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FINAL REPORT

ON

INVESTIGATION OF MEANS FOR EVALUATING THE QUALITY OF HULL PLATE STEEL BY TESTS CONDUCTED ON FURNACE OR LADLE SAMPLES

BY

J. A. DAVIS, S. A. HERRES, C. T. GREENIDGE AND C. H. LORIG

Battelle Memorial Institute
Under Bureau of Ships Contract NObs-45030

COMMITTEE ON SHIP CONSTRUCTION

DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

NATIONAL RESEARCH COUNCIL

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UNDER

Bureau of Ships, Navy Department
Contract NObs-34231

SERIAL NO. SSC-20

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DATE: NOVEMBER 30, 1948

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Washington 25, D. C.

November 30, 1948

Chief, Bureau of Ships
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Washington 25, D. C.

Dear Sir:

Attached is Report Serial No. SSC-20 entitled "Investigation of Means for Evaluating the Quality of Hull Plate Steel by Tests Conducted on Furnace or Ladle Samples." This report has been submitted by the contractor as the final report of the work done on Research Project SR-97 under Contract NObs-45030 between the Bureau of Ships, Navy Department and the Battelle Memorial Institute.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Construction, Division of Engineering and Industrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Navy Department and the National Academy of Sciences.

Very truly yours,

C. Richard Soderberg

C. Richard Soderberg, Chairman
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Industrial Research

CRS:mh
Enclosure

Preface

The Navy Department through the Bureau of Ships is distributing this report to those agencies and individuals who were actively associated with the research work. This report represents a part of the research work contracted for under the section of the Navy's directive "to investigate the design and construction of welded steel merchant vessels."

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FINAL REPORT

on

INVESTIGATION OF MEANS FOR EVALUATING THE QUALITY OF HULL PLATE STEEL BY TESTS CONDUCTED ON FURNACE OR LADLE SAMPLES

Contract No. NObs-45030

to

NAVY DEPARTMENT, BUREAU OF SHIPS
WASHINGTON, D. C.

by

J. A. Davis
S. A. Herres
C. T. Greenidge
C. H. Lorig

BATTELLE MEMORIAL INSTITUTE

May 15, 1948

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ABSTRACT

A simple but reliable method for evaluating the notch sensitivity of hull plate steel before the steel has been rolled into plate was sought.

Tests made on cast ladle samples from open hearth heats verified the results obtained on laboratory steels which showed that small hot-worked ladle samples will distinguish relatively large differences in the notched-bar impact resistance of hull plate steels. Correlation between the deoxidation practice and the notched-bar impact properties was obtained for both the commercially rolled plate and the hot-worked ladle samples although the actual impact values for the ladle samples were higher than for the plate samples.

The Walker Wedge-impact test was investigated as a possible method for evaluating the quality of hull plate steel on samples poured from the furnace or ladle.

The initial experimental work was directed towards the production of sound wedge-impact test castings of hull plate steel analysis. It was found that either by centrifugal casting into a baked core-sand mold or by static casting into a copper chill mold, sound wedge samples could be cast from hull plate type steel when the silicon content was raised to 0.10 per cent. A much higher silicon content was necessary to produce sound wedge samples by static casting into baked core-sand molds. No method for casting sound test specimens from steels containing less than 0.10 per cent silicon was found.

Hull plate type steel containing 0.10 per cent silicon had higher notch-bar impact resistance than steels containing 0.01 to 0.03 per cent silicon. It appears that the addition of silicon required to obtain sound wedge test castings would change the impact resistance of the samples taken from low-silicon hull plate steel melts. No simple method of allowing for this difference is

evident.

The Walker wedge test was not sufficiently sensitive to distinguish a difference in impact resistance between an aluminum-killed steel and a silicon-killed steel when each was either in the as-cast or normalized condition. Notched-bar impact tests showed an appreciable difference in the impact resistance of these two steels. When the as-cast surface was removed by grinding, normalized wedges free from defects failed to break at a testing temperature of minus 80°F.

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May 15, 1948

INTRODUCTION

The object of this investigation was to develop a fairly simple but reliable method of evaluating the quality of hull steel before the steel was rolled into plate. Various testing procedures such as the spiral fluidity test, and hardenability test, are being used to determine a particular steel characteristic before the steel is tapped.

The service performance of hull plate steel is a function of its notch-toughness characteristics. An indication of the notch toughness of steels can be readily obtained by making standard notched-bar impact tests over a suitable range of temperatures. This relatively simple approach to the problem of determining quality of hull steel becomes complicated by the fact that no method is known that will give sound cast test specimens from semikilled steel of the type used in hull plate.

The notch sensitivity of semikilled hull plate steel of Grade M composition is known to depend to a large extent on the following factors:

1. Deoxidation practice.
2. Temperature of hot rolling or normalizing.
3. Rate of cooling following hot rolling or normalizing.
4. Susceptibility to strain aging.

While only the first and fourth of these factors are determined by steelmaking practices, it is necessary to evaluate the effect of these factors before the significance of a test made on a cast sample can be properly evaluated in terms related to the rolled plate.

To accomplish the purpose of developing a test which will show the quality differences between heats of semikilled hull plate steel, it was necessary to overcome three problems:

1. Produce good- and poor-quality steel to "test the test".
   This can be done by varying the deoxidation practice.
2. Obtain sound test samples.
3. Investigate all variables in processing the plate that may have a direct relationship to the notch toughness of the finished plate.

The first progress report, dated May 28, 1947 and designated as SSC-12, contained data on the comparison of high- and low-silicon steels with and without aluminum deoxidation. Notched-bar impact values of silicon-killed steels were similar to silicon-aluminum-killed steels in the as-cast state. Normalizing within a suitable temperature range developed a marked superiority of aluminum-silicon-killed steel over a silicon-killed steel. A superiority of hot-worked aluminum-killed steel over hot-worked silicon-killed steel occurred only when the finish rolling temperature was held within the temperature range of 1600°F to 1800°F. Strain aging after rolling at this finishing temperature further increased the difference in the notched-bar impact resistance of aluminum-killed steel over silicon-killed steel. Notched-bar bend tests made on the same steel did not appear to offer any advantages over notched-bar impact testing.

A testing procedure was proposed to predict the quality of hull plate steel. This test consisted of casting a one-inch-round bar from the ladle of a heat of hull plate steel, hot rolling this bar to about 9/16-inch square at a temperature corresponding to the mill plate rolling practice, strain aging, and testing as notched-bar impact specimens.

An investigation of the Walker wedge-impact test as a possible quality test for hull plate steel was an object of the original program requested by the Navy Department. This report summarizes experimental work intended to evaluate the suitability of the wedge-impact test for the purpose.

The Walker wedge test has been used in the malleable iron industry as a measure of impact resistance of malleable iron after annealing. The test specimen used is a wedge 6 inches long, 1 inch wide, and tapered from 1/2 inch thick at the base to 1/16th inch thick at the top. The thin edge of the wedge is bent slightly before testing.

The test is carried out by placing the wedge specimen in a testing machine and repeatedly dropping a 21-pound tup, from a height of 40 inches, on the thin edge of the wedge. Repeated blows of the tup cause the wedge to curl into a spiral. The tightness of the spiral is controlled by lateral adjustment of the anvil holding the sample. The sample is subjected to repeated blows of the tup until failure occurs or until the sample has withstood a specified number of blows.

A preliminary investigation of the wedge test was reported in the first progress report, SSC-12.

This test requires the use of sound as-cast specimens and preliminary work, therefore, was done in an attempt to produce sound wedge castings without changing the impact resistance of the base steel.

This report includes the experimental data obtained on (1) the attempts made to cast a sound test sample from semikilled steel; (2) an investigation of the effect of small additions of silicon on the soundness and impact resistance of hull plate steel; (3) the evaluation of the wedge-impact test as a possible method of determining quality of steels; and (4) the comparison of the impact resistance of hot-worked ladle samples and commercially rolled plate from the same open hearth steel heats.

EXPERIMENTAL WORK

Effect of Silicon Content and Casting Method on Soundness of Wedge Samples

A series of 25-pound induction furnace steel heats was made to determine the minimum silicon content necessary to produce sound test specimens. A chill-cast wedge sample, a one-inch-diameter by six-inch sample centrifugally cast into baked core sand, and a one-inch-diameter by six-inch sample that was poured into a baked core-sand mold which was jolted during the solidification period, were poured from each heat. The chill-cast sample was poured into the copper mold shown in Figure 1. The jolted sample was poured into a baked core-sand mold and jolted violently on the table of a molding machine until solidification was complete. The centrifugally cast sample was poured into a baked core-sand mold spinning at 275 r.p.m. The minimum distance of the sample from the center of rotation was six inches.

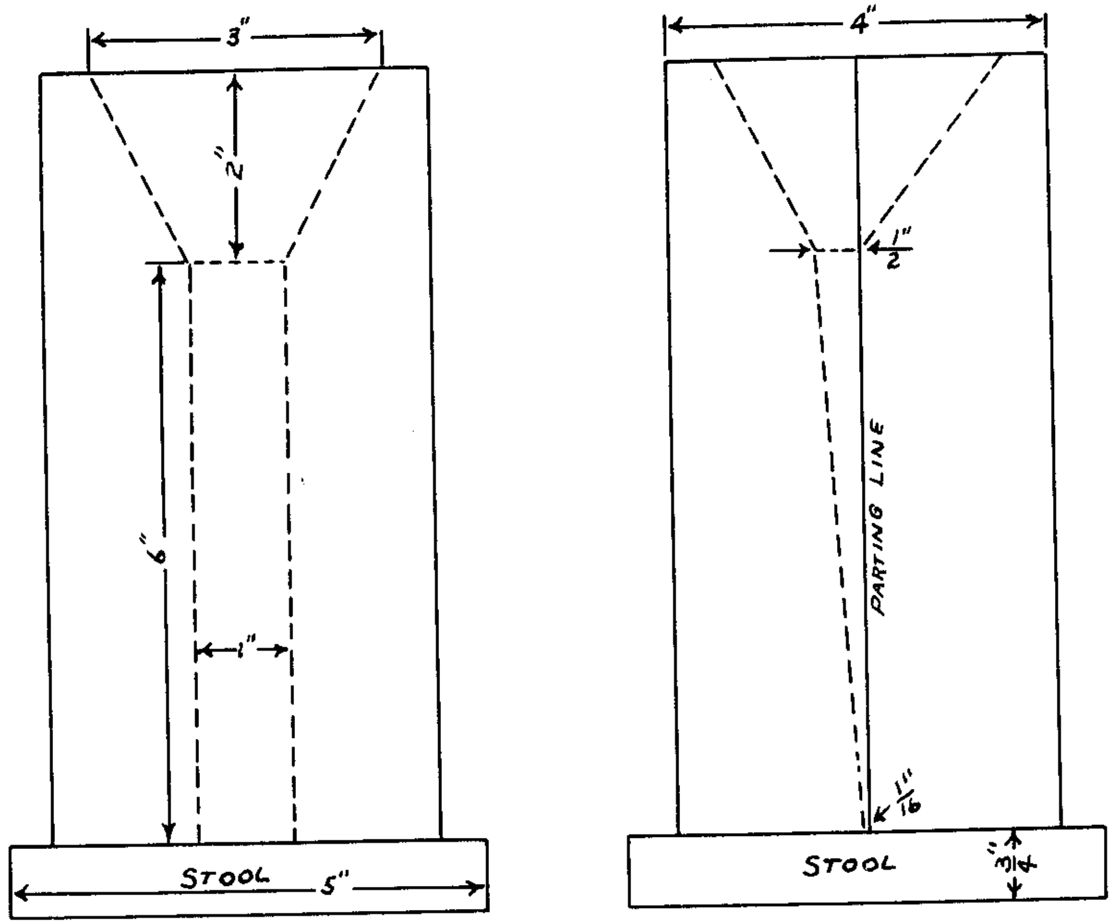

FIGURE 1. COPPER CHILL MOLD FOR WEDGE TEST CASTINGS

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Results of these tests are summarized in Table 1.

TABLE 1. EFFECT OF CASTING CONDITIONS AND SILICON CONTENT ON THE SOUNDNESS OF HULL PLATE STEEL

	Analysis, %					Soundness		
Heat	C	Mn	Si	S	P	Jolted	Chill Cast	Centrifuged*
A-3856	0.24	0.45	0.10	0.029	0.022	Porous	Sound	Sound
A-3867	0.15	0.38	0.01	0.032	0.021	Porous	Porous	Porous
A-3868	0.27	0.47	0.01	0.031	0.022	Porous	Porous	Porous

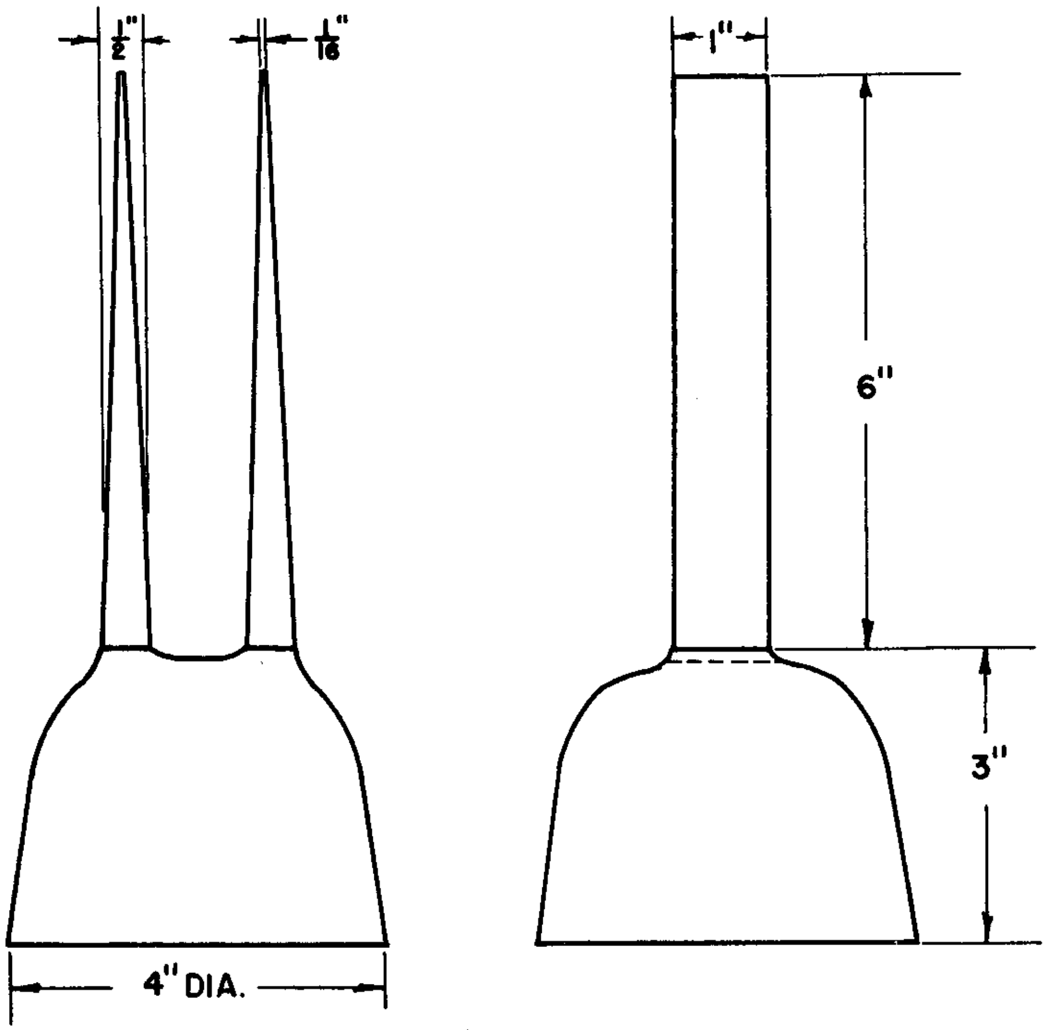
* 275 r.p.m.

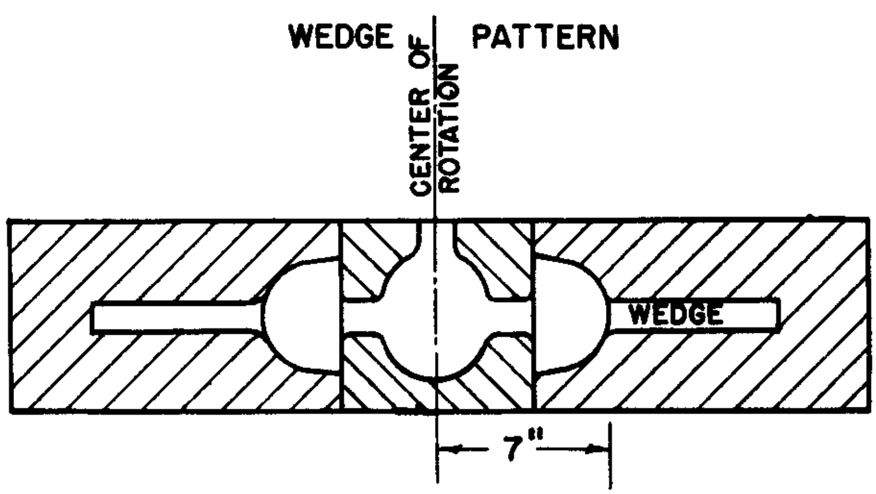
Following these tests, a wedge mold for centrifugal casting was made (see Figure 2) and the speed of the centrifugal casting machine was increased to 350 r.p.m. A second series of castings was then made with the results shown in Table 2.

TABLE 2. COMPARISON OF THE SOUNDNESS OF CHILL-CAST AND CENTRIFUGALLY CAST SEMIKILLED STEEL

	Analyses, %			Soundness	
Heat	C	Mn	Si	Chill Cast	Centrifuged*
A-4149	0.28	0.46	0.04	Porous	Slight porosity
A-4150	0.22	0.49	0.02	Porous	Slight porosity
A-4148	0.21	0.46	0.01	Porous	Moderate porosity

* 350 r.p.m.





SAND CORE ARRANGEMENT FOR CENTRIFUGAL CASTING WEDGES.

FIGURE 2. MOLD FOR CENTRIFUGAL CASTING OF WEDGES.

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Figures 3 and 4 show photographs of longitudinal sections of the samples described in Tables 1 and 2, respectively.

These tests indicate that sound test bars can be cast from a 0.10 per cent silicon hull plate type of steel either in a chill mold or by centrifugal methods. Test castings containing much less than 0.10 per cent silicon were not sound. However, the centrifugally cast samples were much better than the chill-cast samples, both with respect to porosity and surface appearance. A very high centrifugal force might result in sound samples cast from steels containing less than 0.10 per cent silicon, but the metal penetration of the sand mold at the higher pressures would result in a very rough surface.

Effect of Small Silicon Additions on Impact Resistance

Since the minimum silicon content that would result in a sound cast wedge sample was about 0.10 per cent, it was necessary to determine the effect of this amount of silicon on the impact resistance of hull plate type of steels.

A series of 100-pound induction furnace hull plate type steel heats was made with intended silicon contents of 0.01 and 0.10 per cent with and without an aluminum addition of six pounds per ton. Eight 1-1/8 x 1-1/8 x 6-inch bars poured in core-sand molds and one 50-pound chill-cast ingot were obtained from each heat. The chemical compositions of these heats were as follows:

TABLE 3. COMPOSITION OF STEELS USED TO INVESTIGATE THE EFFECT OF DEOXIDIZERS ON IMPACT RESISTANCE

Code Number	Heat Number	Analyses, % C	Mn	Si	S	P	Aluminum Added
O	A-3926	0.20	0.57	0.09	0.027	0.028	6 pounds per ton
T	A-3928	0.21	0.50	0.01	0.028	0.033	6 pounds per ton
N	A-3925	0.22	0.44	0.11	0.035	0.028	None
P	A-3927	0.22	0.46	0.01	0.030	0.032	None
L	A-3929	0.25	0.51	0.03	0.026	0.028	None

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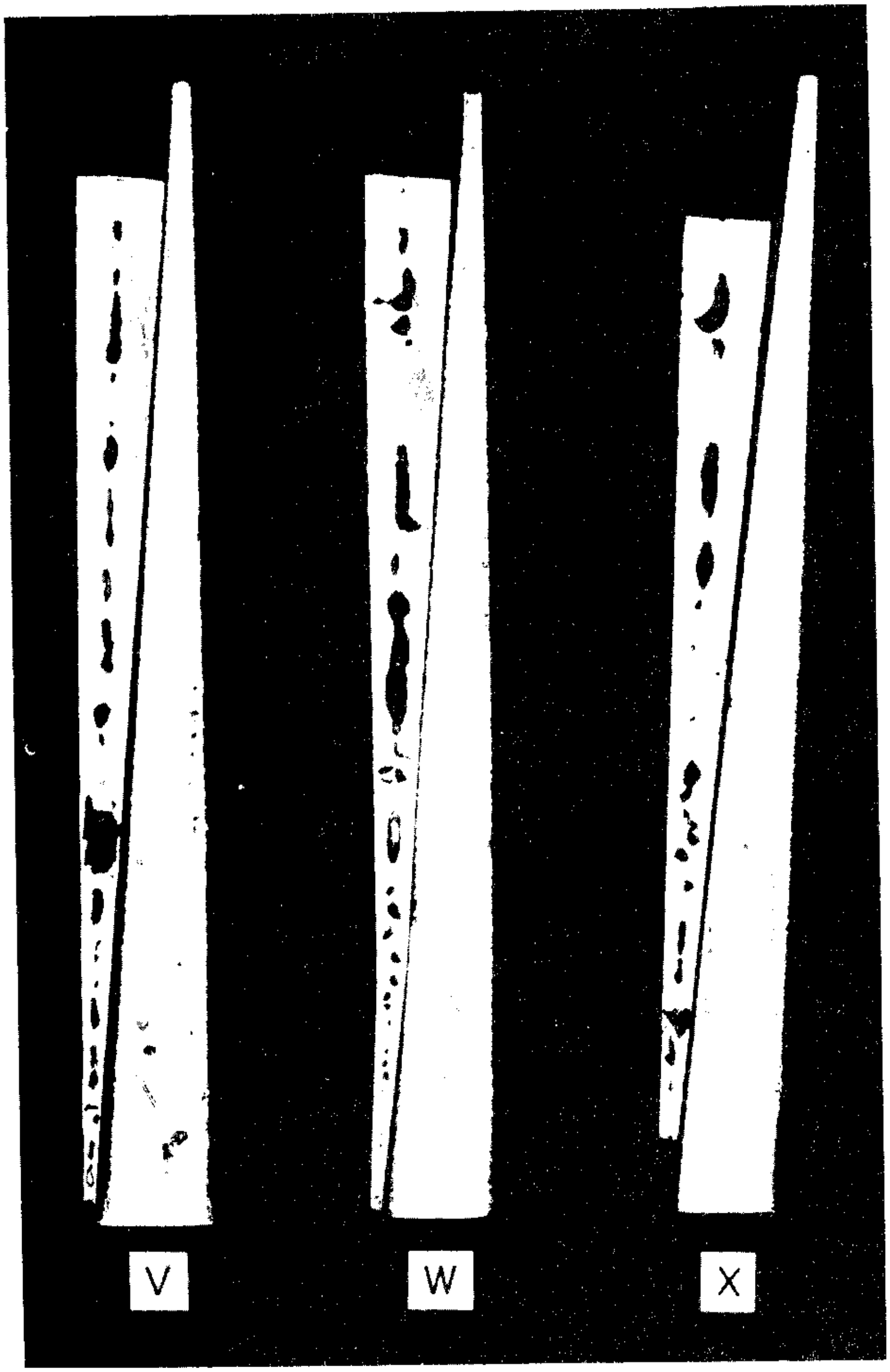
One-inch-diameter bars		Wedge	One-inch-diameter bars		Wedge	One-inch-diameter bars		Wedge
Centrifuged	Jolted	Chill cast	Centrifuged	Jolted	Chill cast	Centrifuged	Jolted	Chill cast
Heat A-3868, 0.01% Si			Heat A-3867, 0.01% Si			Heat A-3856, 0.10% Si		

Figure 3. Effect of silicon content and casting conditions on the soundness of hull plate steel.



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V Heat A-4148, 0.01 per cent silicon
W Heat A-4149, 0.04 per cent silicon
X Heat A-4150, 0.02 per cent silicon

The left wedge of each group was cast into a copper mold. The right wedge of each group was cast centrifugally in core sand mold.

Figure 4. Comparison of the soundness of semikilled steel wedges cast into chill molds and cast centrifugally in core sand mold.

The 1-1/8 inch bars were heated to 1950°F. and hot rolled to 0.735 inch squares, reheated to 1700°F., and rolled to 0.670 inch squares. The rolled bars were machined to 0.500 inch-diameter by 2.00 inch notched bars (as described in the first Progress Report). The notch in these bars was 0.050 inch deep, had a 45° included angle, and a root radius of 0.005 inch.

A comparison of the 0.01 and 0.10 per cent silicon, aluminum-killed steel is given in Fig. 5. No significant difference is apparent in the aluminum-killed steels tested as round impact bars. A comparison of high - (0.11 per cent silicon) and low - (0.01-0.03 per cent silicon) silicon steels without the addition of other deoxidizers is shown in Figure 6. The notched-bar impact values for the 0.11 per cent silicon steel are somewhat better than those for the 0.01 and 0.03 per cent silicon steel.

A comparison of the standard V-notched Charpy values for these same steels is shown in Figure 7. The very high values obtained above the transition temperature of the aluminum-killed steels appeared to be caused by laminations in the steel.

Procedure for Making Samples for the Walker Wedge Test

Sound test wedges could not be made from semikilled hull plate steel. It was, therefore, decided to check the sensitivity of the wedge-impact test by comparing steels with sufficient amounts of silicon to give sound castings in dry sand molds. Since it is well known that the impact resistance of this type steel is improved by a suitable aluminum addition, both silicon and silicon plus aluminum-killed steels were made.

A wedge pattern was made containing eight wedges in a row as indicated by Figures 8 and 9. A stack of six of these sections, with eight wedges per

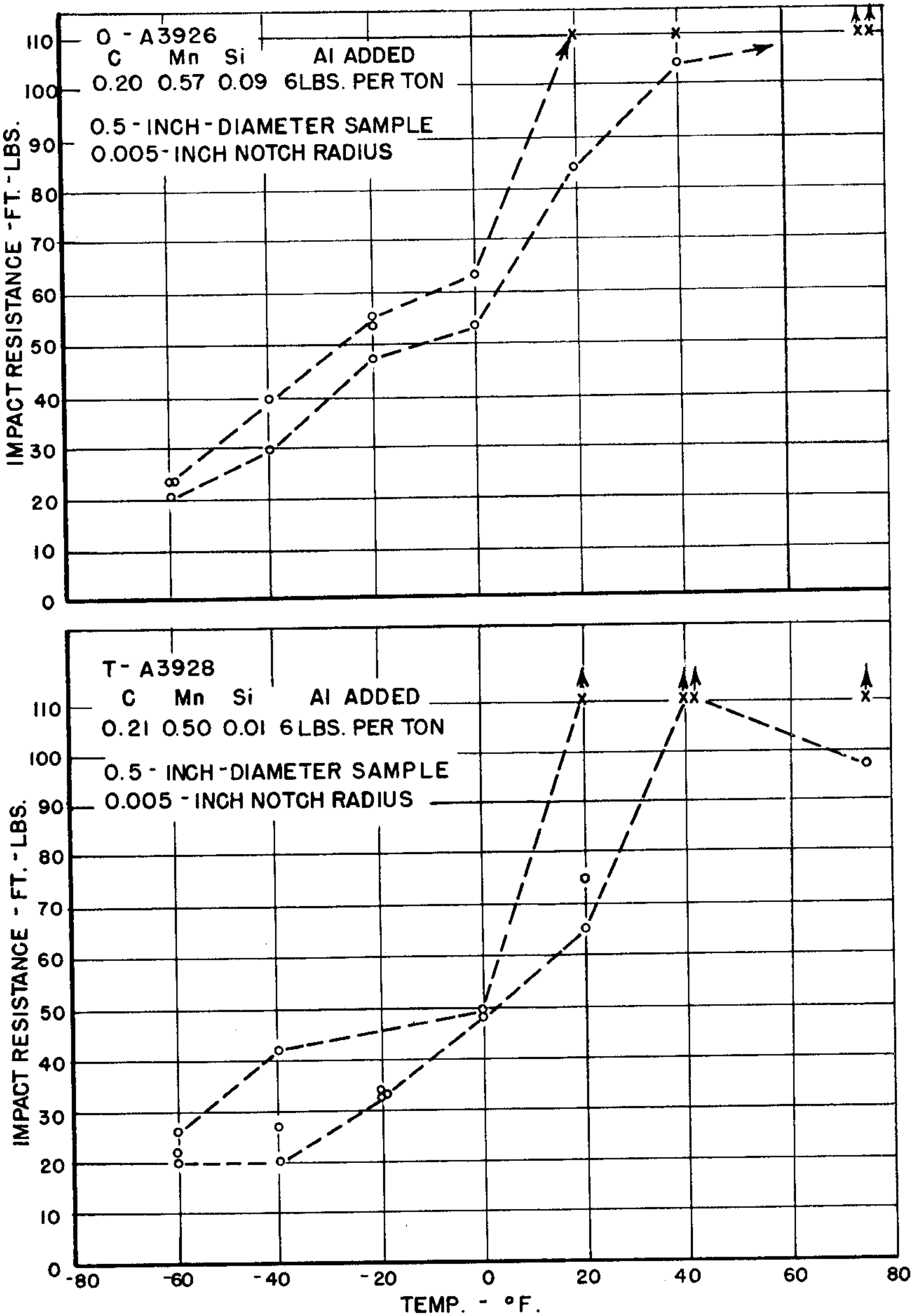

FIGURE 5. COMPARISON OF IMPACT RESISTANCE OF 0.09 AND 0.01 Si STEELS KILLED WITH ALUMINUM.

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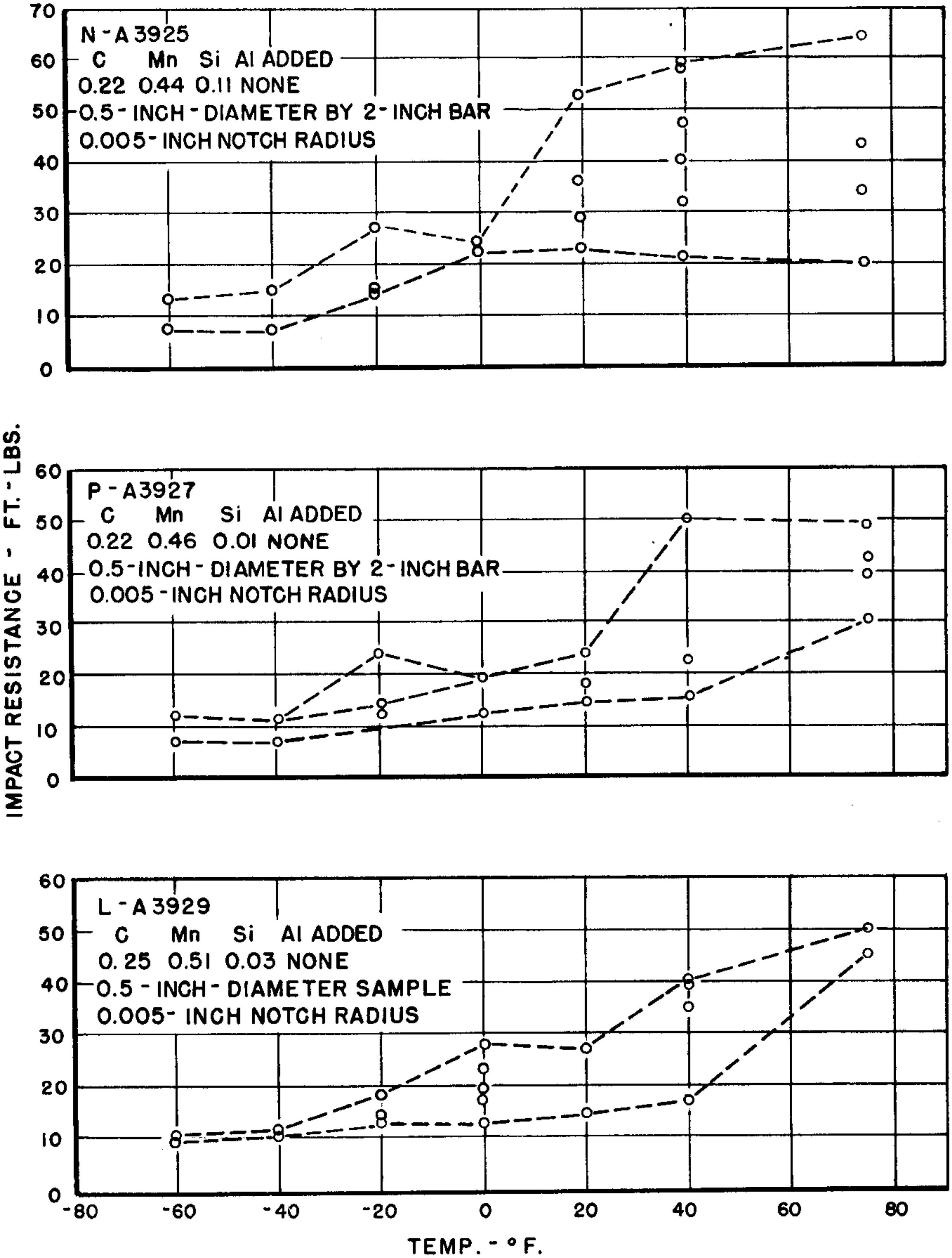

FIGURE 6. EFFECT OF 0.01 AND 0.11 Si ON IMPACT RESISTANCE.

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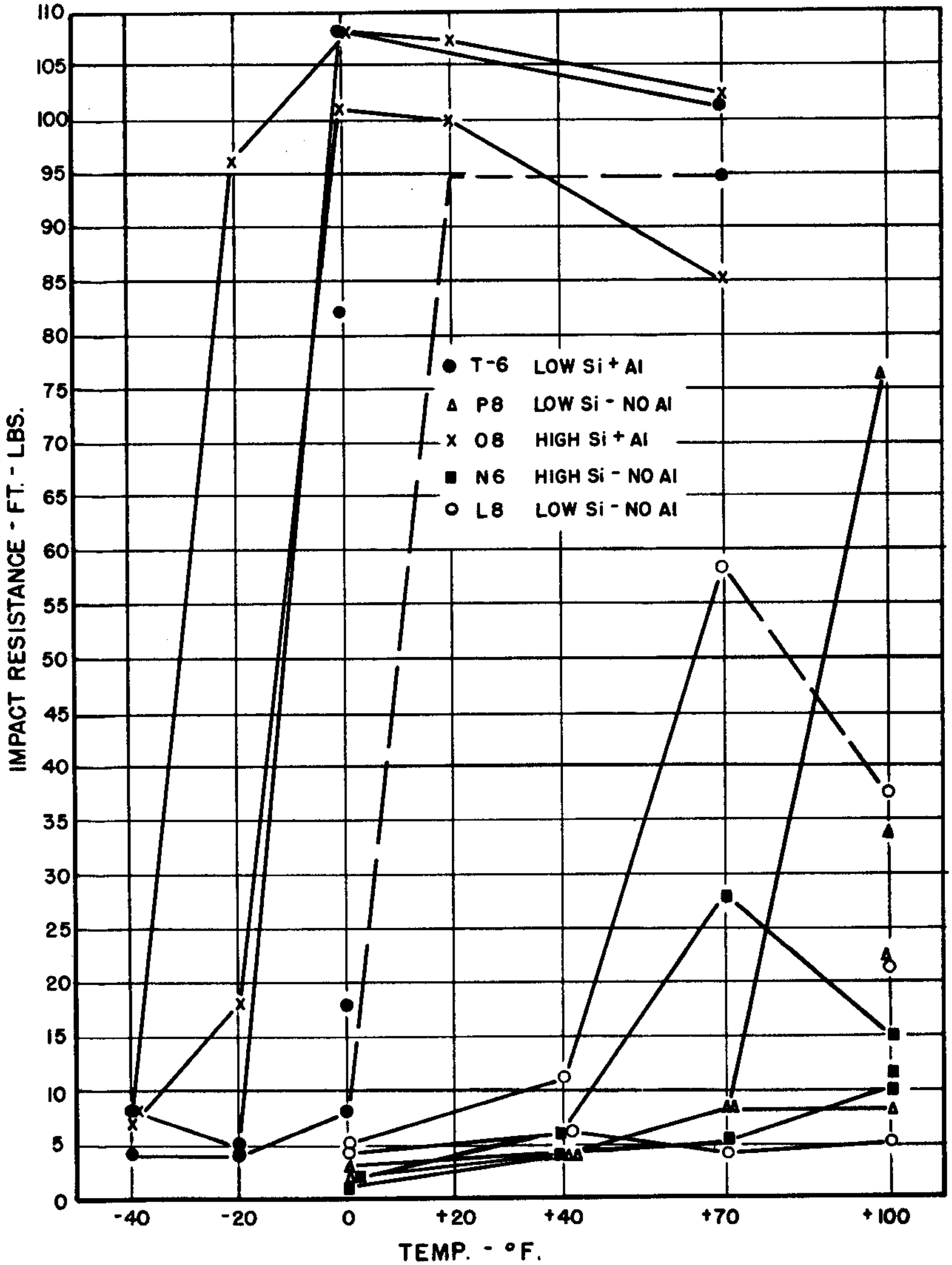

FIGURE 7. COMPARISON OF STANDARD V-NOTCHED CHARPY VALUES OF 0.01 AND 0.10 SILICON STEELS.

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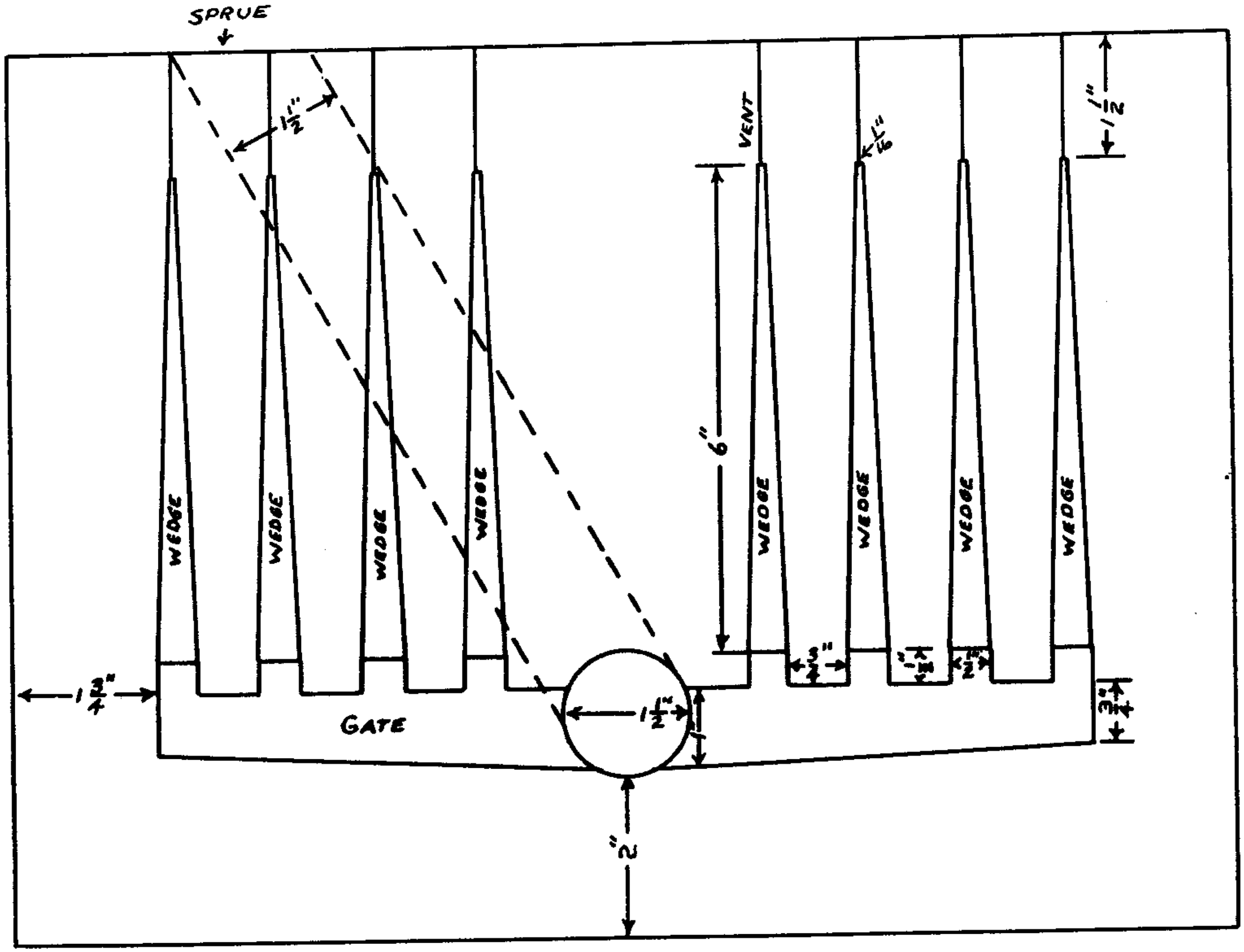

FIGURE 8. MOLD AND GATING ARRANGEMENT FOR BOTTOM-POURED WEDGE TEST CASTINGS.

0-7077

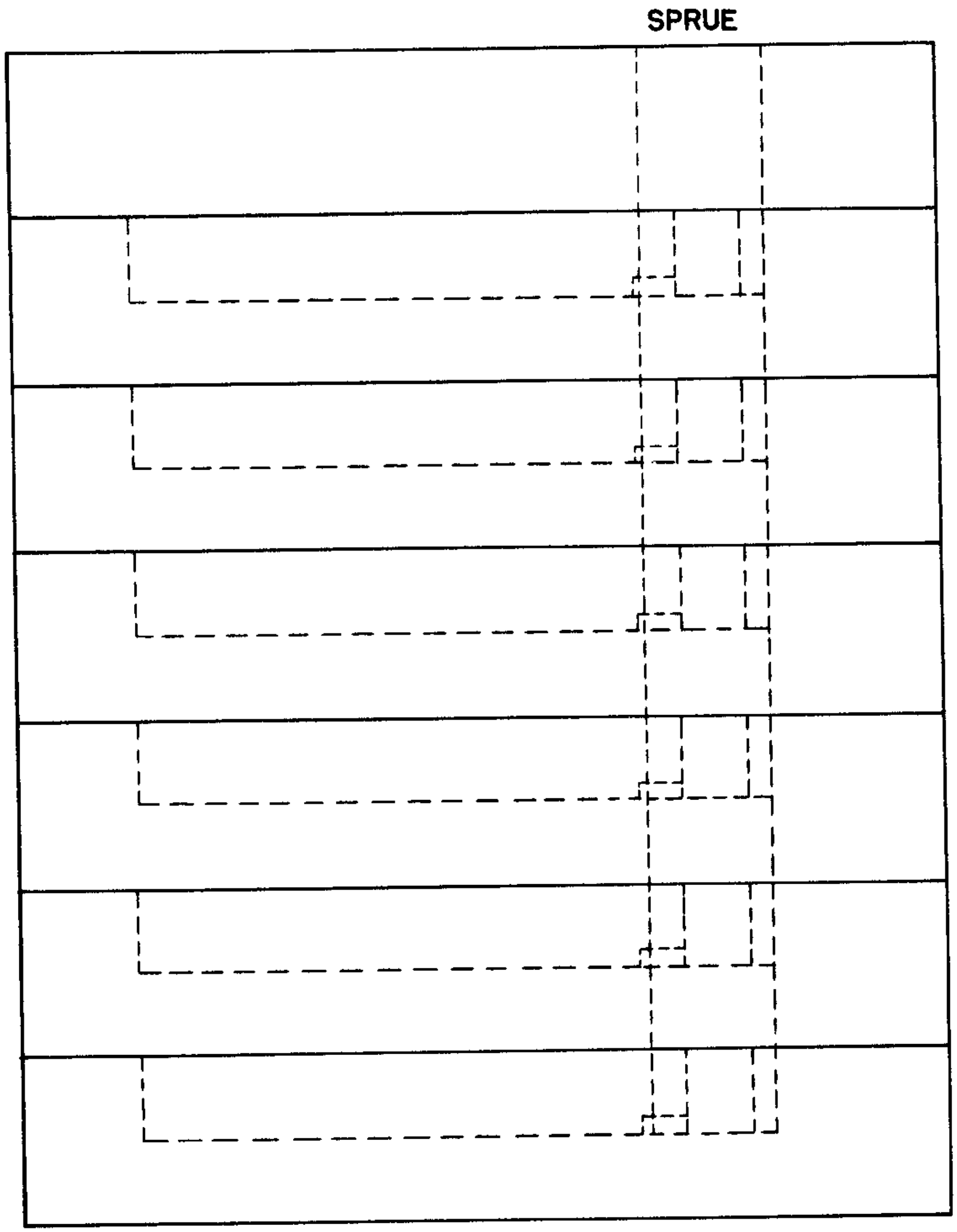

FIGURE 9. STACK ARRANGEMENT FOR CASTING 48 WEDGES IN CORE SAND MOLD

0-7410

section, made a mold containing 48 wedges. A preliminary test poured with the wedges vertical resulted in misruns of some of the wedges. All experimental wedges were then poured with the wedges horizontal, which proved quite satisfactory and gave sound wedges with good surface and dimensional accuracy.

Two 250-pound induction furnace steel heats were made for the wedge-impact test evaluation. Two molds of 48 wedges each and two double-leg keel blocks were poured from each heat. The chemical compositions of the two heats were as follows:

TABLE 4. CHEMICAL COMPOSITION OF STEELS TESTED IN THE WALKER WEDGE TEST

Heat Number	Analysis, % C	Mn	Si	S	P	Aluminum Added
A-4054	0.23	0.53	0.26	0.029	0.021	4 pounds per ton
A-4068	0.25	0.57	0.27	0.029	0.023	None

One-half of the wedges and one keel block from each steel were normalized at 1650°F. All wedges were given a hydrogen removal treatment of 16 hours at 400°F.

Testing Procedure Used in Testing the Impact Resistance of Wedges

The wedges were tested in the wedge-impact machine shown in Figure 10. This machine was built from drawings supplied by Mr. Lansing. The machine drops a tup, weighing 21 pounds, from a height of 3-1/3 feet to give an impact of 70 foot-pounds.

The wedge sample (see Figure 2) was a bar 6 inches long by 1 inch wide, tapering in thickness from 1/2 inch at the base to 1/16 inch at the top. The thin edge of the wedge was given a starting curl by bending the wedge through an angle of 45° around a 1/2 inch-diameter bar.

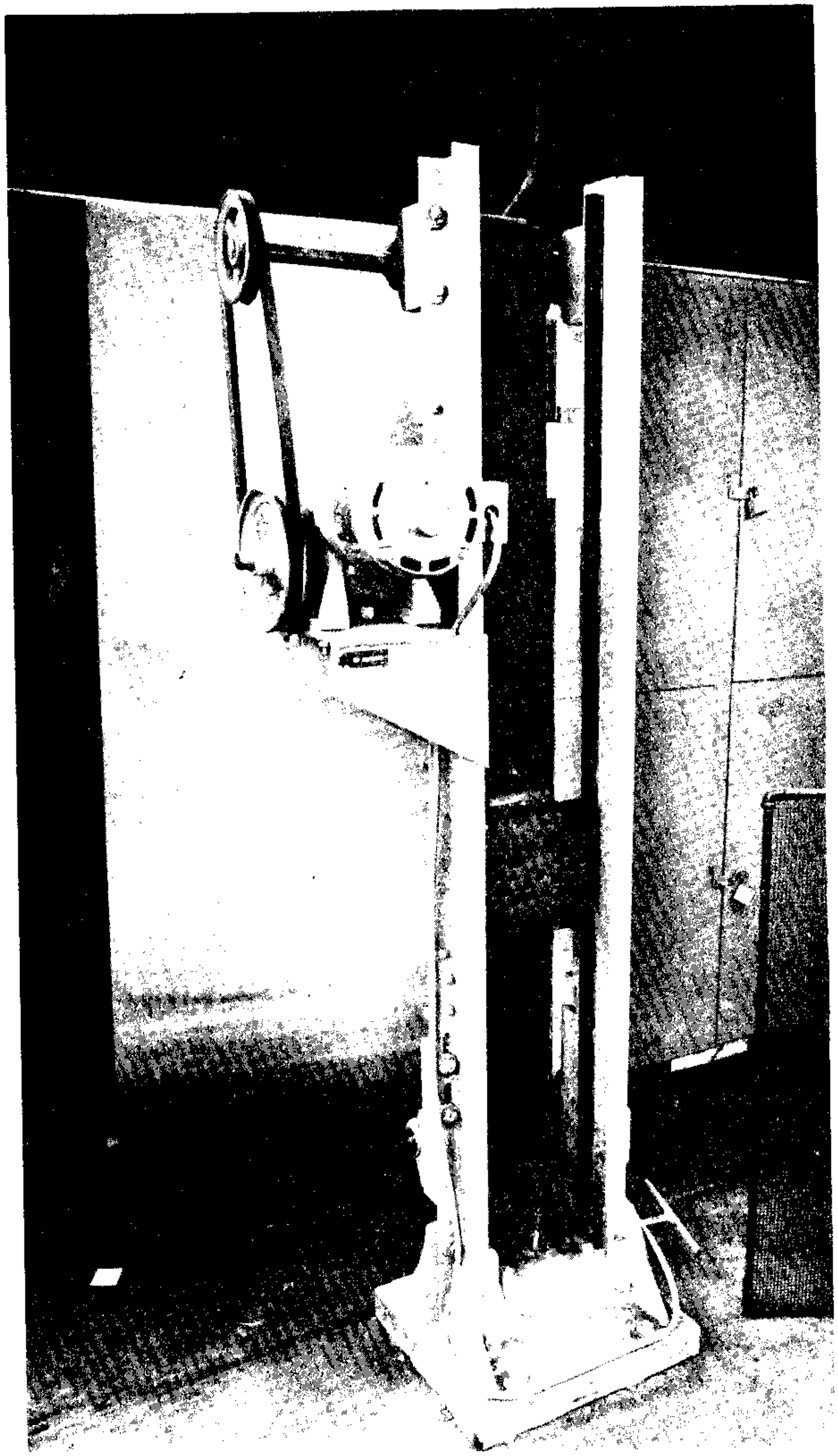

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Figure 10. Wedge-Impact Machine

The wedges were brought to temperature in a water bath for the tests at 70°F. and 210°F. and in an acetone bath, maintained at temperature with dry ice, for the tests conducted at 0°F., -40°F., and -80°F. Experimental work on a previous project established, by thermocouple measurements, a temperature rise of 3.5°F. in the 4 seconds required to transfer a specimen from a bath at -35°F. to the specimen holder and to drop the tup. Actual bath temperatures were maintained at -84°F., -44°F., -3°F., 70°F., and 212°F. The samples were held at temperature for 30 minutes, transferred to the wedge-impact machine, sugjected to two blows of the tup, and returned to the bath for a minimum of ten minutes before the next cycle. The test was terminated if no cracks developed in a specimen after 32 blows.

The wedge holder of the wedge-impact machine is constructed to permit tilting the base to control the tightness of the wedge spiral. Preliminary tests showed that the number of blows necessary to break the wedge could be changed substantially by changing the tightness of the curl. This variable was controlled as nearly as possible by setting two stops to control the amount of tilting of the base and alternating between these stops for each blow of the tup. Even though all of the wedges were tested under similar conditions, some variation of the tightness of the curl resulted.

Results of Wedge-Impact Test

The results of the wedge-impact tests are shown in Figure 11 for the as-cast bars and Figure 12 for the normalized bars. The wedge tests showed an increasing brittleness of the wedges as the temperature decreases and considerable improvement resulting from normalizing. However, no difference between the aluminum-killed and silicon-killed steels was apparent. The difference in the notched-bar impact resistance of the two steels as shown by the results of

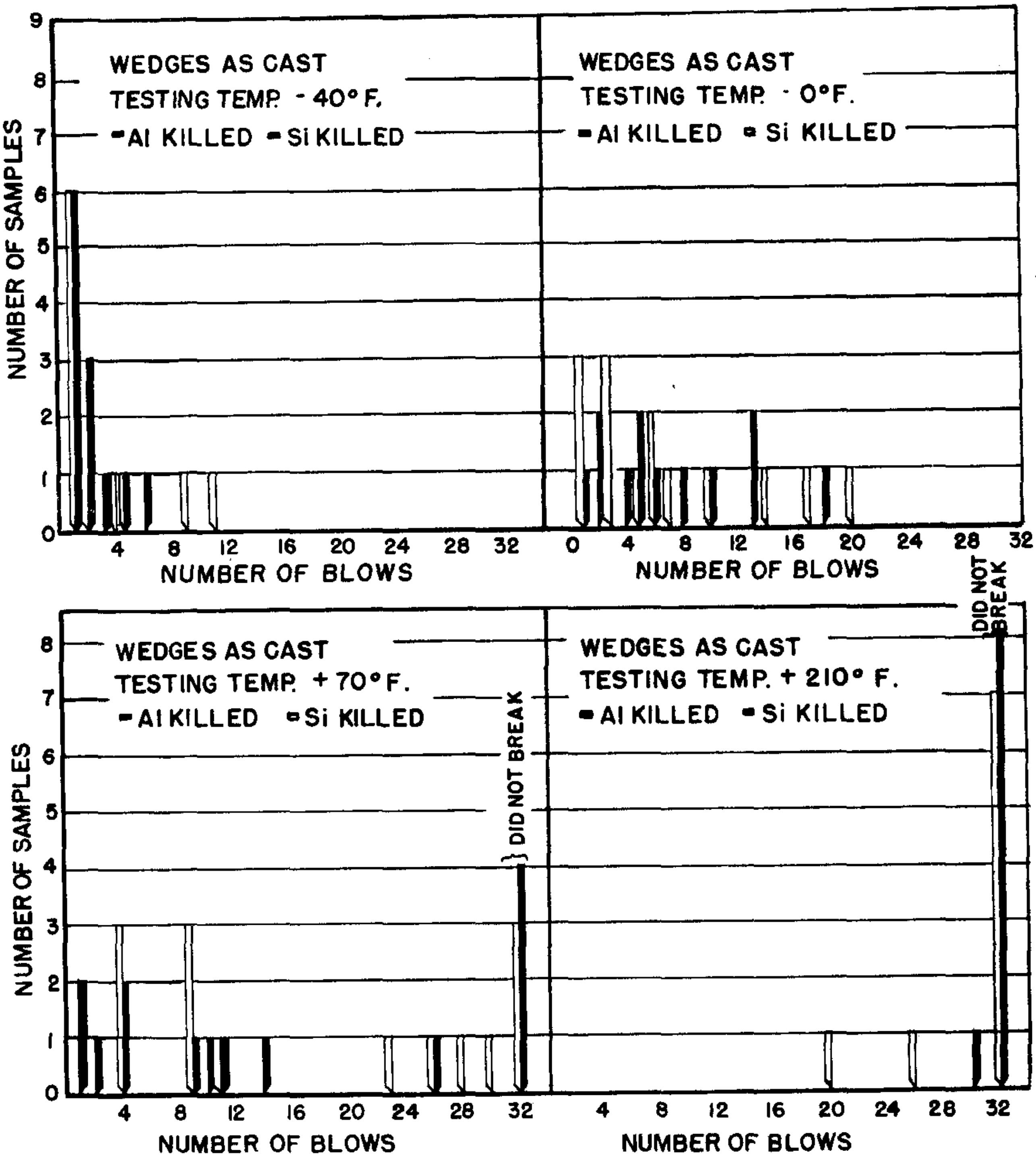


FIGURE 11. COMPARISON OF THE WEDGE-IMPACT RESISTANCE OF A SILICON-KILLED STEEL WITH A SILICON-ALUMINUM KILLED STEEL. WEDGES TEST IN THE AS CAST CONDITION.

0-7025

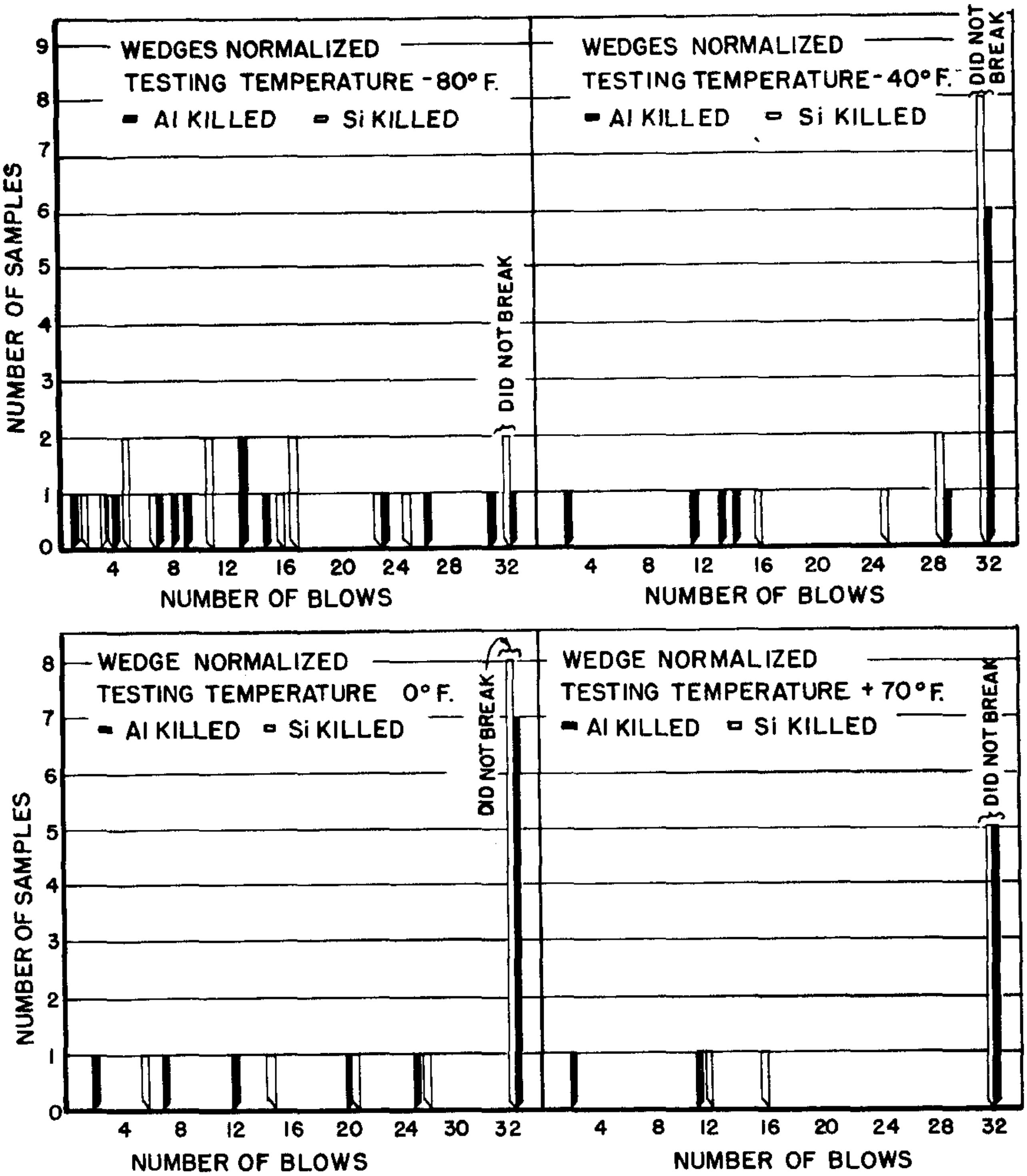


FIGURE 12. COMPARISON OF THE WEDGE - IMPACT RESISTANCE OF A SILICON-KILLED STEEL WITH A SILICON-ALUMINUM KILLED STEEL. WEDGES NORMALIZED AT 1650°F.

0-7026

standard V-notched Charpy bars is shown in Figure 13. The Charpy bars were made from the keel blocks poured from the same heats as the wedge castings. The microstructures of the as-cast and normalized steels are shown in Figure 14.

The position of the wedge in the mold is tabulated in Table 5. The difference in impact resistance of duplicate samples was so great that any possible influence of the position of the wedge in the mold on the wedge test results was obscured. The effect of surface condition on the results of wedge-impact tests was investigated by removing the surface defects from part of a group of wedges cast in the core-sand mold from Heat A-4251 (Table 6).

The wedges were normalized for one hour at 1650°F. followed by a hydrogen removal treatment of 16 hours at 400°F. Half of the wedges were surface ground to remove all surface defects. The dimensions of the wedges after surface grinding were as follows: 6 inches long, 7/8 inch wide, and tapering from 1/16 inch at the top to 7/8 inch at the base. The remaining wedges were tested with cast surfaces for comparison.

Ten wedges tested with cast surfaces did not break with 30 blows at 0°F; 12 wedges having the original cast surface were tested at -40°F. Three of these broke after 9, 25, and 26 blows, respectively, and the remaining 9 did not break with 30 blows.

Five surface-ground wedges tested at -40°F. did not break with 30 blows. The remaining surface ground wedges were tested at -80°F. After the wedge curl reaches the anvil, repeated blows of the hammer cause the curl to flatten and unroll. Two of the surface-ground wedges broke at 28 and 30 blows, respectively, as a result of this reverse bending action. The remaining ten bars did not break after 30 blows.

Silicon-killed hull plate type steel wedges apparently would not break in the wedge test when tested at minus 80°F. in the absence of surface or internal defects.

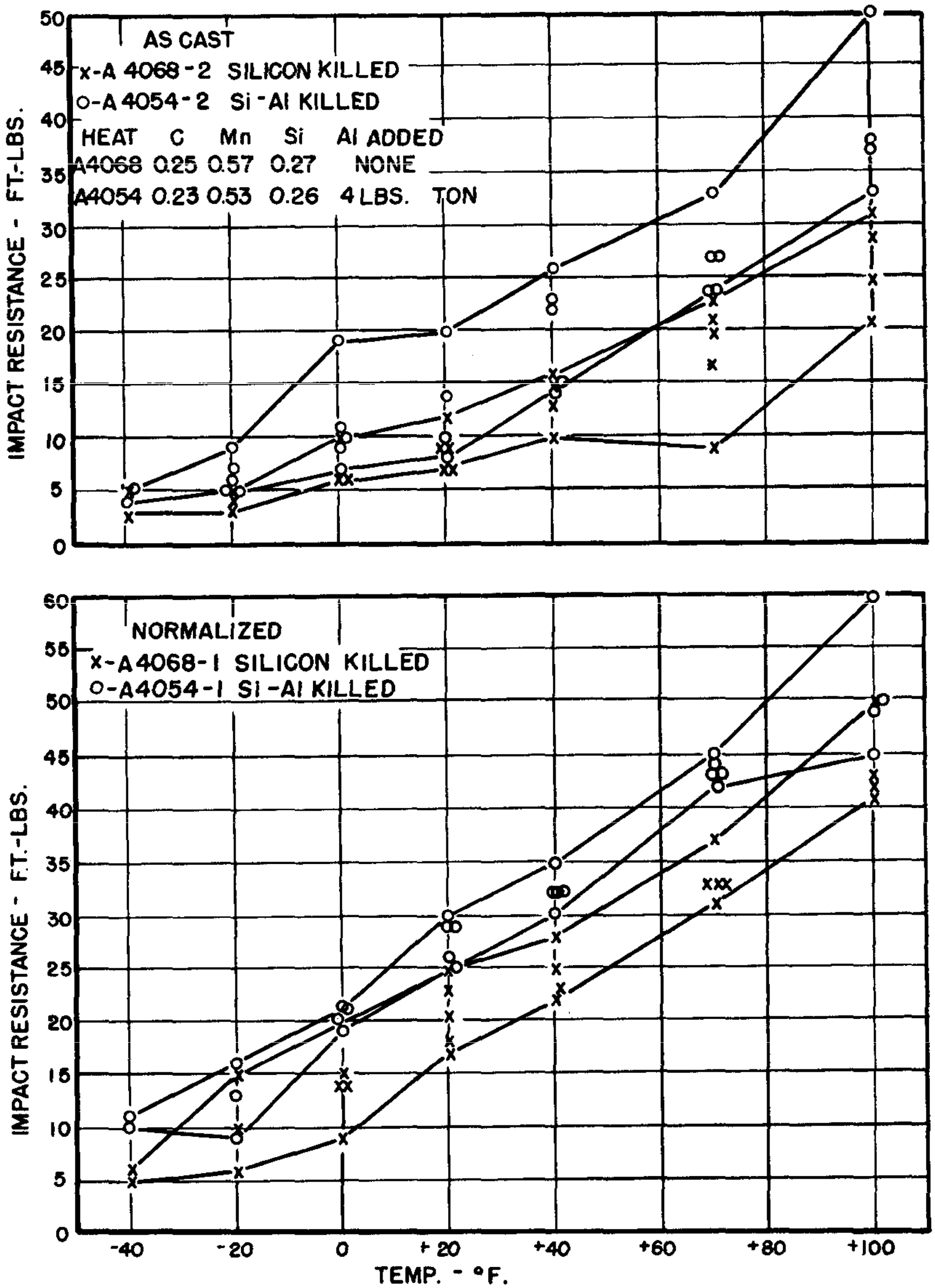
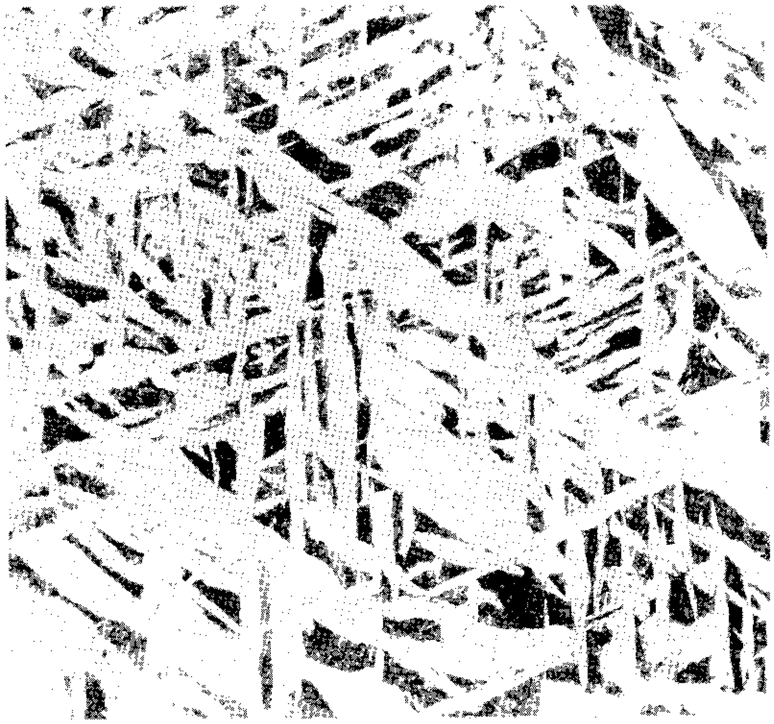


FIGURE 13. STANDARD V-NOTCHED CHARPY IMPACT VALUES OF STEEL TESTED IN THE WEDGE-IMPACT MACHINE.

0-7027



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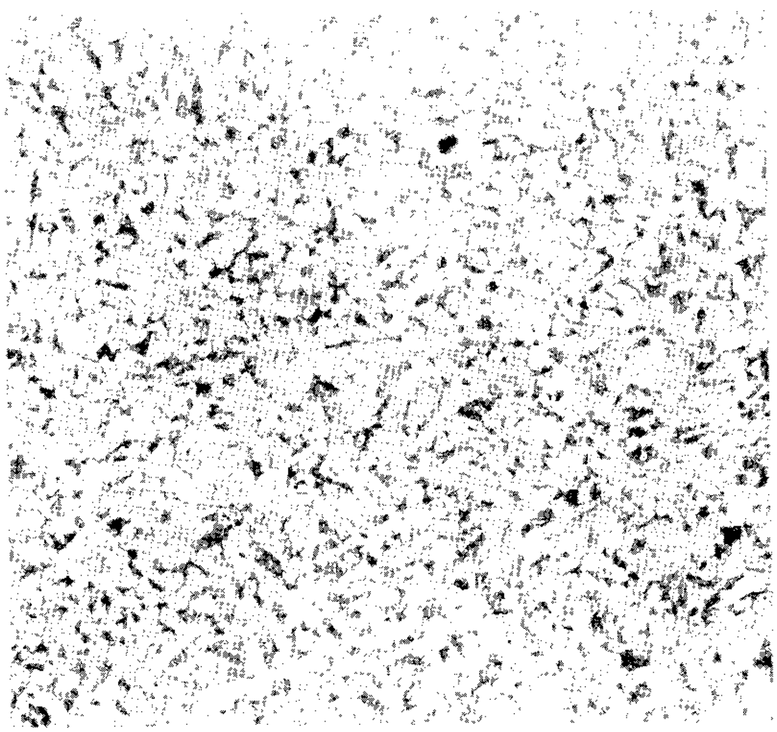
As-cast structure of aluminum-killed steel Heat A-4054. Nital etch



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Structure of Heat A-4054 after normalizing. Nital etch

Figure 14. Microstructure of an as-cast and normalized steel used in the wedge test.

TABLE 5. EFFECT OF WEDGE POSITION ON IMPACT RESISTANCE

Distance from Sprue	Layer (Top A)						Test Conditions
	A	B	C	D	E	F	
1	32 +	-	-	-	-	11,32+	Normalized
2	32+,32+	-	-	-	-	2,32+	Testing temperature, 70°F
3	-	-	-	-	-	-	Aluminum killed
4	32+	-	-	-	-	-	-
1	32+	-	-	-	-	32+,16	Normalized
2	32+,32+	-	-	-	-	32+,16	Testing temperature, 70°F
3	-	-	-	-	-	-	Silicon killed
4	32+	-	-	-	-	-	-
1	-	-	-	-	-	-	Normalized
2	-	20,32+	7,30+	-	-	-	Testing temperature, 0°F.
3	-	-	-	-	32+	12,25	Aluminum killed
4	-	-	30+,30+	-	-	2,30+,30+	-
1	-	-	-	-	-	-	Normalized
2	-	-	30+,30+	-	-	-	Testing temperature, 0°F.
3	-	-	-	-	30+,32+	30+,30+	Silicon killed
4	-	-	30+	27	15,21	30+	-
1	-	-	-	-	14	-	Normalized
2	-	-	-	-	11	-	Testing temperature, -40°
3	30+,30+	30+,30+	2,29	13,30+	-	-	Aluminum killed
4	-	32+,32	-	32+	-	-	-
1	-	-	-	16	-	-	Normalized
2	-	32+	-	-	-	-	Testing temperature, -40°
3	30+,30+	30+,30+	25,30+	30+,30+	-	-	Silicon killed
4	-	32+	-	32+	-	-	-

TABLE 5 (Continued)

Distance From Sprue	Layer (Top A)						Test Conditions
	A	B	C	D	E	F	
1	3	30+,8	1,7	13,9	26	-	Normalized
2	-	-	23,15	-	-	31	Testing temperature, -80°F.
3	-	-	-	-	4	-	Aluminum killed
4	-	-	15	-	-	-	-
1	11	2,30+	17,17	4,16	5,11	-	Normalized
2	-	32+	-	23,7	5	-	Testing temperature, -80°F.
3	-	-	-	-	-	-	Silicon killed
4	-	25	-	-	-	-	-
1	-	-	-	-	-	-	As cast
2	-	2	6	-	-	1	Testing temperature, -40°F.
3	3,2	1,5	1	2	1,1	-	Aluminum killed
4	-	1	-	-	-	-	-
1	-	-	-	-	-	-	As cast
2	1	5	-	-	-	-	Testing temperature, -40°F.
3	1,1	4,1	-	2,9	1,2	-	Silicon killed
4	-	-	11	1	-	-	-
1	-	-	2,5	-	-	-	As cast
2	2	-	-	6	1	-	Testing temperature, 0°F
3	-	-	5,18	-	-	13,10	Aluminum killed
4	-	-	4	-	2	13,8	-
1	-	-	3,5	-	-	-	As cast
2	3,10	6	-	-	-	-	Testing temperature, 0°F.
3	-	-	14,20	-	-	7,6	Silicon killed
4	-	-	-	-	1,1	17,1	-

TABLE 5 (Continued)

Distance From Sprue	Layer (Top A) A	B	C	D	E	F	Test Conditions
1	-	-	-	-	-	9,2	As cast
2	-	-	-	-	-	4,30+	Testing temperature, 70°F
3	-	-	-	-	-	-	Aluminum killed
4	10,14	1,11	-	-	-	-	-
1	-	-	-	-	-	9,9	As cast
2	-	-	26,28	32+,32+	30,23	9,4	Testing temperature, 70°F
3	-	-	-	-	-	-	Silicon killed
4	4	11	-	-	-	-	-
1	30+	30,30+	-	30+,30+	30+,30+	-	As cast
2	30+	-	32+	32+	26	-	Testing temperature, 210°
3	-	-	-	-	-	-	Aluminum killed
4	-	-	32+	1	4	-	-
1	30+,26	30+,30+	-	30+,30+	30+,20	-	As cast
2	-	-	-	-	-	-	Testing temperature, 210°
3	-	-	-	-	-	-	Silicon killed
4	-	-	-	-	-	-	-

Use of Special Ceramic Molds

A number of ceramic molds, made by Alloy Engineering and Casting Company, were poured from two heats of hull plate type of steel in an attempt to obtain better as-cast wedge surfaces.

Chemical analysis of the two 200-pound induction furnace heats were as follows:

TABLE 6. CHEMICAL COMPOSITION OF STEEL HEATS CAST IN CERAMIC MOLDS

Heat	Chemical Composition, Per Cent				
	C	Mn	Si	S	P
A-4251	0.23	0.47	0.24	0.025	0.019
A-4252	0.21	0.50	0.21	0.025	0.018

Three ceramic molds and a 48-wedge core-sand mold were poured from Heat A-4251. Four ceramic molds and a 50-pound ingot were poured from Heat A-4252.

The wedges from the ceramic molds poured from the first heat contained surface blows near the small end and in the riser. All of the wedge castings had rough surfaces and many of them showed some hot tearing. The hot tears were caused by the rigidity of the ceramic mold design which prevented normal contraction of the steel while cooling.

The second group of ceramic molds were dried overnight at a temperature of about 400°F., the number of vents were increased from one to four, and joints between the parts were sealed with adhesive tape instead of alundum cement.

No gas blows were visible in the wedges made in the second group of molds poured from Heat A-4252; however, no improvement in the surface condition or the tendency to hot tear was obtained.

The inferior surface condition of the wedges cast in ceramic molds in conjunction with the other casting defects made testing of these wedges impractical.

Comparison of the Impact Resistance of Ladle Samples and Commercially Rolled Plate from the Same Open Hearth Heat

A series of three open hearth heats, made by Carnegie-Illinois Steel Company, were tested to compare the impact properties of the small cast ladle sample hot worked in the laboratory with those of the commercially rolled plate from the same heat. Data on this series of heats are given in Table 7. Heat 26-M-450 was a semikilled steel similar to steels used in hull plate. Heat 19-M-396 was similar to hull plate steel except that the heat was killed with silicon. Heat 19-M-390 had a chemical analysis similar to semikilled hull plate steel but was completely killed with both silicon and aluminum. These heats were selected because the impact resistance should increase progressively from the semikilled to silicon-killed to silicon-aluminum-killed steel.

A relatively small aluminum addition is normally made to the ingot while teeming ingots from semikilled steel. The effect of this aluminum addition on the impact properties of ladle samples was determined by taking samples directly from the ladle and by dipping a sample from the top of the ingot mold. All samples of killed steels were taken directly from the ladle since no additions to the ingot were made.

Two ladle samples were taken after pouring both the first and second ingot of each heat. The steel samples taken in a standard sample spoon were cast as one-inch squares six inches long in a split cast iron mold. The risers were cut from these samples and steel sheets were welded over the ends of the semikilled ladle samples to prevent excessive oxidation of the voids while heating for rolling. The cast samples were rolled in the laboratory to 0.705 inch square bar at 2200°F. followed by a final reduction from 0.705 inch to 0.510 inch square

TABLE 7. DATA ON OPEN HEARTH LADLE AND PLATE SAMPLES
MADE BY CARNEGIE-ILLINOIS STEEL COMPANY

Heat Number	Steel Type	Ladle Analysis, %(3) C	Mn	P	S	Si	Plate Finish Rolling Temp., ^{o}F(2)	Location of Plate	Size of Plate Sample, Inches
26-M-450(1)	Semikilled	0.21	0.47	0.012	0.033	-	1766	First Ingot	3/4 x 28 x 28
							1739	Second Ingot	1/2 x 28 x 28
19-M-396	Silicon killed	0.20	0.70	0.016	0.027	0.18	1818	First Ingot	3/4 x 28 x 28
							1725	First Ingot	1/2 x 28 x 28
19-M-390	Silicon-aluminum killed	0.17	0.66	0.019	0.029	0.20	1753	First Ingot	3/4 x 28 x 28
							1739	First Ingot	1/2 x 28 x 28

(1) Ladle samples taken both from the ladle and dipped from the first two ingot molds, ladle samples taken from the ladle only for the other two heats.

(2) Optical pyrometer temperature.

(3) Aluminum additions were as follows:
Heat 26-M-450 - 0.75 pound per ton to the ladle.
0.54 pound per ton to the ingot, average.
Heat 19-M-396 - 0.50 pound per ton to the ladle.
No aluminum added to the ingot.
Heat 19-M-390 - 2.70 pounds per ton to the ladle.
No aluminum added to the ingot.

bar at 1800°F. and air cooled.

Standard V-notched Charpy bars having a notch root radius of 0.010 inch were machined from the bars rolled from ladle samples as well as the plate produced from the same heats. All bars were cut in the longitudinal direction. The plate samples, however, were notched perpendicular to the plate surface while the ladle samples obviously were notched parallel to the bar surface. The impact bars were maintained at the desired testing temperature in an acetone bath for a minimum of fifteen minutes and broken immediately in a 220-foot-pound Riehle impact machine. The temperature of the bath was adjusted to compensate for the small temperature change obtained while transferring the sample from the bath to the impact machine.

The results of the impact tests are shown graphically in Figures 15 to 20, inclusive. Figures 15 and 16 show the results obtained on the semikilled steel for the first and second ingot, respectively. Curves in these figures for samples dipped from the two ingot molds and the ladle sample from the second ingot are quite similar and have values above those of the comparable plate samples PC 11 and PC 12. The impact resistance of the 1/2-inch plate sample, shown in Figure 16, is somewhat higher than that of the 3/4-inch plate, see Figure 15.

The impact values obtained on the ladle samples from the silicon-killed steel, Figures 17 and 18, are much alike and considerably higher than those for the ladle samples from the semi-killed steel shown in Figures 15 and 16. The impact values of the plate samples from the silicon-killed heat were higher than those of plate samples from the semi-killed steel. There was very little difference between the impact resistance of the 1/2-inch and 3/4-inch plate from the silicon-killed steel.

The impact values obtained on the ladle samples from the fully killed steel, Figures 19 and 20, are similar to each other, and in general are much

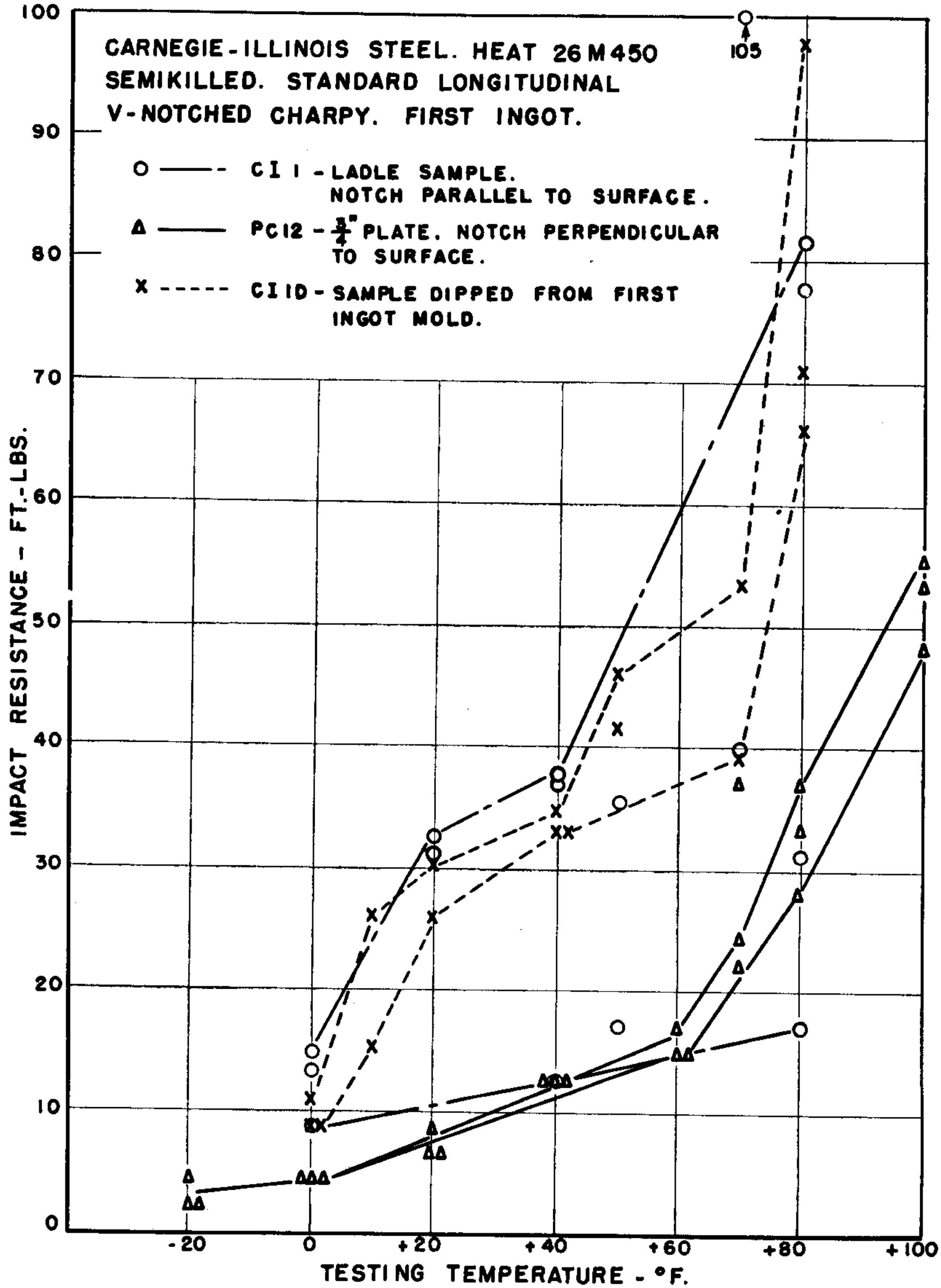

FIGURE 15. COMPARISON OF NOTCHED-BAR IMPACT VALUES OF LADLE SAMPLES AND PLATE FROM THE SAME OPEN HEARTH INGOT.

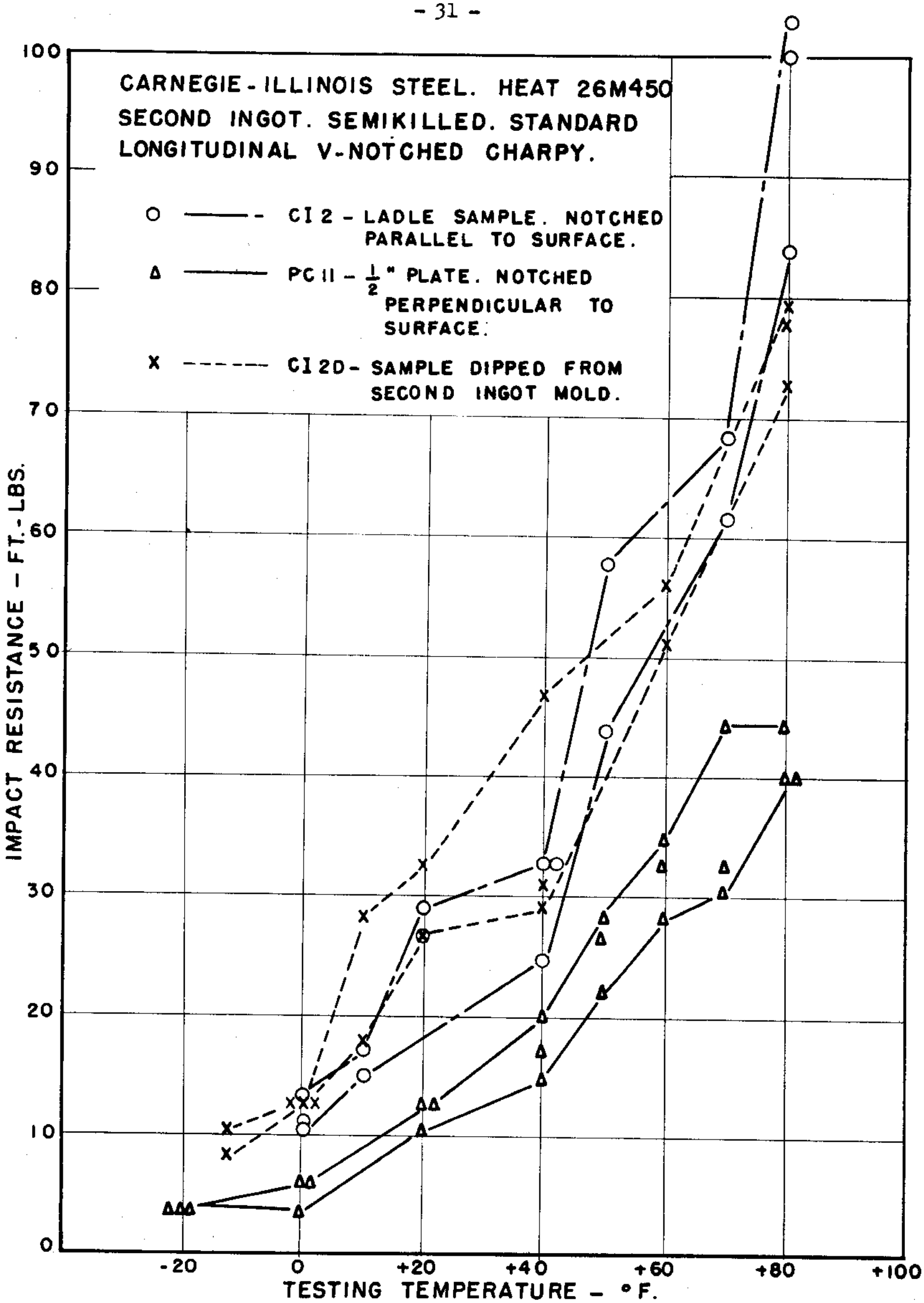

FIGURE 16. COMPARISON OF NOTCHED-BAR IMPACT VALUES OF LADLE SAMPLES AND PLATE FROM THE SAME OPEN HEARTH HEAT.

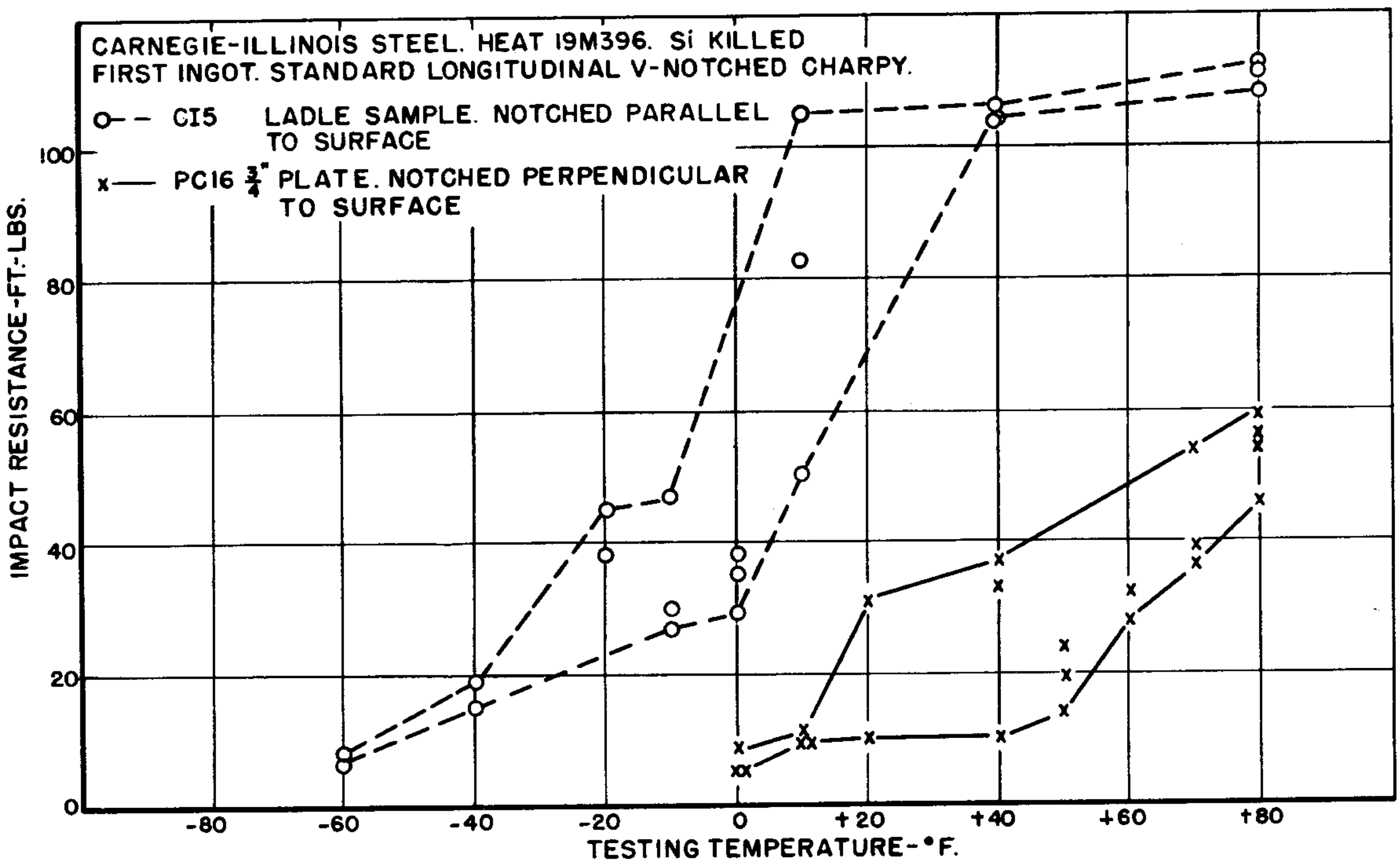

FIGURE 17. COMPARISON OF NOTCHED-BAR IMPACT VALUES OF LADLE SAMPLE AND PLATE FROM THE SAME OPEN HEARTH HEAT.

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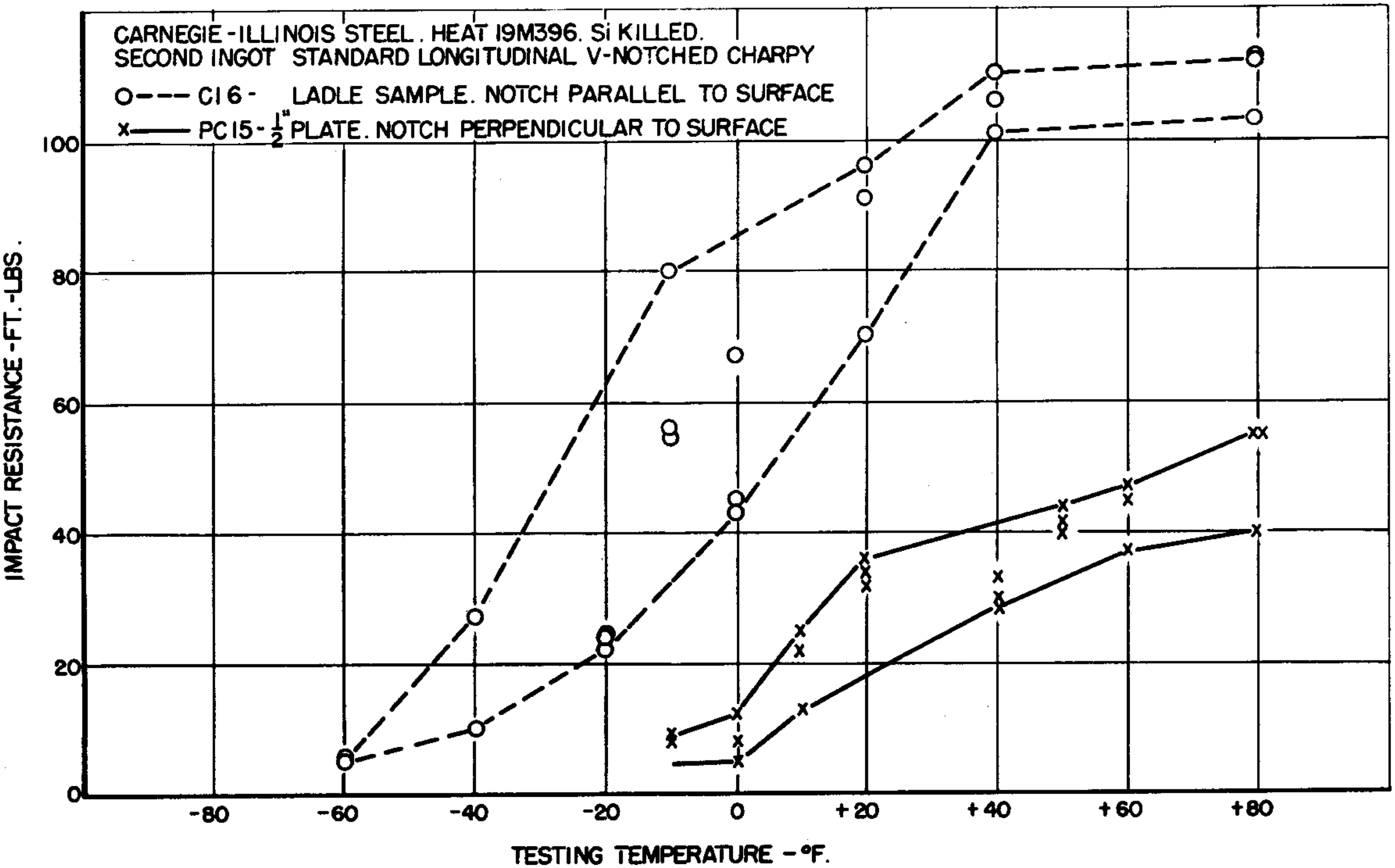

FIGURE 18. COMPARISON OF NOTCHED-BAR IMPACT VALUES OF LADLE SAMPLE AND PLATE FROM THE SAME OPEN HEARTH HEAT

0-7010

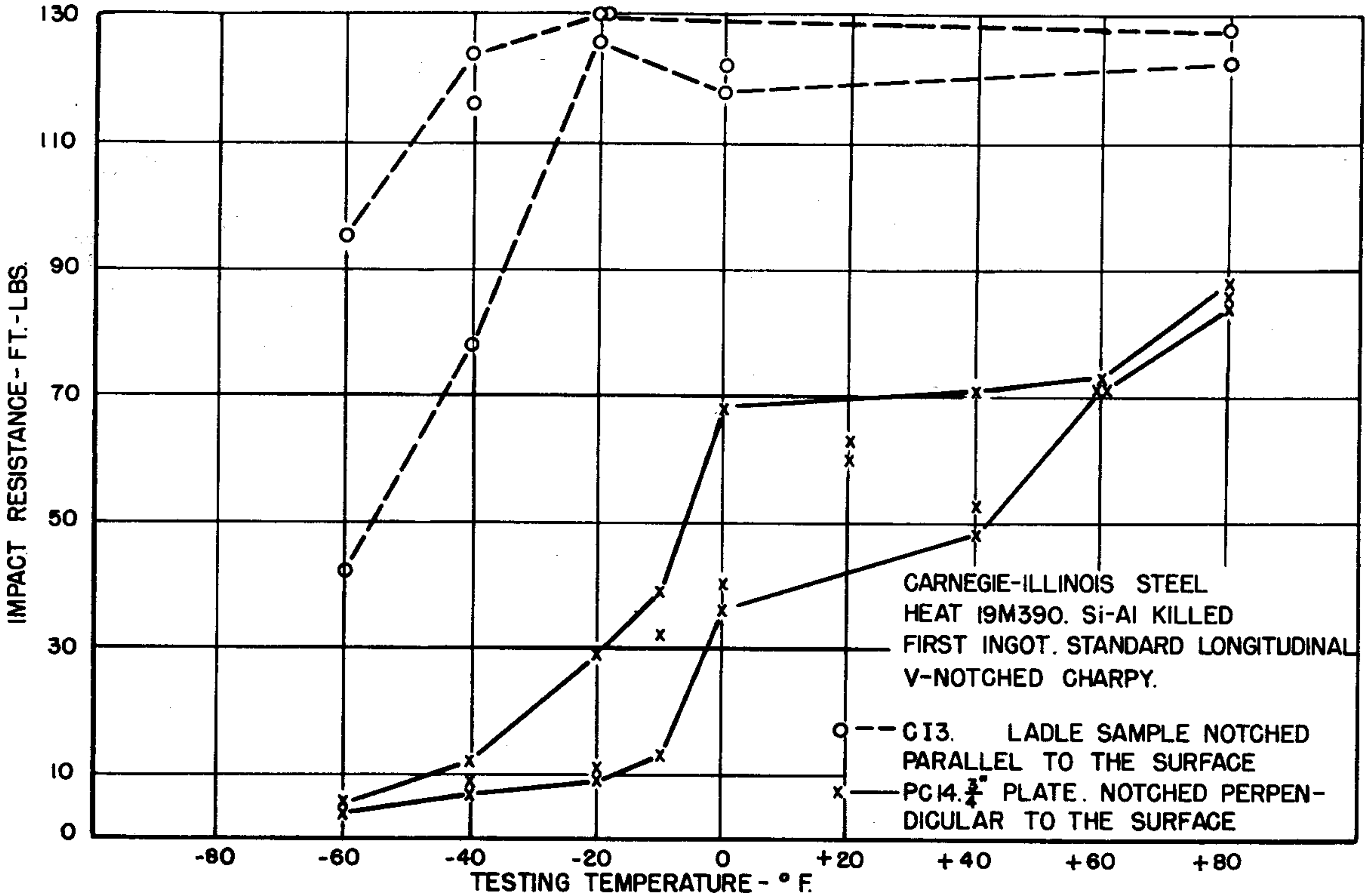

FIGURE 19. COMPARISON OF NOTCHED-BAR IMPACT VALUES OF LADLE SAMPLE AND PLATE FROM THE SAME OPEN HEARTH HEAT.

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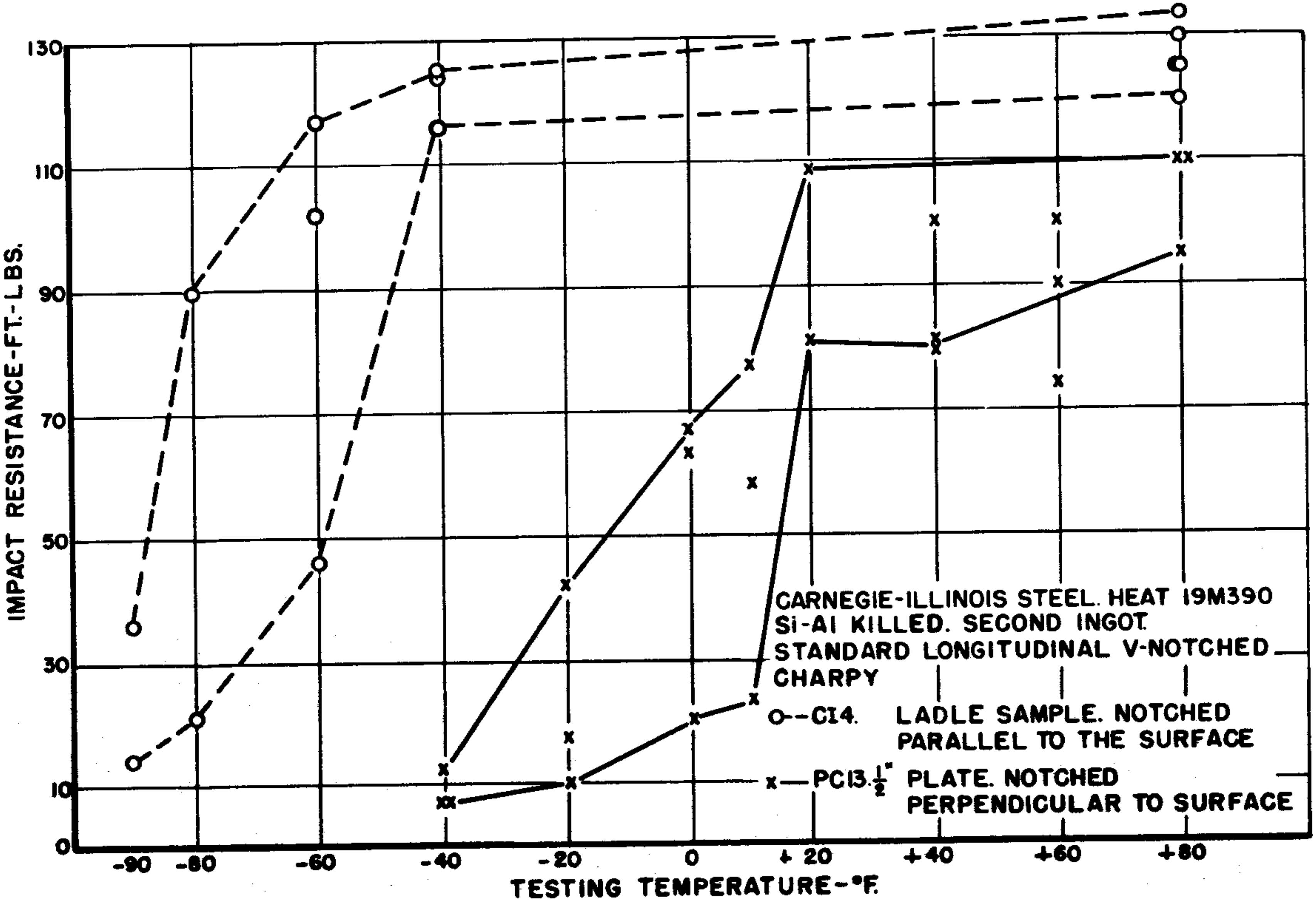

FIGURE 20. COMPARISON OF NOTCHED-BAR IMPACT VALUES OF LADLE SAMPLE AND PLATE FROM THE SAME OPEN HEARTH HEAT.

0-7609

higher than the values obtained from the silicon-killed ladle samples. The plate samples of fully killed steel had impact values considerably lower than those of the companion ladle samples but had higher values than the samples of silicon-killed plate, as is illustrated by Figures 17 and 18. The 1/2-inch plate from the silicon-aluminum-killed (fully killed) steel shown in Figure 19 had a higher impact resistance than the 3/4-inch plate from the same heat, Figure 20.

Notched-bar impact values obtained from these Carnegie-Illinois plate samples and matching ladle samples indicate that both properly classify the steels with respect to the deoxidation practice used. However, the actual values obtained from the ladle samples are considerably higher than those for corresponding plate samples. This variation in impact values could be the result of notch position relative to the rolling direction or to solidification rate and rolling conditions, particularly finish rolling temperature and subsequent cooling rate. A comparison of the microstructure of the commercially rolled plate and ladle samples, Figure 25, shows the latter to have a finer grain structure than the commercial plate and may partially account for the higher impact values.

A series of cast ladle samples and rolled plate were also obtained from four semikilled open hearth steel heats made by the Jones and Laughlin Steel Corporation. Data on these samples are listed in Table 8. Apparently an aluminum addition was made to the ladle samples for the residual aluminum in two heats was appreciable, as is shown in Table 8. Furthermore, ladle samples from all four heats were sound indicating that they had been killed. This addition altered the normal impact resistance and prevented making a true comparison with the plate samples.

Standard V-notched Charpy bars were made from the plates and tested using the same procedure as was used for the Carnegie-Illinois plates. The impact values obtained on a 1/2-inch plate from the first ingot of Heat 123123,

Figure 21, were much the same as those obtained on the similar plate of Carnegie-Illinois steel shown in Figure 16. The impact values of plate from the second and third ingots were slightly lower than values of plate from the first ingot. The impact resistance of the plate from the first ingot of Heat 123171, Figure 22, is quite similar to plate from Carnegie-Illinois steel, Figure 16. Impact values of plate from the second and third ingots were somewhat lower than from the first ingot.

The impact resistance of the plate from semikilled Heat 154930 made from scrap, Figure 23, is about equal to similar plates made by the duplex method, Figures 22 and 24, but is slightly lower than a similar duplex heat shown in Figure 21.

The impact values of Heat 132889, Figure 24, were lower than any of the values for plates cut from similar ingots of other semikilled steels. A marked decrease in the impact values was shown between the first and last ingots tested.

SUMMARY

The object of this research was to develop a test that would distinguish between serviceable and unsatisfactory hull plate steel by tests conducted on laboratory-size samples taken during the teeming of the heat of steel.

No method of casting sound test specimens from semikilled steel is known. Small silicon additions and several casting methods were investigated to determine their effect on the soundness of cast steel samples. Steel containing 0.10 per cent silicon was sound when cast into a copper chill mold or centrifugally cast. Lower silicon steels could not be cast sound. The impact resistance of V-notched round impact bars made from steel containing 0.10 per cent silicon was significantly better than that of the low-silicon steel. The

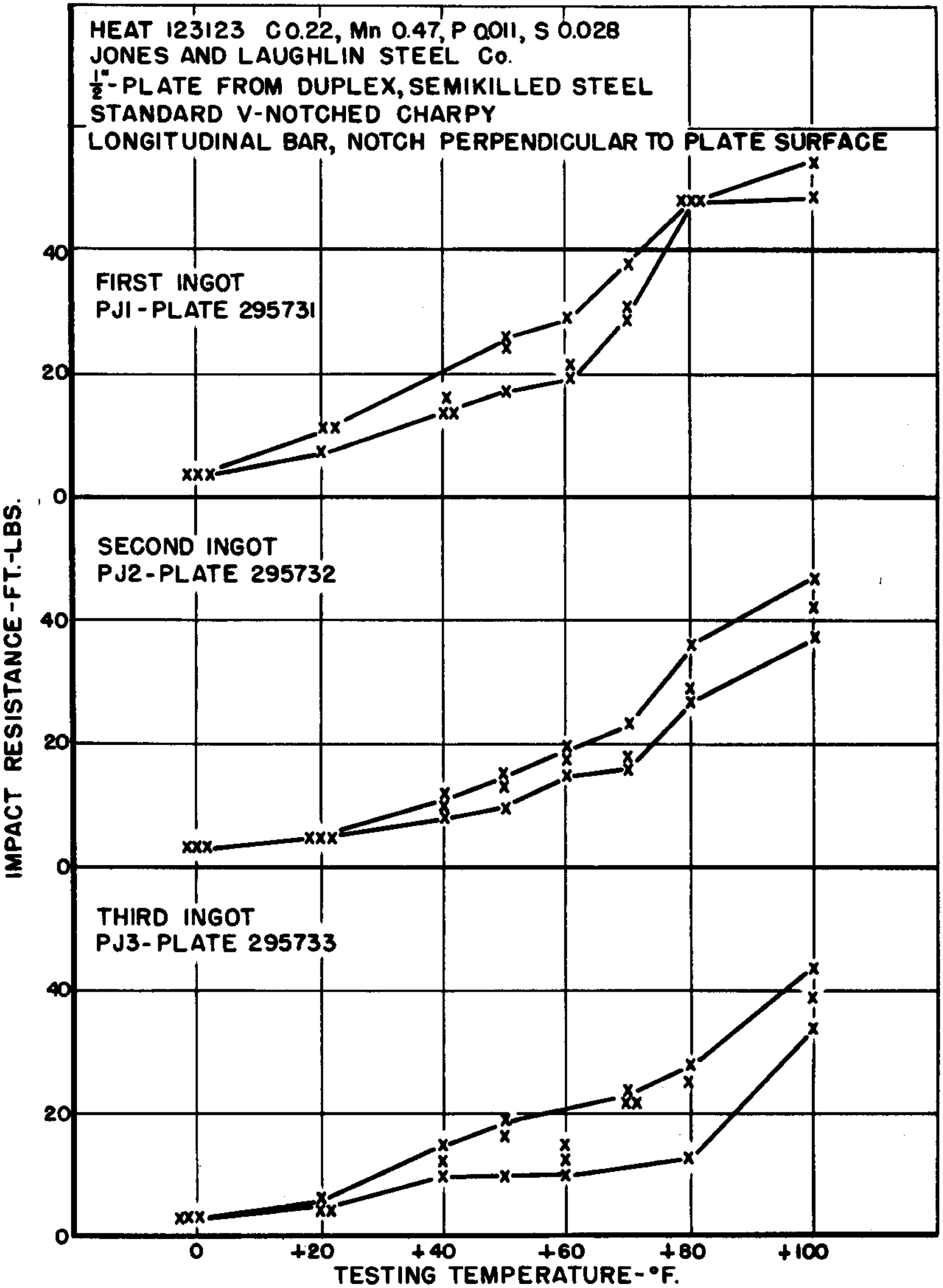

FIGURE 21. COMPARISON OF NOTCHED-BAR IMPACT VALUES OF PLATES ROLLED FROM DIFFERENT INGOTS OF THE SAME HEAT.

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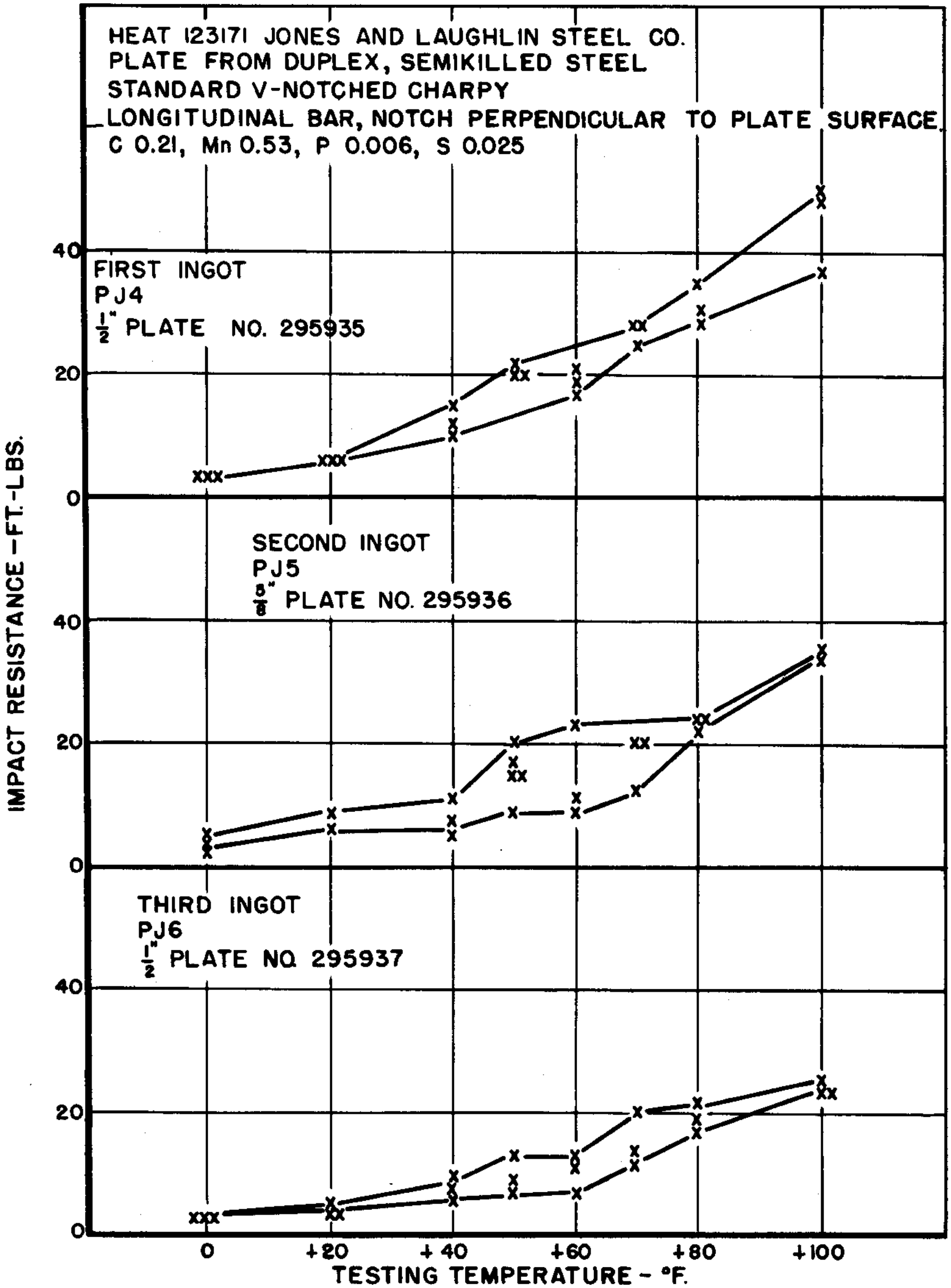

FIGURE 22. COMPARISON OF NOTCHED-BAR IMPACT VALUES OF PLATE ROLLED FROM DIFFERENT INGOTS OF THE SAME HEAT.

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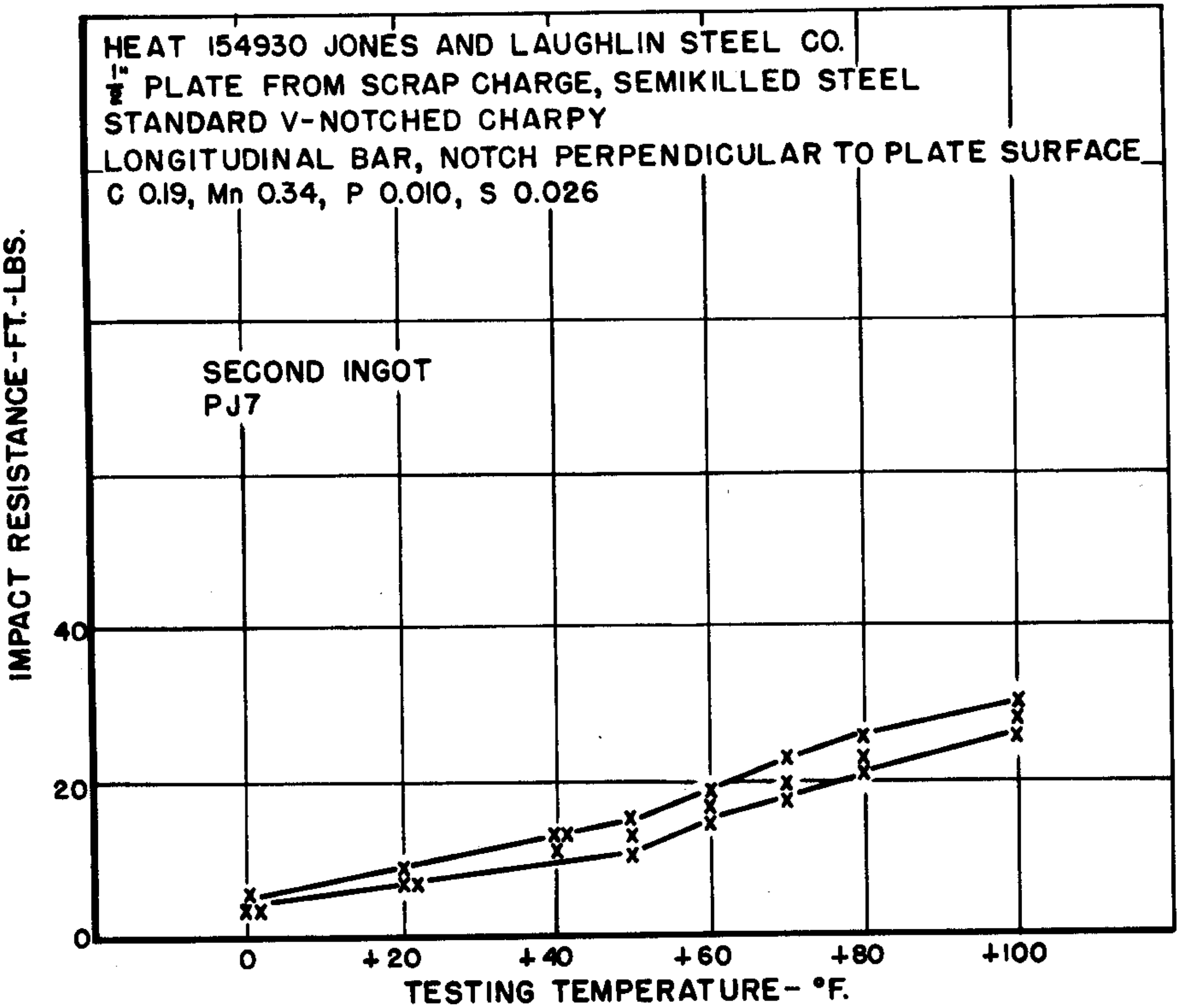

FIGURE 23. NOTCHED-BAR IMPACT VALUES OF PLATE ROLLED FROM A HEAT MADE FROM STEEL SCRAP AND PIG IRON.

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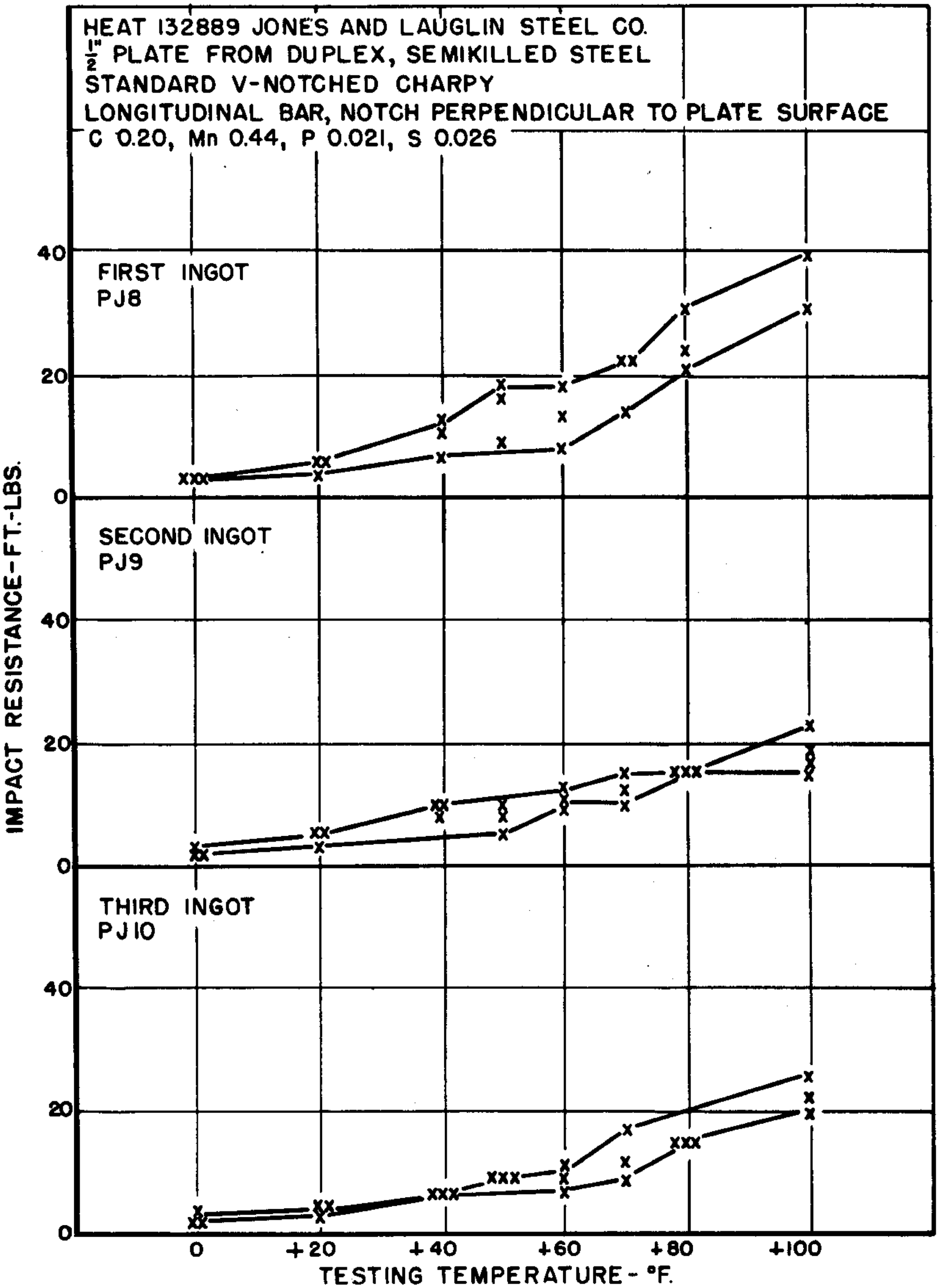
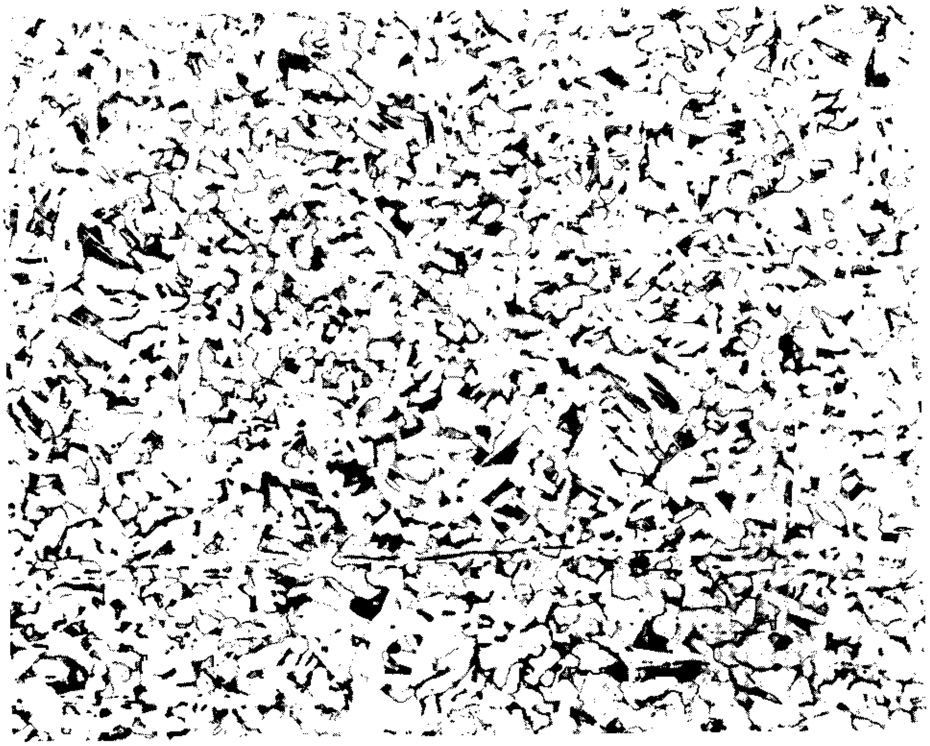


FIGURE 24. COMPARISON OF NOTCHED-BAR IMPACT VALUES OF PLATES FROM DIFFERENT INGOTS OF THE SAME HEAT.

0-7603



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Sample from 1/2-inch plate.

100X 55649

Ladle sample rolled to 1/2-inch-square bar.

Figure 25. Comparison of the microstructure of 1/2-inch plate and a cast ladle sample rolled to 1/2-inch square. Semikilled Heat 26-M-450. Longitudinal section.

TABLE 8. DATA ON OPEN HEARTH LADLE SAMPLES AND ROLLED PLATE FROM JONES AND LAUGHLIN STEEL CORPORATION

Heat Number	Practice	Ladle Analysis, % C	Ladle Analysis, % Mn	Ladle Analysis, % P	Ladle Analysis, % S	Aluminum Analysis, %(1) Cast Sample	Aluminum Analysis, %(1) Rolled Plate	Plate Finish Rolling Temp. °F.	Plate Sample Size, Inches
123123	Duplex, semikilled with silicon	0.22	0.47	0.011	0.028	0.04	0.02	1900-1930	1/2x12x12
123171	Ditto	0.21	0.53	0.006	0.025	0.15	0.02	1850-1900	1/2x12x12 5/8x12x12
132889	"	0.20	0.44	0.021	0.026	-	-	1890-1900	1/2x12x12
154930	Scrap charge. Semi-killed with silicon	0.19	0.34	0.010	0.026	-	-	1840	1/2x12x12

(1) Battelle analysis.

exeprimental data indicate that samples having impact resistance equivalent to semikilled steel cannot be cast sound.

The sensitivity of the Walker wedge-impact test was investigated by comparing the impact resistance of a silicon-killed steel and a silicon-aluminum-killed steel. The wedge-impact test was not sufficiently sensitive to distinguish between the two steels. A difference in notch-sensitivity between the same two steels was shown by standard Charpy tests.

An attempt to produce better wedge surfaces by casting into a ceramic mold resulted in inferior cast surfaces. The removal of the cast surface from wedges cast in core sand resulted in a substantial lowering of the temperature at which breakage would occur in the wedge test.

A comparison of notched-bar impact values for cast ladle samples obtained on the open hearth floor and hot worked in the laboratory and for commercially rolled plate samples from the same ingot was made. Correlation of the notched-bar impact resistance with the deoxidation practice was obtained from both the plate and ladle samples. These tests verify the results obtained on laboratory steels which showed that small hot-worked ladle samples will distinguish relatively large differences in the quality of hull plate steel as evaluated by standard notched-bar impact tests. This test consists of pouring a small sample from the open-hearth ladle, hot working the sample by rolling to about 9/16-inch-square bar, being careful to maintain a finish rolling temperature between 1600°F. and 1800°F., and testing as standard notched-bar impact specimens over a suitable range of temperature. The hot working operation produced sound test specimens from unkilled, low-silicon steels.

To distinguish more subtle differences in hull plate steel quality, prestraining and aging of the notched-bar impact specimens before testing might prove desirable.

CONCLUSIONS

The minimum silicon content in a hull plate type of steel that will give a sound chill cast or centrifugally cast wedge sample is about 0.10 per cent.

The notched-bar impact resistance of steels containing 0.10 per cent silicon is better than that for lower silicon steels; therefore, a silicon addition could not be used to permit casting of sound as-cast test specimens without altering, somewhat, the low-temperature notch-bar test results.

The Walker wedge-impact test is not sufficiently sensitive to distinguish differences in impact resistance of steels which can be separated readily by notched-bar impact tests.

Large differences in the notched-bar impact resistance of rolled plate that result from differences in deoxidation practice can be predicted readily by testing hot-worked ladle samples from the heats in question. Additional experimental work would be necessary to determine whether relatively small differences in the notched-bar properties of semikilled steel plate could be predicted from tests of the ladle samples.

RECOMMENDATIONS

A test of ladle samples that were hot worked under favorable conditions to produce sound specimens would furnish valuable data on the intrinsic notched-bar impact resistance that could be obtained from a particular heat of steel, but could not be expected to show variations resulting from unfavorable conditions introduced during rolling or other parts of the fabrication treatment.

Although the type of test discussed in this report will possibly permit acceptance or rejection of steels intended for hull plate, the operating personnel of steel mills contend that steel poured into the large flat molds, normally used in hull plate production, cannot be diverted to other uses in time of emergency. Therefore, an investigation of the fundamental causes of variation in the notched-bar impact resistance of semikilled steel followed by corrections, if possible, of these causes would greatly benefit both the producers and consumers of this type product.

(Data from which this report was written are recorded in B.M.I. Notebook No. 2756)

JAD:SAH:CTG:CHL:jj
August 30, 1948