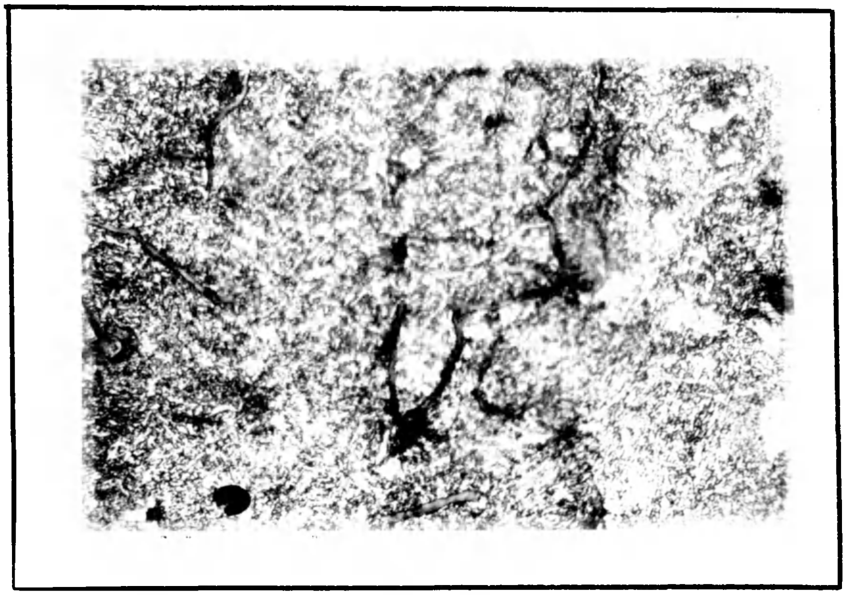
Quenched at 350° F. for 9 minutes.

Figure 10

Mag. 500 X

Quenched at 350° F. for 9 minutes,
tempered at 600° F. for 1 hour.

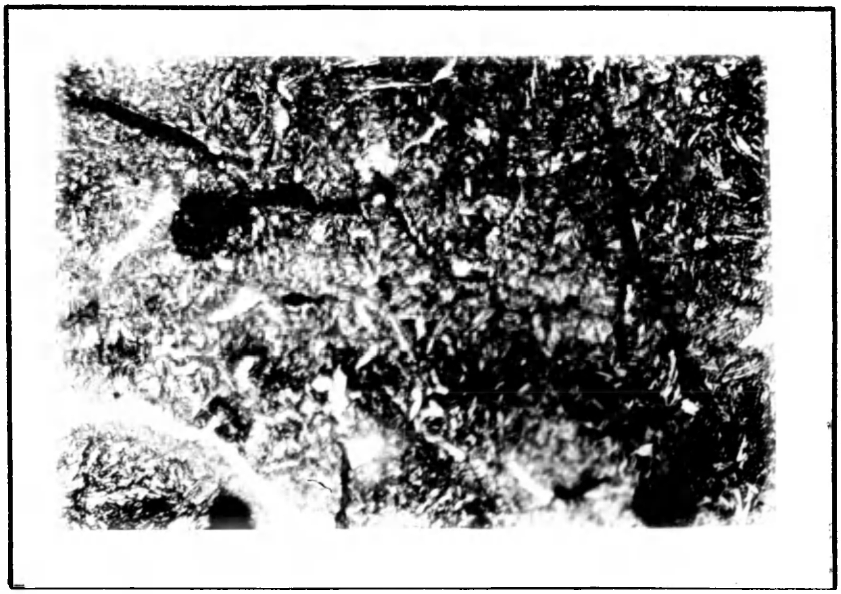
Figure 11



Mag. 500 X

Quenched at 350° F. for 9 minutes, tempered at 800° F. for 1 hour.

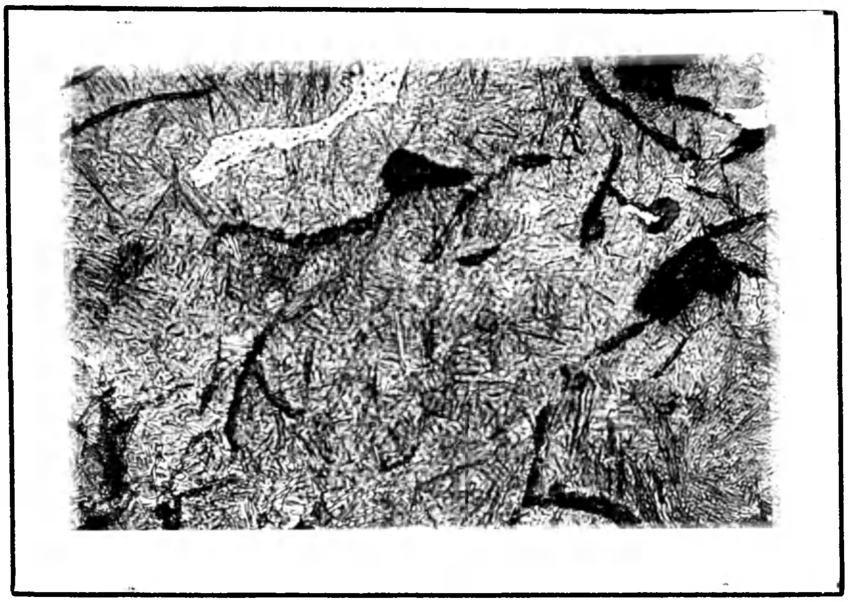
Figure 12



Mag. 500 X

Quenched at 350° F. for 9 minutes,
tempered at 1000° F. for 1 hour.

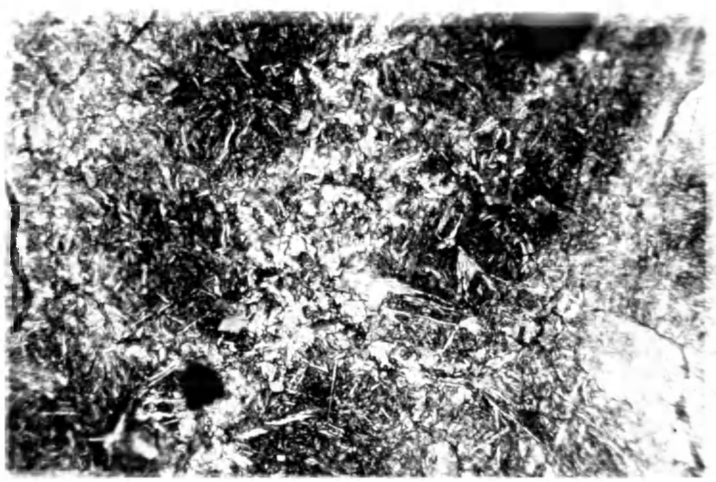
Figure 13



Mag. 500 X

Quenched at 400° F. for 8 minutes.

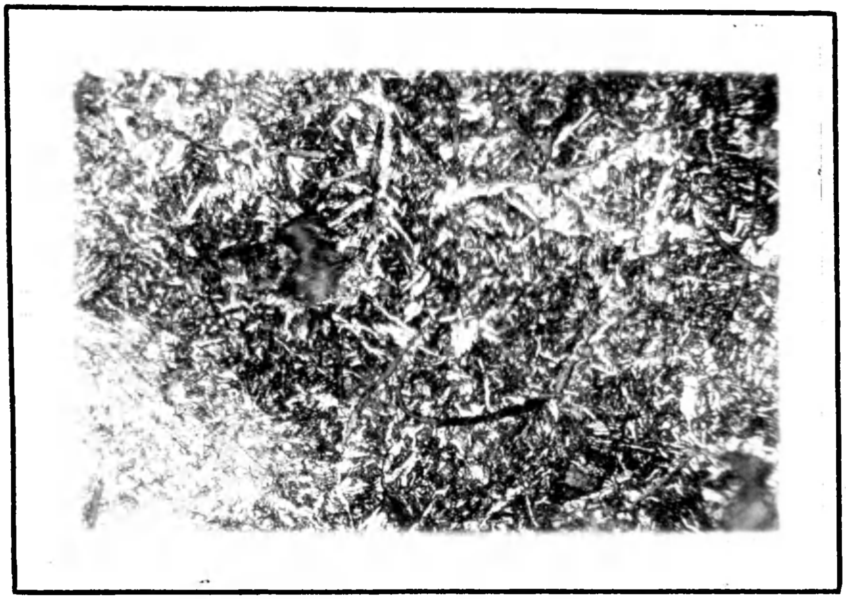
Figure 14



Mag. 500 X

Quenched at 400° F. for 8 minutes, tempered at 600° F. for 1 hour.

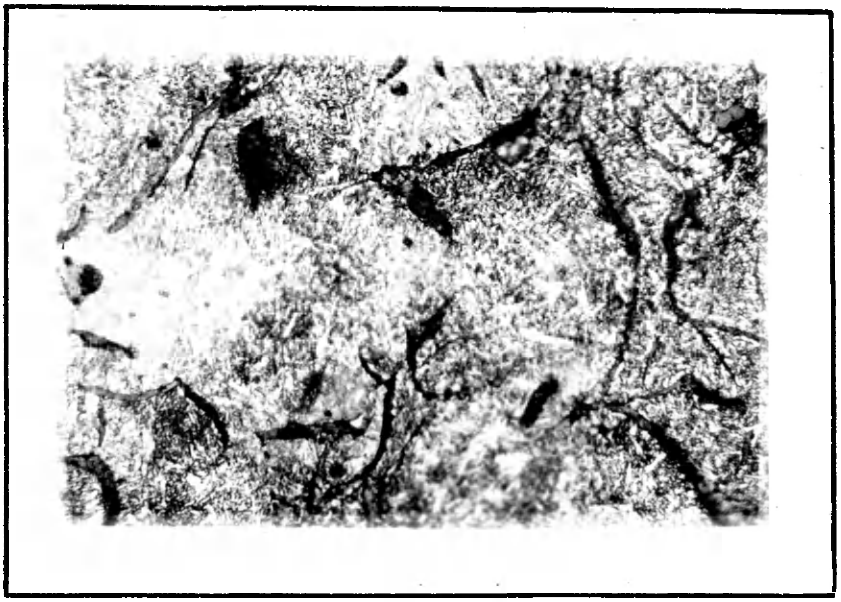
Figure 15



Mag. 500 X

Quenched at 400° F. for 8 minutes,
tempered at 800° F. for 1 hour.

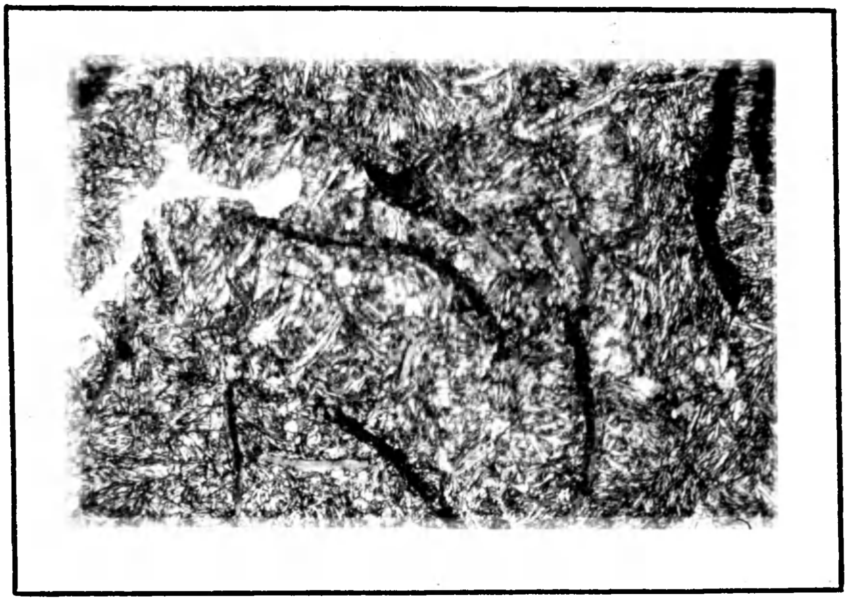
Figure 16



Mag. 500 X

Quenched at 400° F. for 8 minutes,
tempered at 1000° F. for 1 hour.

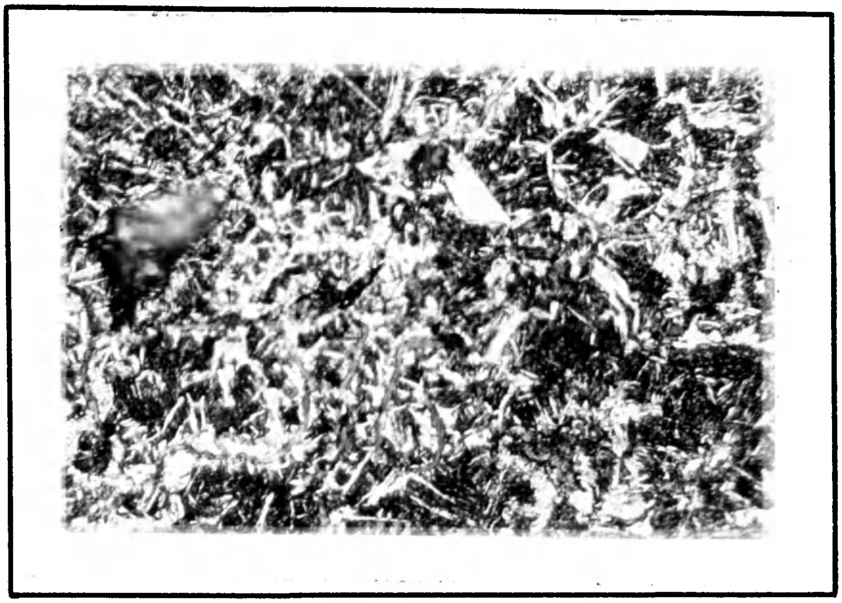
Figure 17



Mag. 500 X

Quenched at 450° F. for 7½ minutes,

Figure 18

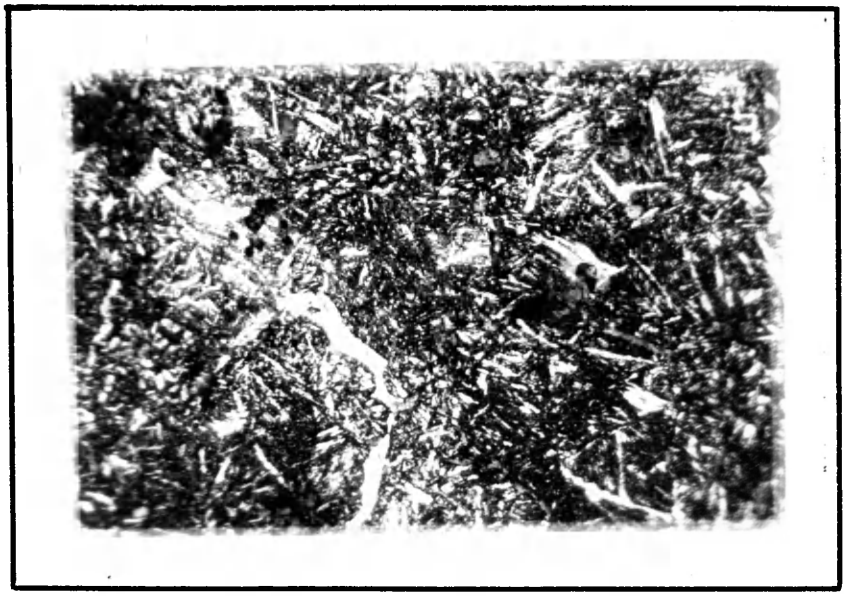


Mag. 500 X

Quenched at 450° F. for 7½ minutes,

tempered at 600° F. for 1 hour.

Figure 19

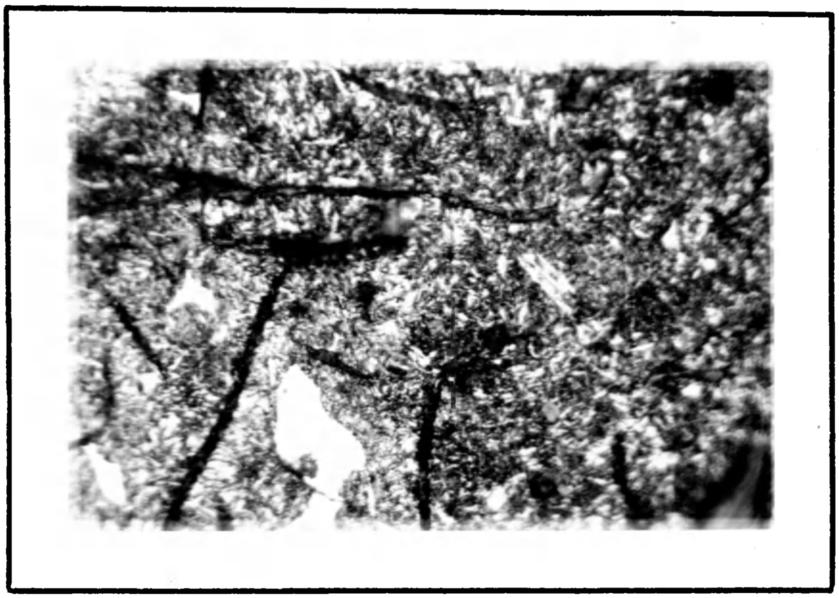


Mag. 500 X

Quenched at 450° F. for 7½ minutes,

tempered at 800° F. for 1 hour.

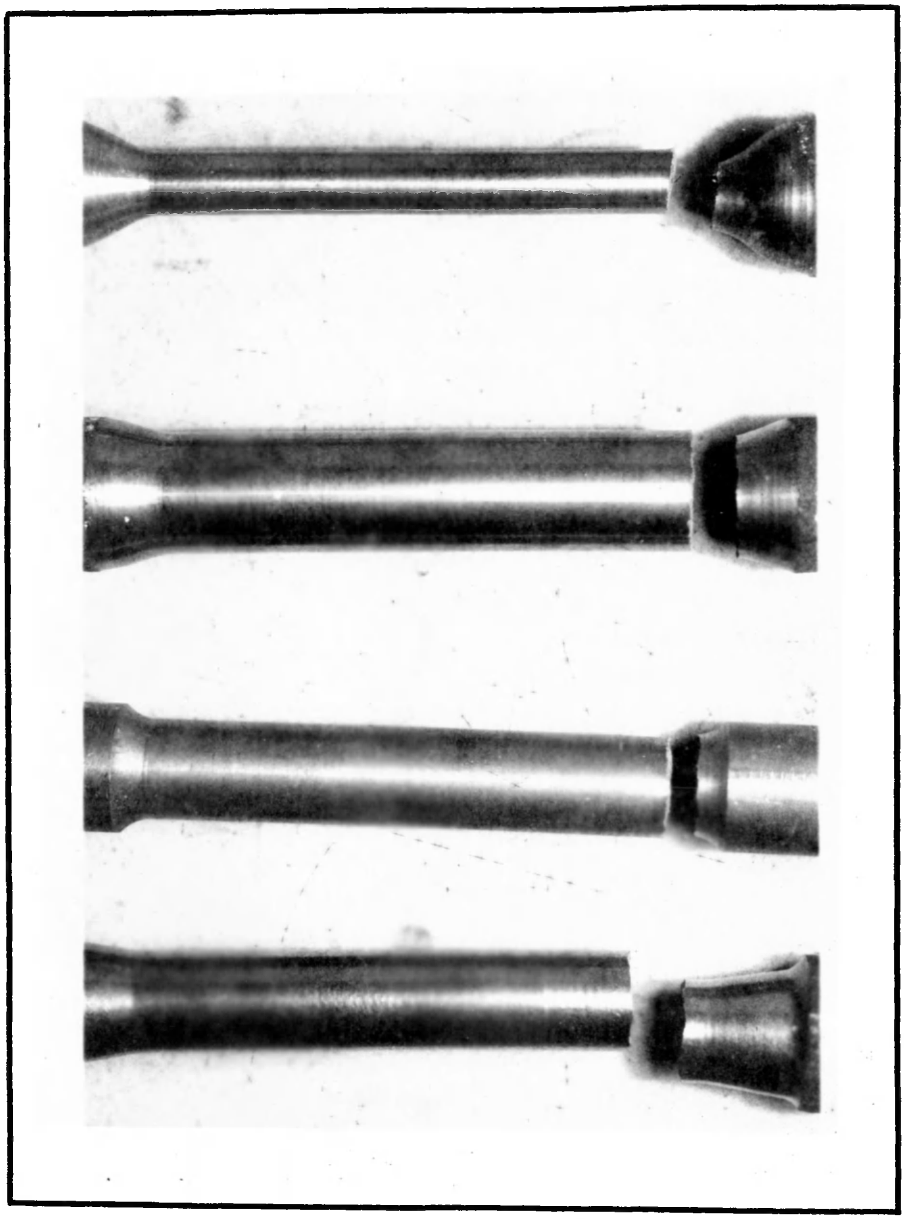
Figure 20



Mag. 500 X

Quenched at 450° F. for $7\frac{1}{2}$ minutes, tempered at 1000° F. for 1 hour.

Figure 21



Test specimen showing section fracture.

CONCLUSIONS

After completion of the experimental work and a study of the results, the following conclusions were drawn.

1. An acicular structure like that of bainite was obtained upon quenching isothermally.

2. Isothermal quenching increased the hardness.

3. Isothermal quenching increased the tensile strength.

4 If screw grips as specified by A. S. T. M. were used, the tensile test values would be more accurate and probably higher than those otherwise obtained.

5. When specimens are isothermally quenched and then tempered, the tempering temperature will govern the resulting hardness provided the tempering temperature is higher than the quenching temperature and the specimens are tempered for one hour.

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