CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION CFSTI
DOCUMENT MANAGEMENT BRANCH 410.11

LIMITATIONS IN REPRODUCTION QUALITY

ACCESSION # AD 604872

- [x] 1. WE REGRET THAT LEGIBILITY OF THIS DOCUMENT IS IN PART UNSATISFACTORY. REPRODUCTION HAS BEEN MADE FROM BEST AVAILABLE COPY.
- [ ] 2. A PORTION OF THE ORIGINAL DOCUMENT CONTAINS FINE DETAIL WHICH MAY MAKE READING OF PHOTOCOPY DIFFICULT.
- [ ] 3. THE ORIGINAL DOCUMENT CONTAINS COLOR, BUT DISTRIBUTION COPIES ARE AVAILABLE IN BLACK-AND-WHITE REPRODUCTION ONLY.
- [ ] 4. THE INITIAL DISTRIBUTION COPIES CONTAIN COLOR WHICH WILL BE SHOWN IN BLACK-AND-WHITE WHEN IT IS NECESSARY TO REPRINT.
- [ ] 5. LIMITED SUPPLY ON HAND: WHEN EXHAUSTED, DOCUMENT WILL BE AVAILABLE IN MICROFICHE ONLY.
- [ ] 6. LIMITED SUPPLY ON HAND: WHEN EXHAUSTED DOCUMENT WILL NOT BE AVAILABLE.
- [ ] 7. DOCUMENT IS AVAILABLE IN MICROFICHE ONLY.
- [ ] 8. DOCUMENT AVAILABLE ON LOAN FROM CFSTI (TT DOCUMENTS ONLY).
- [ ] 9.

PROCESSOR: SF

TSL-107-10/64

Technical Report

Effect of Carbon on the Hardenability and Mechanical Properties of of 5Ni-Cr-Mo-V Steel

Applied Research Laboratory
United States Steel
Monroeville, Pennsylvania

July 1, 1964 Project No. 40.018-001(25)

NObs-88540 SR007-01-01 Task 853 S-11324

EFFECT OF CARBON ON THE HARDENABILITY AND MECHANICAL PROPERTIES OF 5NI-CR-MO-V STEEL

(40.018-001)(25)(a-AS-NP-36)(S-11324)

By S. J. Manganello and L. F. Porter

Approved by J. H. Gross, Division Chief

Abstract

Previous Applied Research Laboratory studies have shown that a 5Ni-Cr-Mo-V steel containing 0.10 C, 0.75 Mn, 0.25 Si, 5.00 Ni, 0.55 Cr, 0.55 Mo, 0.07 V, 0.025 Al, and 0.010 max P and S is extremely promising as an HY-130/150 steel. Therefore, Laboratory studies were initiated to establish the composition ranges in carbon, manganese, silicon, nickel, chromium, molybdenum, and aluminum within which the desired properties of the 5Ni-Cr-Mo-V steel can be obtained.

In the present study, seven Laboratory 5Ni-Cr-Mo-V steels containing 0.05 to 0.27 percent carbon were evaluated to establish the carbon-ordering range for the 5Ni-Cr-Mo-V steel as an HY-130/150 steel and to determine the potential of the 5Ni-Cr-Mo-V steel as an HY-180/210 steel.

The results showed that an average yield strength of about 140 ksi should be obtained in 1/2-inch-thick water-quenched production plates at a carbon content of about 0.045 percent, but that a minimum carbon content of about 0.085 percent should be specified to obtain similar properties at the midthickness of 4-inch-thick water-quenched plates. Therefore, an ordering range of 0.08 to 0.13 percent carbon is recommended for the 5Ni-Cr-Mo-V steel to insure the desired strength, toughness, and weldability for an HY-130/150 steel.

In the tempering range 900 to 1200 F, none of the steels investigated exhibited a yield strength of 180 ksi. The high-carbon steels from the present study and other experimental steels are being evaluated at lower tempering temperatures to determine their potential as HY-180/210 steels.

Introduction

A previous study[1)*] at the Applied Research Laboratory indicated that an 0.10 percent carbon 5Ni-Cr-Mo-V steel is a very promising HY-130/150 steel. An evaluation[2)] of 1- through 4-inch-thick plates from an 80-ton electric-furnace heat of this steel confirmed the Laboratory study. However, the 80-ton heat was ordered to a very restricted composition range because, at the time the heat was ordered, little was known of the hardenability and mechanical properties that would result if the composition, particularly the carbon content, differed significantly from the aim composition. Thus, Laboratory studies were initiated to establish the composition ranges for the 5Ni-Cr-Mo-V steel within which the desired properties can be obtained. The studies include an investigation of the effects of variations in carbon, manganese, silicon, nickel, chromium, molybdenum, and aluminum on the hardenability and mechanical properties of the 5Ni-Cr-Mo-V steel.

In the investigation of the effects of carbon content, carbon was varied from 0.05 to 0.15 percent to establish the carbon range for the 5Ni-Cr-Mo-V steel as HY-130/150 steel. In addition, carbon contents from 0.15 to 0.27 percent were investigated to determine the potential of the 5Ni-Cr-Mo-V steel as an HY-180/210 steel. The present report describes the results of the studies on the effects of carbon content on the properties of the 5Ni-Cr-Mo-V steel.

*See References.

Materials and Experimental Work

Melting and Rolling Procedures

Two 300-pound heats were vacuum-melted and vacuum-carbon-deoxidized at the Laboratory.* One of these heats was melted with a carbon content of about 0.05 percent, and one third of the melt was cast into a 100-pound 3- by 8- by 14-inch slab ingot. The carbon content of the remaining metal was then increased to about 0.10 percent, and a second 100-pound ingot was cast. Finally, the carbon content of the heat was increased to about 0.15 percent, and a third 100-pound ingot was cast. The second 300-pound heat was melted with a carbon content of about 0.15 percent and with no aluminum addition, and a 100-pound 3- by 8- by 14-inch slab ingot was cast.** The carbon content of the heat was then increased to about 0.20 percent and the aluminum content to about 0.020 percent (the same content as that of the first heat), and a second 100-pound ingot was cast. The carbon content of the heat was then increased to about 0.25 percent, and a third 100-pound ingot was cast.

In addition to the two 300-pound split heats, two other 300-pound vacuum-melted, vacuum-carbon-deoxidized heats were melted at the Laboratory. One heat contained about 0.05 percent carbon (low extreme

---

*Silicon and aluminum (when added) were added as alloying elements after vacuum-carbon deoxidation.

**The aluminum-free steel ingot was produced for another study and is not discussed further in the present report.

of carbon content studied), and the second heat contained about 0.25 percent carbon (high extreme of carbon content studied).* Each of these heats was cast into a 300-pound 5- by 12- by 17-inch slab mold. The compositions of the steels are shown in Table I.

Each of the 100-pound slab ingots was straightaway-rolled from 3 inches thick to 1-1/4 inches thick and air-cooled. Each 1-1/4-inch-thick slab was then cut transversely into three 10-1/2-inch-long pieces (A - top, B - middle, and C - bottom of ingot) and each piece was cross-rolled to a 1/2-inch-thick plate approximately 10-1/2 inches wide by 20 inches long and air-cooled. The longitudinal** to transverse rolling ratio for the 1/2-inch-thick plates was about 1 to 1.

The two 300-pound slab ingots were straightaway-rolled from 5 inches thick to 1-3/4 inches thick and air-cooled. Each 1-3/4-inch-thick slab was then cut transversely into four 11-inch-long pieces (A - top, B - top middle, C - bottom middle, and D - bottom of ingot), and each piece was cross-rolled to a 1/2-inch-thick plate approximately 11 inches wide by 40 inches long and air-cooled. The longitudinal** to transverse rolling ratio for these 1/2-inch-thick plates was about 1.2 to 1.

---

*These duplicate heats were produced to determine whether ingot size and/or pouring practice had any effect on the properties of these steels.

**Parallel to the final rolling direction.

Heat Treatment

To determine the mechanical properties of the seven steels (comprising five 100-pound ingots and two 300-pound ingots), Plates B and C from each of the 100-pound ingots were cut to provide ten 5- by 6-1/2-inch plate samples, and Plate B from each of the 300-pound ingots was cut to provide ten 5- by 8-inch plate samples.

Five plate samples of each steel were austenitized for 30 minutes at 1500 F and water-quenched. One of the plate samples was not tempered, whereas the other four plate samples were individually tempered for 30 minutes at 900, 1000, 1100, or 1200 F, and water-quenched.

The remaining five plate samples of each steel were austenitized for 2 hours at 1500 F and blower-cooled within a wind channel to simulate the cooling rate at the midthickness of a water-quenched 4-inch-thick plate.[3)] One of the blower-cooled plate samples was not tempered, whereas the other four plate samples were individually tempered for 2 hours at 900, 1000, 1100, or 1200 F, and then blower-cooled.

Mechanical Tests

Two longitudinal 0.252-inch-diameter tension-test specimens and eight longitudinal Charpy V-notch impact-test specimens were machined from each heat-treated plate sample. The tension-test specimens were tested at room temperature, and duplicate or triplicate impact-test specimens were tested at +80, 0, and -80 F.

The Rockwell C hardness was determined on representative impact-test specimens for each steel and condition of heat treatment.

Metallographic Studies

Heat-treated specimens of each of the steels were metallographically prepared and examined by means of light microscopy. The microstructure of each of the blower-cooled (untempered) steels was photographed.

Results and Discussion

Chemical Composition

Each of the seven 5Ni-Cr-Mo-V steels evaluated contained about 0.75 percent manganese, 0.005 percent phosphorus, 0.003 percent sulfur, 0.25 percent silicon, 4.95 percent nickel, 0.55 percent chromium, 0.55 percent molybdenum, 0.07 percent vanadium, 0.020 percent aluminum (acid soluble), and 0.005 percent nitrogen, Table I. The steels ranged in carbon content from 0.05 percent (Steel A) to 0.27 percent (Steel G).

Although the steels were melted as 300-pound heats, Steels A, B, C, D, and E were poured as 100-pound ingots, and Steels F and G (which were similar in composition to Steels A and E, respectively) were poured as 300-pound ingots. Steels F and G were produced to determine whether ingot size, pouring practice within the vacuum chamber, and/or cross-rolling practice to obtain 1/2-inch-thick plates had any effect on the mechanical properties. A comparison of the mechanical properties, Tables II and III, shows that no significant differences in mechanical properties were observed between heat-treated 1/2-inch-thick plates produced from the 100-pound ingots (Steels A and E) and those produced from the 300-pound ingots (Steels F and G).

Hardenability and Microstructure

Large differences in tensile strength between water-quenched and blower-cooled plates are observed if a steel has inadequate hardenability for 4-inch-thick plates. The effect of carbon content on the difference in tensile strength between the untempered water-quenched and the untempered blower-cooled 1/2-inch-thick plates of the seven steels is shown in Figure 1. The plot shows that there was a large difference in tensile strength (24 to 30 ksi) between the water-quenched and blower-cooled low-carbon (0.05 and 0.06% C) steels, but that this difference in tensile strength decreased sharply as carbon content increased, so that the difference was less than 15 ksi at 0.10 percent carbon and less than 10 ksi above about 0.13 percent carbon.

Figure 1 also shows that the amount of bainite observed in the blower-cooled (untempered) 1/2-inch-thick plates of the seven steels ranged from 60 to 65 percent in the low-carbon (0.05 and 0.06% C) steels to 30 to 35 percent in the 0.10 percent carbon steel to 0 to 1 percent in the 0.16 percent carbon steel. The 0.22, 0.26, and 0.27 percent carbon steels were completely martensitic.

The plot of carbon content versus percent bainite in the blower-cooled plates and the plot of difference in tensile strength between water-quenched and blower-cooled plates break at about the same carbon content (0.14%); thus either criterion reliably indicates the carbon content required to fully harden 4-inch-thick plates.

The microstructures of the blower-cooled 1/2-inch-thick plates of Steels A, B, C, and D (0.05, 0.10, 0.16, and 0.22% C, respectively) are shown in Figure 2. Figures 2A, B, and C depict the decreasing amount of bainite and increasing amount of martensite that formed in the 5Ni-Cr-Mo-V steel as the carbon content increased from 0.05 to 0.16 percent; Figure 2D depicts the appearance of the martensite that is formed when the steel contains 0.22 percent carbon. Figure 3 compares the microstructures of the water-quenched 1/2-inch-thick plates of Steels A and G, the lowest and highest carbon steels investigated (0.05 and 0.27% C, respectively). The microstructure of Steel A is a mixture of low-carbon martensite and bainite, whereas the microstructure of Steel G is 100 percent martensite.

Tensile and Impact Properties

The longitudinal tensile properties of the water-quenched and of the blower-cooled 1/2-inch-thick plates of the seven steels investigated are listed in Table II, and the corresponding Charpy V-notch impact properties are listed in Table III. The data show that, in general, the strength decreased and the ductility and toughness increased as the tempering temperature was raised from 900 to 1200 F.

The strength data confirm the low hardenability of the low-carbon (0.05 and 0.06% C) steels, and show that the highest yield strength (0.2% offset) for the blower-cooled plates (Steels A and F) was 102 ksi in the untempered condition and 113 ksi in the tempered condition. Although the yield strength increased continuously as the carbon content increased, the high-carbon (0.26 and 0.27% C) steels did not attain a yield strength as high as 180 ksi in either the water-quenched or blower-cooled condition when tempered in the range 900 to 1200 F. Studies are in progress to determine whether a yield strength of 180 ksi or higher can be obtained in the 0.22 and 0.27 percent carbon steels (Steels D and G) by tempering at 400, 600, or 800 F.

The ductility and toughness decreased as the carbon content increased, and the decrease was generally inversely proportional to the aforementioned increase in strength with increasing carbon content.

The effect of carbon content on the yield strength and energy absorption at 0 F of untempered water-quenched and blower-cooled 1/2-inch-thick plates of the 5Ni-Cr-Mo-V steel is plotted in Figure 4. The plot shows the increase in yield strength and the decrease in notch toughness that occurred when the carbon content increased. The figure also shows a larger difference in yield strength and a larger difference in energy absorption between the water-quenched and the blower-cooled plates of the lower carbon steels than between those of the higher carbon steels, and thus substantiates the necessity for a minimum amount of carbon for adequate hardenability in 4-inch-thick plates of the 5Ni-Cr-Mo-V steel. Steel G (0.27% C) developed yield strengths of over 180 ksi (183 to 193 ksi) in the as water-quenched and the as blower-cooled conditions but exhibited correspondingly low energy-absorption values at 0 F (23 to 25 ft-lb).

Temperability

The effect of tempering temperature on the longitudinal yield strength (0.2% offset) and Charpy V-notch energy absorption at 0 F for the water-quenched and blower-cooled 1/2-inch-thick plates of each of the seven steels is plotted in Appendix Figures A through G. The large differences in yield strength between the water-quenched and blower-cooled plates of the low-carbon steels (Steels A and F) again emphasize that these steels have insufficient hardenability to fully harden 1/2-inch-thick blower-cooled plates. The Appendix figures also show that the low-carbon steels (Steels A, B, and F) exhibited greater response to secondary hardening (increase in yield strength at a tempering temperature of about 1100 F) than the higher carbon steels.

From the Appendix figures, the energy absorption corresponding to a yield strength of 135 ksi was obtained for the water-quenched and for the blower-cooled plate samples, and the data were then plotted in Figure 5 to show the impairment to notch toughness that results from an increase in carbon content in the 5Ni-Cr-Mo-V steel. At the 135 ksi yield-strength level, each increase of 0.01 percent carbon lowered the energy absorption an average of 2.7 ft-lb. (A yield strength of 135 ksi could not be obtained in the blower-cooled plates of the 0.05 and 0.06 percent carbon steels, Steels A and F, because of their low hardenability.)

From the Appendix figures, the maximum yield strength was selected for each water-quenched and tempered and each blower-cooled and tempered steel. These data were then plotted against carbon content in Figure 6. The figure shows that a yield strength of 135 ksi* can be obtained in water-quenched 1/2-inch-thick plates of the 5Ni-Cr-Mo-V steel containing as little as about 0.045 percent carbon, but that a minimum carbon content of about 0.085 percent is required for a yield strength of 135 ksi in blower-cooled 1/2-inch-thick plates—which correspond to water-quenched plates about 4 to 4-1/2 inches thick. The maximum yield strength versus carbon content curves for the water-quenched and blower-cooled plates converge at about 0.13 to 0.15 percent carbon, and about

---

*A yield strength of about 135 ksi is needed to insure a minimum yield strength of 130 ksi.

0.13 percent carbon is required for the blower-cooled 1/2-inch-thick plates to exhibit a minimum yield strength of 150 ksi.

Although Figure 6 indicates that the maximum yield strength of an 0.10 percent carbon 5Ni-Cr-Mo-V steel is 148 ksi, yield strengths up to 152 ksi have been obtained in production quenched and tempered 1/2-inch-thick plates of 5Ni-Cr-Mo-V steel containing 0.095 percent carbon[2)] (note the filled data point in Figure 6). The higher attainable yield strength in production plates is believed to be due to the higher nitrogen content (0.010%) of the air-melted electric-furnace production heats compared with that (0.005%) of the vacuum-melted induction-furnace Laboratory heats.

General Discussion

The results of the present study have shown that a minimum carbon content of about 0.085 percent is required for the 5Ni-Cr-Mo-V steel to exhibit a minimum yield strength of 135 ksi in blower-cooled 1/2-inch-thick plates (a conservative simulation of 4-inch-thick plates), and that a carbon content of about 0.13 percent is required to provide sufficient hardenability for blower-cooled 1/2-inch-thick plates of average alloy content to exhibit a microstructure of greater than 90 percent martensite and a minimum yield strength of 150 ksi.

Considering that blower-cooled 1/2-inch-thick plates provide a conservative estimate of the properties in the center of 4-inch-thick water-quenched plates and that the yield strength attained in 1/2-inch-thick plates from production heat No. X53185 was about 4 ksi higher than predicted from the current study, a carbon content of 0.085 percent should result in average yield strengths of 150 to 140 ksi for 1/2- and 4-inch-thick plates, respectively, of the 5Ni-Cr-Mo-V steel. For maximum notch toughness and weldability, the carbon content should be kept as low as possible; however, practical steelmaking considerations dictate that a melting range of five points of carbon is desirable. Therefore, an ordering range of 0.08 to 0.13 percent carbon is recommended for the 5Ni-Cr-Mo-V steel.

Summary

The present study of the effect of carbon content (0.05 to 0.27%) on the hardenability and mechanical properties of the 5Ni-Cr-Mo-V steel was conducted to establish a carbon-ordering range for production heats of this steel, and to determine the suitability of this steel, modified with higher carbon content, as a quenched and tempered HY-180/210 steel. The results of this study, which was conducted on water-quenched and blower-cooled 1/2-inch-thick plates of seven steels, may be summarized as follows:

1. A yield strength of 135 ksi was obtained in water-quenched 1/2-inch-thick plates of 5Ni-Cr-Mo-V steel containing as little as about 0.045 percent carbon, but when less than 0.085 percent carbon was present in the 5Ni-Cr-Mo-V steel, large differences in tensile strength (20 ksi

or greater) were observed between the water-quenched and blower-cooled 1/2-inch-thick plates, and the blower-cooled plates exhibited microstructures containing 40 percent or more bainite. At a carbon content of about 0.085 percent, the 5Ni-Cr-Mo-V steel exhibited a maximum yield strength of 135 ksi in blower-cooled 1/2-inch-thick plates (which conservatively simulate the midthickness of water-quenched 4-inch-thick plates). However, quenched and tempered production plates of the 5Ni-Cr-Mo-V steel have exhibited yield strengths about 4 ksi higher than the Laboratory 5Ni-Cr-Mo-V steels.

2. At a carbon content of about 0.13 percent, the 5Ni-Cr-Mo-V steel exhibited a microstructure of greater than 90 percent martensite and a minimum yield strength of 150 ksi in 4-inch-thick plates. A microstructure of 100 percent martensite can be obtained in 4-inch-thick plates when the carbon content is 0.15 percent or higher.

3. At the 135 ksi yield-strength level, each increase of 0.01 percent carbon in the 5Ni-Cr-Mo-V steel lowered the energy absorption at 0 F an average of 2.7 ft-lb.

4. In the untempered condition, the water-quenched and the blower-cooled plates of the 0.27 percent carbon steel (the highest carbon level studied) exhibited yield strengths of 183 to 193 ksi, but also exhibited low Charpy V-notch energy absorptions at 0 F of 23 to 25 ft-lb. When tempered in the range 900 to 1200 F, none of the steels exhibited a yield strength as high as 180 ksi.

The results of the present study indicate that an ordering range of 0.08 to 0.13 percent carbon is optimum for the 5Ni-Cr-Mo-V steel to meet the requirements of an HY-130/150 steel.

Recommendations and Future Work

It may be possible to develop a quenched and tempered HY-180/210 steel by employing low-temperature tempering (in the range 400 to 800 F) following quenching. A study is under way at the Applied Research Laboratory to investigate this approach with five promising steels for this application. Included in the study are Steels D (0.22% C) and G (0.27% C) of the present investigation.

References

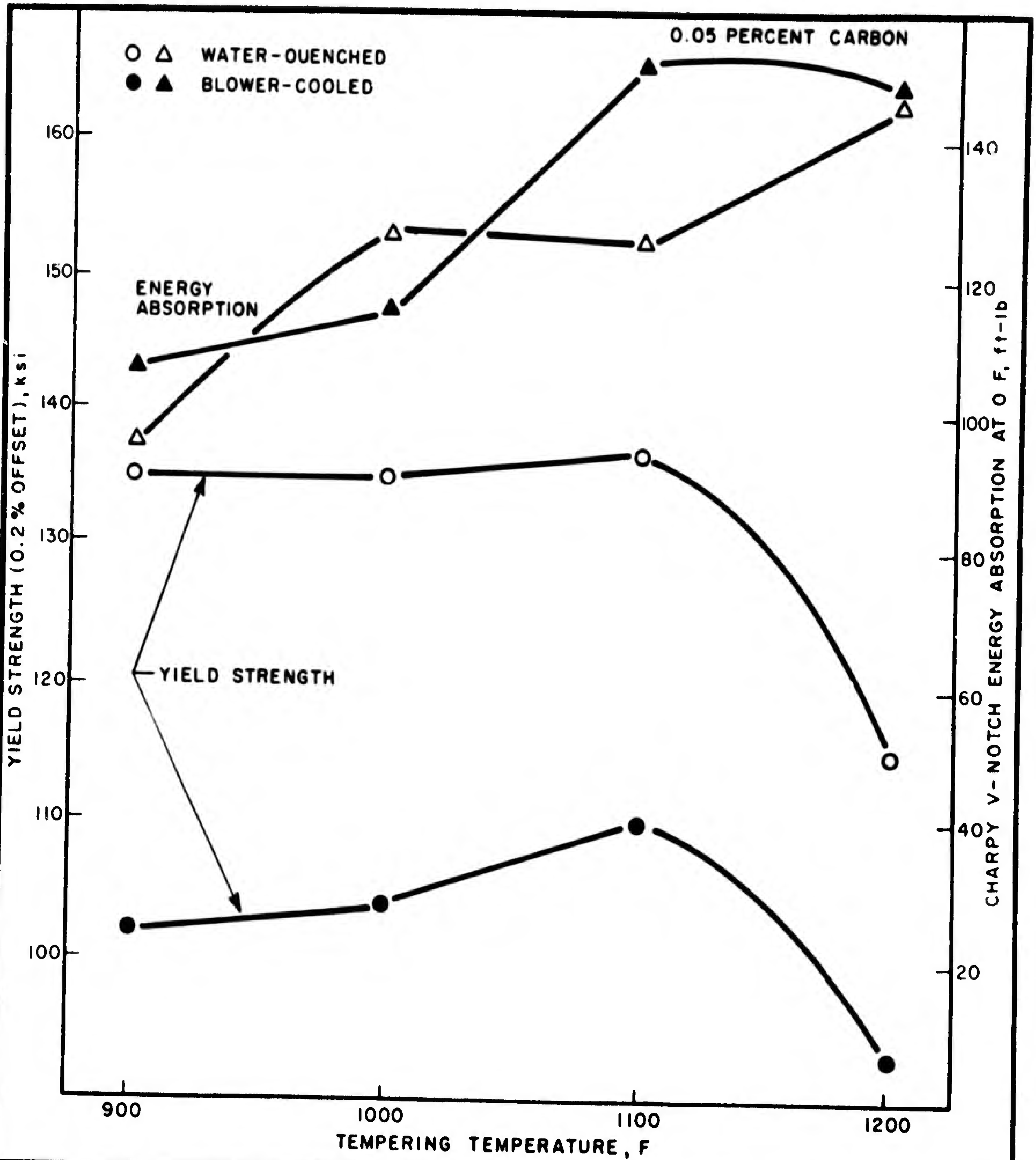
1. S. J. Manganello and L. F. Porter, "Evaluation of the Hardenability, Temperability, and Mechanical Properties of Ten 5Ni-Cr-Mo Steels," Applied Research Laboratory Progress Report, Project 40.18-001(9), (S-11109-1), September 20, 1963.

2. S. J. Manganello and L. F. Porter, "Base-Metal Evaluation of a Production Electric-Furnace Heat of 5Ni-Cr-Mo-V Steel," Applied Research Laboratory Report, Project 40.018-001(21), (S-11104-3), April 1, 1964.

3. S. J. Manganello, L. F. Porter, and R. J. Sitko, "Simulation of the Cooling of a Water-Quenched 4-Inch-Thick Plate," Applied Research Laboratory Progress Report, Project 40.18-001(8), (S-11105), September 18, 1963.

APPENDIX

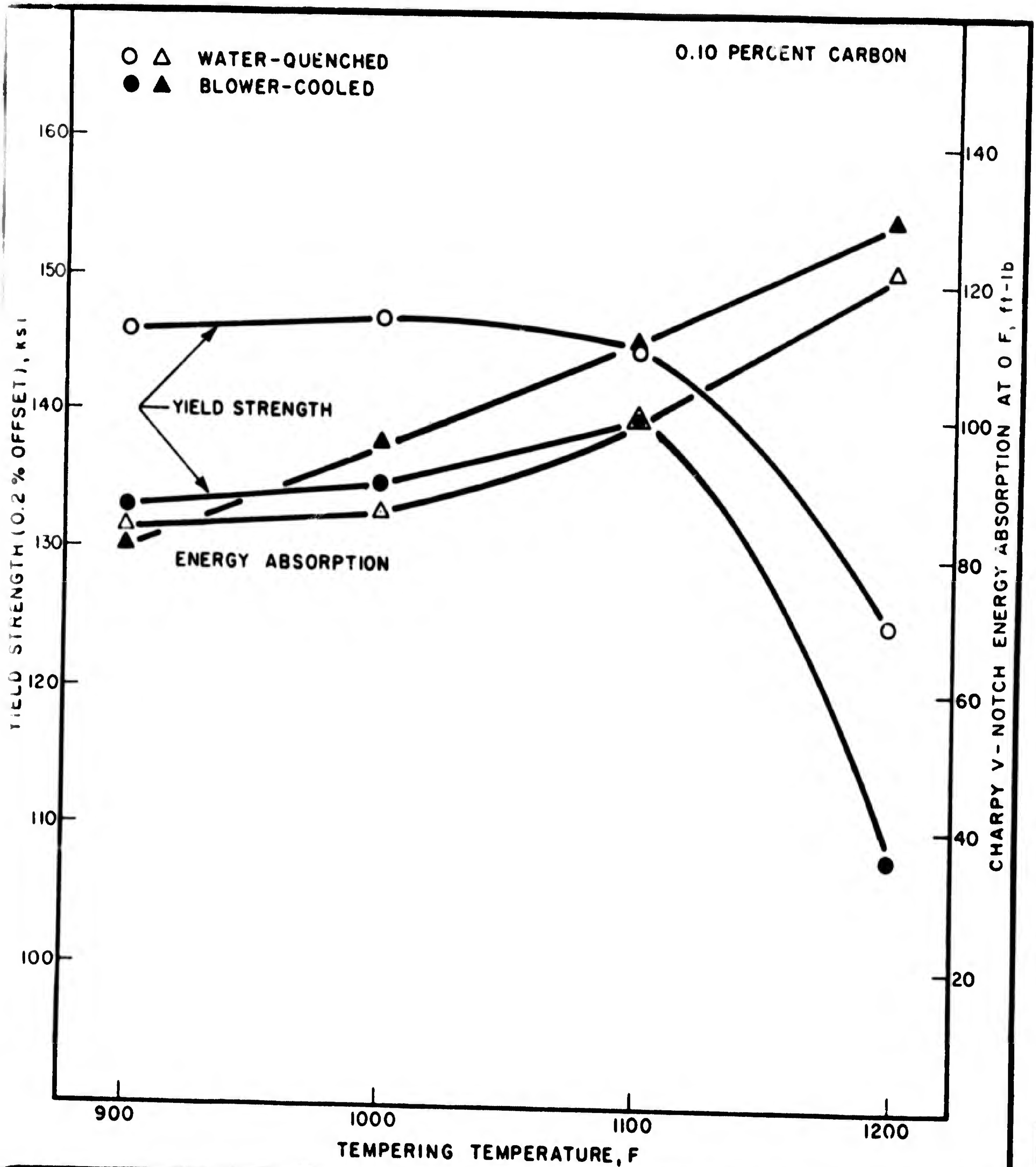
G-18242 REV. 1063



EFFECT OF TEMPERING TEMPERATURE ON THE YIELD STRENGTH AND ENERGY ABSORPTION OF 1/2-INCH-THICK PLATES OF STEEL A

DRAWN BY G.A.Z.	CHK'D BY S.J.M.	APPROVED BY J.H.G.	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. A
DRAWING No ARL 18-370		PROJECT No 40.018-001(25) DATE 5-19-64		

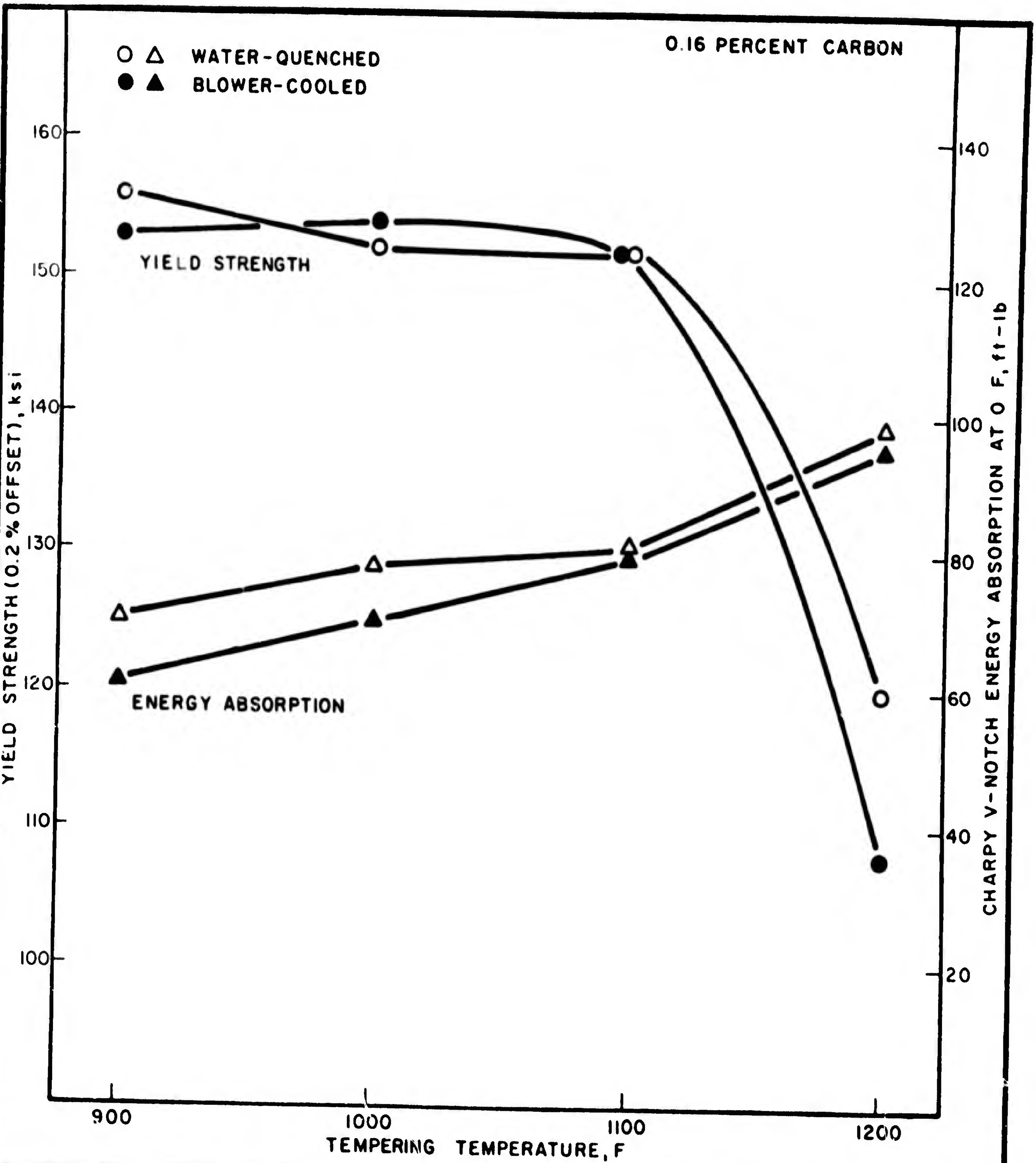
ATLAS LITHO CO PGH PA 1088 CLEARPOINT



EFFECT OF TEMPERING TEMPERATURE ON THE YIELD STRENGTH AND ENERGY ABSORPTION OF 1/2-INCH-THICK PLATES OF STEEL B

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.J.M.	J.H.G.	APPLIED RESEARCH	B
DRAWING No ARL 18-371		PROJECT No 40.018-001(25)	PITTSBURGH, PA.	
		DATE 5-20-64		

G-18242 REV. 1063

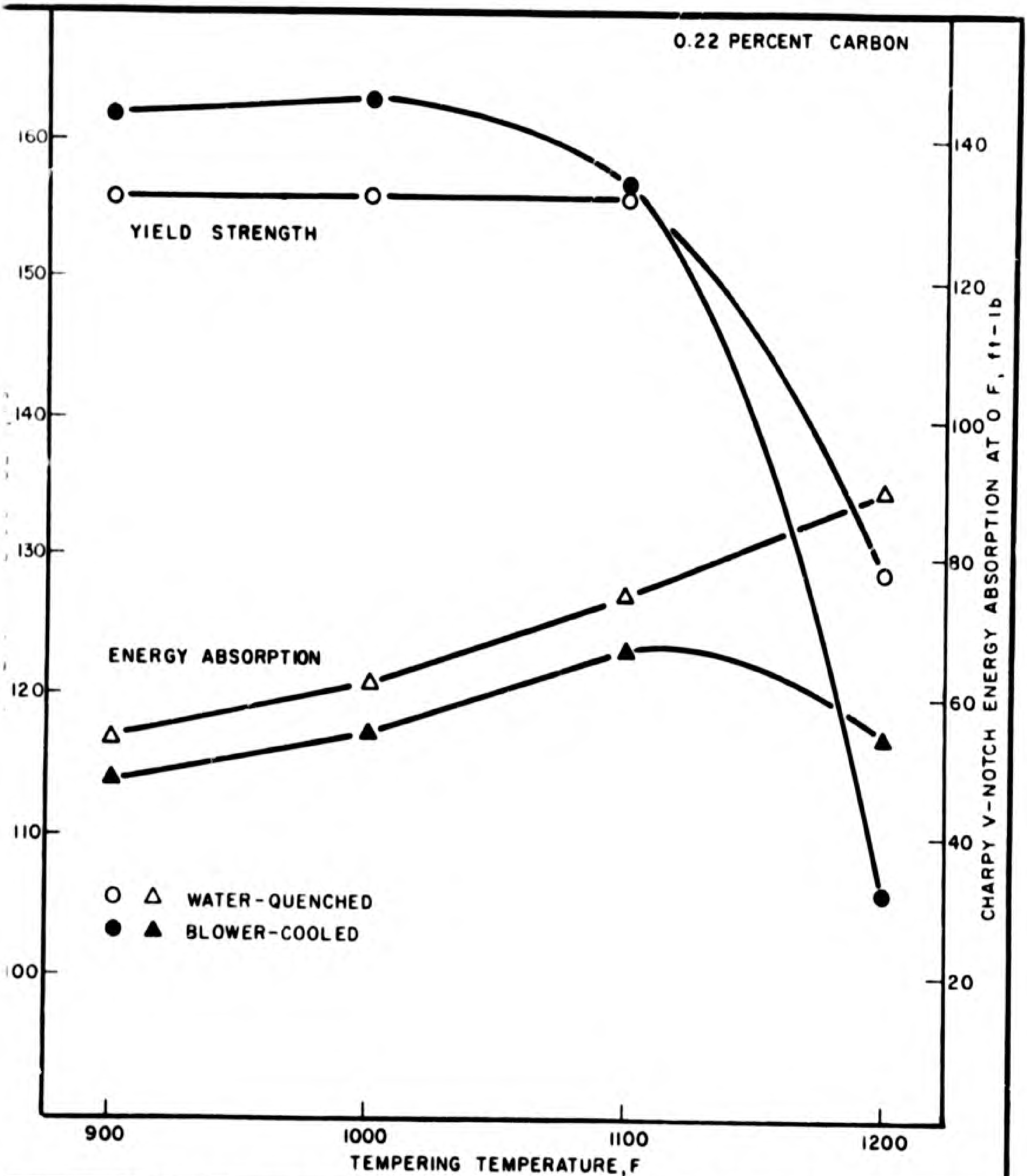


EFFECT OF TEMPERING TEMPERATURE ON THE YIELD STRENGTH AND ENERGY ABSORPTION OF 1/2-INCH-THICK PLATES OF STEEL C

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G A Z	S J M	J H G	APPLIED RESEARCH	C
DRAWING No		PROJECT No 40.018-001(25)	PITTSBURGH, PA.	
ARL 18-372		DATE 5-20-64		

ATLAS LITHO CO. PGH. PA. 1028 CLEARPRINT

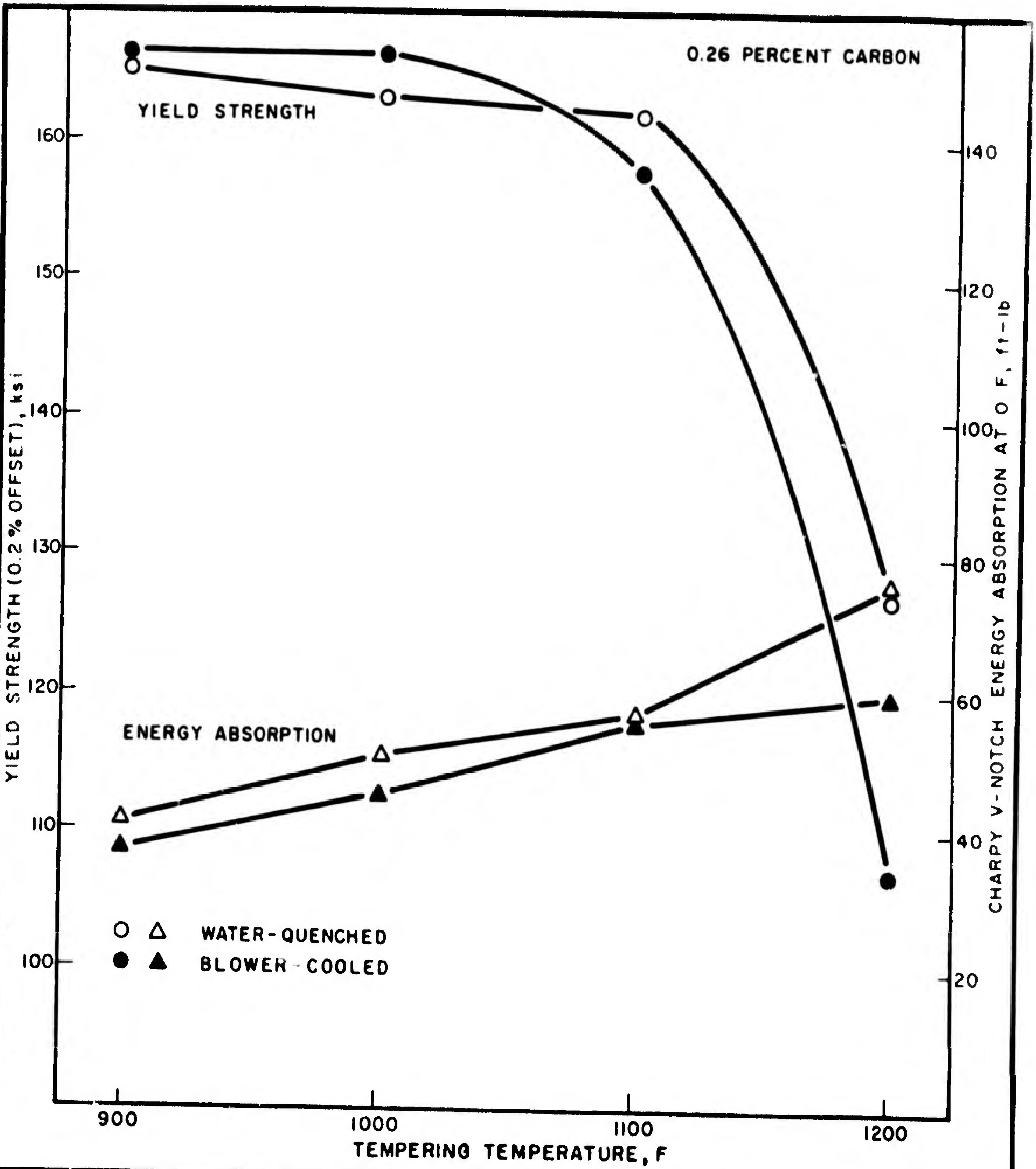
8242 REV. 1063



EFFECT OF TEMPERING TEMPERATURE ON THE YIELD STRENGTH AND ENERGY ABSORPTION OF 1/2-INCH-THICK PLATES OF STEEL D

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.J.M.	J.H.G.	APPLIED RESEARCH	D
DRAWING No		PROJECT No 40.018-001 (25)	PITTSBURGH, PA.	
ARL 18-373		DATE 5-22-64		

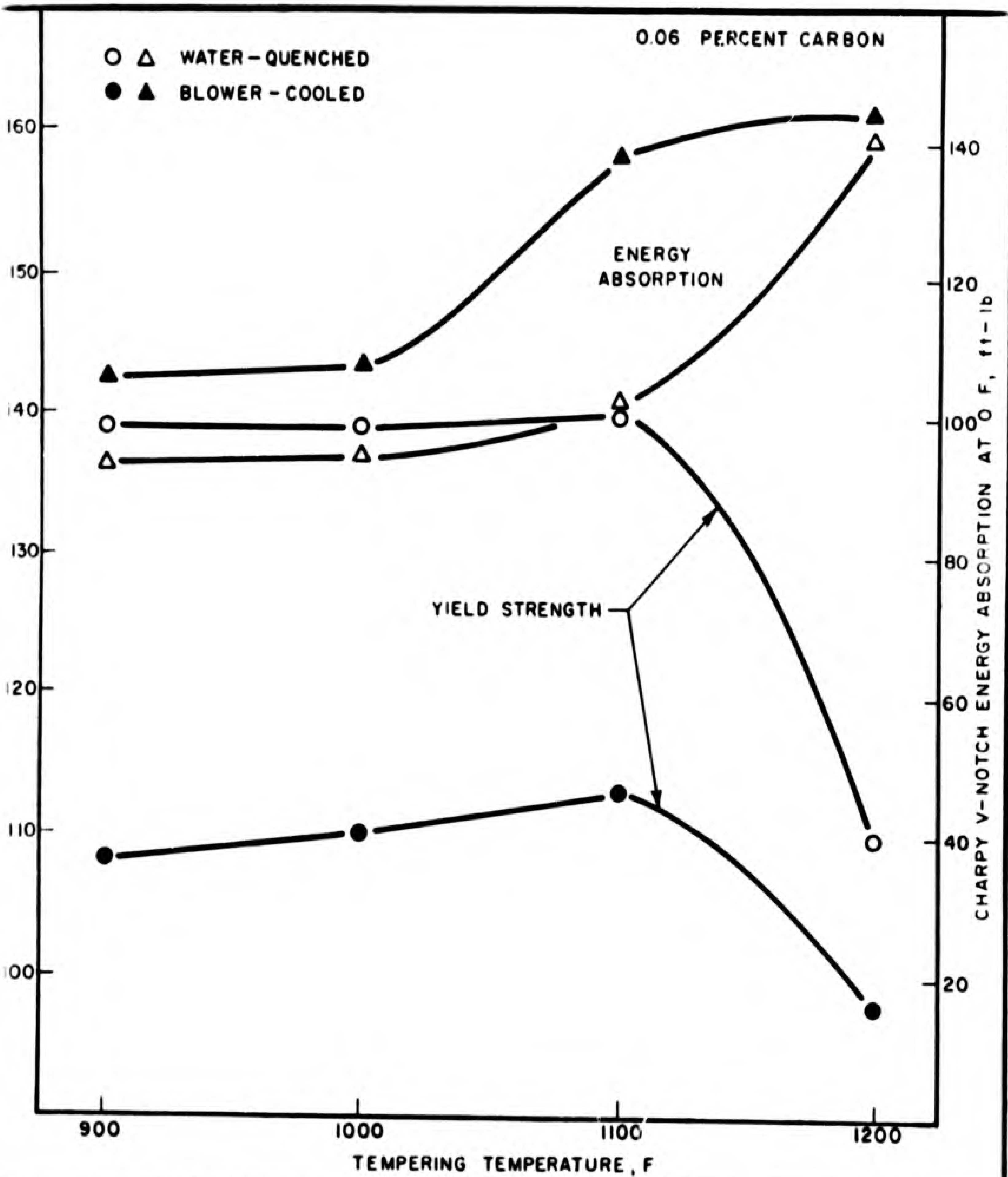
G-18242 REV. 1063



EFFECT OF TEMPERING TEMPERATURE ON THE YIELD STRENGTH AND ENERGY ABSORPTION OF 1/2-INCH-THICK PLATES OF STEEL C

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.J.M.	J.H.G.	APPLIED RESEARCH	E
DRAWING No ARL 18-374		PROJECT No 40.018-001 (25)	PITTSBURGH, PA.	
		DATE 5-22-64		

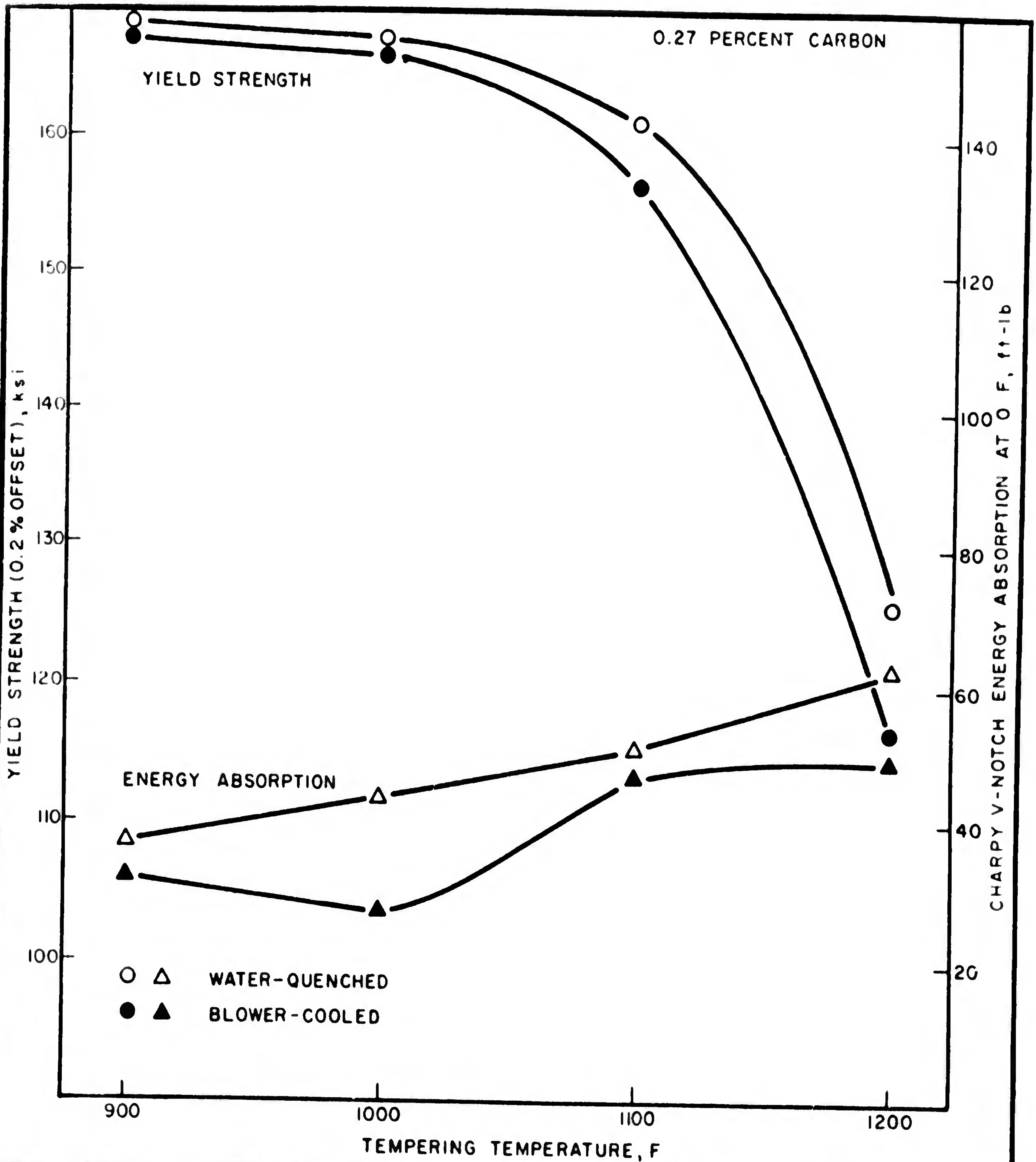
ATLAS LITHO CO PGH PA 1000 CLEARPRINT



EFFECT OF TEMPERING TEMPERATURE ON THE YIELD STRENGTH AND ENERGY ABSORPTION OF 1/2-INCH-THICK PLATES OF STEEL F

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G.A.Z.	S.J.M.	J.H.G.	APPLIED RESEARCH	F
DRAWING No		PROJECT No	PITTSBURGH, PA.	
ARL 18-375		40.018-001(25)		
		DATE 5-22-64		

G 18242 REV. 1063



EFFECT OF TEMPERING TEMPERATURE ON THE YIELD STRENGTH AND ENERGY ABSORPTION OF 1/2-INCH-THICK PLATES OF STEEL G

DRAWN BY	CHK'D BY	APPROVED BY	UNITED STATES STEEL CORPORATION	FIGURE NO.
G A Z	S.J.M.	J H G	APPLIED RESEARCH	G
DRAWING No		PROJECT No 40.018-001 (25)	PITTSBURGH, PA.	
ARL 18-376		DATE 5-25-65		

Table I

Chemical Compositions of Steels Investigated—Percent
(Check Analyses)

Steel	Heat No.	Distinguishing Features	C	Mn	P	S	Si	Ni	Cr	Mo	V	Al*	N**
					100-Pound Ingots								
A	R9422-2A	0.05 C	0.05	0.72	0.005	0.003	0.26	4.90	0.57	0.55	0.074	0.022	0.004
B	R9422-2B	0.10 C	0.095	0.74	0.005	0.003	0.25	4.90	0.57	0.55	0.074	0.022	0.005
C	R9422-2C	0.16 C	0.16	0.74	0.005	0.003	0.25	4.90	0.57	0.55	0.074	0.021	0.006
D	R9423-2B	0.22 C	0.22	0.73	0.006	0.003	0.24	4.92	0.58	0.55	0.073	0.024	0.005
E	R9423-2C	0.26 C	0.26	0.72	0.006	0.003	0.25	5.00	0.57	0.55	0.073	0.021	0.006
					300-Pound Ingots								
F	R9654-1	0.06 C	0.058	0.73	0.005	0.002	0.26	4.94	0.57	0.54	0.073	0.026	0.005
G	R9655-1	0.27 C	0.27	0.74	0.005	0.002	0.26	4.96	0.57	0.56	0.073	0.027	0.004

*Acid soluble.
**Kjeldahl determination.

Table II

Tensile Properties of Steels Investigated

Steel	Carbon Content, %	Tempering Temp, F	Yield Strength, ksi: 0.02% Offset WQ*	Yield Strength, ksi: 0.02% Offset BC*	Yield Strength, ksi: 0.2% Offset WQ	Yield Strength, ksi: 0.2% Offset BC	Tensile Strength, ksi WQ	Tensile Strength, ksi BC	Elongation in 1 Inch, % WQ	Elongation in 1 Inch, % BC	Reduction of Area, % WQ	Reduction of Area, % BC	Yield-Tensile Ratio WQ	Yield-Tensile Ratio BC
Plate Samples From 100-Pound Ingots														
A	0.05	Untempered	92	62	133	99	160	133	17.5	20.0	72.4	74.7	0.83	0.75
		900	123	74	135	102	145	130	18.0	22.0	72.6	73.5	0.93	0.78
		1000	122	80	135	104	144	131	20.0	22.0	75.4	76.6	0.94	0.79
		1100	125	89	137	110	143	131	19.0	22.0	75.3	76.7	0.96	0.84
		1200	98	83	115	93	127	123	24.0	23.0	77.6	77.9	0.90	0.76
B	0.10	Untempered	121	76	153	123	180	164	13.5	18.0	68.8	71.1	0.85	0.75
		900	135	109	146	133	157	152	17.0	18.0	68.2	66.0	0.93	0.88
		1000	135	110	147	135	157	154	18.5	20.5	70.3	66.9	0.94	0.88
		1100	132	126	145	140	153	151	19.5	20.5	70.1	70.9	0.95	0.93
		1200	111	97	125	108	137	135	22.0	21.5	73.4	71.9	0.91	0.80
C	0.16	Untempered	127	99	165	149	199	193	16.0	16.5	61.6	66.4	0.83	0.77
		900	143	137	156	153	166	167	17.5	17.0	63.4	62.0	0.95	0.92
		1000	144**	137	152**	154	164	168	19.0	20.0	67.1	66.5	0.93	0.92
		1100	141	139	152	152	161	161	20.5	18.0	68.6	67.1	0.94	0.94
		1200	107	97	120	108	141	140	22.5	21.0	68.2	66.6	0.85	0.77
D	0.22	Untempered	131	98	178	156	220	213	16.0	15.5	63.2	60.9	0.80	0.73
		900	148	148	156	162	169	177	16.0	16.0	59.8	60.2	0.92	0.92
		1000	147	147	156	163	169	176	16.5	17.0	64.2	62.8	0.92	0.93
		1100	145	144	156	157	165	165	18.5	18.0	67.1	66.2	0.95	0.95
		1200	121	84	129	106	145	152	20.5	21.0	67.0	57.8	0.89	0.70
E	0.26	Untempered	149	124	179	177	242	234	15.0	14.5	57.3	56.6	0.74	0.76
		900	156	155	165	166	180	182	15.0	14.5	57.0	56.3	0.92	0.91
		1000	153	153	163	166	176	181	18.5	16.5	64.1	62.5	0.93	0.92
		1100	150	149	162	158	169	169	17.5	17.5	62.5	63.4	0.96	0.94
		1200	116	89	127	107	149	153	21.0	20.0	63.6	55.9	0.85	0.70

(Continued)

Table II (Continued)

Tensile Properties of Steels Investigated

Steel	Carbon Content, %	Tempering Temp, F	Yield Strength, ksi: 0.02% Offset WQ*	Yield Strength, ksi: 0.02% Offset BC*	Yield Strength, ksi: 0.2% Offset WQ	Yield Strength, ksi: 0.2% Offset BC	Tensile Strength, ksi: WQ	Tensile Strength, ksi: BC	Elongation in 1 Inch, %: WQ	Elongation in 1 Inch, %: BC	Reduction of Area, %: WQ	Reduction of Area, %: BC	Yield-Tensile Ratio: WQ	Yield-Tensile Ratio: BC
Plate Samples From 300-Pound Ingots														
F	0.06	Untempered	94	61	136	102	168	138	17.0	20.0	71.1	72.8	0.81	0.74
		900	129	80	139	108	148	136	18.0	19.5	70.2	70.4	0.94	0.79
		1000	127	82	139	110	147	136	19.0	20.5	73.2	71.5	0.95	0.81
		1100	126	92	140	113	151	135	21.5	21.5	74.5	74.0	0.93	0.84
		1200	95	87	110	98	129	126	23.5	22.5	77.4	75.8	0.85	0.78
G	0.27	Untempered	149	128	193	183	243	239	13.5	15.5	55.7	55.4	0.79	0.77
		900	164	157	168	167	182	184	15.5	14.5	52.8	52.1	0.92	0.91
		1000	155	155	167	166	181	182	17.5	14.5	59.1	54.7	0.92	0.91
		1100	150	147	161	156	172	167	18.0	16.0	60.0	57.3	0.94	0.93
		1200	116	104	126	117	152	162	21.0	20.5	60.7	53.8	0.83	0.72

*WQ means water-quenched; BC means blower-cooled.

**Single test result. All other tests are the average of duplicate tests with 0.252-inch-diameter specimens.

NOTE: Plate samples (1/2-inch-thick) were austenitized at 1500 F for 30 minutes, water-quenched, tempered at the indicated temperature for 30 minutes, and water-quenched; or they were austenitized at 1500 F for 2 hours, blower-cooled, tempered at the indicated temperature for 2 hours, and blower-cooled.

Table III

Charpy V-Notch Impact Properties and Hardnesses of Steels Investigated
(Duplicate or Triplicate Tests)

Steel	Carbon Content, %	Tempering Temp, F	Energy Absorbed, ft-lb +80 F WQ*	Energy Absorbed, ft-lb +80 F BC*	Energy Absorbed, ft-lb 0 F WQ	Energy Absorbed, ft-lb 0 F BC	Energy Absorbed, ft-lb -80 F WQ	Energy Absorbed, ft-lb -80 F BC	Shear Fracture, % +80 F WQ	Shear Fracture, % +80 F BC	Shear Fracture, % 0 F WQ	Shear Fracture, % 0 F BC	Shear Fracture, % -80 F WQ	Shear Fracture, % -80 F BC	Lateral Expansion, mils +80 F WQ	Lateral Expansion, mils +80 F BC	Lateral Expansion, mils 0 F WQ	Lateral Expansion, mils 0 F BC	Lateral Expansion, mils -80 F WQ	Lateral Expansion, mils -80 F BC	Hardness, R_C WQ	Hardness, R_C BC
Plate Samples From 100-Pound Ingots																						
A	0.05	Untempered	96	130	92	129	74	54	100	100	100	100	70	55	54	79	49	76	41	34	35.5	29.5
		900	105	133	95	106	72	65	100	100	90	85	50	40	63	83	54	64	37	35	32.0	27.5
		1000	114	144	126	115	64	95	100	100	100	90	55	65	67	84	70	66	35	55	31.5	28.0
		1100	120	142	125	151	102	106	100	100	100	100	75	65	70	81	71	84	57	62	32.0	27.5
		1200	146	156	146	148	146	125	100	100	100	100	100	90	84	89	83	83	81	72	27.5	25.0
B	0.10	Untempered	71	84	68	82	60	74	100	100	100	100	80	100	36	49	30	44	24	37	40.5	38.5
		900	88	94	83	81	50	54	100	100	95	98	65	60	52	54	46	44	25	27	36.0	34.5
		1000	96	94	86	96	62	72	100	100	98	100	65	70	57	56	47	51	32	33	36.5	34.5
		1100	104	105	100	111	69	93	100	100	98	100	55	75	60	62	55	60	33	50	36.0	33.5
		1200	125	126	122	130	104	122	100	100	100	100	85	100	74	76	71	76	59	72	31.5	27.5
C	0.16	Untempered	52	57	56	54	51	54	100	100	100	100	100	100	21	26	20	19	17	19	44.5	43.5
		900	69	64	70	61	48	38	100	100	100	99	90	60	39	35	38	29	24	15	38.0	38.5
		1000	77	74	78	70	61	49	100	100	100	100	90	55	45	39	42	34	28	20	38.0	38.5
		1100	84	83	81	80	69	68	100	100	100	100	90	80	49	46	43	43	35	33	37.5	37.0
		1200	106	98	99	96	98	87	100	100	100	100	100	100	66	63	61	61	58	52	31.5	30.5
D	0.22	Untempered	39	40	38	39	31	36	100	100	100	100	100	100	10	12	7	9	7	9	48.5	46.0
		900	57	53	54	48	45	34	100	100	100	100	100	75	31	27	26	22	19	12	39.0	40.5
		1000	64	59	62	55	52	43	100	100	100	100	98	98	33	31	31	27	24	17	39.0	40.5
		1100	76	69	75	67	66	60	100	100	100	100	100	100	44	39	39	36	32	29	37.5	38.0
		1200	92	59	90	54	81	50	100	100	100	100	100	100	57	38	55	33	47	26	33.0	33.0
E	0.26	Untempered	27	30	26	29	20	26	100	100	50	100	35	100	3	6	3	3	2	3	52.5	49.5
		900	44	40	41	37	34	27	100	100	100	100	100	100	18	15	16	14	11	7	40.0	40.5
		1000	55	48	51	45	45	36	100	100	100	100	100	100	29	18	23	14	16	10	40.5	41.0
		1100	60	60	57	56	53	50	100	100	100	100	100	100	33	31	30	29	23	21	39.0	38.5
		1200	81	62	76	60	70	56	100	100	100	100	100	100	51	41	45	37	42	31	33.5	32.0

(Continued)

Table III (Continued)

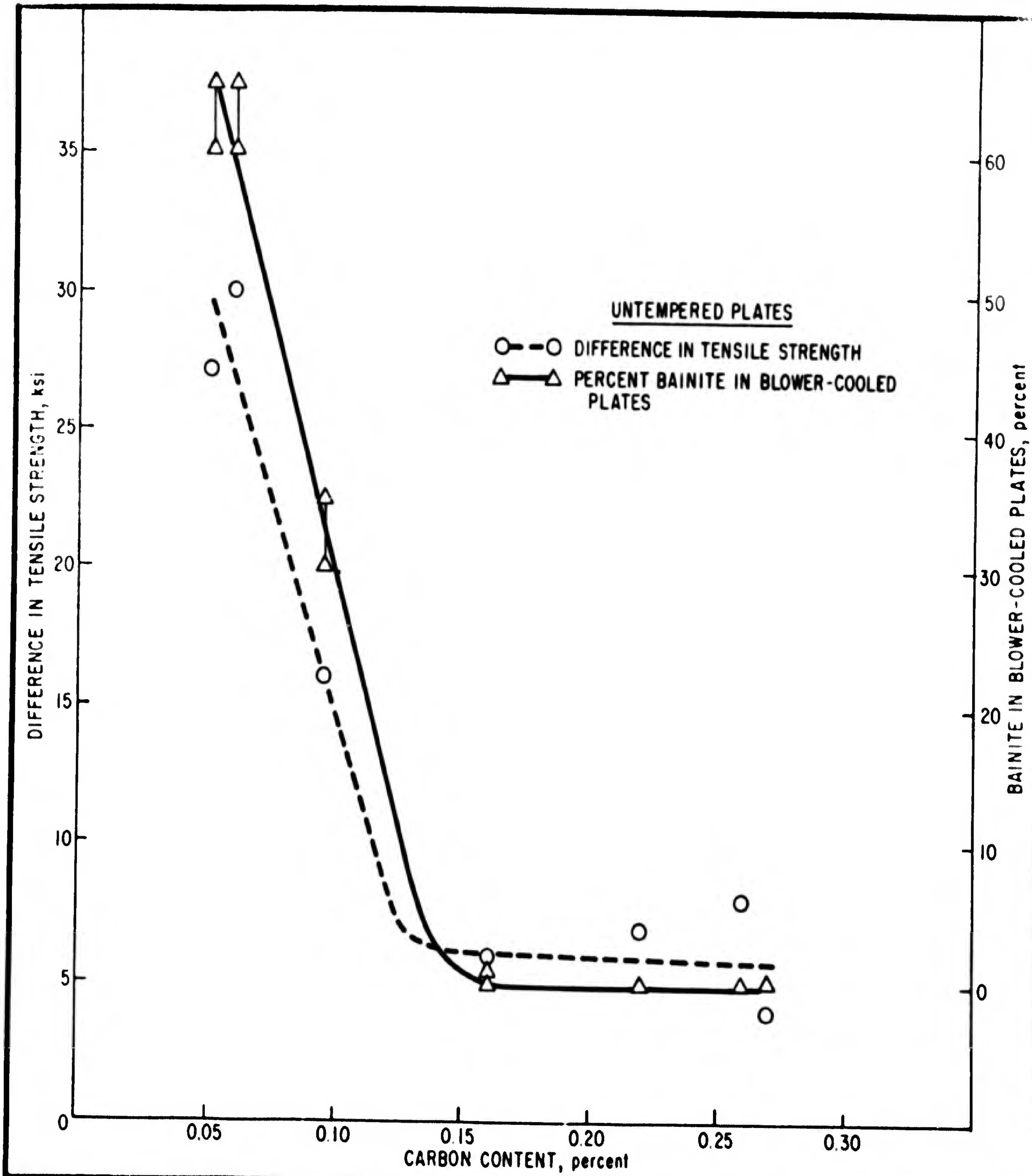
Charpy V-Notch Impact Properties and Hardnesses of Steels Investigated
(Duplicate or Triplicate Tests)

Steel	Carbon Content, %	Tempering Temp, F	Energy Absorbed, ft-lb +80 F WQ*	+80 F BC*	0 F WQ	0 F BC	-80 F WQ	-80 F BC	Shear Fracture, % +80 F WQ	+80 F BC	0 F WQ	0 F BC	-80 F WQ	-80 F BC	Lateral Expansion, mils +80 F WQ	+80 F BC	0 F WQ	0 F BC	-80 F WQ	-80 F BC	Hardness, R_C WQ	Hardness, R_C BC
Plate Samples From 300-Pound Ingots																						
F	0.06	Untempered	88	121	81	118	73	96	100	100	99	100	97	70	51	73	47	66	38	52	37.0	30.5
		900	90	114	93	105	57	71	100	100	100	90	40	50	55	74	53	65	27	38	34.5	30.0
		1000	95	112	94	107	53	79	100	100	100	98	55	60	60	68	52	61	28	42	35.0	30.5
		1100	108	123	102	138	77	10[illegible]	100	100	100	100	65	70	63	71	64	77	42	55	33.5	30.5
		1200	137	135	140	144	130	121	100	100	100	100	100	99	79	82	80	85	77	72	29.0	26.5
G	0.27	Untempered	29	26	23	25	22	22	100	100	100	100	100	100	4	4	2	2	1	2	51.5	49.0
		900	40	36	37	32	32	23	100	100	100	100	100	100	17	11	11	7	8	4	41.0	42.0
		1000	44	40	44	27	37	30	100	100	100	100	100	100	20	18	18	12	13	5	41.5	42.0
		1100	55	51	51	47	47	45	100	100	100	100	100	100	29	25	25	22	19	19	40.0	38.5
		1200	65	48	63	49	58	41	100	100	100	100	100	100	44	27	39	24	34	18	34.0	34.5

*WQ means water-quenched; BC means blower-cooled.

NOTE: Plate samples (1/2-inch-thick) were austenitized at 1500 F for 30 minutes, water-quenched, tempered at the indicated temperature for 30 minutes, and water-quenched; or they were austenitized at 1500 F for 2 hours, blower-cooled, tempered at the indicated temperature for 2 hours, and blower-cooled.

G-1H242 REV. 1063



EFFECT OF CARBON CONTENT ON DIFFERENCE IN TENSILE STRENGTH BETWEEN WATER-QUENCHED AND BLOWER-COOLED 1/2-INCH-THICK PLATES AND ON PERCENT BAINITE IN BLOWER-COOLED PLATES

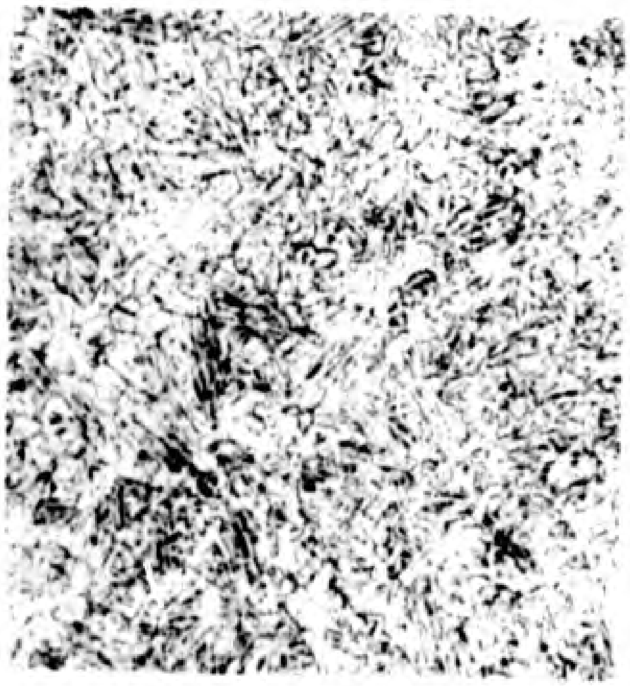
DRAWN BY M.M	CHK'D BY S.J.M.	APPROVED BY J.H.G.	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. 1
DRAWING No ARL 18-366		PROJECT No 40.018-001 (25) DATE 3/20/64		

1025 CLEARPRINT PPL CO PGH. PA

A. Steel A (0.05% C). 60 to 65 percent bainite. Hardness, 29.5 R_C.

B. Steel B (0.10% C). 30 to 35 percent bainite. Hardness, 38.5 R_C.

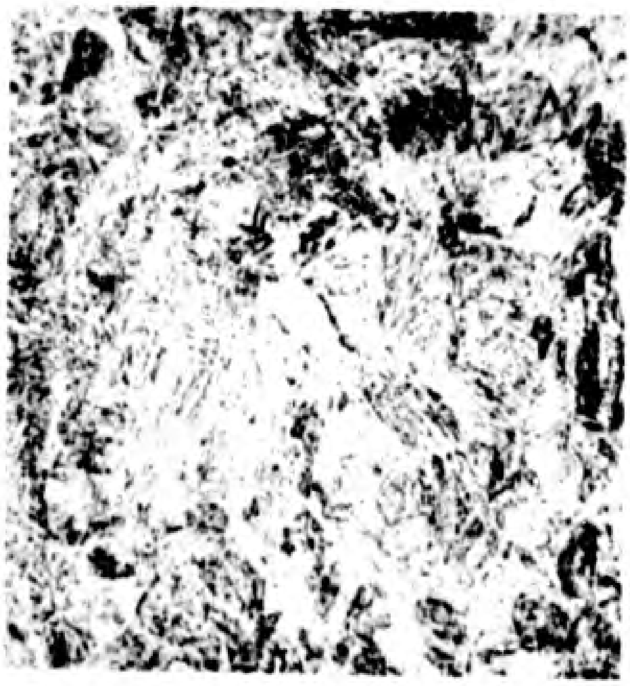
C. Steel C (0.16% C). 0 to 1 percent bainite. Hardness, 43.5 R_C.



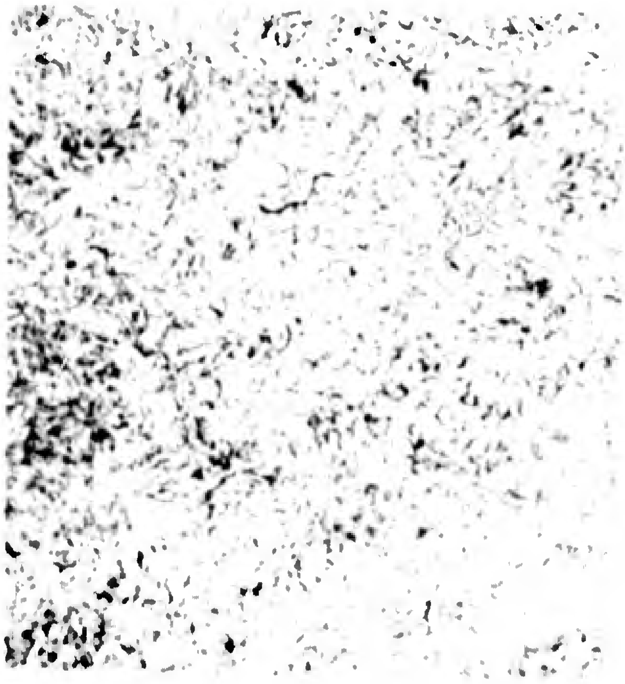
D. Steel D (0.22% C). 100 percent martensite. Hardness, 46.0 R_C.

Figure 2. Microstructures of longitudinal specimens of blower-cooled and untempered 1/2-inch-thick plates. Super picral etch. X500.

8-138A-1
8-139A-1
8-140A-1
8-141A-1



A. Steel A (0.05% C). Hardness, 35.5 R_C.

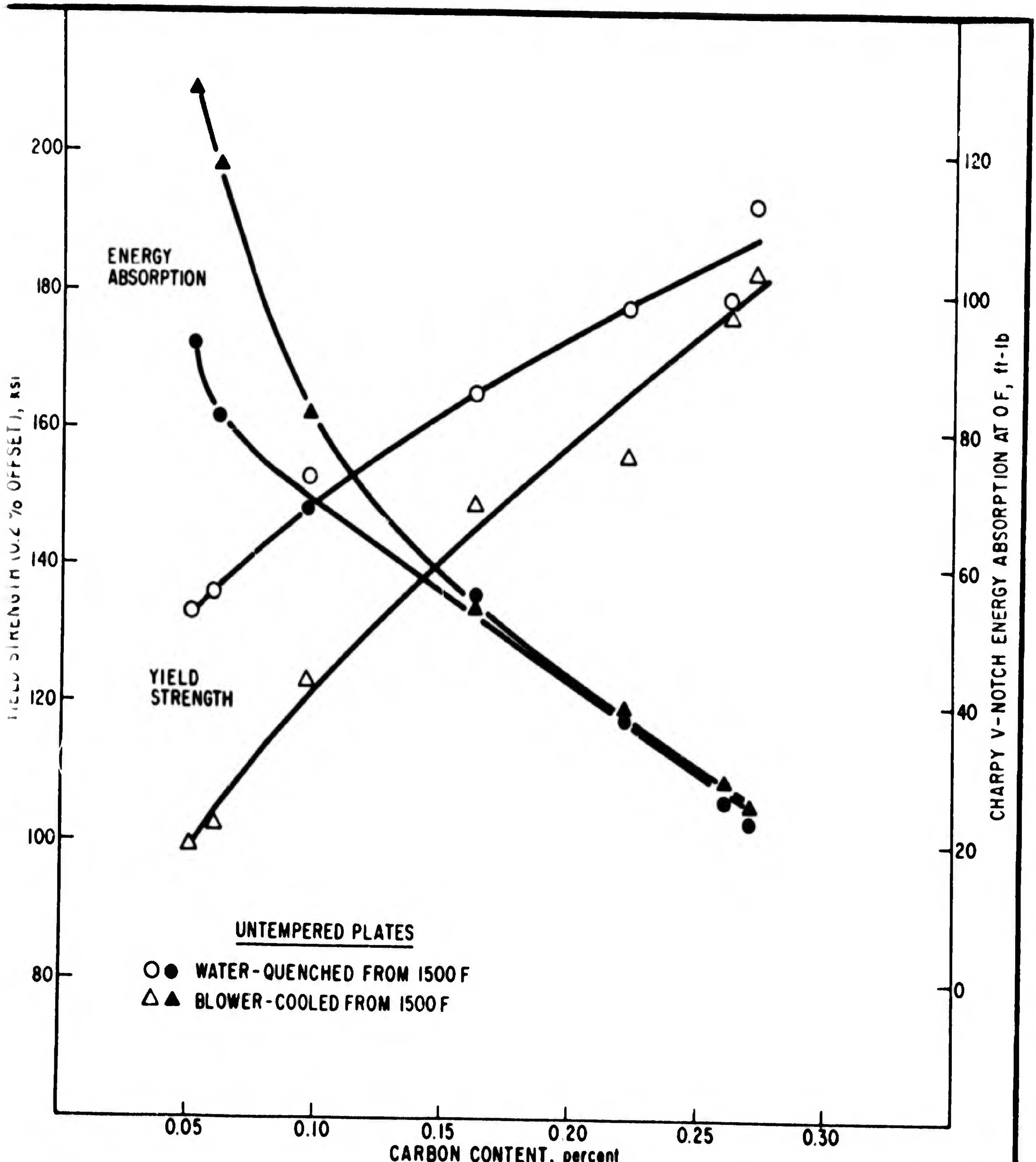


B. Steel G (0.27% C). Hardness, 51.5 R_C.

Figure 3. Microstructures of longitudinal specimens of water-quenched and untempered 1/2-inch-thick plates. Super picral etch. X500.

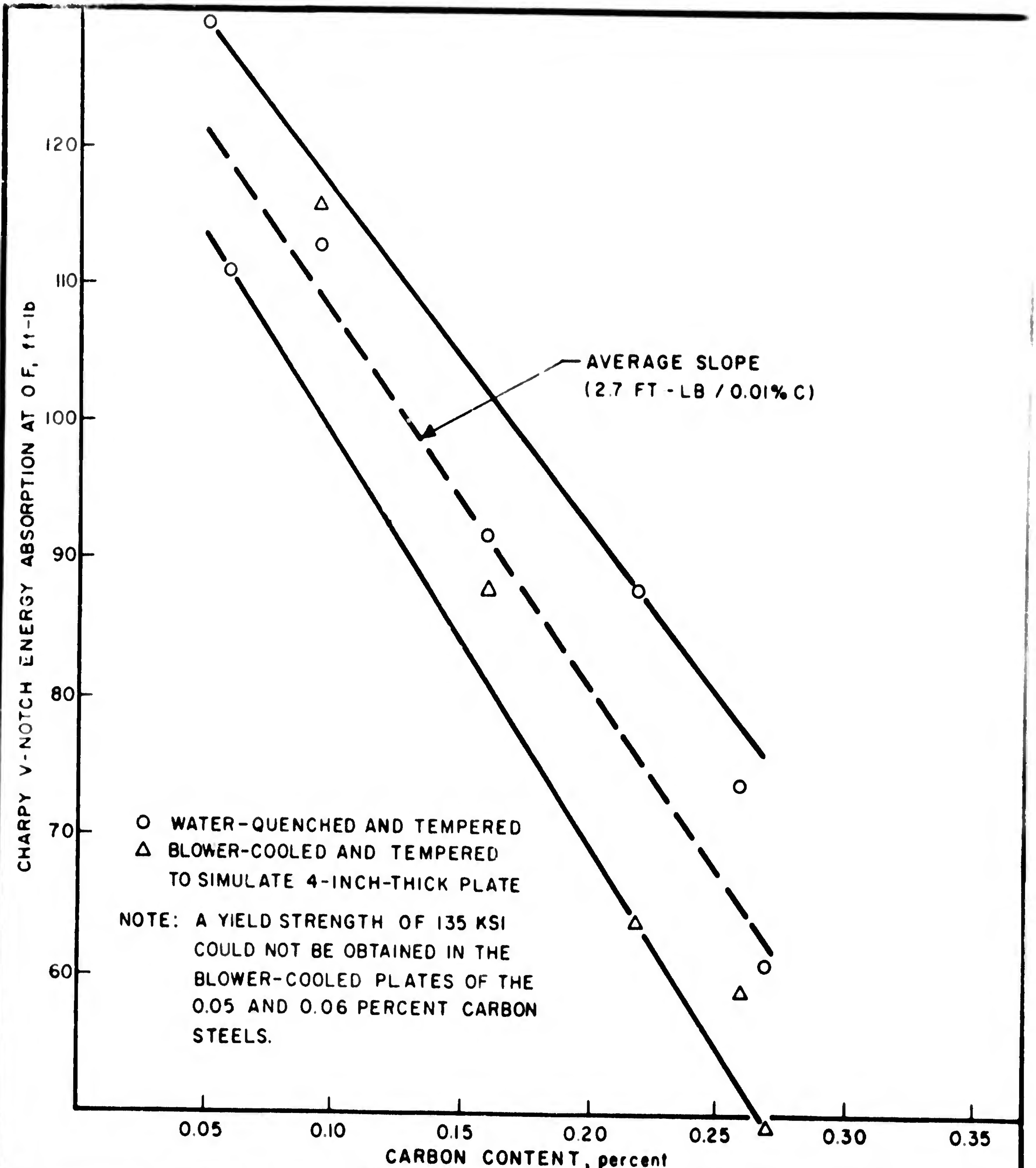
18-142A-1
18-143A-1

(40.018-001)(25)



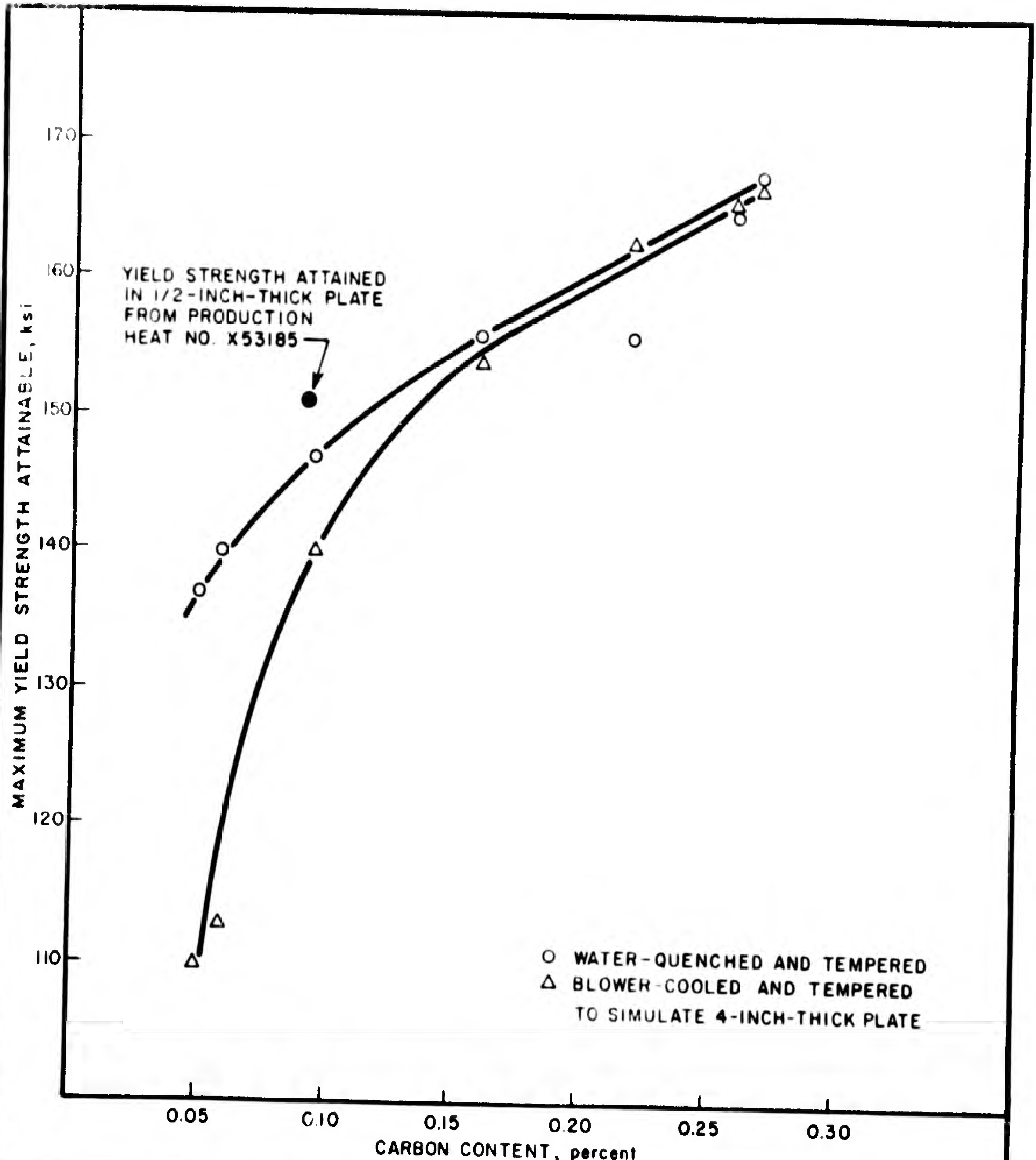
EFFECT OF CARBON CONTENT ON THE YIELD STRENGTH AND ENERGY ABSORPTION OF 1/2-INCH-THICK PLATES OF 5 Ni-Cr-Mo-V STEEL

DRAWN BY M.M.	CHK'D BY S.J.M.	APPROVED BY J.H.G.	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. 4
DRAWING No ARL 18-367		PROJECT No 40.018-001 (25) DATE 5/19/64		



EFFECT OF CARBON CONTENT ON THE NOTCH TOUGHNESS OF 1/2-INCH-THICK PLATES OF 5 Ni-Cr-Mo-V STEEL AT 135 KSI YIELD STRENGTH

DRAWN BY	CHK'D BY	APPROVED BY		
G. A. Z.	S. J. M.	J. H. G.	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. 5
DRAWING No		PROJECT No		
ARL 18-368		40.018-001 (25)		
		DATE 4-20-64		



EFFECT OF CARBON CONTENT ON THE MAXIMUM ATTAINABLE YIELD STRENGTH IN 1/2-INCH-THICK PLATES OF 5Ni-Cr-Mo-V STEEL TEMPERED AT 900F OR HIGHER

DRAWN BY	CHK'D BY	APPROVED BY		
G.A.Z.	S.J.M.	J.H.G.	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. 6
DRAWING No		PROJECT No		
ARL 18-369		40.018-001 (25)		
		DATE 4-20-64		

BLANK PAGE