THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Lehan Hamlin for the degree of Mechanical Engineer They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Mechanical Engineer

John J. Flather
Chairman

Oscar E. Harder

J. H. Rowen

Date June 3, 1922

10-20 5M

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The Impact Properties of
Carbon and Chrome-Nickel Steels.

A Thesis

Submitted to the Graduate Faculty

of the

University of Minnesota.

by

L.H. Hamlin

C.A. Johnson

In partial fulfillment of the requirements

for the

degree of

Mechanical Engineer

June

1922

TABLE OF CONTENTS.

THE IMPACT PROPERTIES OF CARBON AND CHROME-NICKEL STEELS.

I. INTRODUCTION

Purpose and Scope of the Investigation.

This investigation was undertaken for the following objects: 1st, to determine the best heat treatment for the development of impact strength of selected carbon and chrome-nickel steels; 2nd, to determine the relation of drawing temperature to impact properties; 3rd, to compare the impact properties of specimens which have been quenched in water from the draw with those air cooled; 4th, to correlate the impact properties of steel with micro-structure; 5th, to determine the relation of Brinell hardness number to impact property.

With these objects in mind the following S.A.E. steels were investigated:- 1025,1035,1045,3120,3130, and 3140. For those who are not familiar with the steel numbers used by the Society of Automotive Engineers it may be said that the first two numbers indicate the kind of steel (carbon or alloy) and the last two numbers indicate the nominal carbon content. Thus, in the number 1025 the 10 indicates a carbon steel and the 25 indicates a nominal carbon content of .25%. Similarly, in the number 3120 the 31 indicates a chrome-nickel steel of 1 to 1.5% nickel and .45 to .75% chromium and the 20 indicates a nominal carbon content of .2%. These steels were selected because they are extensively used for parts which are subjected to impact. Throughout the work heat treatments recommended by the S.A.E. were used so that the relative value of these steels in the automotive industry could more readily be compared.

Time was lacking to complete the study of the microstructure of all the steels investigated, and as a result this study was confined to the 1035 steel because the increase of impact in this steel is very marked when a drawing temperature of 300 C° or higher is reached.

Acknowledgement.

We thank the following for their assistance in this investigation: Prof. Flather who permitted us to do our thesis work in the Department of Metallography of the School of Mines and who also allowed us to use the machine shop of the Department of Mechanical Engineering for preparing test specimens; Dr. Harder who directed the investigation and assisted us in outlining the method of procedure; Mr. Nilson who assisted us in preparing test specimens; Miss Green who assisted in the photographic work.

II. DISCUSSION OF PREVIOUS WORK.

Impact toughness an independent property of steel.

It is only recently that technical men have realized that impact toughness is an independent property of steel and cannot be determined by the usual static tests. Dr. Hoyt[1] defines toughness in steel as follows: "tough materials are

1. Static, Dynamic and Notch Toughness. S. L. Hoyt. Bulletin of the American Institute of Mining and Metallurgical Engineers - Feb. 1919.

those which offer considerable resistance to permanent deformation but which, once such resistance is overcome, may be deformed plastically but only by the expenditure of considerable energy". Toughness may be static or dynamic, continues Dr. Hoyt; dynamic toughness implies resistance to suddenly applied loads; static toughness implies resistance to slowly applied loads. Dynamic toughness is independent of static toughness; it has been experimentally proven that a steel may have high static toughness and yet be incapable of resisting sudden impact. Static toughness may be greater than, equal to or less than dynamic toughness. This property is also known as impact toughness and because this latter term is more common it shall be used exclusively in this discussion.

The term "notch toughness" is often encountered in articles on impact properties of steel. Now a steel part is considered to be in the notched condition when there is an abrupt change in cross section in the part; the stress in such a part is similar to that in a notched bar. Experiments by Koenigsberger[1] have shown that the neutral axis of a notched bar is shifted toward the notch so as to increase the distance to the extreme fiber opposite the notch. The result is that the stress in the extreme fiber is greatly increased and, unless a large factor of safety was used in the design, failure will occur. If a steel has the ability to resist large forces when in the notched condition it has "notch toughness".

[1]Proc. 4th. Congress Intern. Assoc. for Testing Materials, Brussels, 1906 Poper c4d

Many steel parts are subject to the notch effect because of faulty design, or faulty workmanship or the necessities of construction. Consequently, it is essential for the designer to know how a notched part will resist impact forces to which it may be subjected. Dr. Hoyt asserts that the Charpy machine makes it possible to obtain this information and he believes that impact toughness should be included in specifications.

Previous Investigations.

Impact testing machinery and testing procedure have been developed largely by European investigators within the past twenty-five years. Among those prominent in this development are Charpy, Ehrensberger, Cornu-Thenard, Fremont, Barba and Ast. In 1909 Charpy[1] reported the results of his work to the International Society for Testing Materials. The outcome of Charpy's work is the standard Charpy impact testing machine which has been extensively used with satisfactory results.

Many technical men believe that the Charpy machine is affected by a number of unknown variables which invalidate the results. Charpy has answered the contentions of these men in an article in the Journal of the Iron and Steel Institute 1917 p.61. This article is a report of tests performed by Charpy and Cornu-Thenard to determine the reliability of the Charpy machine. Specimens of the same chemical composition and static properties were used in their experiments. From many tests they found that if the temperature of rolling were constant, if the superficial layers were removed from the steel

[1]Report on Impact Tests of Metals. G. Charpy.
Proc. Inter. Association for Testing Materials. 1909.

after rolling, and if the specimens were heat treated uniformly, or in other words, if the specimens were homogenous the average error recorded by the Charpy machine ranged from .7 to 2.7% on a .33% carbon steel and from 1.2 to 3.6% on a semi hard nickel steel. These figures show that the machine is well within the limits of commercial accuracy for tests of similar character.

Charpy investigated the influence of various factors which might affect the accuracy of his machine. He studied the effect of varying the height of fall of the pendulum and the effect of varying the mass of the pendulum; he found that the variations in results due to varying the height of fall and mass of the pendulum were within the limits of experimental error. Charpy calls attention to the fact that in the experiments on the influence of the mass of the pendulum the specimen was of such size as to absorb practically all the energy of small the machine and to absorb but a small fraction of the energy of the large machine. He further states that the height of fall may vary as 7:1 while the residual rate of speed varies as 12:1 without causing the duration of impact to vary more than .0015 to .0062 seconds; this variation will not affect the results of the machine. Charpy found that varying the weight of the anvil did not affect the results.

Dr. Langenberg, metallurgist of the Watertown Arsenal, one of the foremost authorities on impact testing in this country, has reported favorably regarding the Charpy machine. The arsenal has been equipped with Charpy impact testing machinery for several years. Dr. Langenberg has used this machinery for both experimental and routine testing with satisfactory results. Because of the wide diversity of conditions which control impact service he believes that the impact test is useful for comparative purposes only. The results of the Charpy machine cannot be used for calculations as in the case of tensile tests because there is no known law for calculating the resistance to rupture which a bar of known dimensions will offer under impact. In the Bulletin of the American Institute of Mining and Metallurgical Engineers 1919 p. 1471 Langenberg tells how the Charpy machine enabled him to construct satisfactory gun forgings by revealing the deficient impact properties of forgings which had failed in service.

Recently, the British Engineering Standards Association published Report 75 which is the outcome of an extensive investigation to determine the mechanical properties of British Standard Wrot Automobile Steels. The research was conducted jointly by the Steel Research Committee of the Institute of Automotive Engineers and the Society of Motor Manufacturers and Traders. A large number of men were engaged in the investigation and three independent sets of data were obtained. The committee selected the final accepted values by noting the tendency of many curves plotted from the original data. The Charpy and Izod impact values of three steels which come within the range of the present investigation have been replotted. The curves are shown in figures 1, 2, and 3.

Figure 1 shows the impact drawing temperature curves for a steel of .25% actual carbon content; figure 2 shows the corresponding curves for a steel of .45% actual carbon content;

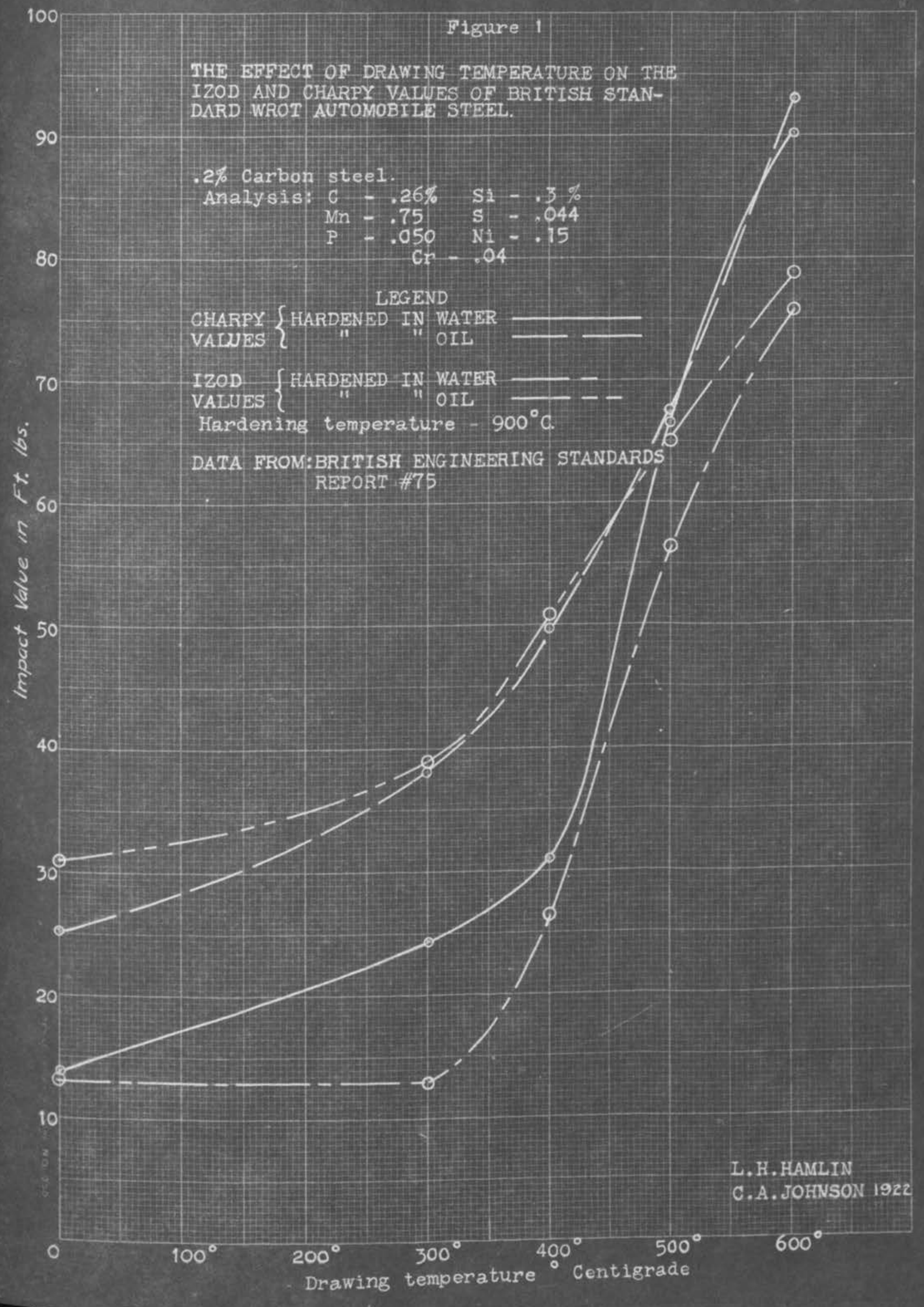


Figure 1
THE EFFECT OF DRAWING TEMPERATURE ON THE IZOD AND CHARPY VALUES OF BRITISH STANDARD WROT AUTOMOBILE STEEL.
.2% Carbon steel.
Analysis: C - .26% Si - .3 %
Mn - .75 S - .044
P - .050 Ni - .15
Cr - .04
LEGEND
CHARPY VALUES { HARDENED IN WATER
" " OIL
IZOD VALUES { HARDENED IN WATER
" " OIL
Hardening temperature - 900°C.
DATA FROM: BRITISH ENGINEERING STANDARDS REPORT #75
L.H.HAMLIN
C.A.JOHNSON 1922
Impact Value in Ft. lbs.
100
90
80
70
60
50
40
30
20
10
0
100°
200°
300°
400°
500°
600°
Drawing temperature ° Centigrade

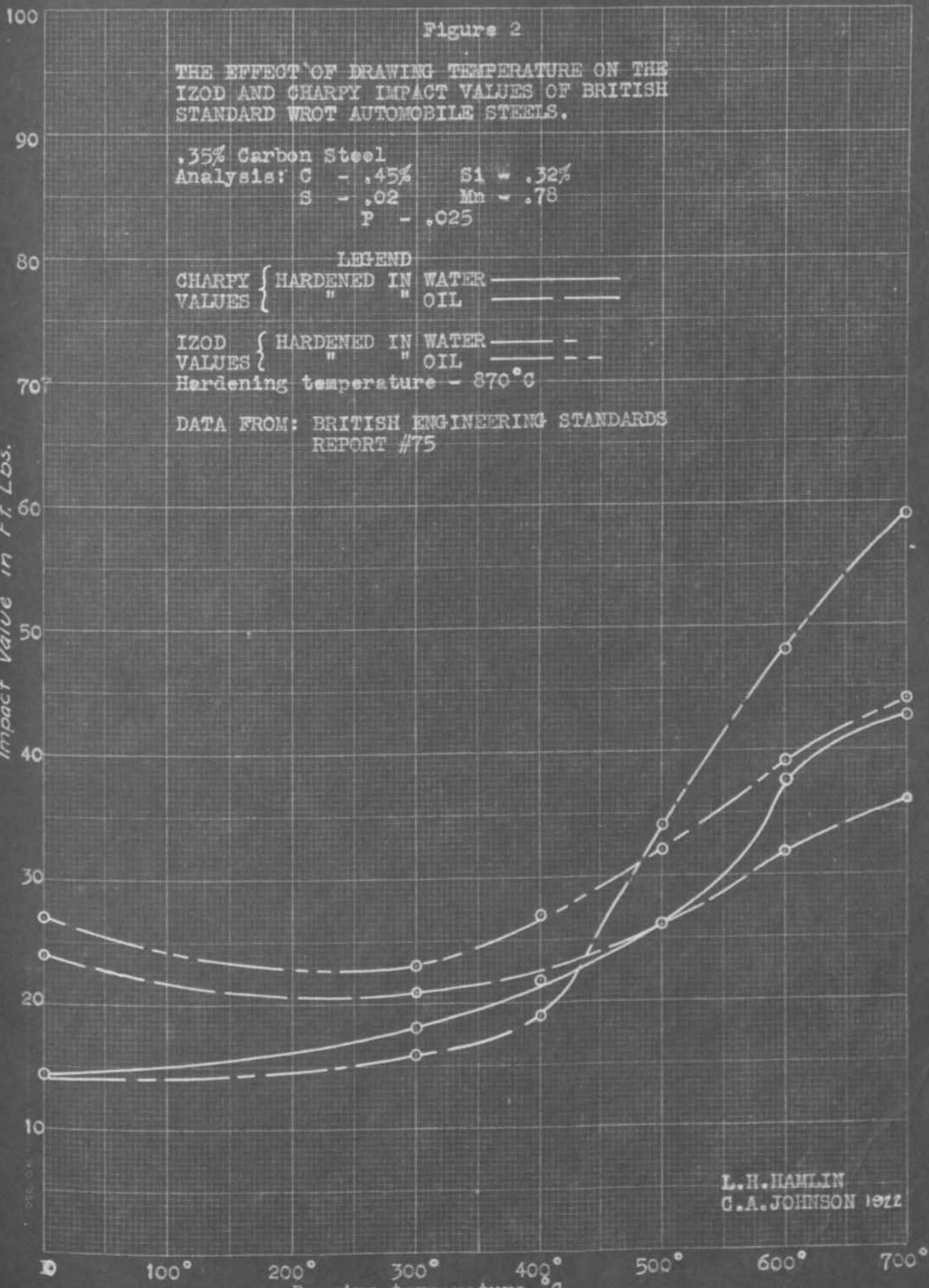


Figure 2
THE EFFECT OF DRAWING TEMPERATURE ON THE IZOD AND CHARPY IMPACT VALUES OF BRITISH STANDARD WROT AUTOMOBILE STEELS.
.35% Carbon Steel
Analysis: C - .45% Si - .32%
S - .02 Mn - .78
P - .025
LEGEND
CHARPY VALUES { HARDENED IN WATER
" " OIL
IZOD VALUES { HARDENED IN WATER
" " OIL
Hardening temperature - 870°C
DATA FROM: BRITISH ENGINEERING STANDARDS REPORT #75
Impact Value in Ft. Lbs.
100
90
80
70
60
50
40
30
20
10
0
100°
200°
300°
400°
500°
600°
700°
Drawing temperature °C.
L.H.HAMLIN
C.A.JOHNSON 1922

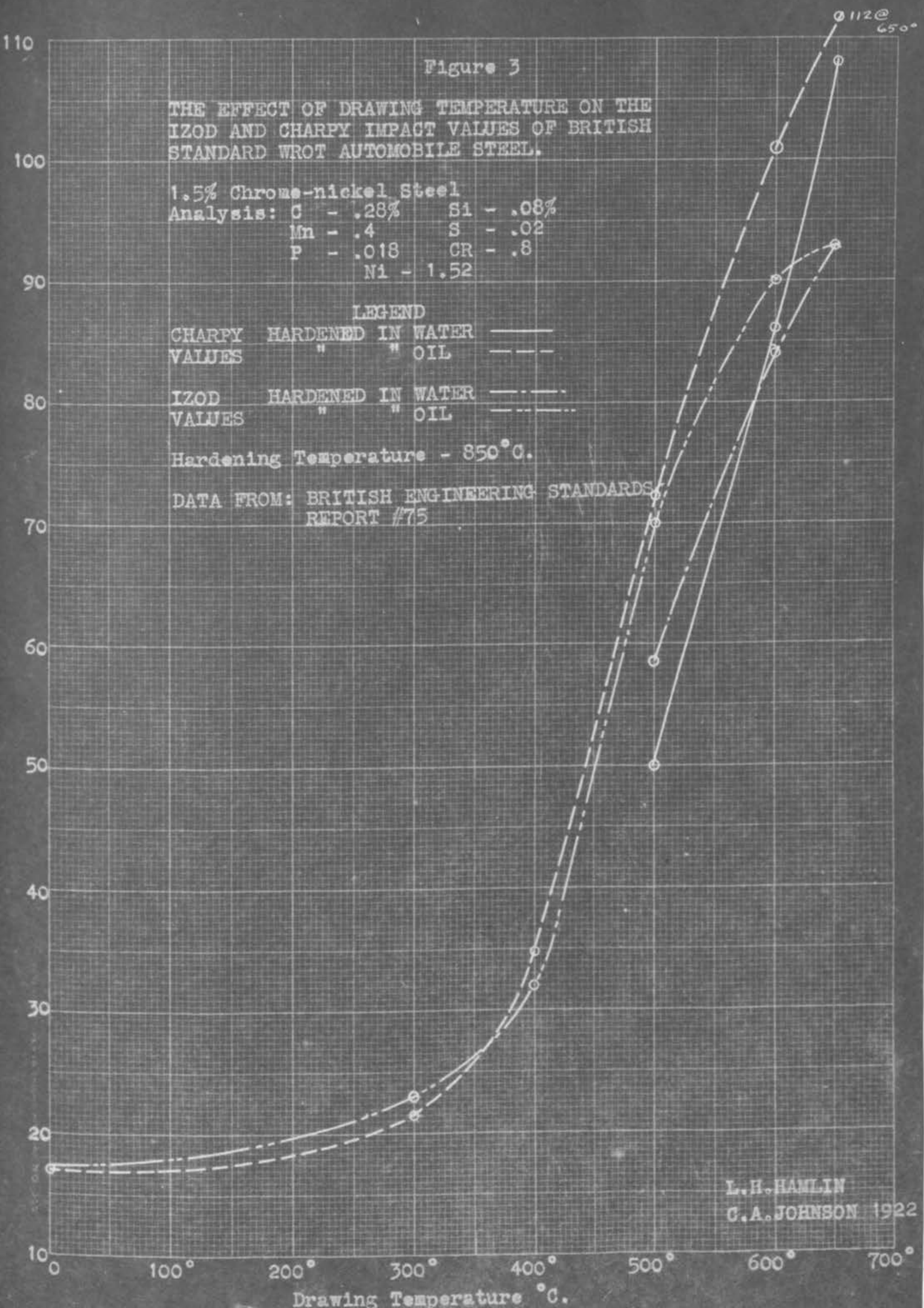


Figure 3
THE EFFECT OF DRAWING TEMPERATURE ON THE IZOD AND CHARPY IMPACT VALUES OF BRITISH STANDARD WROT AUTOMOBILE STEEL.
1.5% Chrome-nickel Steel
Analysis: C - .28% Si - .08%
Mn - .4 S - .02
P - .018 CR - .8
Ni - 1.52
LEGEND
CHARPY VALUES HARDENED IN WATER
" " OIL
IZOD VALUES HARDENED IN WATER
" " OIL
Hardening Temperature - 850°C.
DATA FROM: BRITISH ENGINEERING STANDARDS REPORT #75
112@ 650°
110
100
90
80
70
60
50
40
30
20
10
0
100°
200°
300°
400°
500°
600°
700°
Drawing Temperature °C.
L.H.HAMLIN
C.A.JOHNSON 1922

figure 3 shows the curves for a chrome-nickel steel containing 1.52% nickel, .8% chromium and .28% carbon. These steels are comparable to the S. A. E. 1025, 1045 and 3130 respectively.

The .26% carbon steel has much the better impact values of the two carbon steels. The best recorded Charpy value on the .26% carbon steel is 90 ft. lbs. and the best for the .45% carbon steel is 42 ft. lbs. This clearly shows the superior impact properties of the low carbon steel.

The curves in figure 1 show a characteristic form. There is little rise until 300° is reached, where the typical curve starts to rise abruptly and at 400° the curve is rising very rapidly in an approximately straight line. It is noticeable that the curves for the oil hardened specimens are not so steep as those for the water hardened specimens. The oil hardened specimens have almost twice the impact strength of the water hardened specimens in the hardened and undrawn condition; but as the drawing temperature is increased the difference becomes less until at 500° the Charpy curves are practically coincident and the Izod curves are separate by a comparatively small percentage.

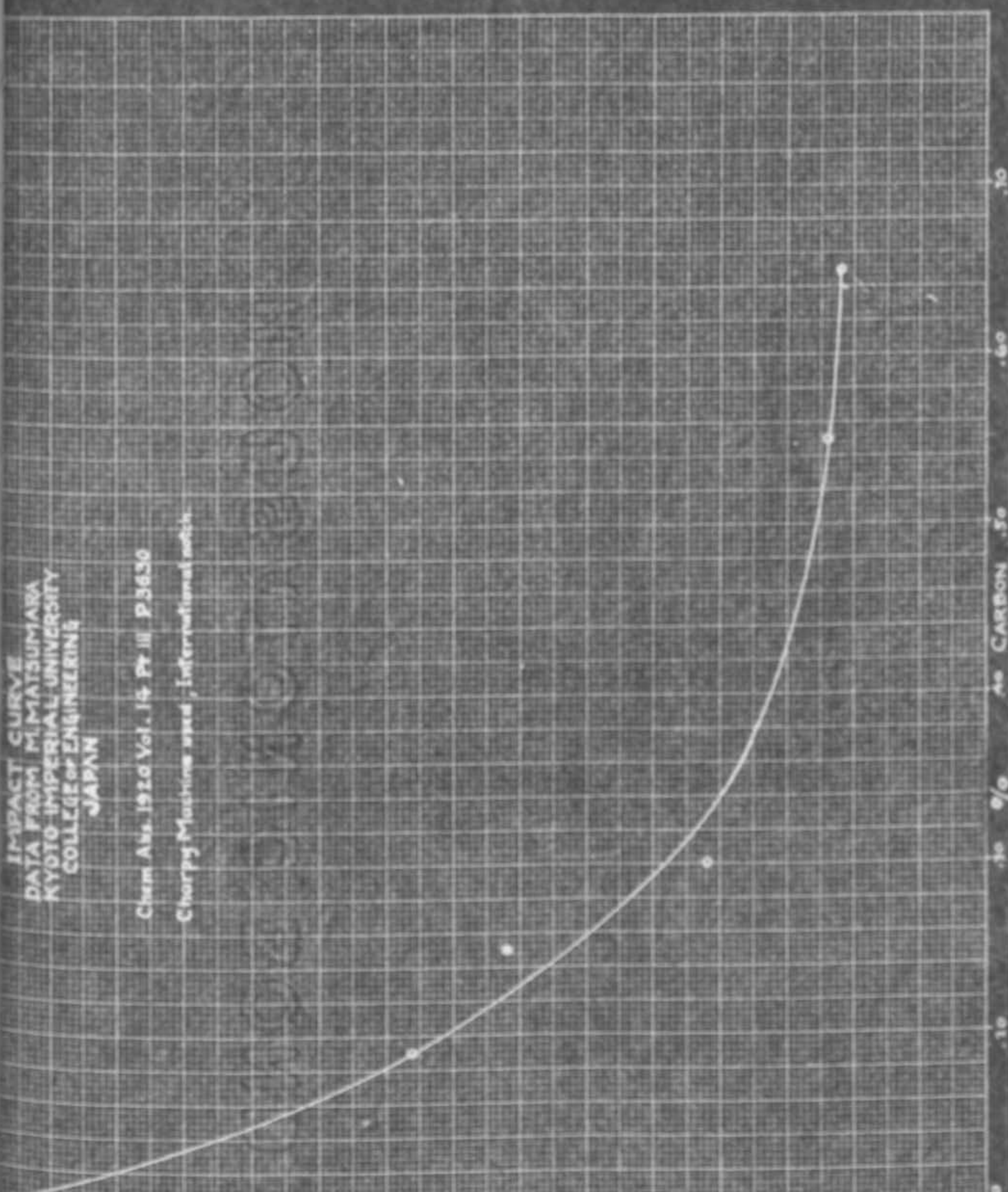
The curves of figure 2 indicate that the .45% carbon steel has relatively low impact properties. With the exception of the Izod curve for water hardened specimens, the highest impact value is 44 ft. lbs. for a specimen quenched in oil and drawn at 700° C, and in the hardened and undrawn condition the same steel registers 27 ft. lbs. This is not comparable to the large increase in impact value which was noted in the .26% carbon steel. The data which were obtained in the present investigation on the S.A.E. 1045 steel indicated a similar lack of impact strength. Referring again to figure 2 it may be possible that the Charpy data for 700° draw is erroneous for the water hardened steel. The curve shows a rise at 500° but the curve flattens at 600° on account of the low 700° value. If there be such an error, however, it would probably not be large enough to allow a substantial increase in impact value when rectified. In general it is concluded that this steel is not capable of developing the best impact properties.

The curves in figure 3 indicate the excellent impact properties which a low carbon chrome-nickel steel will develop under the right heat treatment. The Charpy curve for oil hardened specimens shows an increase in impact value from 16.6 ft. lbs. in the hardened condition to 112 ft. lbs. as hardened and drawn at 650°. The general shape of the curves is similar to that of the .26% carbon steel, the increase is even more marked but occurs at a higher drawing temperature. It is noticeable how closely the Izod and Charpy values check; there is little variation until the high draw is reached. The curves for water hardened specimens are not complete because the committee did not recommend values from the original data. The available data indicates that in the undrawn condition oil hardened specimens have higher impact strength than those which have been water hardened; the difference, however, becomes less as the drawing temperature is increased and is nearly zero at 650°.

Figure 4 shows the results obtained by Prof. M. Matsu-

Figure 4

20 DIVISIONS PER INCH



mura of Kyoto Imperial University from a series of tests on the impact properties of carbon steels varying from .12% to .65% carbon. This curve is almost a rectangular hyperbola and shows that the impact properties of carbon steels vary inversely as the carbon content. Prof. Matsumura does not state what condition the steels were in when tested. The natural assumption is that they were all subjected to a similar heat treatment.

III. METHODS OF PROCEDURE, APPARATUS AND MATERIALS

Preparation of Test Specimens

Normalizing. - The stock from which the test specimens were made was first normalized. Normalizing is defined by the S.A.E. specifications as "heating above the upper critical temperature followed by freely cooling in air". The purpose of this operation is to remove undesirable properties which may be developed in steel by an excessively high rolling temperature or by mechanical working. Heating at a temperature well over the upper critical tends to make the steel homogenous and to dissolve the excess cementite or ferrite which may be present; cooling freely in air prevents segragation of these constituents except in a very finely divided condition. The normalized steel can be annealed to refine the grain.

The carbon steels were normalized for 15 minutes and the chrome-nickel for 30 minutes at temperature recommended by the S. A. E. The chrome-nickel steels were furnace cooled but have been referred to as normalized because an examination of the microstructure showed them to be in a pearlitic condition.

Machining. - The standard Charpy impact specimen is shown in figure 5. This specimen is .354" square and 2.165" long. (10 x 10 x 55 m.m.) There is a notch cut half way through or .197"; this notch is located in the center of the specimen and is .039" wide. The bottom of the notch is rounded to a radius of .026".

The test specimens were made from 3/4" round bars. After normalizing the bars were sawed into 4.5" lengths, sufficient material for two specimens. These pieces were roughed down to .405" in a shaper. It was necessary to square up two sides in a milling machine in order to be able to finish the pieces accurately. In the milling operation .005" was removed from each of the two sides thus leaving the pieces .4" square. They were finished to .394" square by grinding; the milled sides served as guides in this operation. A magnetic chuck was designed and constructed (fig.6) to hold the specimens during the grinding operation. This chuck was satisfactory but was discarded for a larger chuck which arrived in the machine shop after the first series of specimens had been finished. The product of the machining operations thus far described was a piece 4.5" by .394" square. To finish this piece it was sawed in two and the halves ground to 2.165". A 3/32" hole was drilled in one end to permit the insertion of a wire to hold the specimen during the heating operation.

Marking. - For the purpose of identification specimens were marked - thus: carbon steels with the nominal carbon content and the chrome-nickel steels with the stock number. The

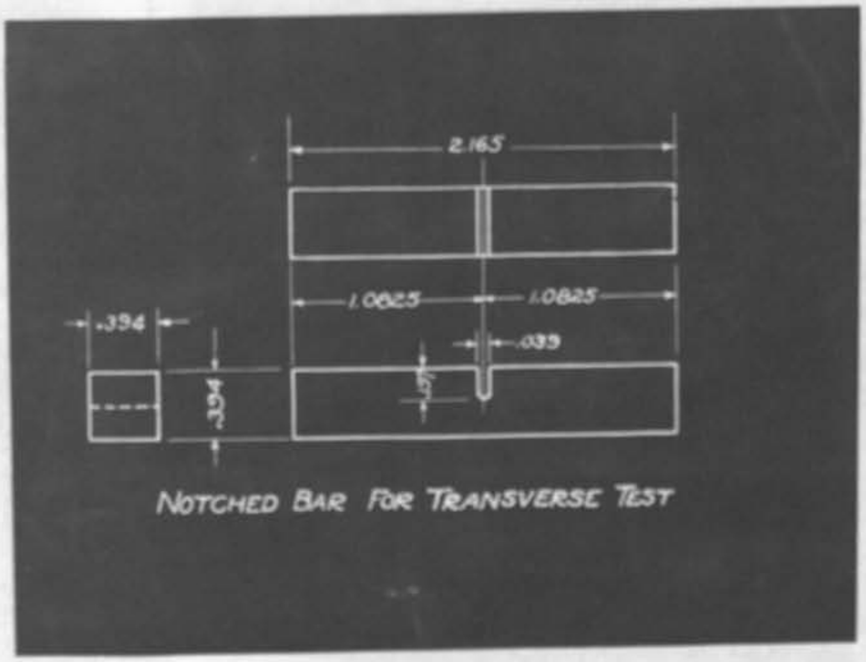
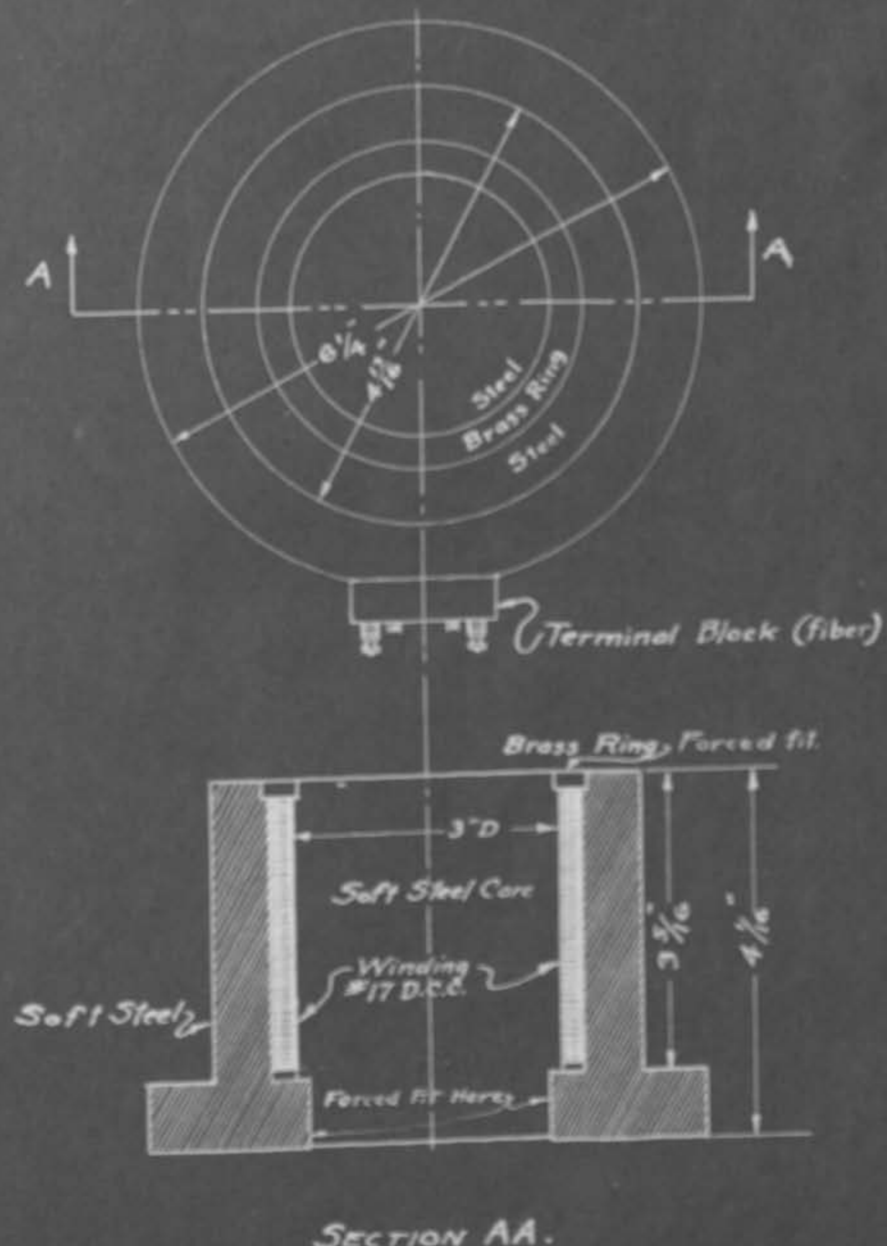

2.165
1.0825
1.0825
.394
.039
.394
.157
NOTCHED BAR FOR TRANSVERSE TEST

Figure 5

Figure 6a

MAGNETIC CHUCK

Scale - $\frac{1}{2}$ Size



SECTION AA.

L. H. Hamlin
C. A. Johnson
1922

stock number of the 3120 steel is 82, of the 3130 - 83, of the 3140 - 84. With the exception of the 1045 steel the heat treatments were indicated by these marks: H indicates a hardened specimen; N a normalized specimen; A a specimen which has been hardened, drawn and air cooled from the draw; W a specimen which has been hardened, drawn and quenched in water from the draw. The drawing temperature is indicated by the number of hundred degrees; for example, 2 indicates 200° C. The tests were made in triplicate and in order to differentiate members of a group they were marked with one dot, two dots and three dots respectively. An example of our marking system is 25 A 4· ; this indicates a specimen of S.A.E. 1025 steel which has been hardened, drawn at 400° C and air cooled from the draw. The dot indicates that the specimen is the first one of the group.

The heat treatments of the 1045 steel were indicated as follows: A-oil hardened and air cooled from the draw; B-oil hardened and water cooled from the draw; C-water hardened and air cooled from the draw.

Notching. - All specimens were notched after heat-treating. Dr. Langenberg in a letter to Dr. Harder states that it is impossible to obtain reliable results from specimens which have been notched before heat-treatment. Non-uniform strains are caused around the notch and this introduces an unknown variable. A milling machine was used to notch the test specimens. On account of the high cost of an accurate milling cutter a No. 18 screw slotting cutter which was .04" thick was substituted. The teeth of this cutter were ground to approximately the specified form. Inasmuch as all the specimens were notched by the same kind of cutter the fact that this cutter was not exactly accurate does not affect the comparative value of the data.

Preliminary Heat Treating Experiments

The procedure which is outlined under this section and the final heat treating procedure which is outlined under the next section were followed in testing each steel except the 1045. The procedure followed in testing this steel is described under the separate discussion.

Effect of temperature. - The object of the first series of tests on each steel was to determine which hardening temperature to use in order to develop maximum impact strength. The recommended S.A.E. hardening temperature was used as a base from which a range of temperatures varying by increments of 10°C was selected. This range was usually 50°C. Duplicate tests were then made using these selected temperatures. A lead bath heated in a gas furnace was the heating medium and the duration of the hardening heat was 10 minutes. Water was used as a quenching medium. After hardening, the specimens were drawn at 500°C for 30 minutes in an electric muffle furnace and cooled freely in air. A drawing temperature of 500°C was used because it was desired to develop high impact strength so as to make a comparison of the results more effective. When the heat treatment was complete, the specimens were notched and tested in the Charpy machine.

Effect of time. - The object of this series of tests was to determine the duration of hardening heat which should be used to develop maximum impact strength. A time range of 10 to 40 minutes with increments of 10 minutes was used. The hardening temperature was selected from the preceding series of tests and the procedure was similar to that of the first series. The tests were in duplicate, the lead bath was the heating medium, and the specimens were drawn for 30 minutes at 500°C with subsequent air cooling. They were then notched and tested.

Heat Treatment and Procedure for Final Tests

Heat treatment. - Upon Dr. Harder's advice it was decided to investigate the relative merits of air cooling from the draw and water quenching from the draw as means of developing the maximum impact properties of steel. The results of some previous investigations[1] indicate that steels which are air cooled from the draw have low impact properties; this phenomenon is called "blue brittleness". It is avoided by quenching in water from the draw. The property of "blue brittleness" is said to be more marked in chrome-nickel steels than in carbon steels. Consequently two series of tests were made: one series of specimens were air cooled from the draw, the other water quenched. The tests were made in triplicate because three specimens was considered the least number which would afford a reliable check. The heating medium for the final heat treatment was the lead bath. Water was used for the quenching medium for all steels except the 3140 for which oil was used. The hardening temperature and the duration of the hardening heat were determined from the data ob-

[1]Physical Changes in Iron and Steel Below the Thermal Critical Range. Jeffries Min. & Met. Eng. 1920 #158 sec.20.

tained in the preliminary tests. The electric muffle furnace was used for the drawing operations. The carbon steels were tested in the normalized and hardened condition but the Chrome-nickel steels were not tested in these conditions because of a shortage of specimens.

Impact tests. - The Charpy machine of the Department of Metallography, School of Mines, was used for all impact tests in this investigation. The physical constants and calibration of this machine are given in figure 6A.

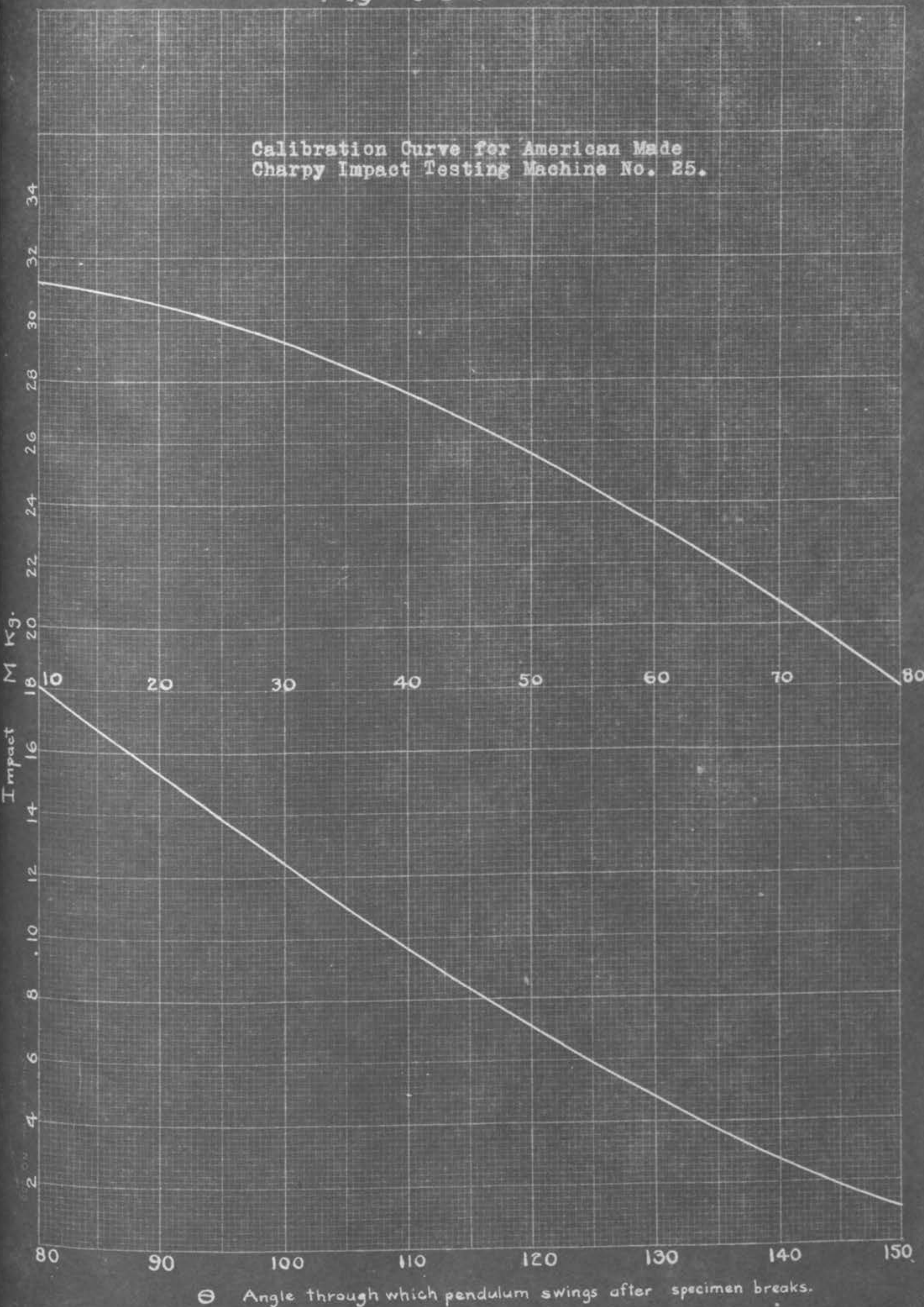
Brinell hardness tests. - One of the halves of each broken specimen was given the Brinell hardness test. The test was made near the center of one lengthwise face. The diameter of the impression was measured twice at right angles and the results averaged.

Examination of Fractures and Micro-structure

The fractures of the broken specimens were examined and representative specimens were photographed. These photographs are shown and discussed elsewhere in this report.

As before stated the study of micro-structure was confined to the S.A.E. 1035 steel. A representative specimen was selected from each group and a section across the fracture was ground, polished and etched. This was examined under a magnification of 1000 diameters, and a photomicrograph was taken near one edge of the section.

Figure 6A


Calibration Curve for American Made
Charpy Impact Testing Machine No. 25.
Impact M Kg.
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
θ Angle through which pendulum swings after specimen breaks.

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Department of Metallography.

Calibration of Charpy Impact Testing Machine, No.25

Given:

H = 1.348 meters (Height at which pendulum begins to oscillate).
W = 23.19 Kg (Weight of pendulum)
R.C.G. = 69.5 cm. (Radius in centimeters to the center of gravity).

Determined:

$\theta = 159°$ for h_o when h_o = height to which pendulum rises in the first free swing.

Let h = the height of swing after breaking specimen,
θ = the angle through which pendulum swings after breaking the specimen.

Then:

$\Delta h = h_o - h$

Δh in meters x W = E (Energy absorbed in breaking test piece, in Meter Kilograms).

Formulae:

$h = 69.5\ (1 - \cos\theta)$ for θ = 0 to 90°.
$h = 69.5\ (1 + \sin\theta - 90°)$ for θ = 90 to 159°.
$h_o = 69.5\ (1 + \sin 69°) = 69.5 + 64.9 = 134.4$.
$\Delta h = 134.4 - 69.5\ (1 - \cos\theta)$ for θ = 0 to 90°.
$\Delta h = 134.4 - 69.5\ (1 + \sin\theta - 90°)$ for θ = 90-159°.

Data:

θ	Δh	E MKg	E Ft.lbs.
159	0	0	0
155	.019	0.44	3.20
150	.047	1.09	7.92
140	.1166	2.72	19.64
130	.2022	4.71	34.06
120	.3005	7.00	50.62
110	.4117	9.59	69.35
100	.5283	12.28	88.79
90	.649	15.12	109.32

θ	Δh	E MKg	E Ft.lbs.
80	.7695	17.92	129.63
70	.8863	20.64	149.30
60	.9965	23.21	167.86
50	1.0958	25.52	184.59
40	1.1814	27.52	199.01
30	1.2510	29.14	210.74
20	1.3021	30.32	219.34
10	1.3335	31.06	224.64
5	1.3413	31.24	225.95
0	1.344	31.30	226.40

Note: MKg per sq.cm. x 46.5984 = Ft-lb per sq.in.
MKg/sq.in. x 2.2 x 3.28 = Ft.lbs/sq.in.

A short method of finding the area of a segment of a circle (necessary when round samples are used) may be found in Carnegie Steel Co's "Pocket Companion," page 394.

IV. RESULTS AND DISCUSSION OF S.A.E. 1045 STEEL.

Composition

C .49% Mn .65 Si .21 S.049 P.042

Preliminary Heat Treatment

The S.A.E. 1045 steel was the first one tested and the method of procedure used on this steel was different from the procedure subsequently adopted. For a preliminary test a specimen was heated at 800°C (S.A.E. 803 - 829°C) for 20 minutes in a gas muffle furnace, quenched in water and examined for micro-structure. It was found to be in the martensitic condition with no trace of free ferrite and this was considered to be evidence of a satisfactory heat treatment. Consequently, no further preliminary investigation was made.

Final Heat Treatment

Three series of heat treatments were used on the S.A.E. 1045 steel as indicated under the description of the marking system. Series A were quenched in oil from 800° C and air-cooled from the draw; series B were quenched in oil from 800° C and quenched in water from the draw; series C were quenched in water from 800° C and air cooled from the draw. All specimens were held at temperature for 20 minutes in a gas muffle furnace. Drawing operations of 30 minutes length were performed in an electric muffle furnace.

Impact Tests, Data and Curves.

The results from the series A and B tests showed that these heat treatments do not develop impact properties. None of the specimens of these two groups showed any improvement in impact properties over the normalized specimens. This may be due to the fact that the gas muffle furnace does not afford a precise control of temperature. The lead bath was used in the subsequent treatments to afford more accurate control of the hardening temperatures.

The results of the series C tests are shown in the impact-drawing temperature curve of figure 7. This curve illustrates the low impact properties of the S.A.E. 1045 steel and clearly demonstrates why it is not advisable to use this steel where resistance to impact is a paramount consideration. The Brinell hardness numbers are also plotted on the same sheet and it will be noted that there is no definite relation between B.h.n. and impact strength.

Plate 1 is a photograph of the fractures of representative samples of each heat treatment. The heat treatment symbols are marked on the slotted portion of the section. The A and the B specimens show a weak granular fracture through the entire range of drawing. This is in agreement with the impact properties previously spoken of. The C specimens show the growth in fiber which takes place as the drawing temperature is increased and as impact strength is developed. It will be noted that there is no marked increase in the fiber until a drawing temperature of 500° C is reached. This is in accord with the data which show no material increase in impact strength until 500° C is reached.

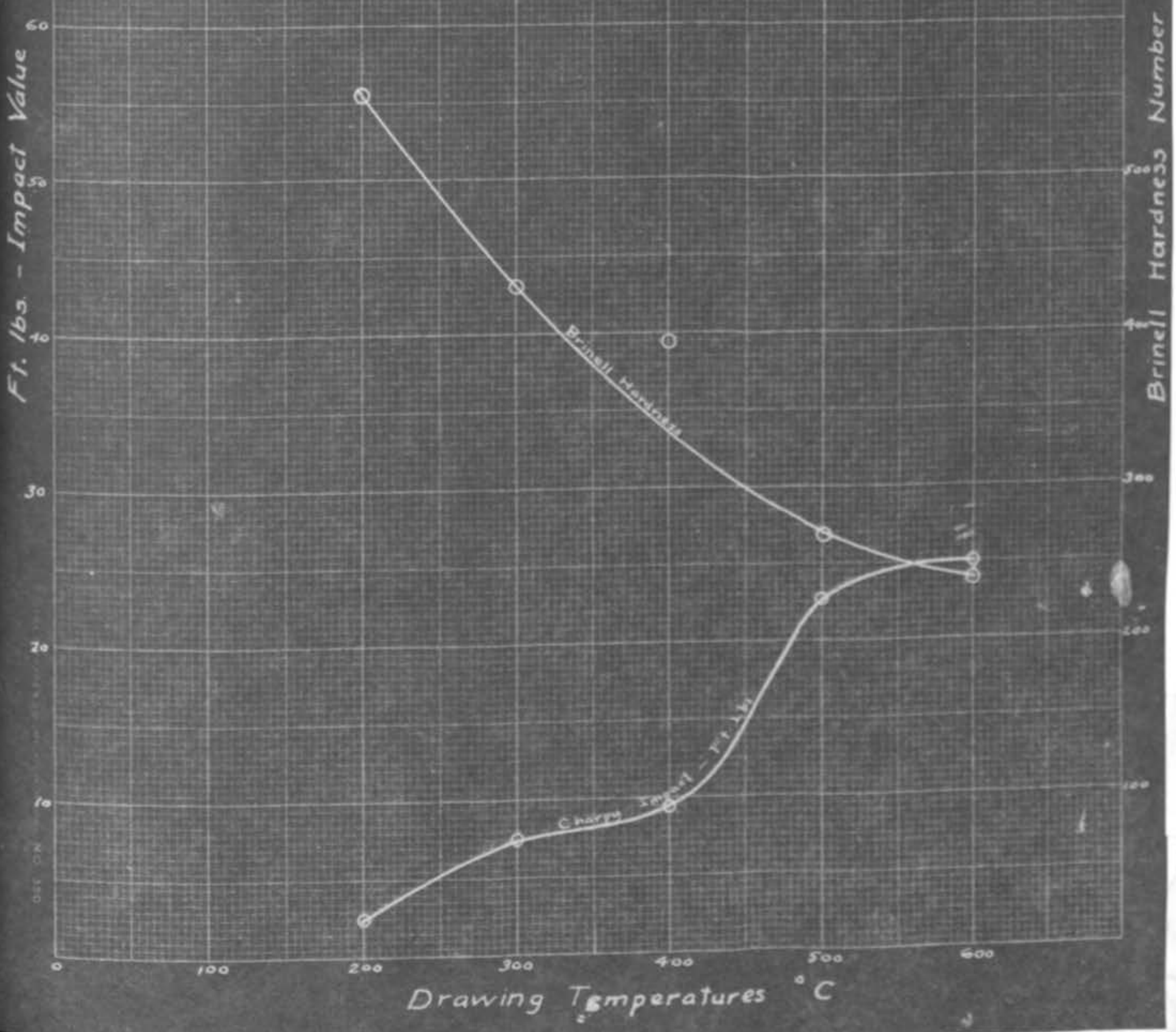
Figure 7

CHARPY IMPACT CURVES

Carbon Steel S.A.E. 1045

DATA

Drawing Temp. °C.	Impact Value Ft. Lbs.
200	2.5
300	7.5
400	9.4
500	22.7
600	25.0



DATA

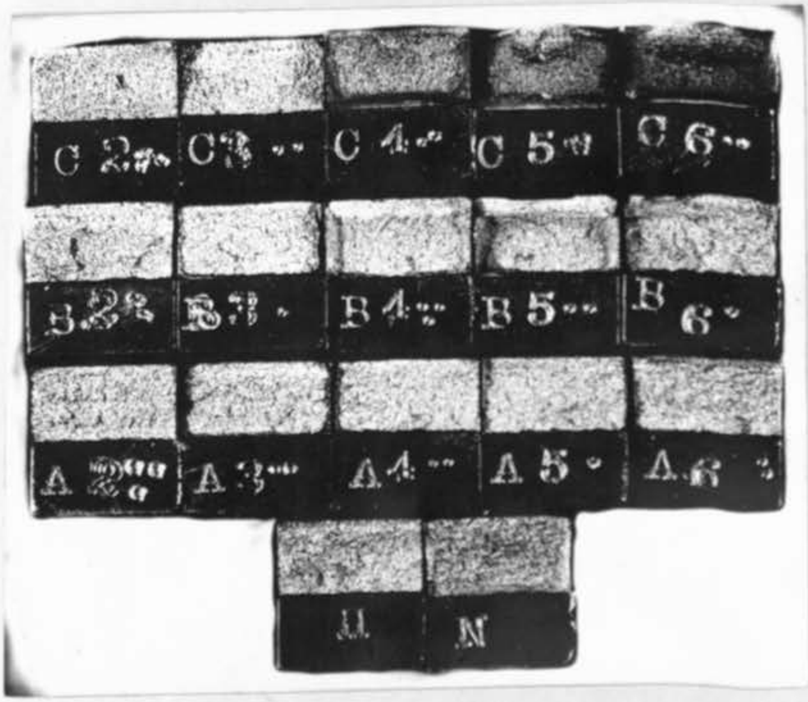
Carbon Steel S.A.E. 1045

Heat treatment: All specimens heated 20 minutes at 800 degs. C. and quenched in water. Subsequent heat treatment as explained in marking system.

Specimen Number	Charpy Angle Degrees (θ)	Impact Value Ft. Lbs.	Brinell Hardness Number
C2 .	156.5	2.55	532
C2 :	155.5	3.2	555
C2 :.	156.8	2.32	555
C3 .	148.4 *	9.38	444
C3 :	155.0	3.2	387
C3 :.	150.0 *	7.9	418
C4 .	152.7	7.2	402
C4 :	151.7	6.03	399
C4 :.	147.2 *	10.8	387
C5 :	137.8	22.7	277
C5 :.	126.0	41.2	255
C6 .	138.4	22.0	255
C6 :	135.3	26.0	288
H .	155.5	3.2	
H :	153.5	6.26	
N .	153.5	6.26	170
N :	150.0	7.92	174

* Specimen jammed in machine.

PLATE 1.



Fractures of representative specimens S.A.E. 1045 steel. Heat treatments indicated by marking symbols.

RESULTS AND DISCUSSION OF S.A.E. 1035 STEEL

Composition

Si C..22% Mn .51% S .004% P .007%

Preliminary Heat Treatment

Effect of temperature. - Temperatures of 820°, 830°, 840°, 850°, and 860° C were used in this preliminary test. The procedure outlined under the section on preliminary heat treating experiments was followed, namely, heating in a lead bath for 10 minutes, quenching in water and drawing for 30 minutes at 500° C. The results of the tests are given below:

Hardening temperature	Charpy impact value ft. lbs.
820° C	40.
830	38.9
840	41.2
850	39.1
860	51.2*

*specimen jammed in machine

These data indicate that the hardening temperature may be varied from 820° to 850° (and probably to 860° for the 860° specimen was too long and jammed in the machine) without causing any marked variation in impact value. Plate 2a is a photograph of the fractures with the temperatures marked on the specimens. All present a well fibered structure. The 830° specimen shows a granulated structure covering about 20% of the area. This is attributable to the fact that this specimen was in the lead bath 10 minutes below temperature in addition to the regular hardening heat. From the these tests 830° C was selected as the proper hardening temperature.

PLATE 2.

a. Fractures of temperature test specimens S.A.E. 1035 steel. Temperatures marked on lower halves of specimens.

b. Fractures of time test specimens S.A.E. 1035 steel. Times marked on lower halves.

Effect of time. - 10,20 and 40 minutes were used as durations of hardening heat in these tests. The procedure was the same as outlined previously.

The averages of two series of tests are given below:

Duration of hardening heat	Charpy impact value ft. lbs.
10 min.	35.6
20 "	33.6
40 "	32.8

These results indicate that 10 minutes is sufficient time to complete the solid solution and attain a condition of equilibrium. Longer times do not improve the impact properties of the steel.

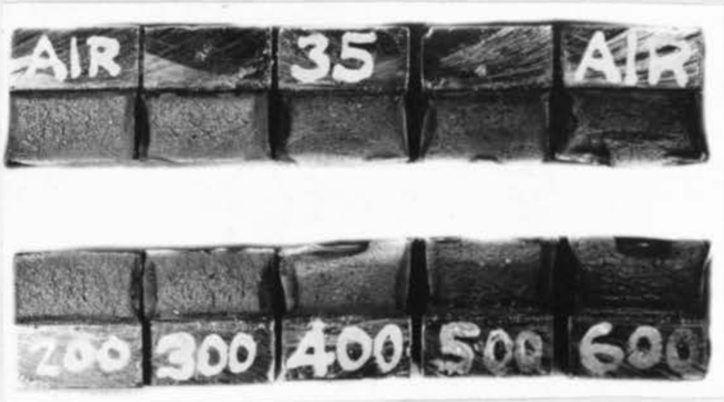
The photograph of the time test specimens (Plate 2b) shows the similarity of fibered structure in the three sample specimens.

Final Heat Treatment

Air cooled from draw. - From the preliminary tests 830° C was selected as the hardening temperature and 10 minutes as the duration of hardening heat. Drawing temperatures of 200°, 300°, 400°, 500°, and 600° were used, and in this series specimens were air cooled from the draw. The character of the fractures is shown in Plate 3a. The 200° and 300° specimens have a granular fracture indicating low impact strength; in the 400° specimen the fracture is fibered and in the 500° and 600° specimens the growth of fiber is well marked.

Water quenched from draw. - The heat treatments used in this series of tests was the same as that of the series A (air

PLATE 3.



a. Fractures of representative series A specimens S.A.E. 1035 steel. Drawing temperatures marked on lower halves.

b. Fractures of representative series W specimens S.A.E. 1035 steel.

cooled from draw) tests except that the specimens were quenched in water from the drawing temperature. A photograph of the fractures is shown in Plate 3b. The character of the fractures is similar to that of the specimens which were air cooled from the draw. Because of an oversight the specimen selected to show the fracture for the 400° draw is not strictly representative of the group. This specimen shows a granular area but it did not exhibit any marked weakness in the impact test. The cause of this irregularity is so far unexplained. Plate 4a shows the fractures of the hardened and normalized specimen.

Impact Tests, Data and Curves

The impact-drawing temperature curve and the Brinell hardness curve for the A series (air cooled from the draw) are presented in figure 8 and in figure 9, the corresponding curves for the W series (water quenched from the draw) are presented with the A impact curve drawn in dotted lines. The B.h.n. curve for the A series is also shown. The impact curves are quite close together throughout the entire range; only at the 500° point does the data show any marked divergence. The increase in impact strength is much larger than that noted in the S.A.E. 1045 steel but not as large as that of the S.A.E. 1025 steel. At 300° there is an increase in impact value and at 400° there is a lessening of the rate of increase. These two changes are probably accompanied by a change in micro-structure but, although it is known in a general way what micro-constituent will be found in steel which has been hardened and drawn to a given temperature, it is

PLATE 4.

a. Fractures of hardened(H) and normalized(N) specimens S.A.E. 1035 steel.

b. Fractures of hardened and normalized specimens S.A.E. 1025 steel.

Figure 8

CHARPY IMPACT CURVES

Carbon Steel S.A.E. 1035

Air Cooled from draw.

DATA

Drawn at °C.	Ft. Lbs.
100	
200	7.94
300	9.91
400	32.30
500	42.20
600	52.40
Not drawn	7.00

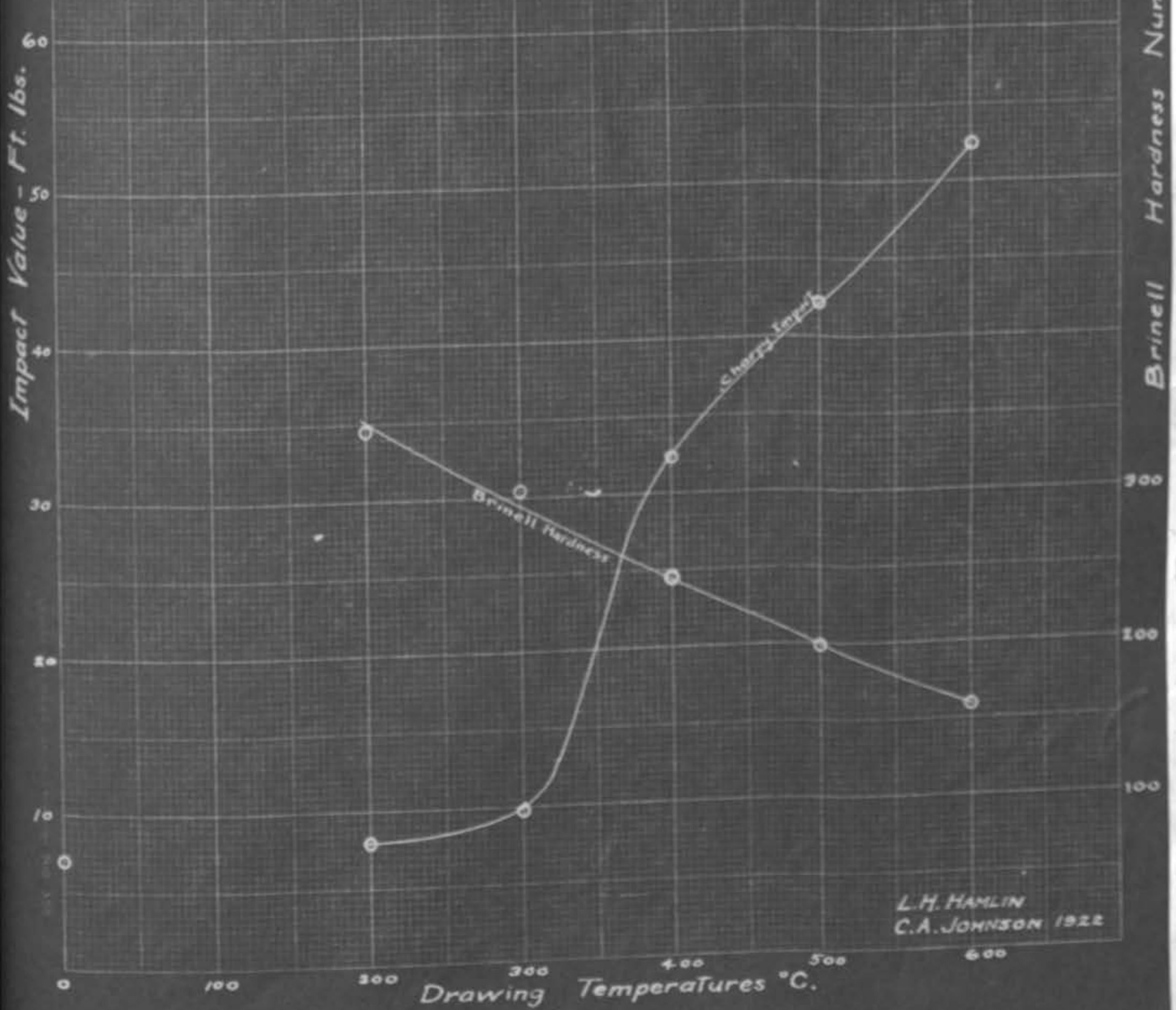
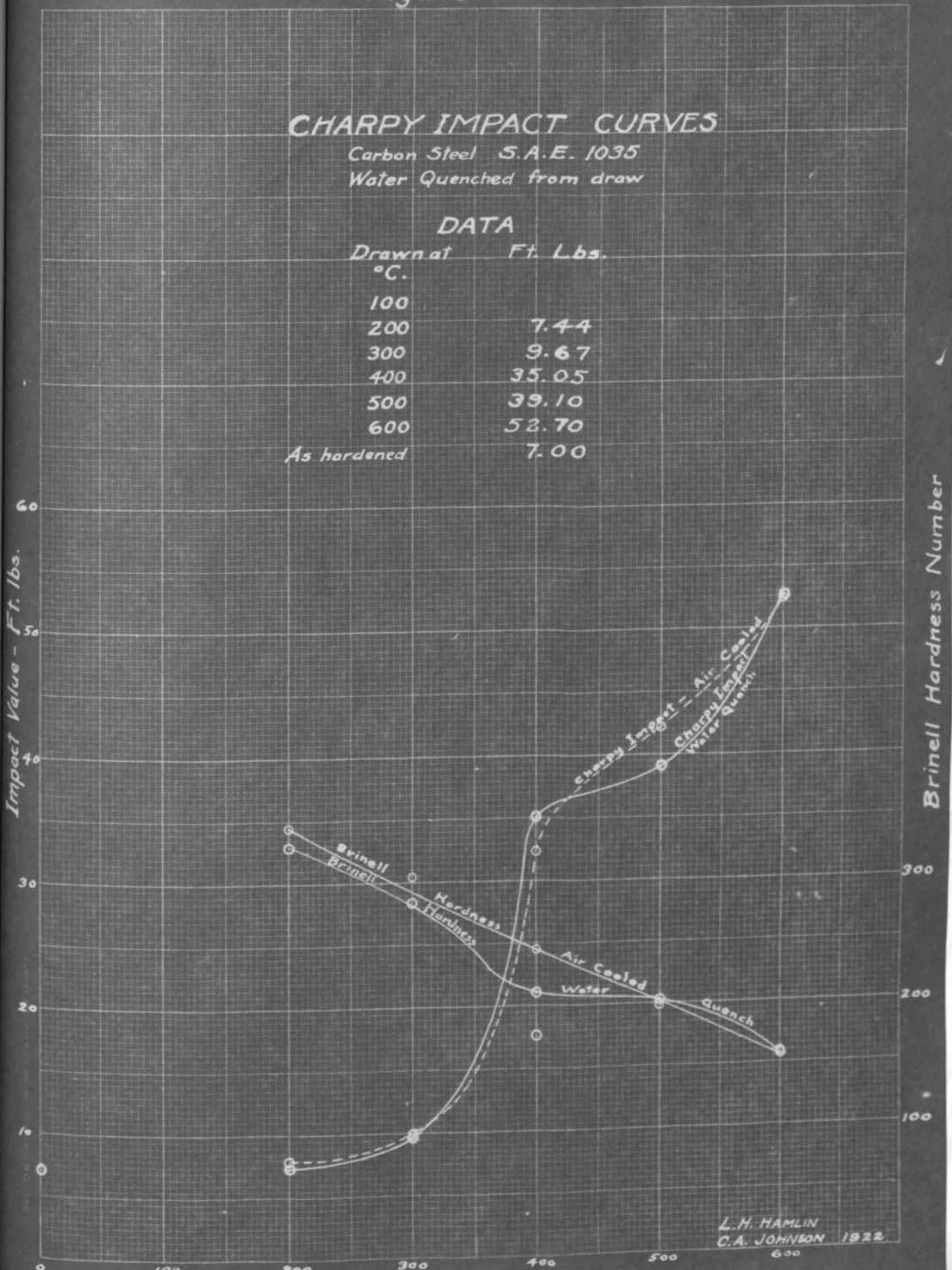


Figure 9


CHARPY IMPACT CURVES
Carbon Steel S.A.E. 1035
Water Quenched from draw
DATA
Drawn at °C. | Ft. Lbs.
100
200 7.44
300 9.67
400 35.05
500 39.10
600 52.70
As hardened 7.00
Impact Value - Ft. lbs.
Brinell Hardness Number
Charpy Impact - Air Cooled
Charpy Impact Water Quench
Brinell Hardness Air Cooled
Brinell Hardness Water Quench
0
10
20
30
40
50
60
100
200
300
0
100
200
300
400
500
600
Drawing Temperatures °C.
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DATA

Carbon Steel S.A.E. 1035

Heat treatment: All specimens heated 10 minutes at 830 degs. C. and quenched in water. Subsequent heat treatment as explained in marking system.

Specimen Number	Charpy Angle Degrees (Θ)	Impact Value Ft. Lbs.	Brinell Hardness Number
A2 .	150.5	7.44	327
A2 :	151.0	7.0	364
A2 :.	149.0	9.39	273
A3 .	148.5	9.75	298
A3 :	148.6	9.53	312
A3 :.	147.6	10.45	293
A4 .	135.6	26.0	241
A4 :	132.0	31.1	199
A4 :.	130.5	33.6	248
A5 .	125.2	42.2	199
A5 :	125.3	42.0	174
A5 :.	127.5	38.3	196
A6 .	119.0	53.1	158
A6 :	121.5	48.4	161
A6 :.	120.0	51.3	156
W2 .	150.0	7.88	311
W2 :	150.0	7.88	358
W2 :.	151.5	6.57	350
W3 .	147.8	10.1	267
W3 :.	148.6	9.75	281
W3 :.	149.0	9.17	302
W4 .	127.5	38.3	172
W4 :	131.5	31.8	179
W4 :.	134.5	27.4	244
W5 .	126.7	39.7	194
W5 :	128.5	36.8	205
W5 :.	126.0	40.8	207
W6 .	119.3	52.7	158
W6 :	122.0	47.7	179
W6 :.	119.5	52.7	156
H .	144.6	13.7	302
H :	150.5	7.44	345
H :.	151.5	6.57	321
N .	148.3	10.1	121
N :	148.5	9.75	121
N :.	141.0	18.4	116

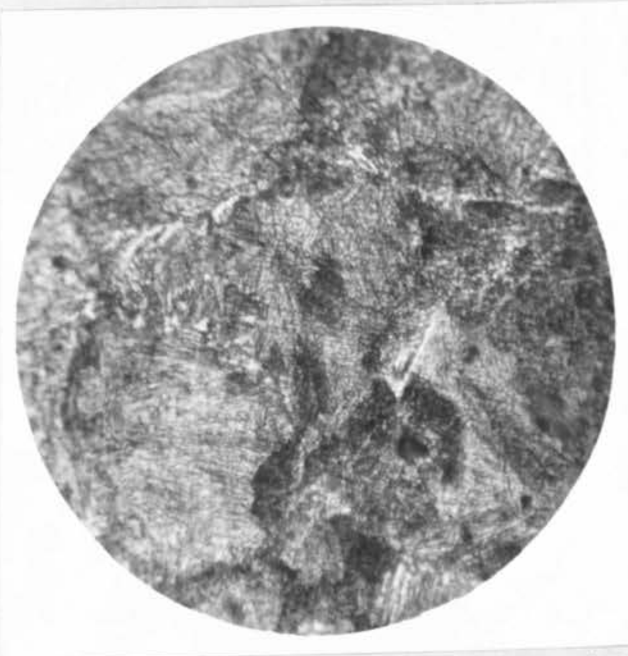
difficult to detect the precise character of these changes.

The Brinell hardness curves give no clue to the impact properties of the steel. The curve for the air cooled specimens is nearly a straight line and the curve for the water quenched specimens shows peculiar irregularities which are probably due to experimental errors in the data.

Photomicrographs

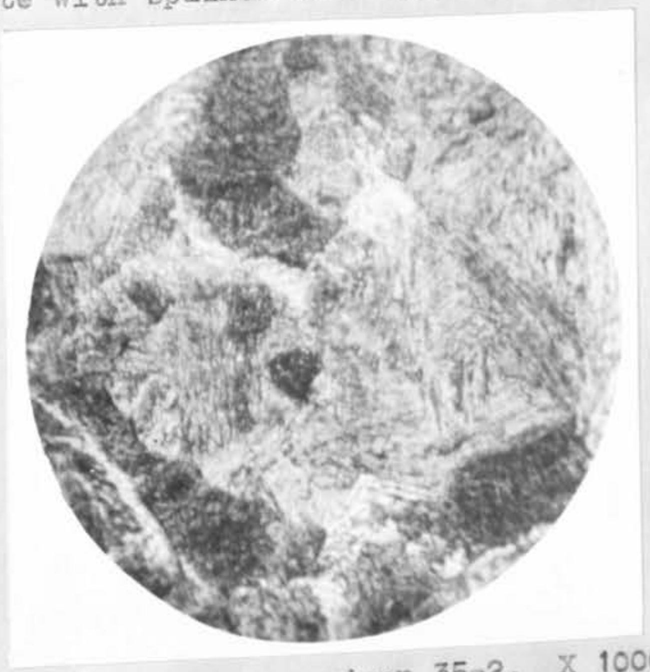
Plates 5, 6, and 7 show the microstructures of representative specimens of the A series and also a hardened undrawn specimen. The hardened specimen is composed of grains of martensite with small patches of troostite and a little free ferrite around the grain boundaries. This free ferrite shows that the hardening temperature was too low but this is due to the fact that the chemical analysis was not made until the tests had been completed and the carbon content was found to be much lower than expected. In the 200° draw specimen the troostite areas are much larger and in the 300° draw specimen the transformation of martensite to troostite has covered the entire section. The 400° draw specimen shows a further breakdown of the troostite into a constituent which is sorbitic in character. In the 500° and 600° draw specimens the whole area is seen to be sorbitic. The increase in impact strength which was noted in the impact-drawing temperature at 300° is probably due to the breakdown of the troostite. At 400° there is a secondary change but of subtle character which has not been definitely determined in this investigation.

PLATE 5.



a. Micro-structure: specimen 35 H. X 1000

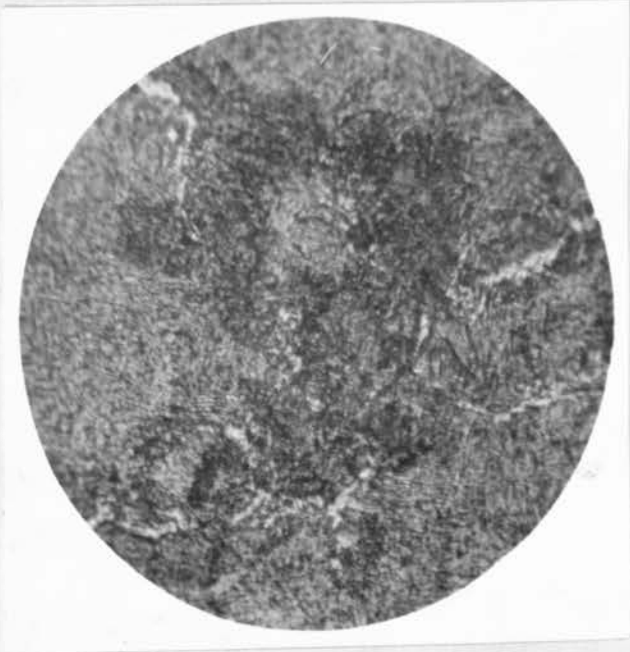
Grains of martensite, boundaries of troostite with splines of ferrite.



b. Micro-structure: specimen 35-2. X 1000.

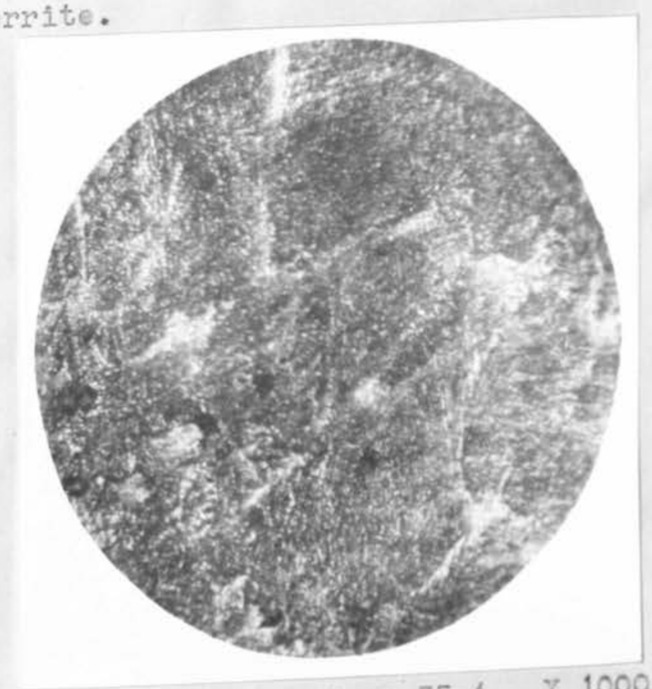
Showing increase of troostite.

PLATE 6.



a. Micro-structure : specimen 35-3. X 1000.

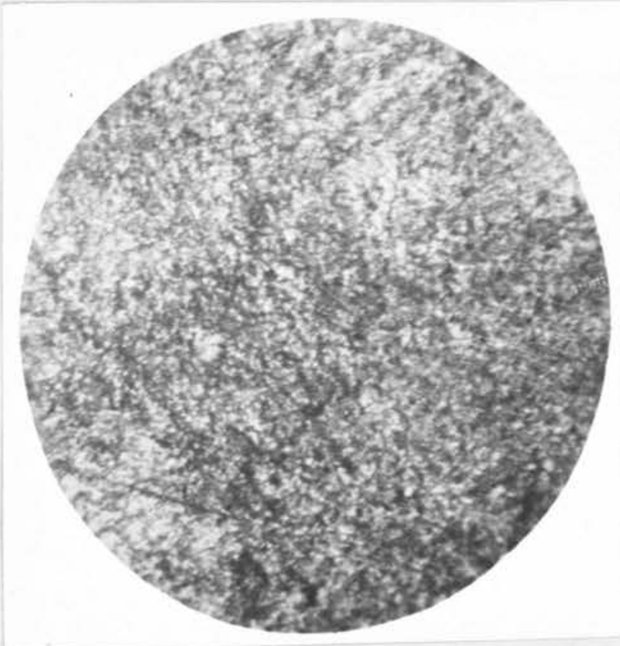
Largely troostite with original splines of ferrite.



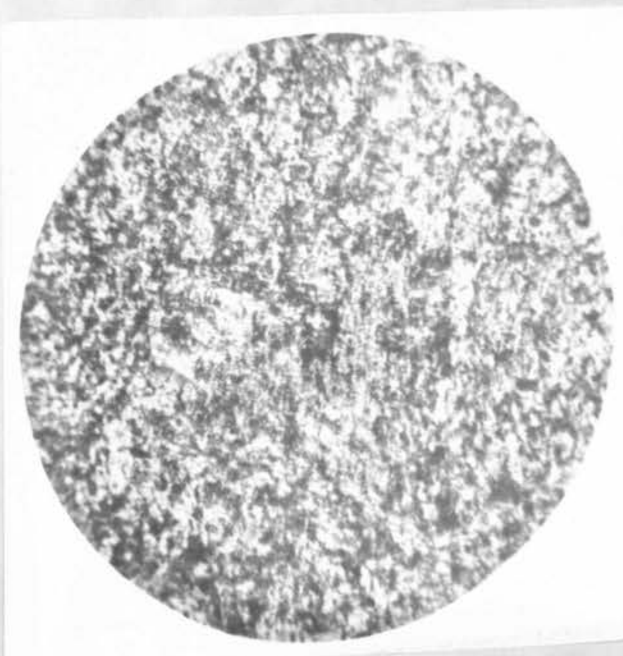
b. Microstructure:specimen 35-4. X 1000.

Troostite with original ferrite.

PLATE 7.



a. Microstructure:specimen 35-5. X 1000. Showing breakdown of troostite into sorbite.



b. Microstructure:specimen 35-6. X 1000. Sorbite.

Composition.

C .23%

S.A.E. 1025

Preliminary Heat Treatment

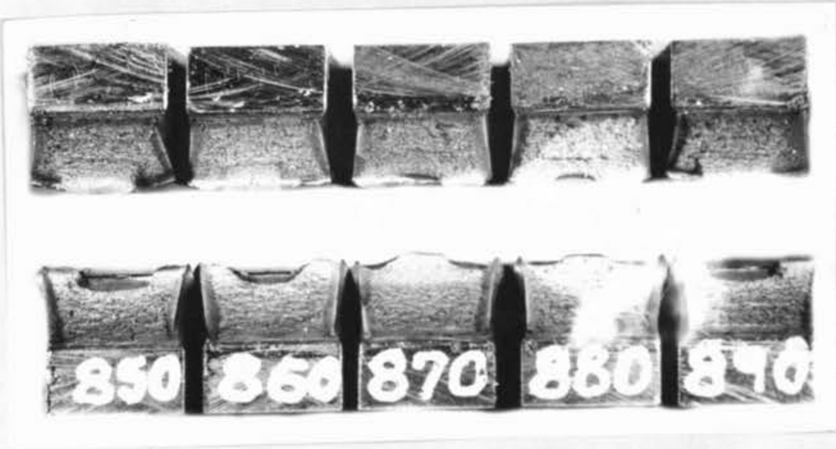
Effect of temperature. - To determine the effect of temperature the following temperatures were tried: 850, 860, 870, 880 and 890 degrees C. The specimens were held at temperature for 10 minutes in every case and all were drawn, after hardening, at 500 degrees C. for 30 minutes and cooled in air from the draw. The results of the impact tests of these specimens are tabulated below:

Hardening Temperature	Impact Value ft. lbs.
850	46.2
860	44.8
870	43.3
880	43.3
890	47.6

Examination of the above data shows that the hardening temperature may be varied through quite a range without having any marked effect on the impact value of the specimen. Plate 8a shows the photograph of the fractures, both halves of each fracture being shown. The photograph of the fracturs also shows that the structure of the steel is not much effected by the variation of hardening temperatures between the limits chosen.

Effect of time. - From the above test it was concluded that 860 degrees C. would be satisfactory to use as the hardening temperature. The length of time that the specimens were

PLATE 8.



a. Fractures of temperature test specimens S.A.E. 1025 steel.

b. Fractures of time test specimens S.A.E. 1025 steel.

held at the hardening temperature was determined by subjecting them to this temperature for periods of 5, 10, 20, 30, and 40 minutes; these tests were made in duplicate. All specimens for the above temperature test and the temperature tests of all other steels tested were drawn in an electric furnace and air cooled from the draw. The hardening was done in water. The results of the impact tests of these specimens are tabulated below.

Time at temperature minutes	Impact value ft. lbs.
5	41.2
10	40.1
20	40.4
30	40.6
40	40.1

An examination of these impact values shows that the time at temperature has little effect on the impact value; this may be due to the fact that the section is small and therefore the time need not be long to effect a condition of equilibrium.

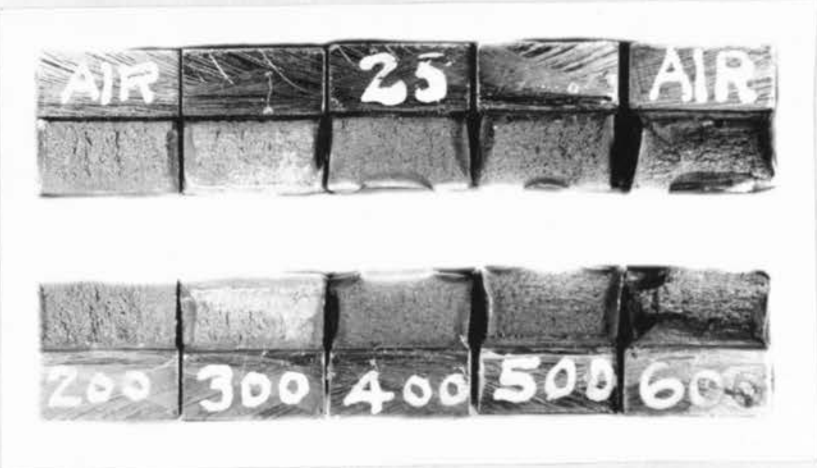
The photograph of the fractures (Plate 8b) will also bear out the above statement, as little or no difference can be noted between the specimen which was held at temperature for 5 minutes, and that which was held for 40 minutes. The time is indicated by the figures I. E. 5 = 5 minutes. All specimens show the fibrous structure characterisitc of tough steels.

Final Heat Treatment

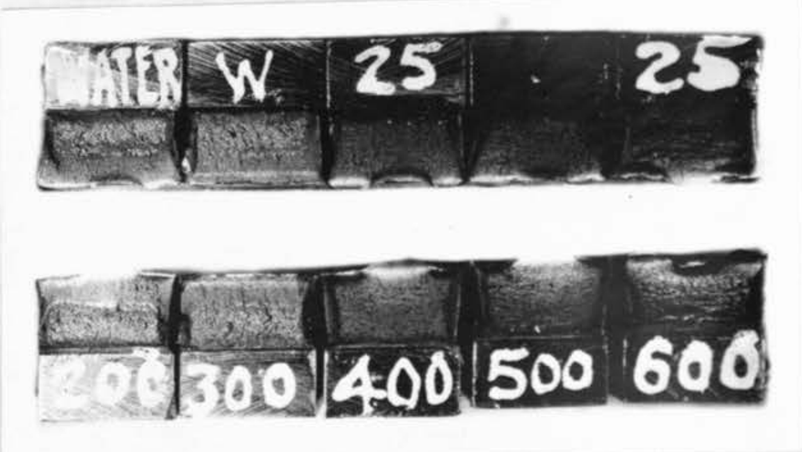
Sufficient specimens were now hardened by heating to 860 degrees C. as chosen above, and holding at this temperature for 10 minutes. The drawing temperatures selected were 200°, 300°, 400°, 500°, and 600° C. Six specimens were drawn at each of these temperatures, three specimens of each of these groups were air cooled from the draw and the remaining three were water quenched. The photograph of the air cooled group (Plate 9a) shows the fracture of both halves of a representative specimen for each drawing temperature. The drawing temperature is written in white on each specimen and the figure 25 stands for S.A.E. 1025. Examination of the fractures shows what a close relation there exist between the appearance of the fracture and the results of the tests in the Charpy machine. The 200 degree draw shows a marked crystaline fracture while the 300° indicates that a fibered structure has started to form. The fractures of the 400, 500, and 600, degree draws show the increase in this fibered structure which is indicative of high impact value.

The photograph of the water quenched group is shown on Plate 9b. The drawing temperatures are lettered in white on each specimen, the "W" indicating that the group was quenched in water. This group also shows that the structure becomes more fibered as the drawing temperature is increased. By comparing the photograph of the air cooled from draw with the water quenched, it appears that the latter might be expected to have the higher impact values at the lower draws; this is substantiated by the curves. In figure 11 the curves for this steel show clearly that the impact value increases with an increase in drawing temperature. By examining the curves for the group which was air cooled from the draw, it will be seen that the rate of increase becomes greater for each increase

PLATE 9.



a.. Fractures of representative series A specimens S.A.E. 1025 steel.



b. Fractures of representative specimens W series S.A.E. 1025 steel.

Figure 10

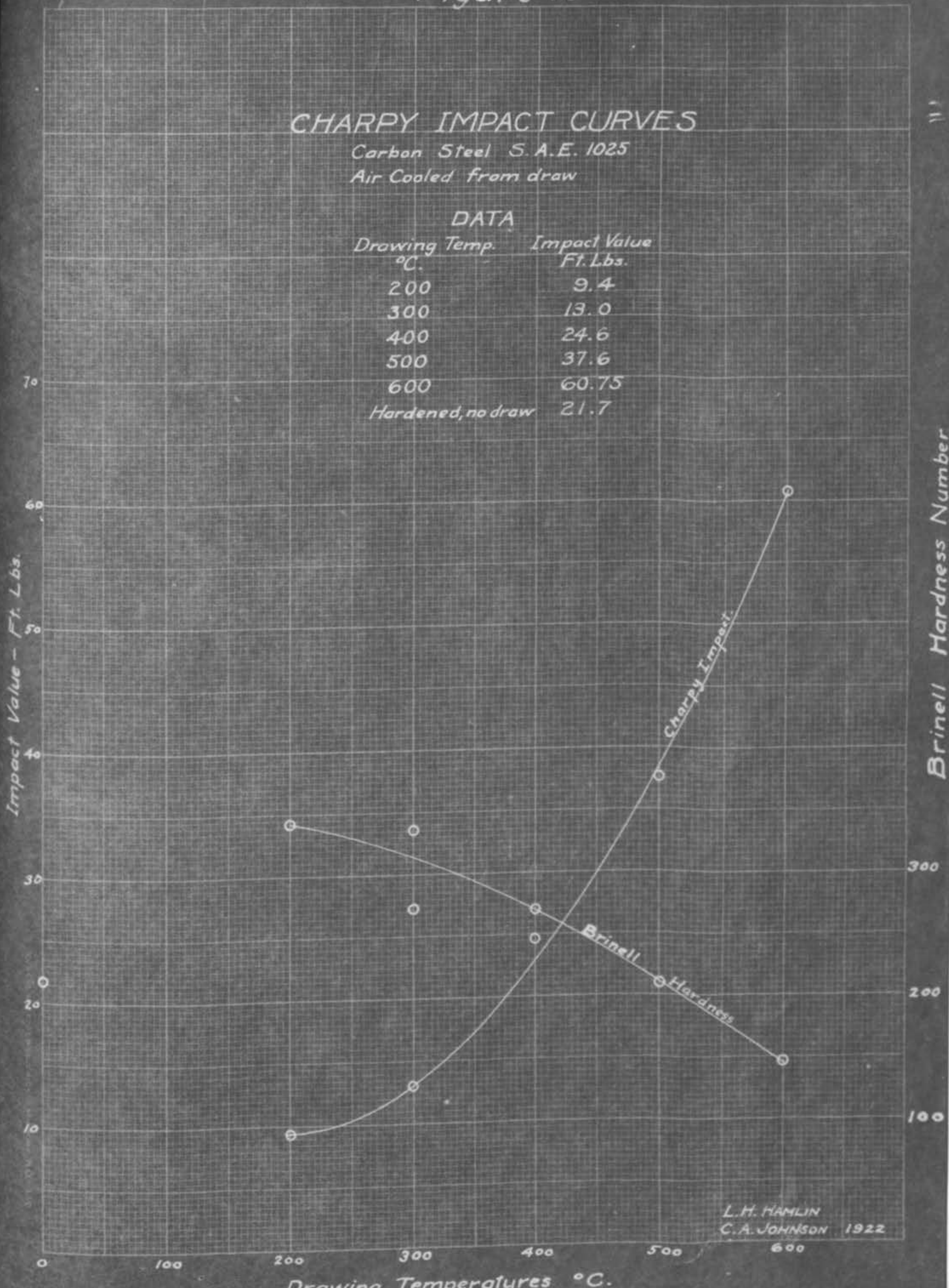

CHARPY IMPACT CURVES
Carbon Steel S.A.E. 1025
Air Cooled from draw
DATA
Drawing Temp. °C. | Impact Value Ft. Lbs.
200 | 9.4
300 | 13.0
400 | 24.6
500 | 37.6
600 | 60.75
Hardened, no draw | 21.7
Charpy Impact
Brinell Hardness
Impact Value - Ft. Lbs.
Brinell Hardness Number
Drawing Temperatures °C.
0
100
200
300
400
500
600
10
20
30
40
50
60
70
100
200
300
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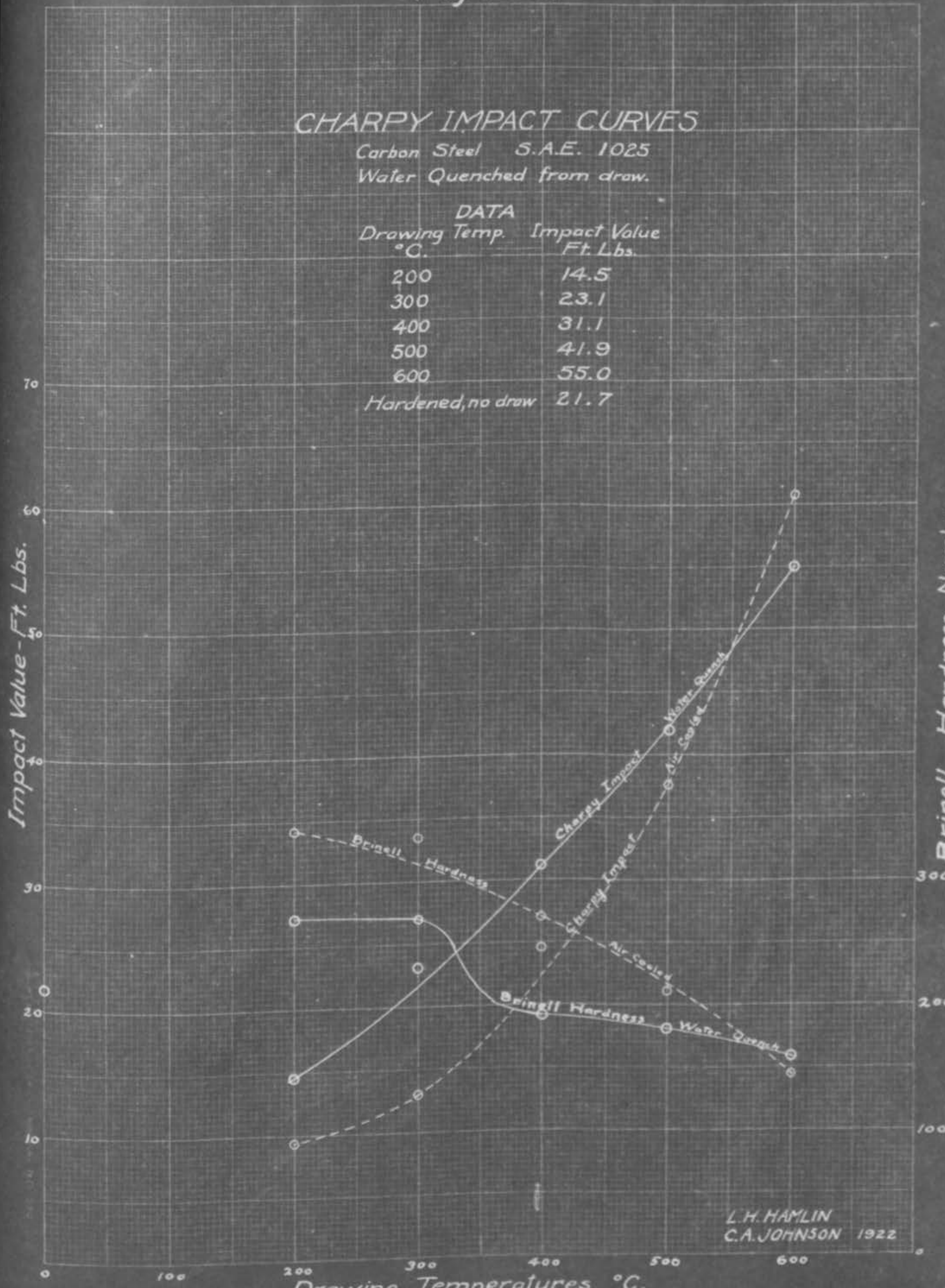
Figure 11


CHARPY IMPACT CURVES
Carbon Steel S.A.E. 1025
Water Quenched from draw.
DATA
Drawing Temp. °C.
Impact Value Ft. Lbs.
200 14.5
300 23.1
400 31.1
500 41.9
600 55.0
Hardened, no draw 21.7
Charpy Impact
Water Quench
Air Cooled
Charpy Impact
Brinell Hardness
Air Cooled
Brinell Hardness
Water Quench
Impact Value - Ft. Lbs.
Brinell Hardness Number
Drawing Temperatures °C.
0
100
200
300
400
500
600
10
20
30
40
50
60
70
100
200
300
L.H. HAMLIN
C.A. JOHNSON 1922

DATA

Carbon Steel S.A.E. 1025

Heat treatment: All specimens heated 10 minutes at 860 degs. Cent. and quenched in water. Subsequent heat treatment as explained in marking system.

Specimen Number	Charpy Angle Degrees (θ)	Impact Value Ft. Lbs.	Brinell Hardness Number
A2 .	151.0	6.69	364
A2 :	149.0	8.66	321
A2 :.	145.5	12.7	277
A3 .	137.0	23.9	293
A3 :	149.0	8.66	351
A3 :.	149.0	8.66	321
A4 .	139.0	21.0	281
A4 :	134.0	28.2	269
A4 :.	127.0	39.4	262
A5 .	125.0	42.6	228
A5 :	129.0	35.1	205
A5 :.	130.5	33.2	199
A6 .	114.5	61.0	155
A6 :	116.5	57.4	152
A6 :.	113.5	62.8	132
W2 .	126.0 *	41.2	266
W2 :	147.5	10.8	277
W2 :.	140.0	19.5	217
W3 .	139.0	20.9	327
W3 :	138.0	22.4	286
W3 :.	126.0	41.2	255
W4 .	132.0	31.0	192
W4 :	134.0	28.2	192
W4 :.	130.0	34.6	192
W5 .	127.0	39.4	170
W5 :	129.3	35.7	173
W5 :.	120.5	50.5	202
W6 .	116.0	58.1	149
W6 :	120.0	50.9	152
W6 :.	117.0	56.3	175
H .	144.4	14.1	340
H :	141.2	18.1	340
N .	148.0	10.1	114
N :	143.4	15.15	112

* Specimen jammed in machine.

in the drawing temperature, while in the case of the water quenched group the variation is almost linear. The Brinell Hardness shows a decrease, for an increase in drawing temperature, in both air cooling and water quenching from the draw. It is interesting to note that the Brinell hardness is greater for the steel which was air cooled from the draw than it is for that which was water quenched.

RESULTS AND CONCLUSIONS ON S.A.E. 3120 STEEL.

Composition.

C .18% Mn .65% P. .011% S .024%

Ni 1.20% Cr .64%

Preliminary Heat Treatment

Effect of temperature. - The effect of temperature on the hardening of this steel was determined by using 860, 870 and 880 degrees C. as hardening temperatures. This test was run in duplicate and the specimens were kept at the hardening temperature for a period of ten minutes, all of this set were hardened in water and air cooled from the draw at 500 degrees C. The results of the impact test of these specimens are tabulated below.

Hardening temperature	Impact value ft. lbs.
860 .	44.8
860 ..	36.1
870 .	36.8
870 ..	37.5
880 .	41.2
880 ..	39.4

Examination of the above data shows that the hardening temperature may be varied through quite a range without having any marked effect on the impact value. Plate 10a shows the photograph of fractures of representative specimens from this group. This photograph shows a well fibered structure in all cases, and there is no marked difference between them.

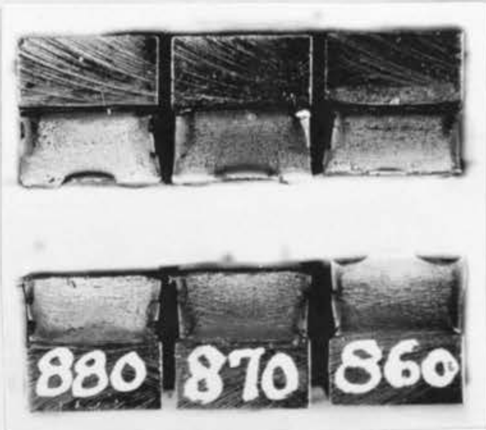
Effect of time. - No tests relative to the effect of time were made with this steel as this was the last steel to be investigated and since past experience had proven that ten minutes was sufficient time to obtain the desired results with specimens of such dimensions as are required by the Charpy machine.

Final Heat Treatment

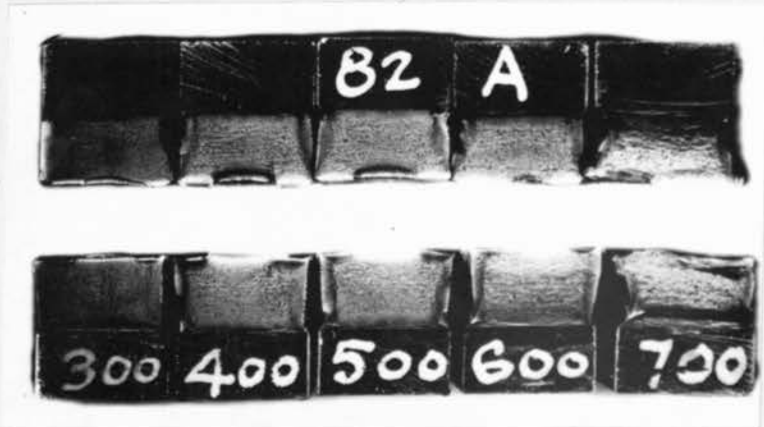
From the above preliminary tests it was decided that 880 C. would be the hardening temperature used. All specimens were hardened by heating to 880° C, holding for 10 minutes and quenching in water. They were then drawn at 300, 400, 500, 600, and 700 degrees C. for 30 minutes. One group was air cooled from the draw and the other group was water quenched from the draw. This test was also made in triplicate. Plate 10b shows the photograph of the group which was air cooled from the draw. Examination of this photograph shows that the fibered structure increases with the drawing temperature. From the fact that the structure becomes more fibered as the drawing temperature is increased, it follows from the results of former tests that the impact value should increase also, and by referring to the curves on figure 12 it can be seen that this is true.

The photograph of the water quenched group on Plate 10c

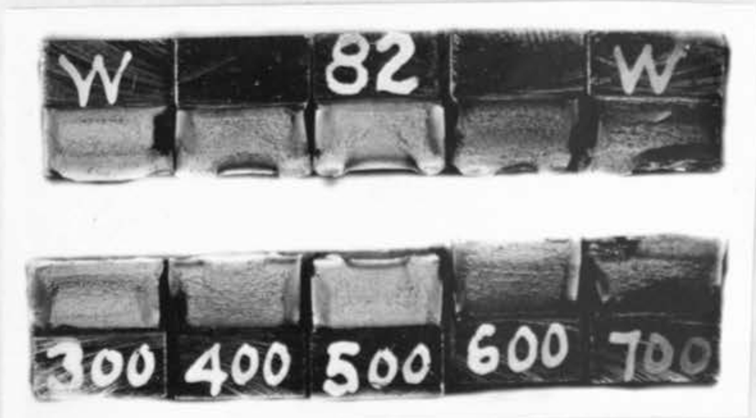
PLATE 10.



a. Temperature test specimens S.A.E. 3120 steel.



b. Representative series A specimens 3120 steel.



c. Representative series W specimens 3120 steel.

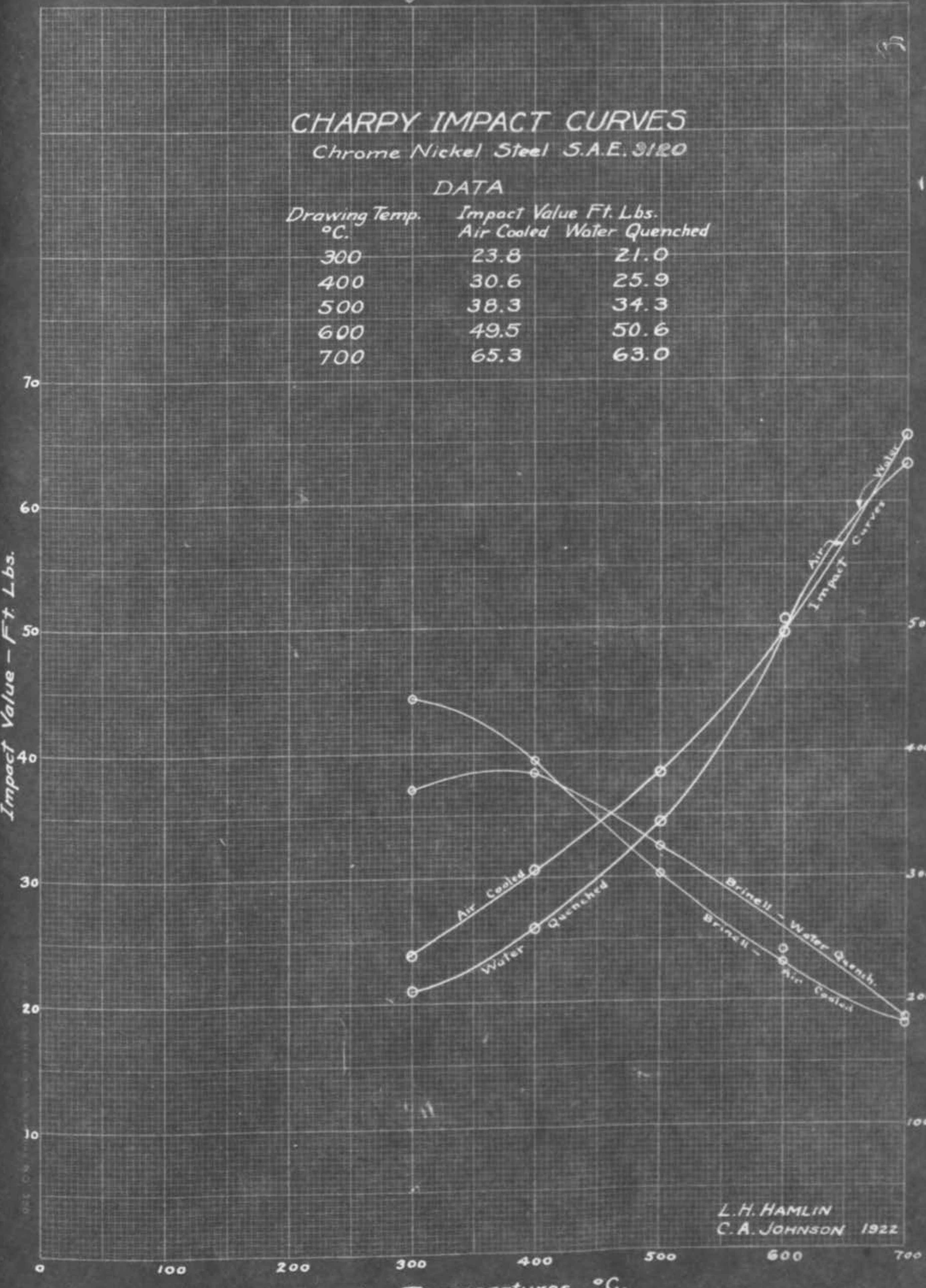
Figure 12

CHARPY IMPACT CURVES

Chrome Nickel Steel S.A.E. 3120

DATA

Drawing Temp. °C.	Impact Value Ft. Lbs. Air Cooled	Impact Value Ft. Lbs. Water Quenched
300	23.8	21.0
400	30.6	25.9
500	38.3	34.3
600	49.5	50.6
700	65.3	63.0



DATA

Chrome Nickel Steel S.A.E. 3120

Heat treatment: All specimens heated 10 minutes at 880 degs. C. and quenched in water. Subsequent heat treatment as explained in marking system.

Specimen Number	Charpy Angle Degrees (Θ)	Impact Value Ft. Lbs.	Brinell Hardness Number
A3 .	135.5	26.0	332
A3 :	140.5	18.8	444
A3 :.	135.2	26.7	444
A4 .	131.1	32.5	387
A4 :	132.3	30.3	402
A4 :.	133.3	28.9	
A5 .	128.2	37.6	302
A5 :	124.5	43.4	277
A5 :.	130.4	34.0	302
A6 .	121.2	49.2	241
A6 :	119.5	52.0	235
A6 :.	121.9	47.7	228
A7 .	110.5	68.7	174
A7 :	113.7	62.2	
A7 :.	112.5	65.0	187
W3 .	138.0	22.5	364
W3 :	142.5	16.6	364
W3 :.	137.0	23.8	387
W4 .	131.1	32.5	387
W4 :	132.3	30.3	387
W4 :.	133.3	28.9	375
W5 .	128.2	37.6	340
W5 :	124.5	43.4	321
W5 :.	130.4	34.0	311
W6 .	122.3	47.0	241
W6 :	120.0	51.3	241
W6 :.	118.5	53.5	241
W7 .	113.9	62.2	179
W7 :	112.9	63.6	187
W7 :.	113.1	63.2	192

would lead one to believe that the lower draws would have a lower impact value than the corresponding specimens which were air cooled from the draw. Referring again to the curve sheet figure 12 it will be seen that this is the case.

Impact Tests Curves and Data

The curves on this steel are shown in figure 12. The impact value increases with the drawing temperature for both the groups - those specimens which were air cooled from the draw and those which were water quenched. It will be seen that for the best impact properties it is necessary to draw at a high temperature and also that it makes little difference whether the specimens are allowed to cool in the air or are water quenched from the draw. The Brinell Hardness decreases as the drawing temperature increases and is higher for the air cooled specimens for the 300 degree draw, but this relation is reversed for the 500 and 600 degree draws. This steel gave the highest impact value of any of the steels tested. The specimens which were drawn at 700 degrees did not break in two but pulled apart at the notch and then bent in the form of a V, the two ends sliding through the anvils of the Charpy machine. These specimens were broken apart in a vise before being photographed.

RESULTS AND DISCUSSION OF S.A.E. 3130 STEEL.

Composition

C .31% S .013% P .010% Ni 1.42% Cr .58% Mn .67%

Preliminary Heat Treatment

Effect of temperature. - The temperatures used were 800°, 815°, and 830°. The usual procedure was followed in heat treating and testing. The tests were made in duplicate. Average results are tabulated below:

Hardening temperature	Charpy impact value ft. lbs.
800° C	36.9
815°	36.5
830°	35.6

These data confirm the conclusions drawn from previous preliminary tests on the effect of temperature. The photograph of fractures (Plate 11a) shows their well fibered character.

Effect of time. - Twenty and forty minutes were used in these tests; data for the 10 minute test were taken from the temperature test. A hardening temperature of 830°C was used. The average results of duplicate tests are given below:

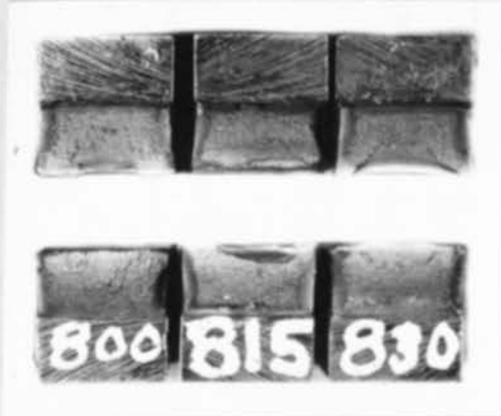
Duration of hardening heat	Charpy impact value ft. lbs.
10 minutes	35.6
20 "	34.4
40 "	33.4

From these data it was concluded that 10 minutes is sufficient duration of hardening heat for this steel. The fractures of the 20 minute and 40 minute specimens are shown in Plate 11b.

Final Heat Treatment

Air cooled from draw. - Specimens for these tests were heated 10 minutes at 830°C in the lead bath and quenched in water. The drawing range for the chrome-nickel steel was 300° to 700° varying by increments of 100°. The range was raised for the chrome-nickel steels because the micro-constituents in these steels are less affected by the lower drawing temperatures than the carbon steels. The fractures (Plate 12a) show

PLATE 11.



a. Fractures of temperature test specimens S.A.E.3130 steel.

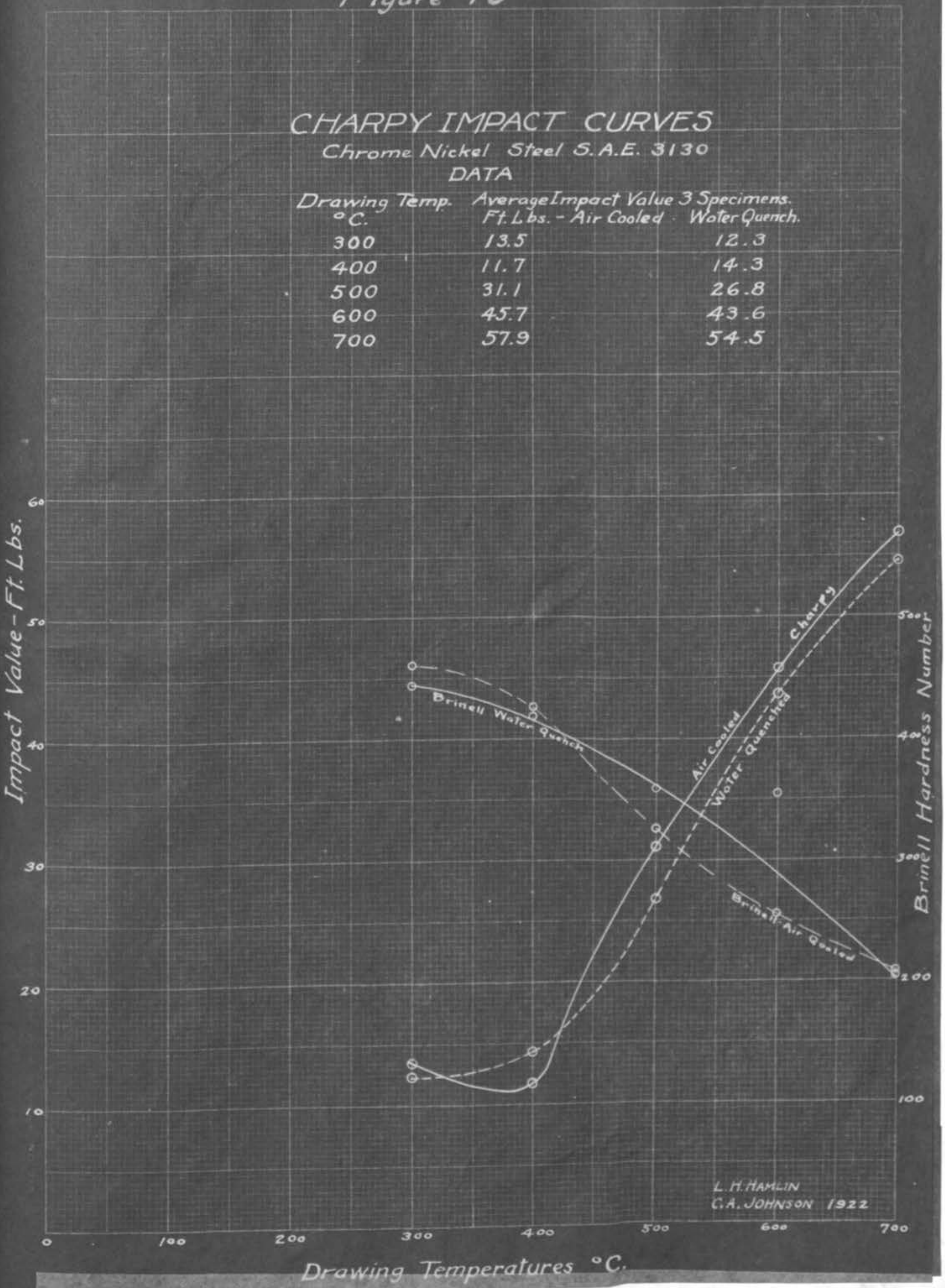
b. Fractures of time test specimens S.A.E. 3130 steel.

PLATE 12.

a. Fractures of representative series A specimens S.A.E. 3130 steel

b. Fractures of representative series W specimens S.A.E. 3130 steel.

Figure 13



CHARPY IMPACT CURVES
Chrome Nickel Steel S.A.E. 3130
DATA
Drawing Temp. °C.
Average Impact Value 3 Specimens.
Ft. Lbs. - Air Cooled
Water Quench.
300 13.5 12.3
400 11.7 14.3
500 31.1 26.8
600 45.7 43.6
700 57.9 54.5
Impact Value - Ft. Lbs.
Brinell Hardness Number
Drawing Temperatures °C.
Charpy
Air Cooled
Water Quenched
Brinell Water Quench
Brinell Air Cooled
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DATA

Chrome Nickel Steel S.A.E. 3130

Heat treatment: All specimens heated 10 minutes at 830 degs. C. and quenched in water. Subsequent heat treatment as explained in marking system.

Specimen Number	Charpy Angle Degrees (Θ)	Impact Value Ft. Lbs.	Brinell Hardness Number
A3 .	145.8	12.1	477
A3 :	144.3	14.1	444
A4 .	147.0	9.75	444
A4 :	146.0	12.3	418
A4 :.	146.7	11.3	418
A5 .	132.5	30.3	351
A5 :	132.7	30.0	302
A5 :.	131.2	32.5	302
A6 .	123.0	45.8	255
A6 :	123.3	45.5	251
A6 :.	123.5	45.2	248
A7 .	116.5	57.2	207
A7 :	114.4	61.3	207
A7 :.	118.0	54.9	207
W3 .	145.6	12.6	
W3 :	146.5	11.4	
W3 :.	146.0	12.3	444
W4 .	145.6	12.6	418
W4 :	143.5	15.2	418
W4 :.	143.3	15.5	418
W5 .	136.0	25.3	364
W5 :	135.6	26.0	364
W5 :.	133.7	28.9	351
W6 .	125.2	41.8	235
W6 :	123.6	44.6	262
W6 :.	124.0	44.0	269
W7 .	119.4	52.7	196
W7 :	117.2	56.3	210
W7 :.	118.3	54.2	207

that there is no marked growth of fiber in either the 300° or 400° specimens. In the carbon steels fibrous structure is found in specimens which have been drawn at 400°. The remaining specimens of the A series have fibered tough fractures.

Water cooled from draw. - The heat treatment of this series of specimens was similar to that of the A series with the exception of the quench from the draw. The fractures (Plate 12b) are similar to those of the A series.

Impact Tests, Data and Curves

Curves for both series of tests on the S.A.E. 3130 steel are given in figure 13 as well as the B.h.n. curves. The impact curves are parallel from 500° to 700°, with the series A curve showing better impact strength than the series W. At 400° is found evidence of "blue brittleness". It would be expected that this property would increase as the drawing temperature is increased but this does not occur. There is no evidence of increased impact toughness in this steel due to quenching from the draw; in fact the air cooled specimens gave slightly higher values except in the "blue brittleness" range.

Composition

C .40% Mn .65% P .024% S .015% Ni 1.37% Cr .68%

S.A.E. 3140

Preliminary Heat Treatment

Effect of temperature. - The effect of varying the hardening temperature on this steel was determined by using temperatures of 790, 800, 810 and 820 degrees C. Due to some error the data for the 820 degree specimens were not recorded. The tests were run in duplicate. The time at the hardening temperature was 10 minutes and water was the quenching medium used. After hardening all of the specimens were drawn at 500 degrees C. and allowed to cool in the air from the draw. The specimens were now notched and broken in the Charpy machine, the results of the impact test are recorded below:

Hardening Temperatures	Impact value ft. lbs.
790	18.75
790	18.4
800	14.45
800	19.5
810	21.7
810	20.4

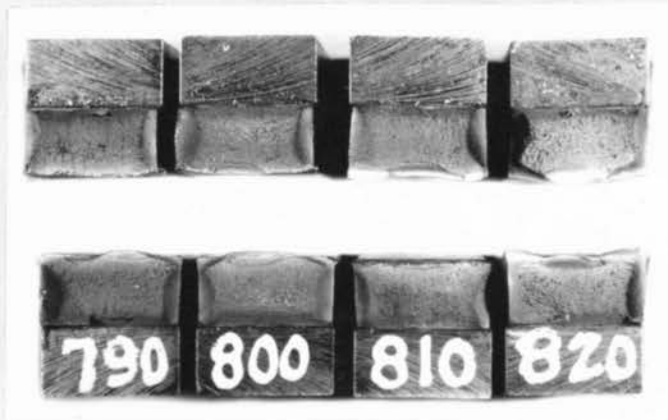
Examination of the above data shows that the hardening temperature may be varied through a considerable range without having any marked effect on the impact value. Plate 13a shows the photograph of representatives of this series of test. This photograph shows a well fibered structure in all cases and there is no marked difference between them.

Effect of time. - To determine the effect of time at the hardening temperature, periods of 20 and 40 minutes were used. These tests were run in duplicate. The temperature chosen was 800 degrees C. and as before, the hardened specimens were drawn at 500 degrees C. and air cooled from the draw, The impact values obtained from this test are tabulated below:

Time at temperature minutes	Impact value ft. lbs.
20	28.9
20	23.8
40	27.4
40	30.3

These data show that 20 minutes at the hardening tempera-

PLATE 13.



a. Fractures of temperature test specimens S.A.E. 3140 steel.

b. Fractures of time test specimens S.A.E. 3140 steel.

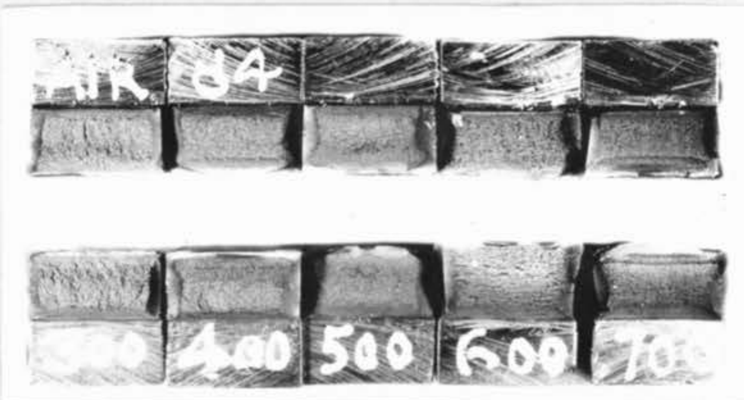
ture is sufficient to maintain a condition of equilibrium. On Plate 13b will be seen the photographs of the fractures of the specimens tested for the effect of time. It will be seen that there is practically no difference between the fractures obtained from the specimen which was held at the hardening temperature for 20 minutes and that which was held for 40 min.

Final Heat Treatment

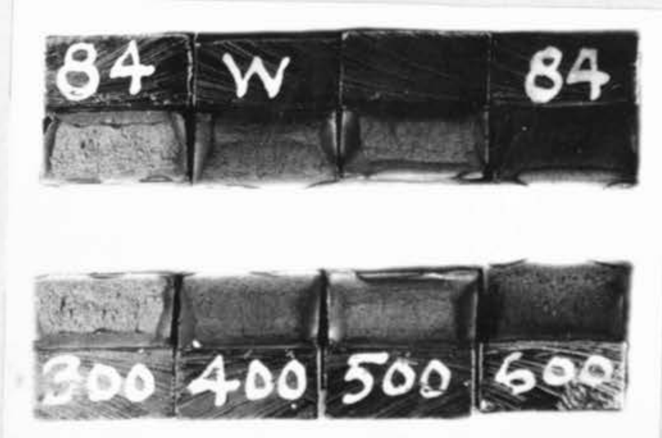
Air cooled from the draw. - The drawing temperatures chosen were 300°, 400°, 500°, 600°, and 700° C. The time the specimens were held at the drawing temperature was 30 minutes. Plate 14a shows the photograph of the fractures of the specimens which were air cooled from the draw. It will be seen that the 300 degree draw gives a granular fracture which is not much improved at 400 degrees but the 500 degree draw shows a marked improvement which increases with the further increases in the drawing temperatures. By looking at this photograph and noting the increase in the fibered structure and then looking at the curve in figure 14 it will be seen that impact value increases as the structure becomes more fibered.

Specimens water quenched from the draw. - The same drawing temperatures were used in this group as in the air cooled group, but it was found that the 700 degree draw specimens cracked in quenching. Due to the cracking of the 700 degree draw in quenching it has been omitted in the photograph and in the data. The photograph Plate 14b shows the 300° specimen to be of a granular structure. The 400° , 500°, and 600° specimens show an increase in the fibered structure. The curve for the water quenched draw, figure 14, shows the increase in im-

PLATE 14.



a. Fractures of representative series A specimens S.A.E. 3140 steel.



b. Fractures of representative series W specimens S.A.E. 3140 steel.

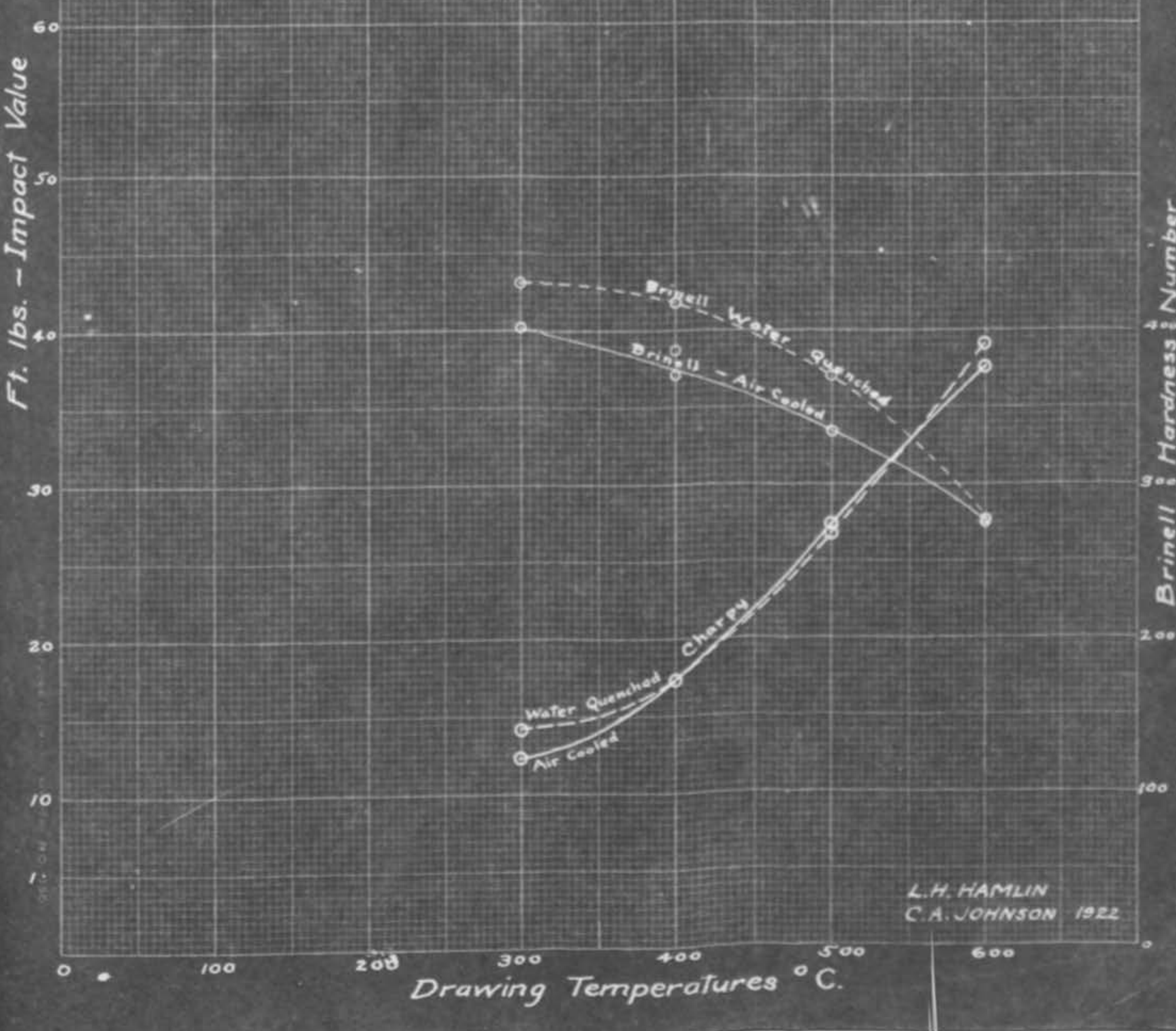
Figure 14

CHARPY IMPACT CURVES

Chrome Nickel Steel S.A.E. 3140

DATA

Drawing Temp. °C.	Impact Value Ft. Lbs. Average of 3 Specimens Air Cooled	Water Quenched
300	12.30	14.10
400	17.35	17.35
500	27.45	26.75
600	37.60	39.08



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DATA

Chrome Nickel Steel S.A.E 3140

Heat treatment: All specimens heated 20 minutes at 800 degs. C. and quenched in oil. Subsequent heat treatment as explained in marking system.

Specimen Number	Charpy Angle Degrees (θ)	Impact Value Ft. Lbs.	Brinell Hardness Number
A3 .	145.0	13.0	402
A3 :	144.0	14.5	430
A3 :.	149.0	9.17	402
A4 .	145.3	12.7	364
A4 :	134.0	28.2	375
A4 :.	146.0	12.3	375
A5 .	143.7	14.9	364
A5 :	135.3	26.0	340
A5 :.	124.5	43.3	302
A6 .	122.5	47.0	255
A6 :	127.5	38.3	277
A6 :.	129.0	36.1	277
A7 .	127.7	38.3	248
A7 :	123.0	45.8	241
A7 :.	125.4	42.0	241
W3 .	138.3	22.0	418
W3 :	146.0	12.3	340
W3 :.	149.3	8.67	444
W4 .	152.0	5.85	418
W4 :	144.0	14.5	387
W5 :.	130.0	34.6	364
W5 .	135.0	26.7	387
W5 :	140.0	19.5	387
W6 :.	128.5	36.8	269
W6 :	129.5	35.4	286
W6 :.	124.0	44.0	

pact value with rising drawing temperatures, which checks with the examination of the photograph.

Impact Tests, Curves and Data

The curves show the characteristic rise in impact value with increase in drawing temperatures. It will be noted that the impact value for the specimens which were air cooled from the draw is nearly the same as that of those specimens which were water quenched. Further examination of the curves shows that the Brinell hardness is higher for all draws when the steel is water quenched from the draw. This increased hardness might be a valuable property for certain classes of work where hardness is a desirable quality and the increase can be obtained without sacrificing impact strength.

V. SUMMARY AND CONCLUSIONS.

Carbon Steels

The impact properties of three representative carbon steels, S.A.E. 1025, 1035, and 1045, have been investigated. The investigation has included: selection of proper temperatureand duration of heat for hardening operations, the relation of drawing temperature to impact value, the relative merits of air cooling from the draw as contrasted with quenching in water from the draw, the relation of B.h.n. to impact value, the relative impact properties of the different steels. From the data obtained in this work the following conclusions are drawn:

The temperatures recommended by the Society of Automotive Engineers may be increased by as much as 50 C. without causing a variation in impact value exceeding the probable experimental error. Ten minutes in a lead bath is sufficent time to complete the solid solution of a Charpy specimen made from any of these steels.

There is no marked increase in the impact strength of a hardened and drawn specimen over that of a hardened and undrawn specimen unless a drawing of 300°C. or higher is used. Beyond 300°the impact-drawing temperature curves rise rapidly so that at 600° the impact strength increased to 600-700% of that found in the hardened and undrawn specimen.

In the study of the S.A.E. 1035 steel it was found that there is little difference in the impact value of specimens which have been air cooled from the draw and those which have been quenched in water. From this it is concluded that the S.A.E. 1035 steel does not have the property of blue brittleness . The data obtained on the S.A.E. 1025 steel show that specimens which are quenched in water have the better impact value until the drawing temperature is increased to 540° where the impact values of specimens which have been quenched in water from the draw and those which have been air cooled from the draw are equal. At 600 drawing temperature the air cooled specimen is superior. The difference in impact value is not large, however, in any part of the drawing temperature range; the largest difference is 7.5 ft. lbs at 300 .

There is no uniform relation between B.h.n. and Charpy impact value. Consequently, Brinell hardness cannot be used to predict impact value.

The lowest carbon steel has the best impact values. The highest impact value recorded is 60.8 ft. lbs. for the

S.A.E. 1025 at 600° drawing temperature.

In the S.A.E. 1035 steel there is no marked increase in impact value until the martensite has been transformed into troostite. The toughest specimens are in the sorbitic condition. Throughout the change of troostite to sorbite there is an increase in the impact value. This seems to be the general relation, although the micro-examination has been completed on only one steel.

Chrome Nickel Steels

The impact properties of three kinds of chrome-nickel steels, S.A.E. 3120, 3130 and 3140 (corresponding in carbon content to the carbon steels studied) have been investigated. The investigation has been similar in all respects to that of the carbon steels: temperature and duration of heat for hardening, the relation of drawing temperature to impact value, the relative merits of air cooling and water quenching from the draw, the relation of B.h.n. to impact value and the relative impact properties of the three steels have been investigated. From the data which have been obtained the following conclusions are drawn:

The temperatures recommended by the S.A.E. may be increased by 50° without causing a marked changed in impact value. Ten minutes is sufficient time to complete the solid solution of Charpy specimens made of these steels.

These steels require a higher draw than the corresponding carbon steels to develop their potential impact properties. In order to effect a material increase in impact value over the hardened specimen a drawing temperature of 400°C must be used. At 700° the impact value is about 600% of that of the hardened and undrawn specimen.

There is no marked superior impact strength in specimens which have been quenched in water from the draw. The difference between the impact value of specimens which have been quenched in water from the draw and those which have been air cooled is small; some of the data show the air cooled specimen as better. There is no indication of blue brittleness with the possible exception of the S.A.E. for a draw of 400°.

The relation of the B.h.n. to impact value is not uniform.

The impact properties of the lowest carbon steel, 3120, are the best. The maximum value is 65 ft. lbs. at 700°.

The impact properties of the chrome-nickel steels are not much better than those of corresponding carbon steels; in some cases they are lower at the same drawing temperature, for example at 500° and 600°.

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