SERIAL NO. **SSC-53**

Second

PROGRESS REPORT

(Project SR-110)

on

AN INVESTIGATION OF THE INFLUENCE OF DEOXIDATION AND CHEMICAL COMPOSITION ON NOTCHED-BAR PROPERTIES OF SEMIKILLED SHIP STEEL

by

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BATTELLE MEMORIAL INSTITUTE

Under Bureau of Ships Contract NObs-53239
(BuShips Project NS-011-078)

Transmitted through
NATIONAL RESEARCH COUNCIL'S
COMMITTEE ON SHIP STEEL
Advisory to

SHIP STRUCTURE COMMITTEE

under
Bureau of Ships, Navy Department
Contract NObs-50148
(BuShips Project NS-731-036)

Division of Engineering and Industrial Research
National Academy of Sciences - National Research Council
Washington, D. C.

November 28, 1952

SERIAL NO. **SSC-53**

NATIONAL RESEARCH COUNCIL
2101 CONSTITUTION AVENUE, WASHINGTON 25, D. C.

COMMITTEE ON SHIP STEEL
OF THE
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

November 28, 1952

Dear Sir:

Attached is Report Serial No. SSC-53 entitled "An Investigation of the Influence of Deoxidation and Chemical Composition on Notched-Bar Properties of Semikilled Ship Steel" by Frazier, Boulger and Lorig. This report has been submitted by the contractor as a Second Progress Report on Contract NObs-53239, Bureau of Ships Project NS-011-078, between the Bureau of Ships, Department of the Navy and the Battelle Memorial Institute.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Steel, Division of Engineering and Industrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Department of the Navy and the National Academy of Sciences (Contract NObs-50148, BuShips Project NS-731-036).

Very truly yours,

P. E. Kyle

P. E. Kyle, Chairman
Committee on Ship Steel

Advisory to the SHIP STRUCTURE COMMITTEE, *a committee representing the combined research activities of the member agencies - Bureau of Ships, Dept. of Navy; Military Sea Transportation Service, Dept. of Navy; United States Coast Guard, Treasury Dept.; Maritime Administration, Dept. of Commerce, American Bureau of Shipping.*

SECOND PROGRESS REPORT

on

AN INVESTIGATION OF THE INFLUENCE OF DEOXIDATION AND CHEMICAL COMPOSITION ON NOTCHED-BAR PROPERTIES OF SEMIKILLED SHIP STEEL

to

SHIP STRUCTURE COMMITTEE
via
Bureau of Ships
Department of the Navy

Final Report on Contract Nobs 53239
Index No. NS-011-078
(Project SR-110)

by

R. H. Frazier, F. W. Boulger and C. H. Lorig

BATTELLE MEMORIAL INSTITUTE

TABLE OF CONTENTS

LIST OF FIGURES

FIGURES (Continued)

FIGURES (Continued)

LIST OF TABLES

TABLES (Continued)

Page

SECOND PROGRESS REPORT

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AN INVESTIGATION ON THE INFLUENCE OF DEOXIDATION AND CHEMICAL COMPOSITION ON NOTCHED-BAR PROPERTIES OF SEMIKILLED SHIP STEEL

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INTRODUCTION

The performance of ship-plate steel in welded ship structures is closely associated with the ductile to brittle transition temperature of the plate steel. A low transition temperature is desirable. It indicates that a steel will exhibit greater toughness at lower ambient temperatures. The transition temperature, as defined in this report, is the apparent temperature at which the type of fracture changes from ductile to brittle for a specific design of specimen. Both the Navy tear-test specimen and the keyhole-notch Charpy specimen were used. For that reason, transition temperatures for both types of specimens are reported. It should be remembered there are as many transition temperatures as there are types and sizes of specimens.

Late in 1949, the Bureau of Ships, on behalf of the Ship

Structure Committee under the guidance of the Committee on Ship Steel of the National Research Council, established a research project, Contract NObs-50020, for the purpose of studying the influence of chemical composition and deoxidation upon the transition characteristics and tensile properties of semi-killed ship steel. In this investigation steels of two base compositions are being studied. One of these contains approximately 0.25 per cent carbon and 0.45 per cent manganese and the other, approximately 0.21 per cent carbon and 0.75 per cent manganese. Since these base compositions approximate those for hull steel supplied in accordance with current American Bureau of Shipping specifications under Class A and Class B, respectively, the steels in this report are identified as Type A or Type B on the basis of carbon and manganese content. All plates prepared for this study were 3/4 inch in thickness in order to permit direct comparison of properties. This thickness is, however, not characteristic of commercial Class A steel. In practice, Class A steel is restricted to plates 1/2 inch or less in thickness.

Previous work, done on Contract NObs-50020 and reported in Ship Structure Committee Report SSC-49(5), showed that 200-pound semikilled laboratory heats can be made with satisfactory reproducibility for use in studying the influence of chemical composition and deoxidation upon the transition-temperature characteristics of 3/4-inch plate. This earlier work indicated that the transition temperature was raised by increasing the carbon, phosphorus, and vanadium contents within the limits studied. Limited data also indicated that increasing sulfur contents up to 0.050 per cent did not affect the transition temperature.

Increased manganese contents were found to lower the transition temperature. However, the interrelationships between carbon and manganese contents and toughness were not explored. More data were also needed to establish definitely the effect of silicon content. Prior data indicated that the transition temperature was lowered by decreasing the finishing temperature of the hot-rolled plate.

Work in this same field was continued in 1951 under Contract NObs-53239 and is summarized and reported herein.

PREPARATION AND TESTING OF LABORATORY STEELS

The laboratory steels were prepared from 200-pound induction-furnace melts. The charge was melted under an atmosphere of argon to insure low, uniform nitrogen contents of the order found in commercial ship plate. After the charge was melted and the desired temperature was obtained, the melt was partly deoxidized by an addition of silicomanganese. This addition was made to obtain consistent recovery of subsequent ferro-manganese and ferrosilicon additions. Carbon, in the form of graphite, was added just prior to tapping to meet the intended composition.

The entire heat was poured directly into a 6 x 6-inch big-end-up mold and the ingot capped with a steel plate when necessary. The killed steels were poured with a hot-top containing 14 per cent of the total volume of the ingot.

The ingots were processed by heating to 2250 F, followed by forging to slabs 1-3/4 inches thick and 6 inches wide. After reheating to 2250 F, the slabs were rolled to 0.9-inch gage, using reductions of approximately 1/6 inch per pass. The 0.9-inch-gage plates were immediately recharged in a furnace held at 1850 F. After 20 minutes or more in the furnace at 1850 F, the plates were rolled to 3/4 inch in one pass. Following the final pass, the plates were stacked on edge on a brick floor, with a brick separating one from another. They were allowed to cool in air.

Drillings for chemical analysis were taken from the top and bottom of each ingot following rolling.

Duplicate standard plate tensile specimens, using the full thickness of the plate, were prepared from each heat. From these tests, the upper and lower yield strengths, the tensile strength, and the elongation were determined. The upper yield strength is the highest strength obtained before the drop of the beam, while the lower yield strength is the lowest strength after the drop of the beam and before the ultimate strength is reached. The elongation was measured over an 8-inch gage length.

The transition temperature of the steels was determined by two methods: first, by using the Navy tear-test specimen, and second, from notched-bar impact data obtained from keyhole Charpy specimens.

The tear tests were made using the type of specimen and procedure described by Kahn and Imbembo(1). The transition temperature was defined as the highest temperature at which one or more in a group of four test specimens exhibited a fracture area having less than 50 per cent of the ductile-shear type.

For the keyhole Charpy tests, the transition temperature was defined as the temperature on the average temperature-energy curve corresponding to the 20 foot-pound level. All Charpy specimens had the long axis in the direction of rolling and were notched perpendicular to the original plate surface.

REPRODUCIBILITY STUDY

At intervals during this investigation, "standard" Type A and Type B steels were processed to check the constancy of experimental procedures. They provide information on the reproducibility of data for 200-pound semi-killed heats made and tested in the laboratory.

Results for five such steels processed in 1951 are given in Table 1 and additional data are recorded in Table 1 of the Appendix. All of these materials had compositions and properties within ranges expected from results obtained in 1950 and reported previously(5).

Table 2 summarizes the data obtained, during 1950 and 1951, for eight Type A and seven Type B "standard" steels. Obviously

TABLE 1. CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES OF TYPE A AND TYPE B STEELS IN REPRODUCIBILITY STUDY OF LABORATORY STEELS MADE IN 1951

Grade of Steel	Heat No.	Chemical Analysis, per cent						Tensile Properties					Tear Test Properties			Charpy Keyhole Transition Temperature(2), F
								Yield Strength, psi		Tensile Strength, psi	Elongation in 8", per cent	Maximum Load, lb	Energy to Start Fracture(1), ft-lb	Energy to Propagate Fracture(1), ft-lb	Transition Temperature, F	
		C	Mn	P	S	Si	N	Upper	Lower							
Type A	A6650	0.22	0.46	0.012	0.023	0.04	0.004	35,600	34,250	60,550	28.0	36,740	820	640	70	+24
Type A	A6705	0.21	0.49	0.016	0.025	0.05	0.004	37,050	35,900	63,000	24.5	36,340	760	580	60	+4
Type A	A7663	0.22	0.44	0.015	0.027	0.03	0.003	35,050	34,500	61,100	31.5	37,590	870	790	90	+23
Type B	A6651	0.19	0.74	0.017	0.023	0.01	0.005	37,200	35,700	62,300	28.5	39,090	880	730	70	−13
Type B	A7664	0.18	0.69	0.015	0.026	0.03	0.003	36,100	34,800	62,300	29.5	38,980	940	740	80	−7

(1) Average energy of the four ductile specimens broken at 10 degrees F above the transition temperature.

(2) Temperature at which the Keyhole Charpy energy is 20 ft-lb.

TABLE 2. SUMMARY OF PROPERTIES FOR "STANDARD" LABORATORY STEELS ROLLED AT 1850 F, SHOWING REPRODUCIBILITY OF DATA

Property	Type A Steel		Type B Steel	
	Average	Standard Deviation(1)	Average	Standard Deviation(1)
Upper Yield Strength, psi	36,700	1200	36,500	540
Ultimate Strength, psi	61,800	1000	62,300	400
Elongation in 8", per cent	28.0	2.4	28.0	2.0
Transition Temperature, F Tear Test	75	13	73	4.5
Keyhole Charpy	14	8.6	−15	7.1
Carbon, per cent	0.22	0.005	0.20	0.014
Manganese	0.465	0.017	0.76	0.037

(1) The standard deviation is the root-mean-square of the deviations of each observation from the average for that type of steel. The averages and standard deviations are for 8 Type A steels and 7 Type B steels made in the laboratory. Care was taken to secure reproducible results. Five heats of each type of steel were made and tested in 1950, the others in 1951.

the agreement was good for compositions and tensile properties of different heats of the same type. The standard deviations of the Charpy transition temperatures are of the order expected for this criterion, according to Rinebolt and Harris(8). All measurements on these heats fell within limits equal to twice the standard deviations listed. This indicates the data were obtained under "statistically controlled" conditions. The reproducibility of the data appears to be satisfactory.

The Charpy data for the standard steels indicate that Type B steels are more resistant to brittle fracture than Type A steels. The tear test, on the other hand, did not discriminate between the two grades. Since the differences in carbon and manganese contents were expected to influence transition temperatures, this point was studied intensively. Data in the next section indicate that the difference in tear test transition temperatures between Type A and Type B steels, expected on the basis of composition, is within the limit of reproducibility of tear-test data.

INFLUENCE OF CARBON AND MANGANESE

A comprehensive study of the effect of carbon and manganese on properties of ship-plate steel was made to supplement data reported previously(2,5). Steels with manganese contents ranging from 0.20 to 1.50 per cent, at each of five carbon levels, were made and tested. The steels were prepared by the standard procedures, then forged and rolled in the usual manner to 3/4-inch plate. Chemical analyses of these steels are listed in Table 3. Averages for the "standard" steels, discussed above, are listed in the appropriate places in the table.

Tensile properties and transition temperatures of the steels used to establish the effects of carbon and manganese are listed in Table 4. Since the carbon and manganese contents of the steels were varied independently, the series covers a range in tensile strengths. Figure 1 shows the effect of manganese-carbon ratio on the tear-test transition temperature for seven steels with tensile strengths between 60,000 and 64,500 psi. Data for the other heats, except for two steels of entirely different strengths, are plotted in Figure 2. Both graphs show that, at equal strength levels, higher manganese-carbon ratios are desirable. This is also true, and the effect is more pronounced, in Charpy tests.

Standard multiple correlation methods were used to develop formulas for the various properties. These formulas and the standard errors of estimate are as follows:

Upper yield strength, psi = 23,000 + 39,200 x %C + 7200 x %Mn
Standard error = 1500 psi

Lower yield strength, psi = 20,700 + 39,800 x %C + 8400 x %Mn
Standard error = 1300 psi

Tensile strength, psi = 30,800 + 104,000 x %C + 13,000 x %Mn
Standard error = 2200 psi

Elongation = 38.2 - 32.6 x %C - 3.2 x %Mn
Standard error = 2.4%

TABLE 3. CHEMICAL ANALYSIS OF 3/4-INCH LABORATORY STEEL PLATE WITH VARIOUS CARBON AND MANGANESE CONTENTS

Heat Number	Composition, per cent					
	C	Mn	P	S	Si	N
		0.15% Carbon Series				
A7448	0.17	0.23	0.015	0.021	0.04	0.004
A6539	0.15	0.41	0.017	0.027	0.02	0.004
A6586	0.14	0.76	0.011	0.023	0.07	0.004
A7516	0.18	1.06	0.016	0.025	0.08	0.004
A7517	0.15	1.23	0.016	0.021	0.07	0.004
		0.20% Carbon Series				
A6590	0.19	0.22	0.015	0.026	0.05	0.003
A7532	0.19	0.45	0.015	0.031	0.03	0.004
Std. B steels	0.20	0.76	0.015	0.023	0.05	0.004
A7518	0.19	0.96	0.017	0.028	0.04	0.004
A7519	0.21	1.31	0.017	0.025	0.07	0.005
A6599	0.20	1.46	0.015	0.022	0.06	0.004
		0.25% Carbon Series				
A6589	0.25	0.23	0.016	0.024	0.08	0.004
Std. A steels	0.22	0.46	0.014	0.024	0.05	0.004
A6547	0.21	0.83	0.015	0.028	0.05	0.004
A6554	0.18	0.93	0.016	0.017	0.11	0.005
A6598	0.24	1.27	0.016	0.026	0.07	0.004
		0.30% Carbon Series				
A7520	0.27	0.21	0.014	0.027	0.02	0.004
A7521	0.26	0.43	0.015	0.029	0.02	0.003
A7522	0.28	0.66	0.016	0.025	0.03	0.004
A7533	0.26	1.00	0.016	0.030	0.03	0.003
A7524	0.31	1.39	0.018	0.026	0.03	0.005
		0.35% Carbon Series				
A7527	0.31	0.21	0.016	0.027	0.03	0.004
A6596	0.34	0.49	0.015	0.023	0.06	0.003
A6597	0.32	0.80	0.017	0.024	0.06	0.004
A7525	0.31	0.88	0.016	0.025	0.04	0.004

TABLE 4. TENSILE AND NOTCHED-BAR PROPERTIES OF 3/4-INCH LABORATORY STEEL PLATES WITH VARIOUS CARBON AND MANGANESE CONTENTS

	Tensile Properties				Tear-Test Properties				Keyhole
	Yield Strength, psi								
Heat No.	Upper	Lower	Tensile Strength, psi	Elongation in 8", per cent	Maximum Load, lb	Energy to Start Fracture, ft-lb	Energy to Propagate Fracture, ft-lb	Trans. Temp, F	Charpy Trans. Temp, F
0.15% Carbon Series									
A7448	33,300	28,700	50,700	35.0	33,510	950	670	50	+21
A6539	31,850	30,750	53,300	30.5	35,650	930	690	60	+10
A6586	33,000	32,000	54,400	28.0	38,490	1270	1130	40	-24
A7516	36,200	34,700	59,600	31.5	40,790	1220	840	40	-38
A7517	37,150	36,000	61,400	29.5	42,570	1180	870	30	-41
0.20% Carbon Series									
A6590	33,100	31,450	55,100	30.5	34,110	840	740	90	+26
A7532	31,700	31,450	56,050	32.5	36,930	870	770	70	+12
Std. Type B	36,350	35,350	62,250	28.0	39,460	870	750	73	-15
A7518	36,200	35,350	61,700	33.0	40,080	960	820	50	-21
A7519	37,700	37,000	64,200	29.0	43,570	980	810	50	-29
A6599	43,850	43,400	72,350	24.5	46,820	970	850	60	-38
0.25% Carbon Series									
A6589	34,050	32,800	58,400	29.5	35,180	820	670	100	+36
Std. Type A	36,950	35,150	61,900	28.0	37,030	780	660	75	+14
A6547	36,850	35,950	65,400	26.5	39,230	760	730	80	-27
A6554	38,550	37,100	64,900	29.5	40,920	890	800	70	-45
A6598	42,850	42,150	74,200	23.0	45,490	950	830	70	-60

TABLE 4. (Continued)

Heat No.	Tensile Properties: Yield Strength, psi: Upper	Tensile Properties: Yield Strength, psi: Lower	Tensile Properties: Tensile Strength, psi	Tensile Properties: Elongation in 8", per cent	Tear-Test Properties: Maximum Load, lb	Tear-Test Properties: Energy to Start Fracture, ft-lb	Tear-Test Properties: Energy to Propagate Fracture, ft-lb	Tear-Test Properties: Trans. Temp, F	Keyhole Charpy Trans. Temp, F
				0.30% Carbon Series					
A7520	34,250	32,000	58,600	29.0	34,960	670	710	90	+67
A7521	36,450	33,900	62,300	30.0	36,800	720	710	100	+61
A7522	38,450	36,950	68,450	25.5	37,780	600	560	90	+22
A7533	41,900	39,250	73,600	27.5	43,240	700	640	80	-9
A7524	45,800	45,450	80,800	26.5	47,250	740	660	100	-4
				0.35% Carbon Series					
A7527	34,650	33,800	62,950	30.0	35,700	590	640	120	+90
A6596	41,300	38,550	72,900	21.0	36,470	520	570	120	+75
A6597	40,900	40,100	75,100	24.5	40,970	640	610	90	+19
A7525	40,500	40,100	76,250	27.0	43,790	670	540	90	+16

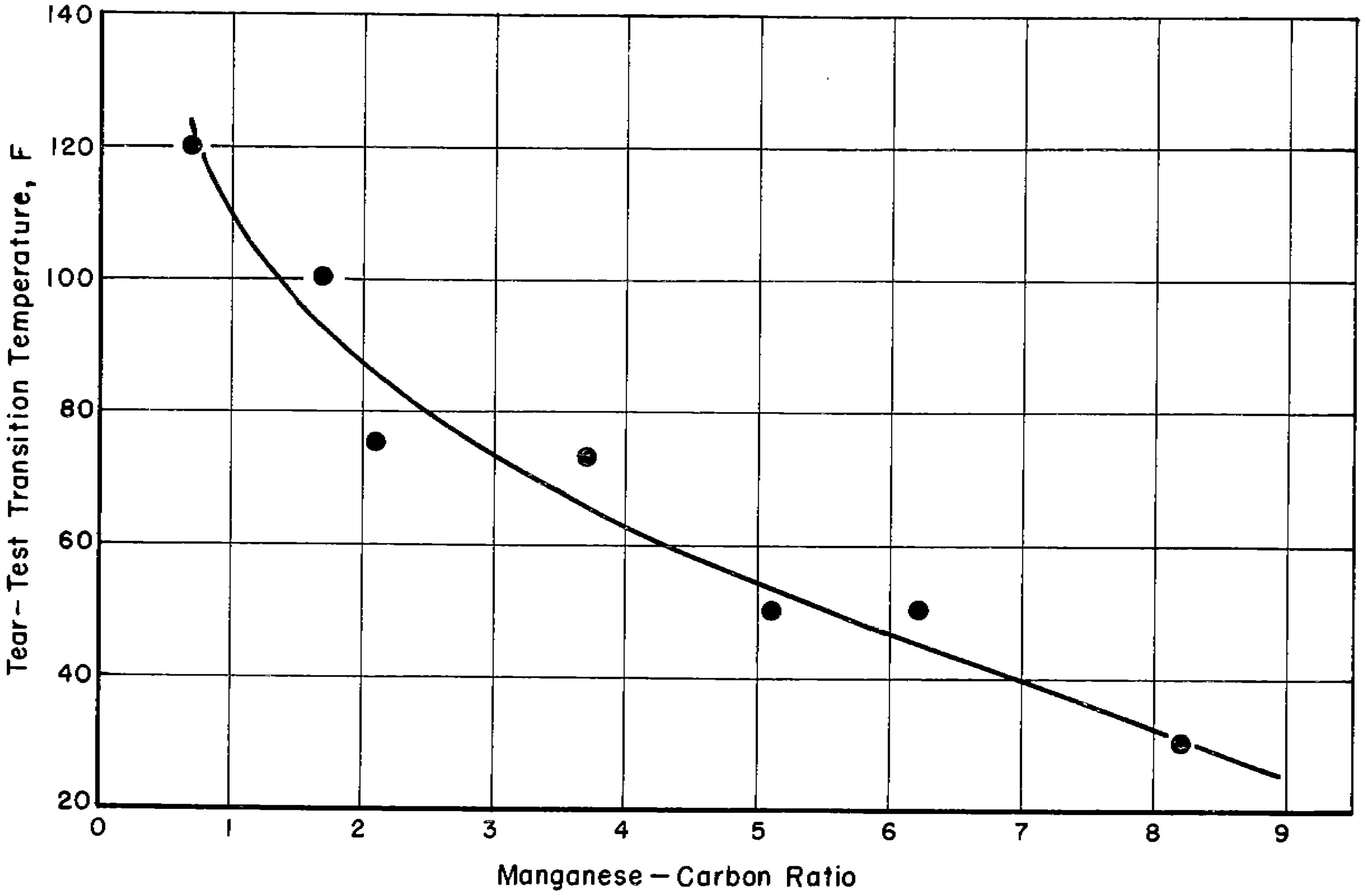

FIGURE I. RELATIONSHIP BETWEEN MANGANESE-CARBON RATIO AND TEAR-TEST TRANSITION TEMPERATURE FOR EXPERIMENTAL SEMIKILLED STEELS WITH ULTIMATE STRENGTHS BETWEEN 60,000 AND 64,500 PSI

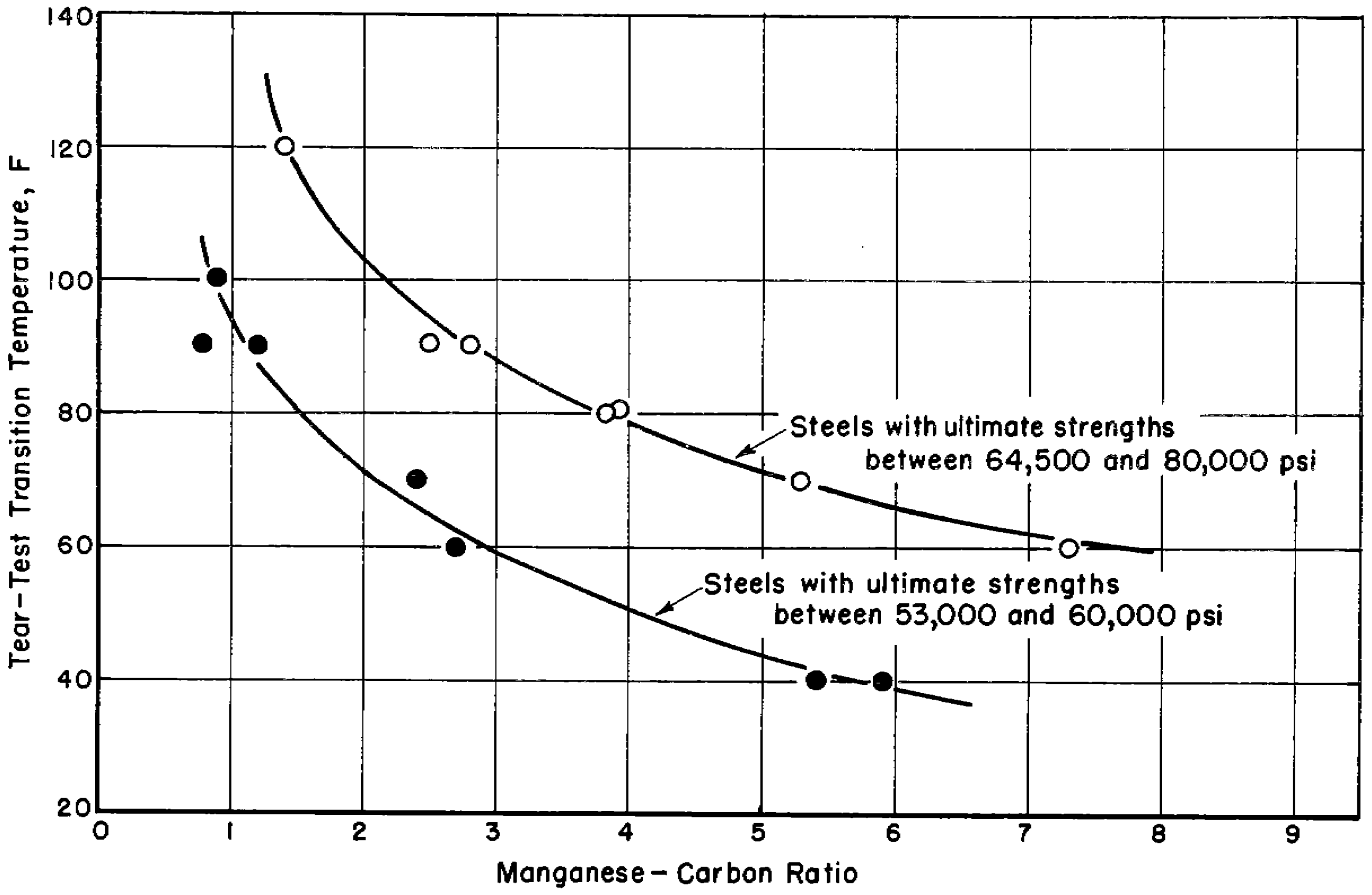

FIGURE 2. RELATIONSHIP BETWEEN MANGANESE-CARBON RATIO AND TEAR-TEST TRANSITION TEMPERATURE FOR EXPERIMENTAL SEMIKILLED STEELS OF DIFFERENT STRENGTHS

Tear-test transition temperature = +17 + 330 x %C - 23 x %Mn
Standard error = 10 F

Keyhole Charpy transition temperature = -19 + 349 x %C - 74 x %Mn
Standard error = 15 F

These formulas indicate that manganese has a greater effect on transition temperatures measured by Charpy tests than by tear tests. The formulas for tensile properties of the experimental steels agree quite well with those reported for commercial steels(8).

Table 5 compares calculated transition temperatures for 25 commercial steels with actual data obtained by Kahn(6) and Battelle. In all but one case, the actual and calculated Charpy transition temperatures agree within twice the standard error of the formula. This indicates good agreement as do the group averages for the actual and calculated temperatures.

On the other hand, only 14 of the 25 calculated tear-test transition temperatures agree with actual values within twice the standard error, 20 F, of the formula. Most of the calculated temperatures are lower than the actual ones, probably because the commercial steels were rolled above 1850 F, the temperature used for the steels on which the formula is based. As will be shown later, increasing the rolling temperature 100 F raises the tear-test transition temperature of commercial steel 20 F. The effect on Charpy transition temperatures is about 10 F

TABLE 5. TRANSITION CHARACTERISTICS OF COMMERCIAL SEMIKILLED, 3/4-INCH SHIP PLATE

Plate Code	Composition, per cent		Actual Transition Temperature, F		Calculated Transition Temperature, F	
	C	Mn	Tear Test	Keyhole Charpy	Tear Test	Keyhole Charpy
G-3	0.25	0.42	100	–	90	–
A	0.25	0.49	70	+10	89	+32
C	0.25	0.51	135	+15	88	+31
S-7	0.21	0.49	120	+17	75	+18
S-6	0.20	0.55	100	+14	71	+10
S-9	0.18	0.50	80	+10	65	+7
S-10	0.19	0.54	90	0	68	+8
S-11	0.20	0.55	90	+36	71	+10
S-8	0.14	0.46	90	+22	53	−4
58 x 428	0.33	0.55	130	+43	114	+57
5779	0.25	0.44	80	+20	91	+36
Average	0.22	0.50	99	+19	80	+21
G-6	0.18	0.96	50	–	55	–
S-2	0.17	0.60	110	+7	60	−4
S-21	0.22	0.81	70	−5	71	−2
S-23	0.20	0.75	100	+12	66	−5
S-1	0.17	0.66	100	+19	58	−8
S-13	0.17	0.68	90	−1	58	−10
S-22	0.19	0.77	100	+8	62	−10
S-20	0.18	0.73	80	+1	60	−10
S-19	0.19	0.78	80	+10	62	−10
S-18	0.17	0.73	100	−8	57	−14
B	0.16	0.76	60	−34	53	−19
S-5	0.17	0.90	70	+5	53	−27
50 x 426	0.21	0.78	80	−24	69	−4
1046	0.20	0.77	50	−28	66	−6
Average	0.18	0.76	81	−3	60	−10

for Type B steels and 5 F for Type A steels. If appropriate corrections be made to the calculated temperatures, on the assumption that the commercial steels were rolled at 1950 F, the agreement is much better than indicated in Table 5.

VERIFICATION OF THE INFLUENCE OF SILICON

The first study(5) left some doubt about the effect of silicon, in the range between 0.15 and 0.30 per cent, on the notched-bar properties of the two types of steel. Raising the silicon content of Type A steels decreased the tear-test transition temperature only slightly. On the other hand, the Type B steels showed a significant decrease in transition temperature when the silicon content increased from 0.01 to 0.15 per cent. Larger silicon contents seemed harmful as shown by a steel containing 0.29 per cent silicon which had a transition temperature 30 F higher than the steel with 0.15 per cent silicon. Therefore, steels of each type, containing about 0.21 per cent silicon were made and tested. The compositions and mechanical properties of the two steels are listed in Table 6.

Tear-test data for these heats are plotted in Figures 3 and 4.

Tear-test properties of Type A steels are not affected appreciably by changes in silicon content up to 0.30 per cent. Figure 4 shows, however, that this is not true for steels with lower carbon and higher mahganese contents. Apparently, silicon contents between 0.10 and 0.20 per cent benefit steels with compositions otherwise meeting specifications for Type B steels. The

TABLE 6. TENSILE AND TRANSITION-TEMPERATURE CHARACTERISTICS OF TYPE A AND TYPE B STEELS OF VARIOUS SILICON CONTENTS(1)

Grade of Steel	Heat No.	Tensile Properties: Yield Strength, psi: Upper	Tensile Properties: Yield Strength, psi: Lower	Tensile Properties: Tensile Strength, psi	Tensile Properties: Elong. in 8", %	Tear-Test Properties: Max. Load, lb	Tear-Test Properties: Energy to Start Fracture, ft-lb	Tear-Test Properties: Energy to Propagate Fracture, ft-lb	Tear-Test Properties: Transition Temperature, F	Charpy Keyhole Transition Temperature, F
Type A	A7526	36,950	34,900	65,000	29.0	39,640	740	630	70	-12
Type B	A7528	36,350	35,950	63,650	32.5	41,920	980	750	50	-40

(1) Compositions of these steels were as follows:

	Composition, per cent: C	Mn	Si	P	S	N
Heat A7526	0.30	0.43	0.20	0.018	0.027	0.005
Heat A7528	0.21	0.74	0.21	0.018	0.030	0.004

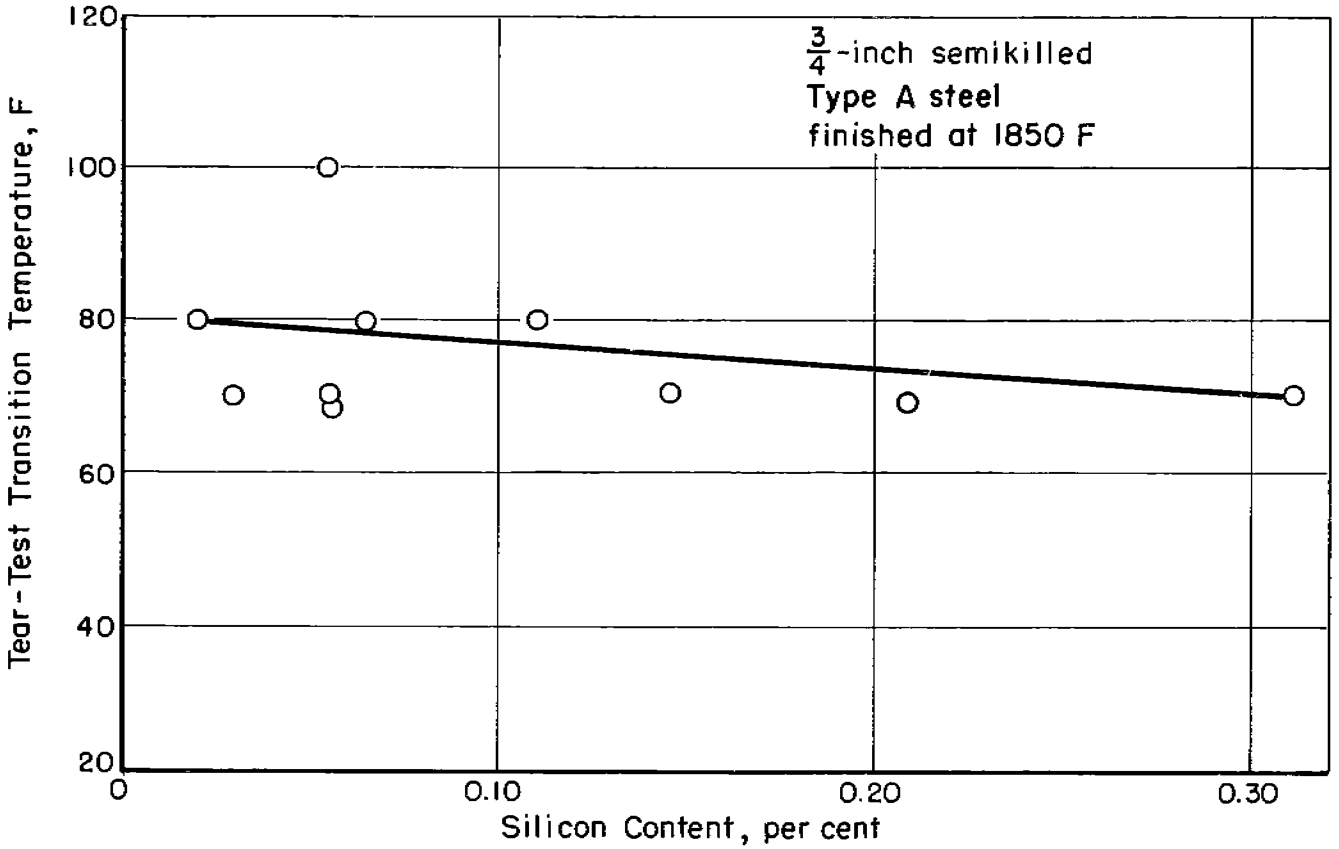

FIGURE 3. INFLUENCE OF SILICON CONTENT UPON THE TRANSITION TEMPERATURE OF TYPE A LABORATORY STEELS

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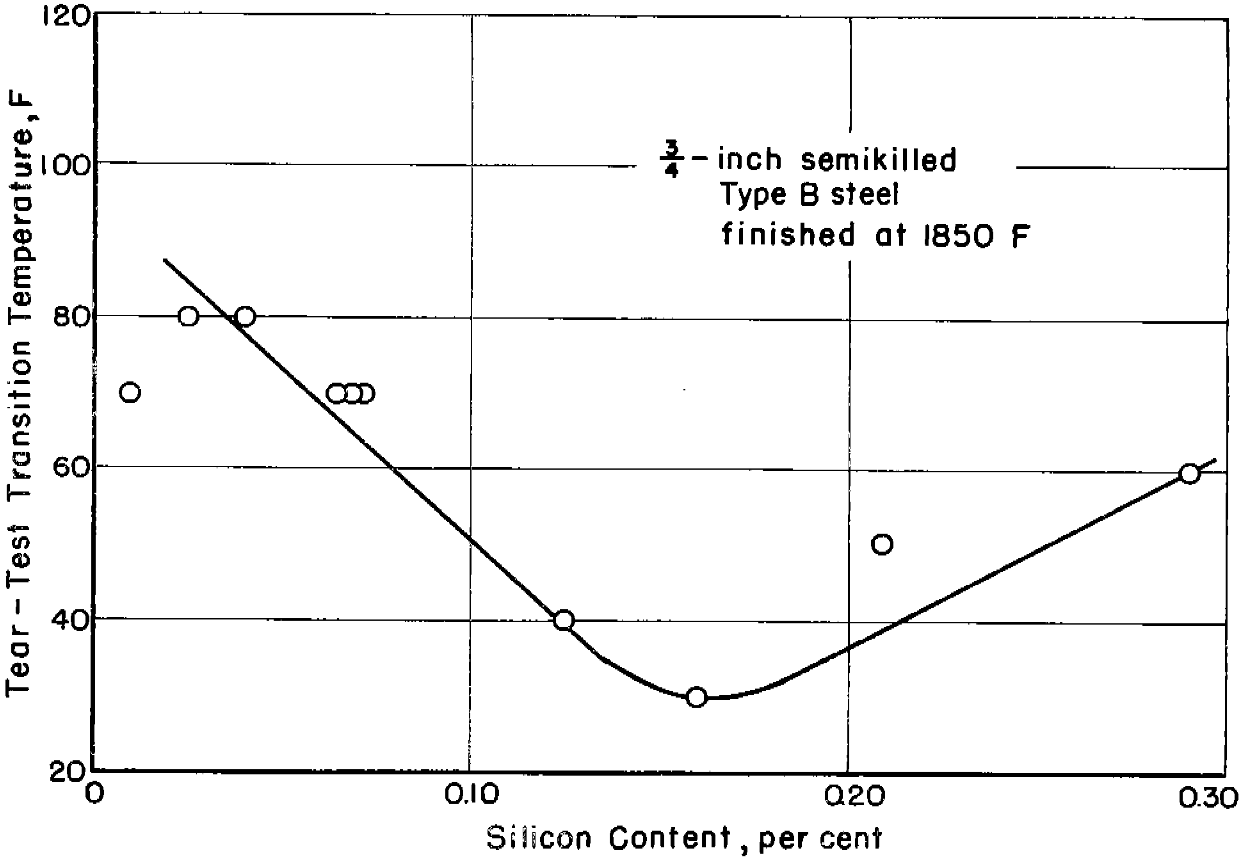

FIGURE 4. INFLUENCE OF SILICON CONTENT UPON THE TRANSITION TEMPERATURE OF TYPE B LABORATORY STEELS

A-1388

difference in behavior of silicon in the two types of steel suggests an interrelationship between the effects of carbon, manganese, and silicon. This possibility will be investigated later.

INFLUENCE OF NITROGEN

The influence of nitrogen in Type A and Type B steels was studied by melting and rolling semikilled steels with various nitrogen contents. These steels were made by adding calcium cyanamide to the melt immediately before tapping. One additional steel containing 0.017 per cent aluminum and 0.010 per cent nitrogen was made to determine the combined effect of aluminum and nitrogen. The chemical analyses of these steels are given in Table 7.

Duplicate tensile tests were made on all of the steels. A summary of these tests is given in Table 8. The influence of nitrogen on the tensile strength is shown in Figure 5. The Type A steels and the Type B steels fall on the same trend line. This shows that variations in nitrogen content have the same effect on strength in both grades.

The addition of nitrogen raised the tear-test transition temperature of both grades of steel. This is shown quantitatively in Figure 6. Increasing the nitrogen content appears to be more harmful in Type A than in Type B steels. The steel containing 0.017 per cent aluminum had the transition temperature expected for aluminum-free steels with the same nitrogen content. This confirms the tensile data indicating that in this type of steel the aluminum

TABLE 7. CHEMICAL ANALYSIS OF 3/4-INCH LABORATORY STEEL PLATE WITH VARIOUS NITROGEN CONTENTS

Heat No.	Composition, per cent					
	C	Mn	P	S	Si	N
A6600	0.21	0.53	0.016	0.024	0.03	0.005
A7440	0.21	0.54	0.015	0.018	0.08	0.013
A7441	0.23	0.52	0.014	0.018	0.07	0.016
A6601	0.18	0.83	0.018	0.023	0.05	0.008
A7439	0.18	0.84	0.015	0.017	0.07	0.015
A7437	0.16	0.82	0.015	0.017	0.07	0.020
A7659*	0.18	0.76	0.016	0.031	0.05	0.010

*Contains 0.017 per cent aluminum.

TABLE 8. TENSILE, TEAR-TEST, AND KEYHOLE CHARPY IMPACT PROPERTIES OF 3/4-INCH, HOT-ROLLED LABORATORY STEEL PLATE WITH VARIOUS NITROGEN CONTENTS(1)

	Tensile Properties				Tear-Test Properties				Keyhole Charpy Trans. Temp, F
	Yield Strength, psi								
Heat No.	Upper	Lower	Tensile Strength, psi	Elongation in 8", per cent	Maximum Load, lb	Energy to Start Fracture, ft-lb	Energy to Propagate Fracture, ft-lb	Trans. Temp, F	
A6600	36,650	35,000	62,100	24.5	37,700	850	710	60	-8
A7440	40,250	37,750	67,250	28.5	37,280	630	530	130	+24
A7441	42,200	39,350	69,350	26.5	38,520	520	770	160	+42
A6601	39,650	36,950	63,250	26.0	38,470	880	700	90	-30
A7439	42,700	40,650	70,700	29.0	40,500	710	710	130	+3
A7437	45,250	42,400	73,000	20.0	40,980	700	770	140	+20
* A7659	38,050	36,700	66,100	28.5	40,580	900	1100	100	-6

(1) Compositions given in Table 6.

* Contains 0.017 per cent aluminum.

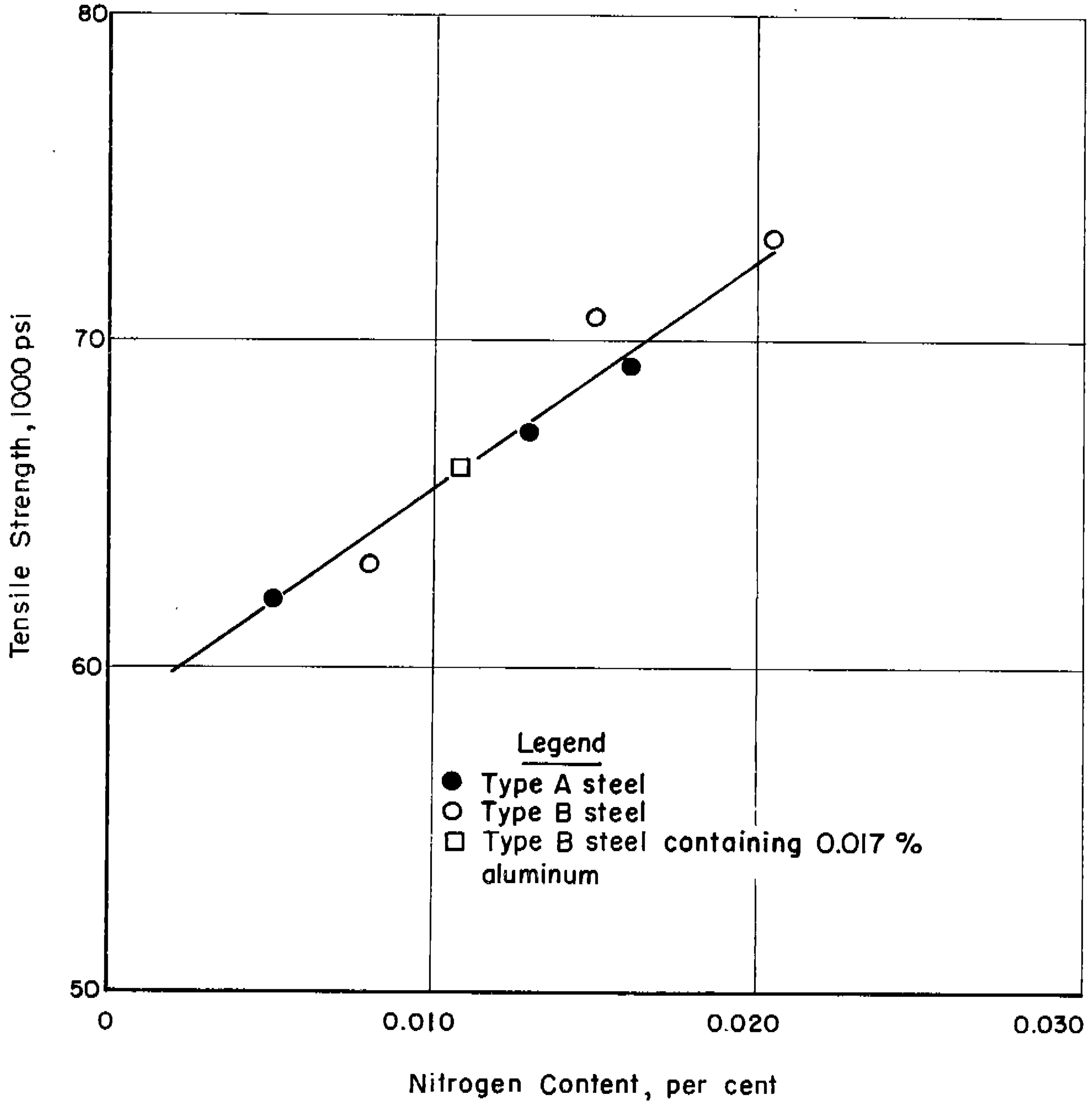

FIGURE 5. INFLUENCE OF NITROGEN ON TENSILE STRENGTH

A-1389

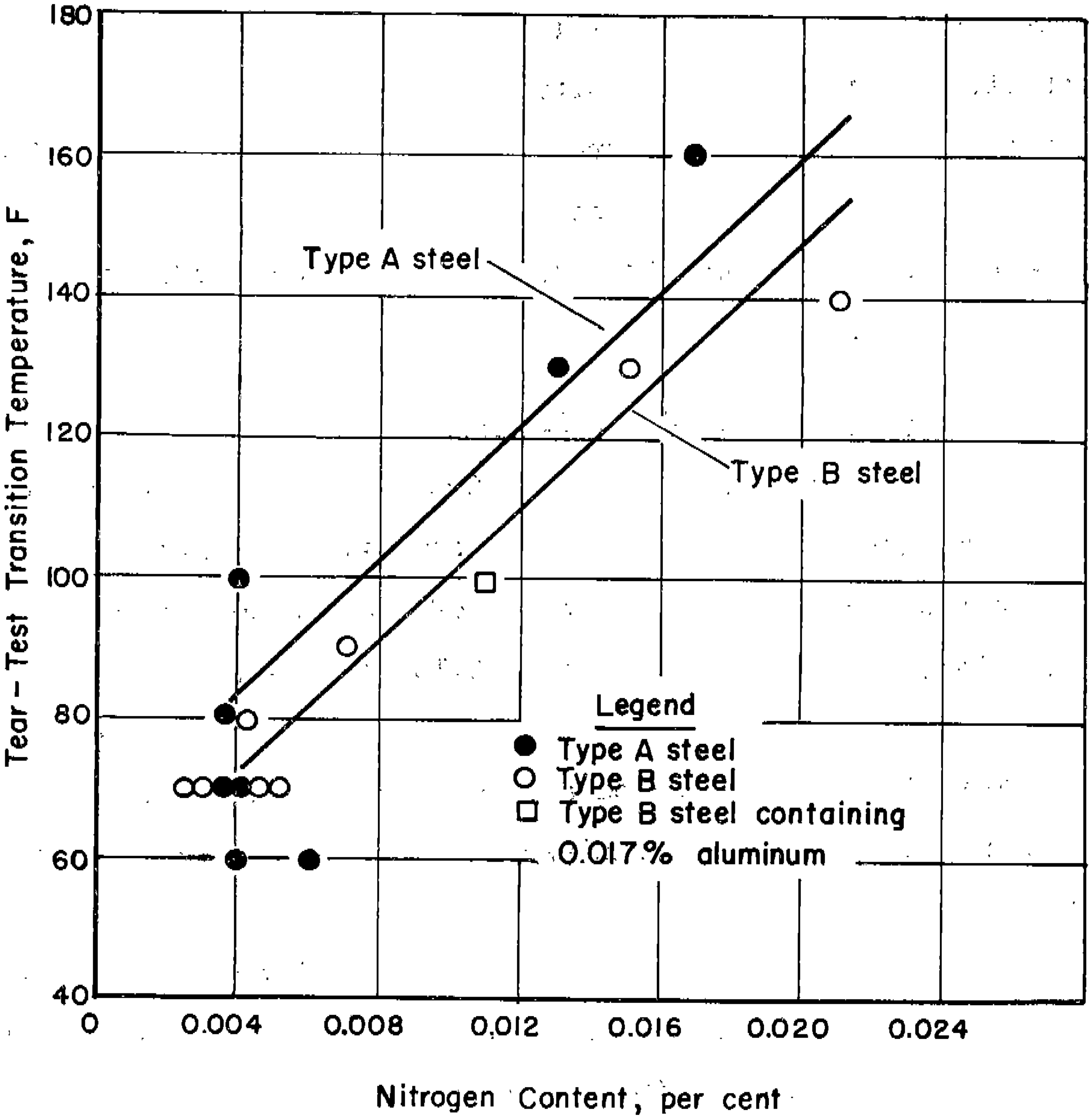

FIGURE 6. INFLUENCE OF NITROGEN ON TEAR-TEST TRANSITION TEMPERATURE

A-1390

did not combine with the nitrogen to reduce its effect.

The addition of nitrogen also raises the transition temperature of keyhole Charpy specimens. Figure 7 indicates that increasing the nitrogen content 0.001% increases the Charpy transition temperature about 2.1 F. This holds for both types of steel. The tear-test transition temperature was raised about twice as much as the Charpy transition temperature for each increase of 0.001 per cent nitrogen. The slopes of the lines indicate that the tear test is more sensitive to the effect of nitrogen.

INFLUENCE OF TITANIUM, ZIRCONIUM, AND ALUMINUM

The influence of titanium and zirconium was studied by adding various amounts of these elements to semikilled steels of Type A and Type B composition. The amounts of these elements retained in the final composition were below 0.10 per cent. The titanium was added as ferrotitanium alloy immediately before tapping the heat. The zirconium was added as a 40 per cent zirconium silicon-zirconium alloy. Chemical analyses of these heats are listed in Table 9.

The aluminum was added to steels with 0.01 or 0.05 per cent silicon. In the case of the base steels with 0.01 per cent silicon, part of the aluminum (0.05 per cent) was added in place of silicomanganese. This addition gave a total aluminum content in the steel of 0.005 per cent. The remaining aluminum addition was

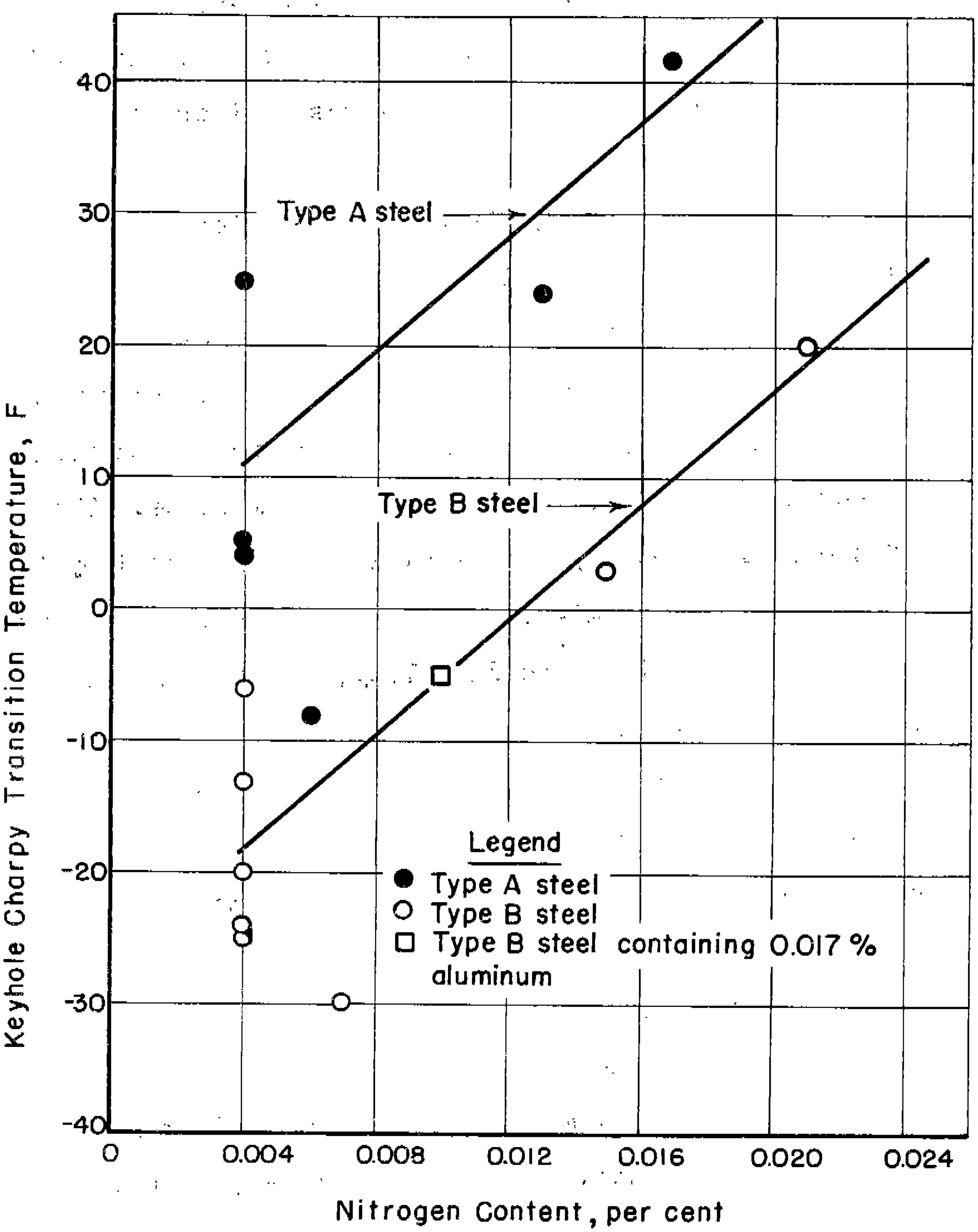

FIGURE 7. INFLUENCE OF NITROGEN ON KEYHOLE CHARPY TRANSITION TEMPERATURE

A-1391

added before tapping. The steels with 0.05 per cent silicon were made by adding the aluminum at one time -- immediately before tapping. Complete chemical analyses of these steels are given in Table 9.

The tensile and notched-bar properties of these 25 steels are given in Table 10. It will be noted that only titanium increased the tensile strength of the steel plate; zirconium and aluminum had no effect on tensile strength. Along with the increase of tensile strength resulting from titanium, there was a decrease in the ductility of the steel plate. The elongation of the semikilled type of steel was not affected by the addition of zirconium or aluminum. Aluminum additions to rimmed types of steel seemed to increase ductility, as shown in the case of steels of the low-silicon series.

The tear-test and the Charpy transition temperatures of both grades of steel were increased by the addition of titanium. This effect of titanium is shown in Figures 8 and 9. The tear-test transition temperatures of the Type B steels with 0.02 and 0.04 per cent titanium are lower than the average of the five standard steels containing no added titanium, indicating that very minute quantities of titanium probably lower the tear-test transition of this greade of steel. The transition temperature apparently increases, however, when the amount of titanium present exceeds 0.02 per cent.

TABLE 9. CHEMICAL ANALYSIS OF 3/4-INCH HOT-ROLLED LABORATORY STEEL PLATE

Heat Number	Composition, per cent						
	C	Mn	P	S	Si	N	Others
			Titanium Series - Type A				
A7667	0.23	0.45	0.015	0.028	0.07	0.004	0.03 Ti
A7668	0.23	0.45	0.016	0.027	0.09	0.004	0.08 Ti
A7665	0.23	0.47	0.016	0.020	0.10	0.004	0.10 Ti
			Titanium Series - Type B				
A7669	0.19	0.76	0.020	0.026	0.04	0.003	0.02 Ti
A7670	0.19	0.76	0.019	0.027	0.05	0.004	0.04 Ti
A7671	0.19	0.79	0.020	0.028	0.10	0.004	0.10 Ti
			Zirconium Series -Type A				
A7431	0.25	0.57	0.016	0.023	0.07	0.005	0.03 Zr
A6699	0.23	0.50	0.016	0.024	0.10	0.004	0.02 Zr
A7432	0.25	0.55	0.015	0.022	0.08	0.005	0.06 Zr
			Zirconium Series -Type B				
A7433	0.19	0.85	0.018	0.023	0.05	0.004	0.04 Zr
A7434	0.21	0.85	0.015	0.023	0.12	0.004	0.05 Zr
A7435	0.21	0.87	0.027	0.023	0.17	0.004	0.06 Zr
			Aluminum Series - Low Silicon - Type A				
A6648	0.27	0.59	0.016	0.021	0.01	0.004	0.005 Al
A6707	0.20	0.50	0.019	0.025	0.01	0.004	0.016 Al
A6708	0.21	0.52	0.020	0.025	0.01	0.003	0.027 Al
A6709	0.21	0.53	0.018	0.025	0.01	0.004	0.075 Al
			Aluminum Series - Low Silicon - Type B				
A6649	0.22	0.87	0.015	0.022	0.01	0.004	0.005 Al
A7319	0.18	0.81	0.017	0.022	0.02	0.004	0.045 Al
A7320	0.20	0.85	0.016	0.025	0.02	0.004	0.060 Al
			Aluminum Series - 0.05% Silicon -Type A				
A7531	0.22	0.48	0.016	0.032	0.05	0.003	0.020 Al
A7661	0.21	0.45	0.015	0.033	0.05	0.003	0.045 Al
A7529	0.25	0.41	0.016	0.028	0.05	0.004	0.090 Al
			Aluminum Series - 0.05% Silicon -Type B				
A7660	0.20	0.74	0.017	0.032	0.05	0.003	0.015 Al
A7662	0.20	0.75	0.016	0.028	0.05	0.003	0.045 Al
A7530	0.21	0.71	0.018	0.027	0.05	0.003	0.080 Al

TABLE 10. TENSILE PROPERTIES AND NOTCHED-BAR PROPERTIES OF 3/4-INCH LABORATORY STEEL PLATE WITH VARIOUS TITANIUM, ZIRCONIUM, AND ALUMINUM CONTENTS

	Tensile Properties				Tear-Test Properties				Keyhole Charpy Trans. Temp, F
	Yield Strength, psi		Tensile Strength, psi	Elongation in 8", per cent	Maximum Load, lb	Energy to Start Fracture, ft-lb	Energy to Propagate Fracture, ft-lb	Trans. Temp, F	
Heat No.	Upper	Lower							
				Titanium Series - Type A					
A7667	40,550	39,000	66,400	27.5	39,270	770	680	110	+41
A7668	39,500	37,400	66,900	27.0	40,760	870	790	120	+51
A7665	43,250	40,800	69,650	23.5	42,320	850	770	160	+64
				Titanium Series - Type B					
A7669	37,500	35,850	62,050	29.5	40,340	990	760	50	-15
A7670	37,100	35,600	61,400	28.0	40,630	1050	780	60	-13
A7671	46,050	44,500	70,000	25.5	44,440	950	810	150	+37
				Zirconium Series -Type A					
A7431	34,550	31,350	63,250	28.5	40,480	890	790	60	-5
A6699	30,550	30,300	64,200	26.0	38,880	780	680	100	+5
A7432	29,700	29,650	63,950	27.5	39,180	780	790	70	-17
				Zirconium Series -Type B					
A7433	31,700	31,000	62,850	29.5	41,630	1010	870	50	+2
A7434	34,850	33,200	64,550	31.5	41,430	1010	720	50	-42
A7435	31,500	31,300	65,050	29.5	41,230	910	820	90	-43
				Aluminum Series - Low Silicon - Type A					
A6648	38,000	37,200	65,800	27.0	37,150	660	680	100	-14
A6707	35,400	33,400	59,000	28.5	36,400	870	720	90	0
A6708	38,350	35,450	61,550	30.5	38,000	910	670	80	-2
A6709	35,750	34,150	59,850	33.0	38,800	940	800	50	-40

TABLE 10. (Continued)

Heat No.	Tensile Properties: Yield Strength, psi: Upper	Tensile Properties: Yield Strength, psi: Lower	Tensile Properties: Tensile Strength, psi	Tensile Properties: Elongation in 8", per cent	Tear-Test Properties: Maximum Load, lb	Tear-Test Properties: Energy to Start Fracture, ft-lb	Tear-Test Properties: Energy to Propagate Fracture, ft-lb	Tear-Test Properties: Trans. Temp, F	Keyhole Charpy Trans. Temp, F
				Aluminum Series - Low Silicon - Type B					
A6649	37,700	36,850	64,700	24.0	39,490	800	730	80	-14
A7319	35,200	33,850	59,250	30.0	38,590	1040	940	80	-22
A7320	34,400	33,400	59,950	32,0	39,300	980	810	70	-20
				Aluminum-Silicon Series - Type A					
A7531	35,550	33,950	60,550	32.5	38,080	860	850	80	+2
A7661	33,350	32,800	59,800	31.5	38,330	930	780	80	-6
A7529	37,750	34,800	62,450	31.5	38,800	780	780	80	-5
				Aluminum-Silicon Series - Type B					
A7660	36,050	34,600	61,400	31.0	39,470	930	830	70	-20
A7662	36,300	34,450	62,450	28.5	40,600	1020	760	60	-29
A7530	36,600	35,400	62,550	31.0	41,140	930	630	40	-61

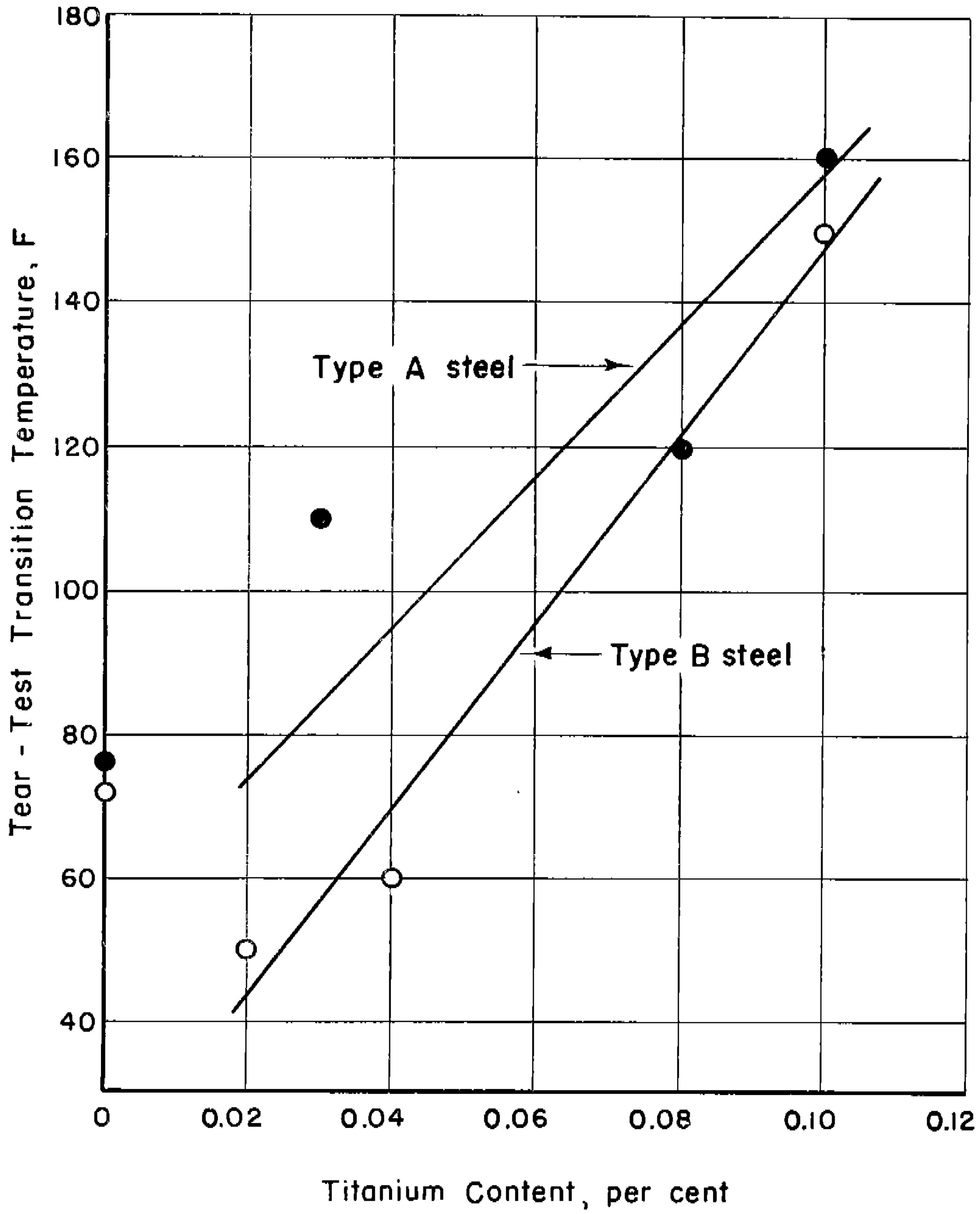

FIGURE 8. INFLUENCE OF TITANIUM ON TEAR-TEST TRANSITION TEMPERATURE

A-1392

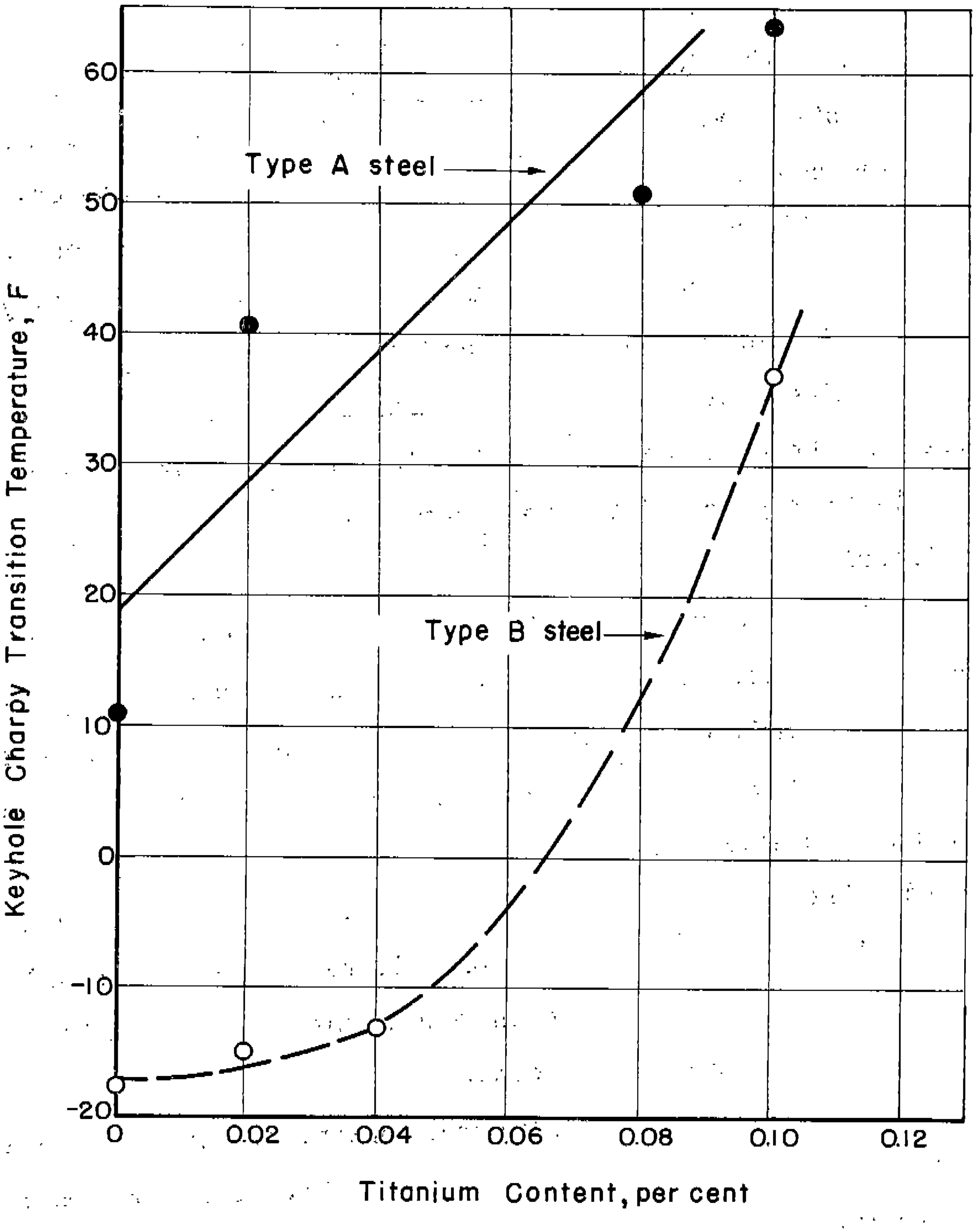

FIGURE 9. INFLUENCE OF TITANIUM ON KEYHOLE CHARPY TRANSITION TEMPERATURE

A-1393

Zirconium had no detectable effect on the Charpy notched-bar transition temperature of Type A steel. The transition temperatures of the Type A steels are all within the range of the standard steels without zirconium. The Type B steels with low zirconium contents have the lowest transition temperatures. When however, 0.10 per cent zirconium is added, the transition temperature is higher than for steels with no zirconium. In this grade of steel, the effect of small quantities of zirconium appears to be not unlike that of titanium. Further studies are needed to establish the effect the zirconium in the two grades of steel.

The Charpy transition temperature was lowered by the addition of zirconium.

Small additions of aluminum decrease the notched-bar transition temperatures of most grades of steel. Figure 10 shows the tear-test transition temperatures of the laboratory steels treated with different amounts of aluminum. Three of the four series of steels showed increasing toughness as the aluminum additions increased. The Type A steels containing 0.05 per cent silicon were an exception. The three steels of this base composition had the same transition temperature even though the aluminum contents varied from 0.02 to 0.09 per cent.

The influence of total aluminum content on keyhole Charpy transition temperature is shown in Figure 11. The aluminum contents of the steel were determined spectrographically. In all cases, the transition temperatures decrease somewhat with an increase in total aluminum content. The Type A steels appeared to

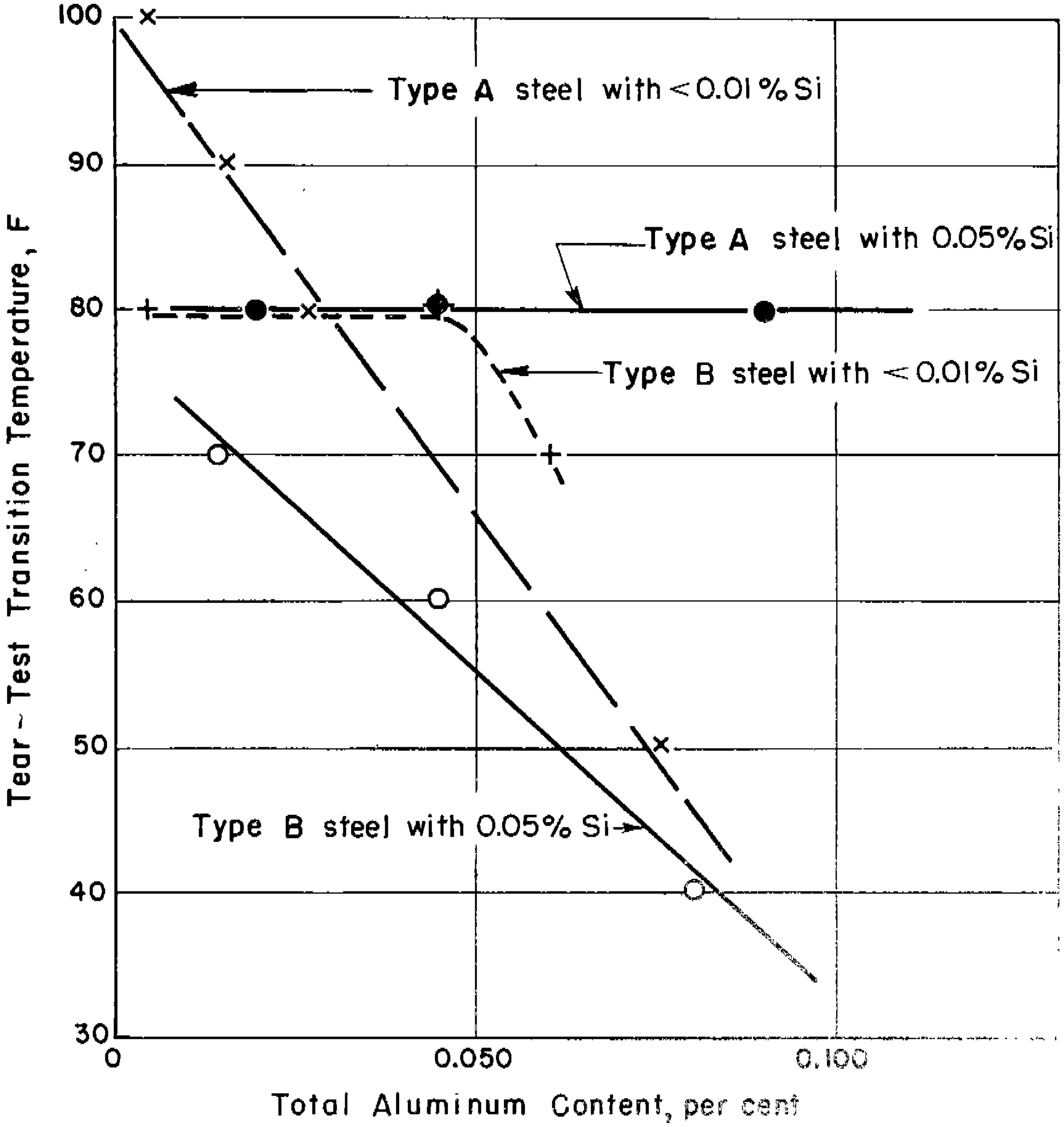

FIGURE 10. INFLUENCE OF ALUMINUM, DETERMINED BY SPECTROGRAPHIC ANALYSIS, ON TEAR-TEST TRANSITION TEMPERATURE

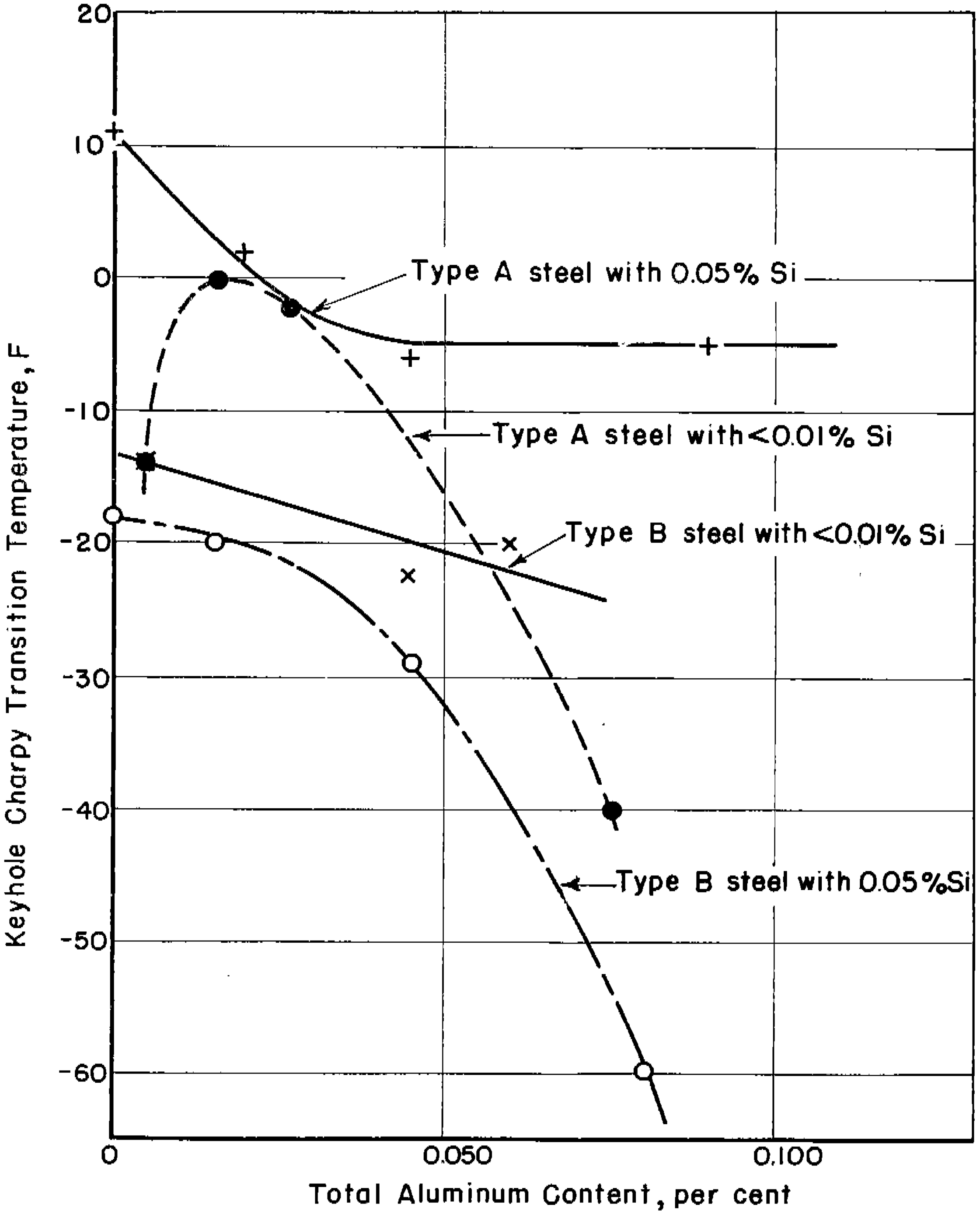

FIGURE 11. INFLUENCE OF ALUMINUM, DETERMINED BY SPECTROGRAPHIC ANALYSIS, ON KEYHOLE CHARPY TRANSITION TEMPERATURE

A-1395

behave in an unusual manner. The transition temperature of the 0.05 per cent silicon steel appeared to decrease with small amounts of aluminum and then remained constant. The transition temperature of the 0.01 per cent silicon steel tended to increase slightly on increasing the total aluminum content from 0.005 per cent to 0.016 per cent, but then decreased rather sharply up to 0.075 per cent aluminum.

The apparent difference in the effect of aluminum in the two different grades of steel and at the two different silicon levels suggests the need for additional work. Several heats have been made to supplement the work already done and will be tested in the continuation of the program.

An interesting comparison of the effects of titanium, vanadium,(2) aluminum, and silicon on the tear-test transition temperatures of the two classes of steels is shown in Figures 12 and 13. In Type A steels, small additions of the elements, titanium and vanadium, tend to increase the transition temperature, while small additions of aluminum and silicon have no effect on the transition temperature. In Type B steel, with its higher manganese content, small amounts of titanium, aluminum, and silicon tend to decrease the transition temperature. Additional amounts of titanium and silicon increase the transition temperature. Steels with vanadium contents between zero and 0.09 per cent have not been tested, so that its effect in very small quantities has not been determined. For that reason, the curve for vanadium in

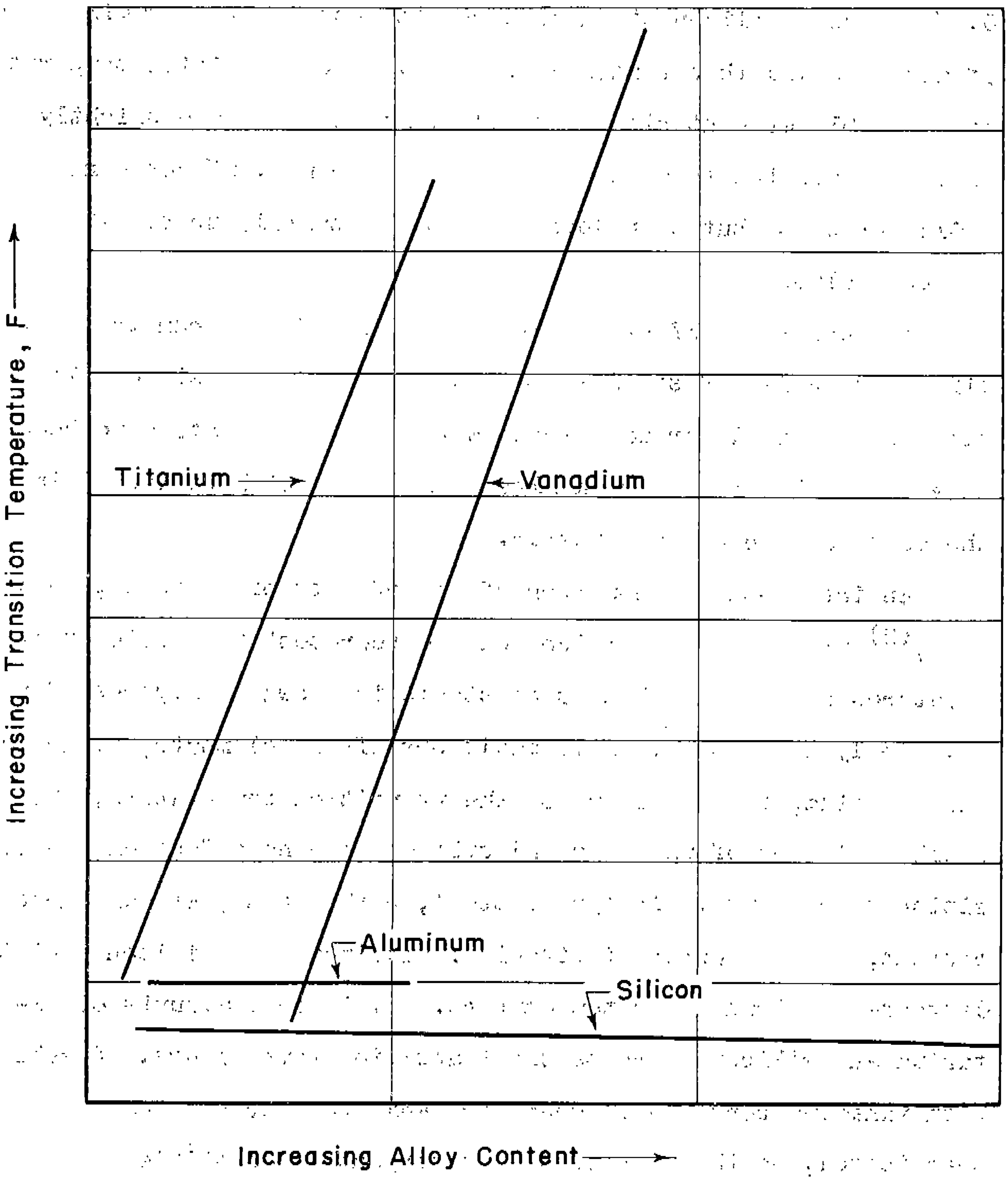

FIGURE 12. INFLUENCE OF TITANIUM, VANADIUM, ALUMINUM, AND SILICON ON THE TEAR-TEST TRANSITION TEMPERATURE OF A 0.25 % C, 0.45 % Mn, 0.05 % Si STEEL

A-1396

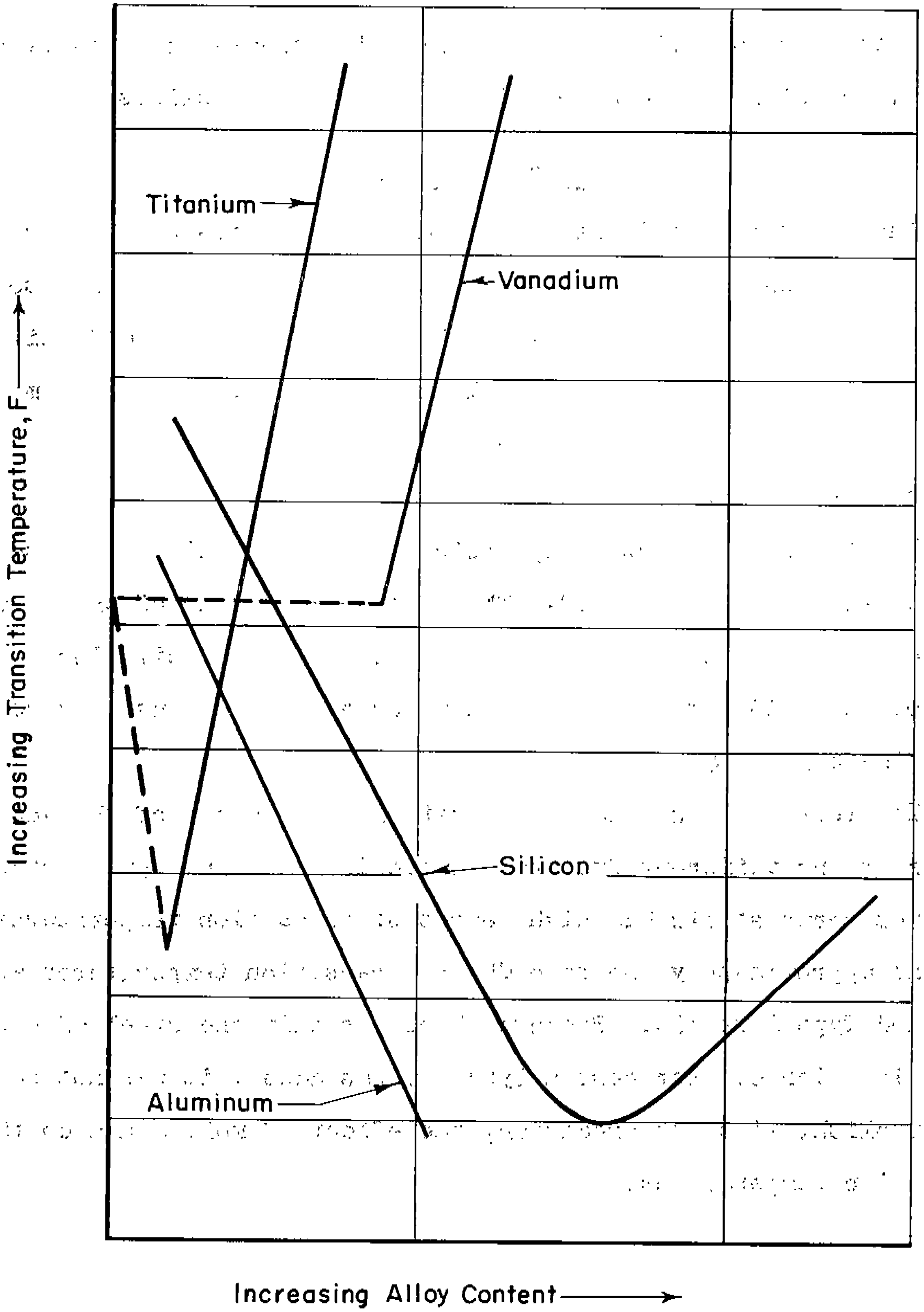

FIGURE 13. INFLUENCE OF TITANIUM, VANADIUM, ALUMINUM, AND SILICON ON THE TEAR-TEST TRANSITION TEMPERATURE OF A 0.21 % C, 0.75 % Mn, 0.05 % Si STEEL

A-1397

Figure 13 shows no evidence of an initial decrease in transition temperature with this element, if such a decrease exists.

SPECIAL STEELS

The advisory Committee recommended that steels containing vanadium and phosphorus be made with reduced carbon contents so that their tensile strengths would be approximately 60,000 psi. Along with these steels, two steels containing 0.10 per cent molybdenum with normal carbon contents were also requested. Chemical analyses of these steels are shown in Table II.

The tensile properties and notched-bar properties of these steels are given in Table 12. The tensile strengths of the vanadium and phosphorus steels ranged from 59,000 to 60,600 psi. The addition of the 0.10 per cent molybdenum increased the tensile strength approximately 3,600 psi.

The tear-test and Charpy transition temperatures of the vanadium steels are no different from the standard Type A and Type B steels. The phosphorus steels had high tear-test transition temperatures but had approximately the same Charpy transition temperatures as standard Type A steels. Because there was only one steel of each class in which 0.1 per cent molybdenum was added, it was not possible to establish, with any precision, the effect of molybdenum on the transition temperatures.

TABLE 11. CHEMICAL ANALYSIS OF 3/4-INCH LABORATORY STEEL PLATE (Special Steels)

Heat Number	Composition, per cent C	Mn	P	S	Si	N	Other
			Vanadium Series				
A7446	0.19	0.48	0.014	0.017	0.07	0.004	0.03 V
A7310	0.19	0.49	0.018	0.022	0.08	0.003	0.06 V
A7447	0.17	0.83	0.015	0.016	0.08	0.004	0.03 V
A7311	0.14	0.86	0.021	0.023	0.10	0.003	0.06 V
			Phosphorus Series				
A7312	0.13	0.52	0.105	0.023	0.10	0.004	--
A7436	0.09	0.47	0.095	0.022	0.05	0.005	0.02 V
A7442	0.14	0.48	0.099	0.020	0.05	0.004	0.06 Mo
			Molybdenum Series				
A7313	0.24	0.49	0.017	0.023	0.07	0.004	0.10 Mo
A7314	0.21	0.75	0.017	0.021	0.07	0.003	0.10 Mo

TABLE 12. TENSILE AND NOTCHED-BAR PROPERTIES OF 3/4-INCH LABORATORY STEEL PLATE

(Special Steels)

	Tensile Properties				Tear-Test Properties				Keyhole Charpy Trans. Temp, F
	Yield Strength, psi								
Heat No.	Upper	Lower	Tensile Strength, psi	Elongation in 8", per cent	Maximum Load, lb	Energy to Start Fracture, ft-lb	Energy to Propagate Fracture, ft-lb	Trans. Temp, F	
				Vanadium Series					
A7446	36,000	34,850	59,000	33.0	37,920	930	690	80	+3
A7310	39,500	37,750	60,600	28.0	37,770	760	740	70	+12
A7447	38,400	35,650	59,500	32.0	39,830	1080	770	60	-16
A7311	39,100	38,350	60,600	29.5	40,280	960	800	70	-36
				Phosphorus Series					
A7312	37,850	36,500	60,100	28.0	38,640	1050	770	120	+30
A7436	39,600	38,000	59,150	30.0	41,600	1270	710	100	-2
A7442	38,200	36,350	58,700	32.5	38,270	1140	680	110	+12
				Molybdenum Series					
A7313	39,900	36,050	63,000	27.0	36,770	670	640	100	+20
A7314	38,900	37,500	64,900	25.0	40,160	940	630	60	+12

GRAIN-SIZE MEASUREMENTS

Several investigations(2,3) have indicated that ferrite grain size influences the transition temperatures of low-carbon and ship-plate steels. Therefore, grain-size measurements were made on many of the steels tested during this investigation on deoxidation and composition.

Various methods(4) of measuring ferrite grain size were investigated. They included counting grains in measured areas, counting grains intercepted by lines of fixed lengths, comparisons with charts of standard micrographs, and visual comparisons of fractured surfaces. All of these methods were used to determine the ferrite grain sizes of a series of heat-treated samples from a particular Type A ship-plate steel. This steel, designated by earlier investigators as Project Steel "A", contained 0.25% carbon, 0.49% manganese, 0.011% phosphorus, 0.04% silicon, and 0.045% sulphur. The samples were prepared by austenitizing at temperatures between 1400 and 2000 F and cooling them at different rates. These treatments produced a wide variety of grain sizes and microstructures. This study indicated that counting grains within measured areas was the most reliable method of determining ferrite grain size. It was used, therefore, in evaluating the effect of grain size on transition temperatures.

With the method used in this investigation, the amount of pearlite in the microstructure affects the ferrite grain-size counts. Therefore, the percentage of pearlite was estimated, by the point counting method, for most of the samples. Table 13 shows that the standard Type A and Type B steels contained about 15 per cent pearlite. If the amount of pearlite in a steel varies appreciably from this value, this fact must be considered in comparing data obtained by other methods.

Figure 14 shows the relationship between ferrite grain size and the tear-test transition temperature of Project Steel "A" cooled in air from various austenitizing temperatures. Lower normalizing temperatures resulted in smaller ferrite grain sizes and substantial improvements in toughness. The ferrite grain sizes of these specimens were determined by averaging counts made on specimens taken parallel and transverse to the rolling direction of the plate.

The effect of finishing temperature on the relationship between the tear-test transition temperature for two steels is illustrated in Figure 15. These grain counts are for longitudinal sections and show the same trend as those for normalized specimens. The graphs show a good correlation between grain size and transition temperature for either grade of ship plate. Lower finishing temperatures resulted in finer ferrite grain sizes and lower transition temperatures.

Figure 16 shows the ferrite grain sizes and transition temperatures for plates of Type A steel rolled at 1650 and 1850 F. Figure 17 gives similar information on Type B steels. For both

TABLE 13. TRANSITION TEMPERATURES AND GRAIN-SIZE DATA FOR STANDARD EXPERIMENTAL HEATS OF TYPE A AND B STEELS

Heat Number	Type of Steel	Finishing Temp, F	Tear-Test Transition Temp, F	Keyhole Charpy Transition Temp, F	Ferrite Grain Size*, grains/sq in. at 100X	Pearlite, %
A-1	A	1650	+50	-2	134(140)	--
A-2	A	1650	+45	-16	125(118)	--
A-3	A	1650	+55	+16	128(125)	--
A-4	A	1650	+50	0	153(163)	--
A-5	A	1650	+50	+10	143	--
B-2	B	1650	+40	-16	92(103)	--
B-3	B	1650	+40	-32	87**	--
B-4	B	1650	+40	-25	118(113)	--
B-5	B	1650	+40	-34	141(157)	--
B-6	B	1650	0	-38	147**	
A-6424A	A	1650	+50	--	119**	11
A-6424B	A	1750	+60	--	87**	19
A-6424C	A	1850	+95	--	73**	15
A-6365A	B	1650	+10	--	132**	15
A-6365B	B	1750	+20	--	99**	12
A-6365C	B	1850	+40	--	76**	13
A-6555	A	1850	80	+12	157***	--
A-6556	A	1850	70	+4	103	--
A-6587	A	1850	100	+12	82	--
A-6650	A	1850	70	+25	91	17
A-6705	A	1850	60	+5	97	--
A-6557	B	1850	70	-13	93	--
A-6584	B	1850	70	-6	92(96)	--
A-6588	B	1850	70	-20	77	17
A-6641	B	1850	80	-25	94	18
A-6651	B	1850	70	-24	73	14

* Determined by counting method; average values for counts on longitudinal and transverse sections. Values in parentheses were obtained by a second investigator.

** Counts on longitudinal sections only.

*** Questionable value; not plotted in Figure 16.

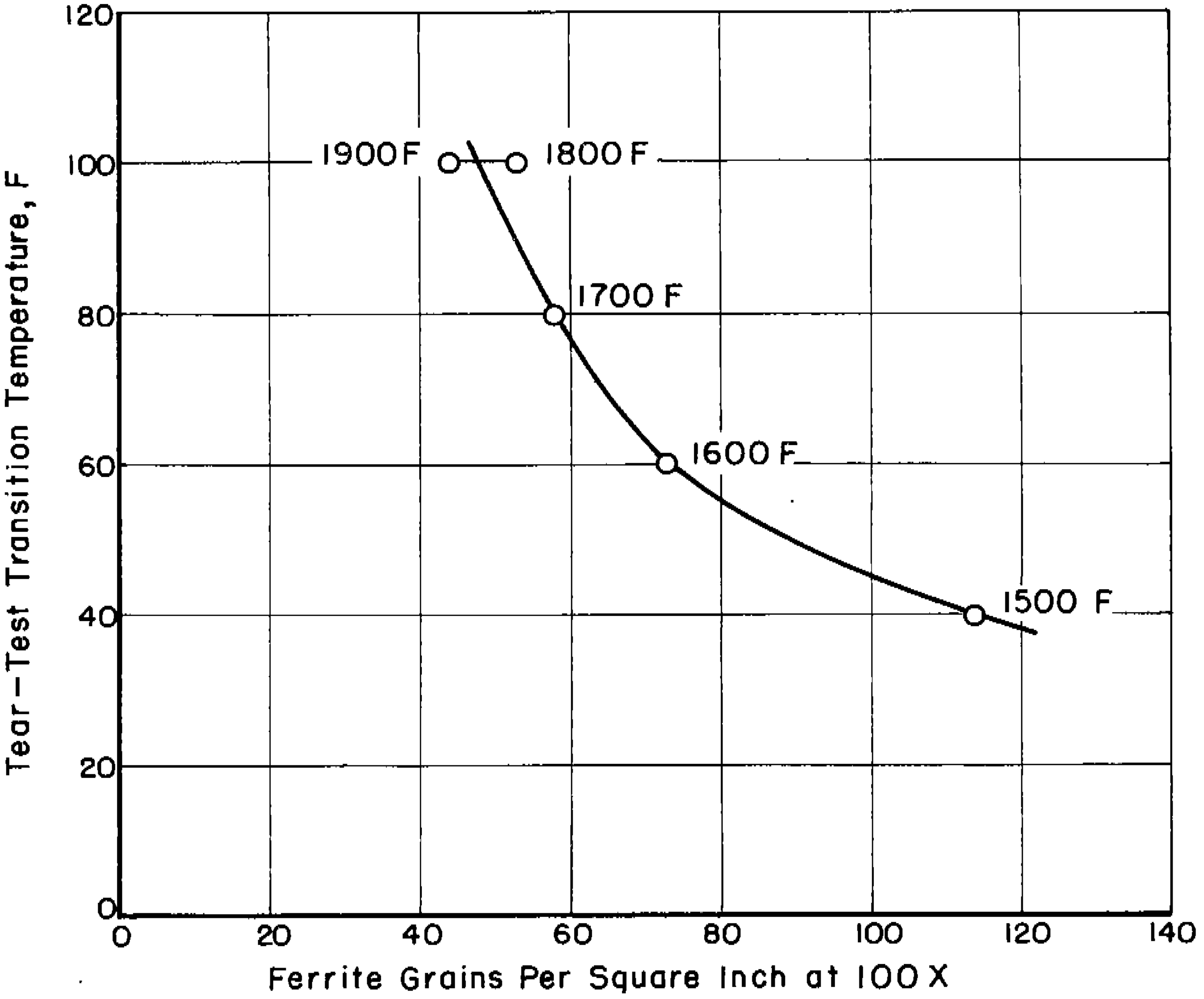

FIGURE 14. EFFECT OF NORMALIZING TEMPERATURE ON THE RELATIONSHIP BETWEEN TEAR-TEST TRANSITION TEMPERATURE AND FERRITE GRAIN SIZE OF PROJECT STEEL A

A-1398

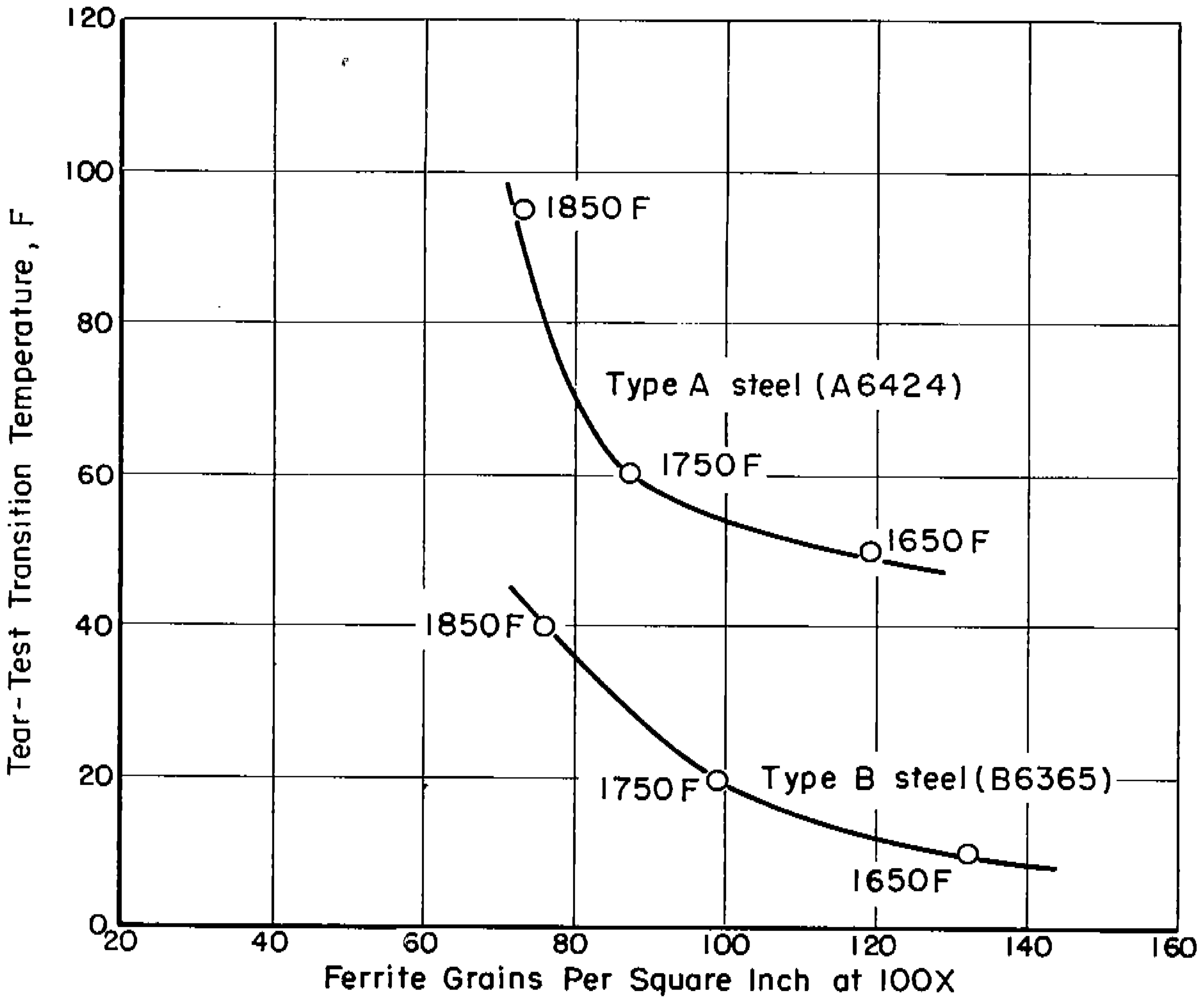

FIGURE 15. EFFECT OF FINISHING TEMPERATURE ON THE RELATIONSHIP BETWEEN TEAR-TEST TRANSITION TEMPERATURE AND FERRITE GRAIN SIZE FOR ONE TYPE A AND ONE TYPE B STEEL (GRAIN COUNTS ON LONGITUDINAL SECTIONS ONLY)

A-1399

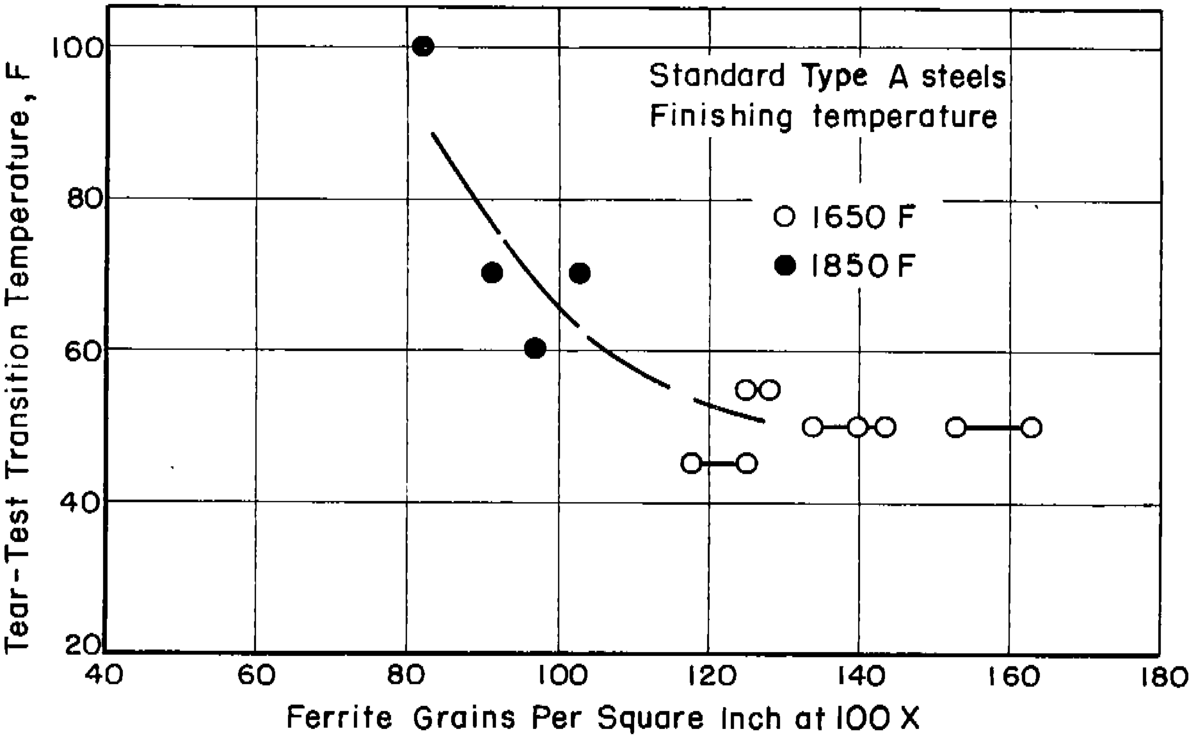

FIGURE 16 EFFECT OF FINISHING TEMPERATURE ON THE RELATIONSHIP BETWEEN TEAR-TEST TRANSITION TEMPERATURE AND FERRITE GRAIN SIZE FOR STANDARD TYPE A STEELS

A-1400

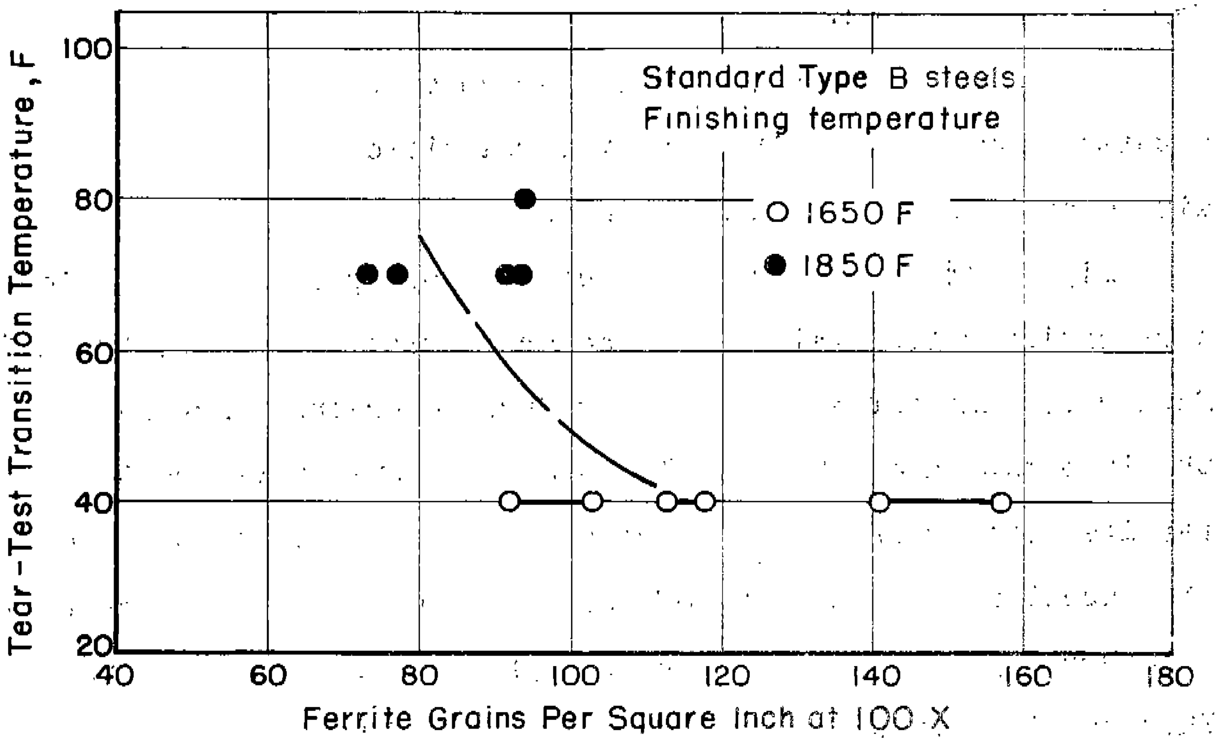

FIGURE 17. EFFECT OF FINISHING TEMPERATURE ON THE RELATIONSHIP BETWEEN TEAR-TEST TRANSITION TEMPERATURE AND FERRITE GRAIN SIZE FOR STANDARD TYPE B STEELS

A-1401

grades, the trend is for lower transition temperatures and finer ferrite grain sizes with lower rolling temperatures. The relationship between transition temperature and ferrite grain size is general rather than precise when several steels are considered. This indicates that the tear-test transition temperatures are sensitive to small differences in the steels not reflected by ferrite grain sizes.

Table 13 shows that the grain-size data for these steels gave a better correlation with tear-test transition temperatures than with Charpy transition temperatures.

Figure 18 shows the influence of cooling rate from various austenitizing temperatures on the grain size of Project Steel "A". Faster cooling rates gave smaller ferrite grains. According to the information on this steel discussed above, refinement of ferrite grain size should improve the toughness. This suggests that accelerating the rate of cooling from the hot-rolling temperature may improve the tear-test properties of ship-plate steels. This possibility will be checked in laboratory tests because it is easier for commercial mills to control cooling rates than finishing temperatures.

Table 14 presents grain-size and notched-bar transition temperature data for a number of laboratory steels varying in composition. The series contains steels with considerable variations in carbon, manganese, silicon, phosphorus, and vanadium contents.

Increasing the carbon or manganese content of a steel increases the amount of pearlite. This reduces the number of ferrite grains in a standard volume of metal independently of the actual size of

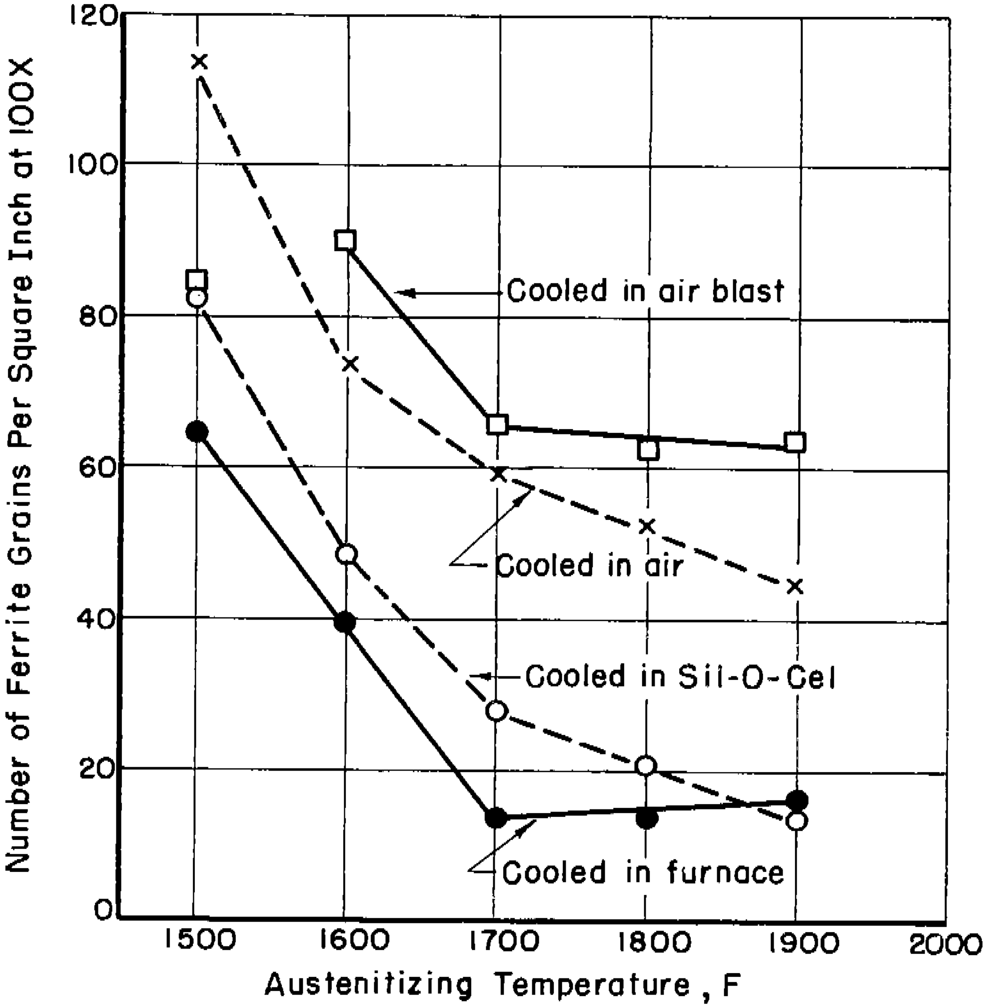

FIGURE 18. EFFECT OF AUSTENITIZING TEMPERATURE AND COOLING RATE ON FERRITE GRAIN SIZE OF "PROJECT STEEL A"

A-1402

TABLE 14. TRANSITION TEMPERATURES AND GRAIN-SIZE DATA FOR EXPERIMENTAL HEATS OF TYPE A AND B BASE STEELS WITH VARIATIONS IN CARBON, MANGANESE, PHOSPHORUS, SULPHUR, SILICON, AND VANADIUM CONTENTS

Heat Number	Base Composition of Steel	Element Varied, %	Tear-Test Transition Temp, F	Keyhole Charpy Transition Temp, F	Ferrite Grain Size*, grains/sq in. at 100X	Pearlite, %
A-6539	A***	0.16 C	+60	+10	66(76)	--
A-6596	A	0.35 C	+120	+75	106	26
A-6586	B	0.14 C	+40	-24	84	6
A-6597	B	0.32 C	+90	+19	111	23
A-6589	A	0.26 Mn	+100	+36	93	--
A-6598	A	1.28 Mn	+70	-60	82	24
A-6590	B	0.22 Mn	+90	+26	80(90)	--
A-6599	B	1.46 Mn	+60	-38	101	21
A-6135	A	0.011 P	+80	-1	102(107)	--
A-6652	A	0.038 P	+110	+20	74	20
A-6706	A	0.054 P	+110	+50	66	--
A-6638	B	0.016 P	+60	-26	84	--
A-6653	B	0.046 P	+90	-11	89	18
A-6655	B	0.053 P	+110	+10	71	16
A-6647	A	0.042 S	+60	+10	82	13
A-6646	B	0.045 S	+50	-24	81	15
A-6602	A	0.02 Si	+80	+14	72	14
A-6594	A	0.11 Si	+80	-7	158	--
A-6657	A	0.15 Si	+70	-2	77	19
A-6696	A	0.31 Si	+70	-28	66	17
A-6603	B	0.03 Si	+80	-29	89	16
A-6595	B	0.13 Si	+40	-43	100	16
A-6695	B	0.16 Si	+30	-57	70	20
A-6697	B	0.29 Si	+60	-29	91	18
A-6642	A	0.08 V	+80	+15	76	20
A-6368	A	0.09 V	+100	+10	104**	19
A-6366	A	0.19 V	+160	+73	108**	21
A-6643	B	0.08 V	+70	-25	92	12
A-6644	B	0.12 V	+100	-20	92	15
A-6645	B	0.20 V	+160	+70	92	17

* Determined by counting method; average values for counts on longitudinal and transverse sections. Values in parentheses were obtained by a second investigator.

** Counts on longitudinal sections only.

*** The finishing temperature during hot rolling was 1850 F for all steels.

the ferrite grains. Increasing carbon raises the transition temperature, but higher manganese contents improve toughness. Therefore, the ferrite grain counts do not correlate closely with transition temperatures of steels differing in carbon or manganese contents.

Varying the silicon content from 0.02 to 0.31 per cent did not cause consistent changes in the grain size of the Type A or Type B steels. Nevertheless, in both grades, there were significant differences in Charpy transition temperatures associated with changes in silicon contents. The tear tests also indicated that the Type B steel, containing 0.16 per cent silicon, was significantly tougher than the other steels in this series.

Increases in phosphorus contents were accompanied by coarsening of the ferrite grain size and loss in toughness as measured by either Charpy or tear tests. Conversely, vanadium additions lowered the toughness of both grades of steel without affecting the grain size.

In general, the data for these steels indicate that the effect of ferrite grain size on notched-bar properties is often outweighed by other effects of changes in composition.

INFLUENCE OF FINAL HOT-ROLLING TEMPERATURE ON PROPERTIES OF COMMERICAL STEELS

A study(2) of two laboratory steels indicated that the transition temperature was raised by increasing the finishing temperature of hot-rolled 3/4-inch steel plate. A similar investigation was made on commercial steel of similar analysis. Two steel companies cooperated by providing sections of 3/4-inch plate and 1-3/4-inch plate. Each producer supplied plates of the two gages from the same heat. Another steel company furnished a 3/4-inch plate of rimmed steel. Chemical analyses of these steels are shown in Table 15.

The 3/4-inch plate was tested in the as-recived condition. The 1-3/4-inch plate was divided into two portions and rerolled. The steels were rerolled using finishing temperatures of 1650 F and 1850 F. Steel Company "X" shipped twice the quantity of 1-3/4-inch plate as Company "Y". This made it possible to reroll the "X" steel at four finishing temperatures.

The 1-3/4-inch slabs were heated to 2250 F and were rolled to 0.9-inch gage, using reduction of approximately 1/6 inch per pass. The 0.9-inch-gage plates were immediately recharged in a furnace. held at the desired finishing temperature. After 20 minutes or more in this furnace, the plates were rolled to 3/4 inch in one pass. Following the final pass, the plates were placed on edge on a brick floor, with a brick separating each plate, and allowed to air cool. This procedure is the same as that used for slabs from heats made in the laboratory.

Duplicate tensile test specimens were taken from each plate. The tensile properties are shown in Table 16. It will be noted that the yield strength decreased with an increase in finishing

TABLE 15. CHEMICAL ANALYSIS OF COMMERCIAL STEEL PLATES

Grade of Steel	Heat No.	Manufacturing Company	Composition, per cent					
			C	Mn	Si	P	S	N
Type A	58 x 428	Company X	0.33	0.55	0.08	0.009	0.032	0.005
Type B	50 x 426	"	0.21	0.78	0.08	0.010	0.033	0.006
Type A	5779	Company Y	0.25	0.44	0.02	0.007	0.031	0.005
Type B	1046	"	0.20	0.77	0.14	0.009	0.029	0.005
Type A	24666**	Company Z	0.23	0.40	0.01	0.021	0.031	0.005

** Rimmed steel.

TABLE 16. TENSILE PROPERTIES OF COMMERCIAL STEEL REROLLED TO 3/4-INCH PLATE USING VARIOUS FINISHING TEMPERATURES

Heat No.	Finishing Temp, F	Yield Strength, psi		Tensile Strength, psi	Elongation in 8", %
		Upper	Lower		
58 x 428	1650	40,250	39,200	69,550	27.0
	1850	41,450	38,300	69,900	28.0
	1950	39,700	37,700	69,800	26.5
	1960*	35,350	34,250	71,350	26.0
	2050	38,550	35,900	68,950	25.0
50 x 426	1650	39,650	38,700	61,000	31.5
	1850	35,950	34,750	59,250	33.0
	1950	35,350	34,400	61,550	30.0
	1970*	32,700	31,000	59,050	30.5
	2050	34,000	33,250	61,300	30.5
5779	1650	35,800	34,400	59,200	34.0
	1700*	33,600	32,600	59,100	30.0
	1850	35,100	33,600	59,500	32.0
1046	1650	39,350	37,450	61,250	34.0
	1700*	36,950	32,800	60,900	31.0
	1850	40,700	39,100	66,250	28.5
24666	1725*	31,300	29,200	59,450	27.0

* Commercial rolled 3/4-inch plate.

temperature. The yield strength of the commercial rolled 3/4-inch plate is much lower than the laboratory rerolled plate of the same finishing temperature. This might be due to a difference in cooling rates from the finishing temperature. The elongation decreased as the finishing temperature was increased.

The tear-test and keyhole Charpy transition temperatures were determined for each plate. These temperatures are shown in Table 17. The effect of finishing temperature upon the tear-test transition temperature of Type A steel is shown graphically in Figure 19. For this figure, the transition temperatures of the Type A steels were corrected to correspond to a 0.25 per cent carbon and 0.45 per cent manganese steel. The corrections in transition temperatures, for slight differences in carbon and manganese contents, were based on the formulas given on page 14 of this report. The Battelle steel is included for comparison. All Type A steels finished at 1650 F have approximately the same transition temperature. The transition temperature of the Battelle laboratory steel increases immediately after raising the finishing temperature above 1650 F. The transition temperature of the commercial steels increased only when finished above 1850 F.

The effect of finishing temperature upon the tear-test transition temperature of Type B steel is shown graphically in Figure 20. Here, the transition temperatures of all plates are corrected to a 0.21 per cent carbon and 0.75 per cent manganese steel. The transition temperatures of all three steels are alike when finish

TABLE 17. TEAR-TEST PROPERTIES, KEYHOLE CHARPY TRANSITION TEMPERATURES, AND FERRITE GRAIN SIZES OF COMMERCIAL STEEL REROLLED TO 3/4-INCH PLATE AT VARIOUS FINISHING TEMPERATURES

		Tear-Test Properties					
Heat Number	Finishing Temperature, F	Max Load, lb	Energy to Start Fracture, ft-lb	Energy to Propagate Fracture, ft-lb	Trans. Temp, F	Keyhole Charpy Trans. Temp, F	Ferrite Grain Size, grains/sq in. at 100X
58 x 428	1650	40,190	760	720	90	+17	112
	1850	39,440	630	590	90	+27	89
	1950	37,530	640	560	110	+35	98
	1960*	40,040	550	580	130	+43	66
	2050	36,430	520	560	130	+39	80
50 x 426	1650	41,710	1200	1070	50	-57	93
	1850	39,040	1260	1230	50	-37	69
	1950	40,630	1060	760	80	-23	79
	1970*	40,640	1100	870	80	-24	61
	2050	39,840	1130	740	90	-16	68
5779	1650	38,650	890	1110	80	+21	113
	1700*	38,270	820	1120	80	+20	106
	1850	36,830	810	780	70	+15	80
1046	1650	41,970	1130	2010	40	-44	92
	1700*	41,000	1080	1090	50	-28	50
	1850	40,920	1060	1170	50	-49	73
24666	1725*	34,330	480	460	80	+82	81

* Plates rolled commercially.

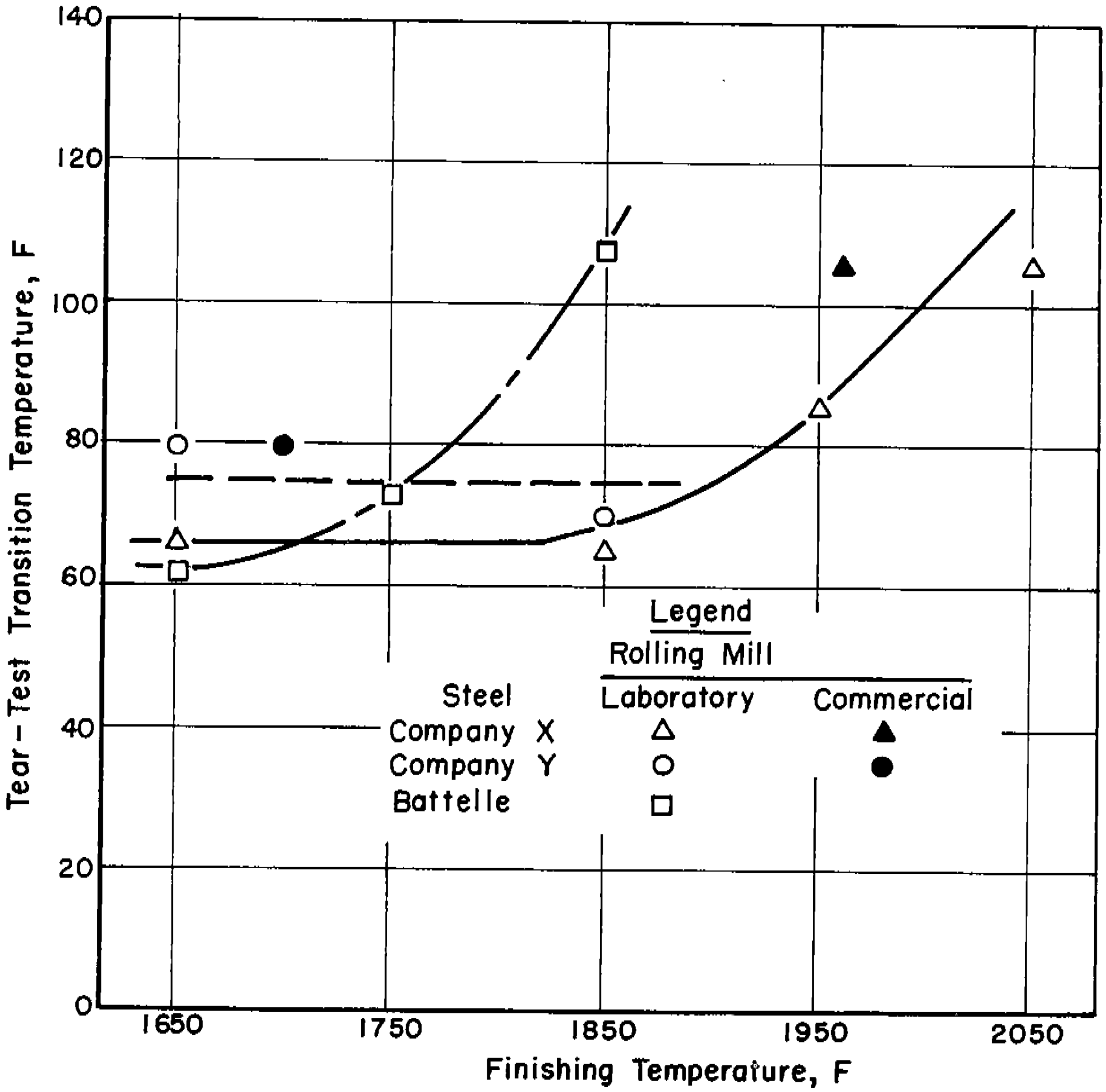

FIGURE 19. INFLUENCE OF FINISHING TEMPERATURE UPON THE TEAR-TEST TRANSITION TEMPERATURE OF $\frac{3}{4}$-INCH STEEL PLATE

Transition temperatures corrected to 0.25% C, 0.45% Mn steel

A-1403

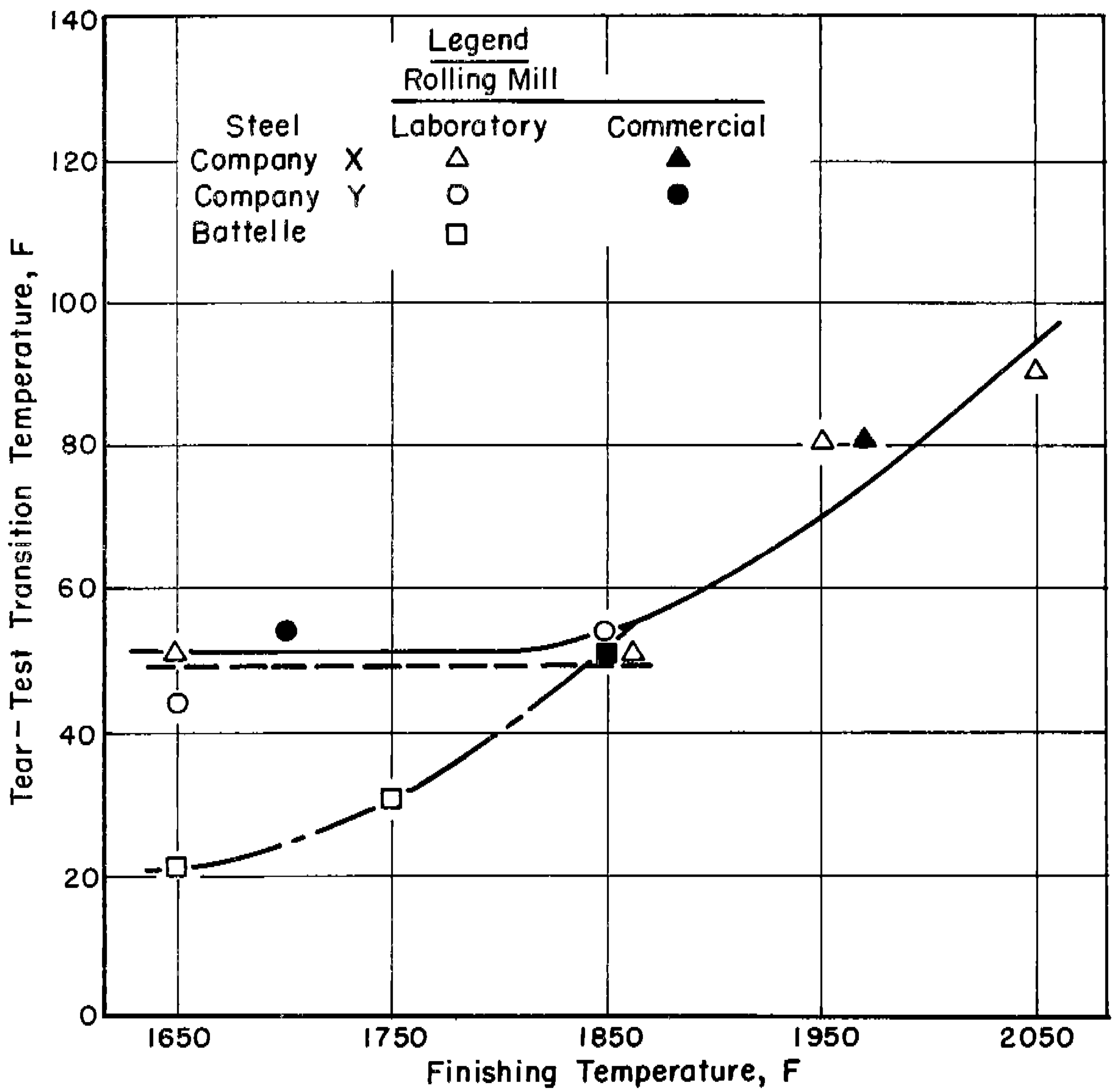

FIGURE 20. INFLUENCE OF FINISHING TEMPERATURE UPON THE TEAR-TEST TRANSITION TEMPERATURE OF $\frac{3}{4}$-INCH STEEL PLATE
Transition temperatures corrected to 0.21% C, 0.75% Mn steel

A-1404

rolled at 1850 F. The transition temperature of the Battelle steel decreased with reduction in finishing temperature below 1850 F, but the commercial steels were unaffected by this change. The transition temperatures of the two commercial steels increased when the finishing temperature was increased above 1850 F. Qualitatively, the laboratory and commercial steels respond alike to increasing finishing temperatures, but the points of inflection of the curves are near 1650 and 1850 F, respectively, for the steels in question.

The influence of finishing temperature upon the Charpy transition temperature of Type A steel is shown in Figure 21. The transition temperature of Battelle steel and Company "X" steel increased with an increase in finishing temperature. The transition temperature for steel from Company "Y" changed very little with finishing temperature, though the tendency seemed to be for the transition temperature to decrease slightly with increased temperature. It will also be noted that the transition temperature of Battelle steel was approximately 45 degrees higher than that of the steel for Company "X".

The effect of finishing temperature on Charpy transition temperature on Type B steels is shown in Figure 22. The effect was the same for the Type B steels as it was for the Type A steels.

The ferrite grain size of all steels was determined by counting the number of ferrite grains in a 2-inch square laid out on a

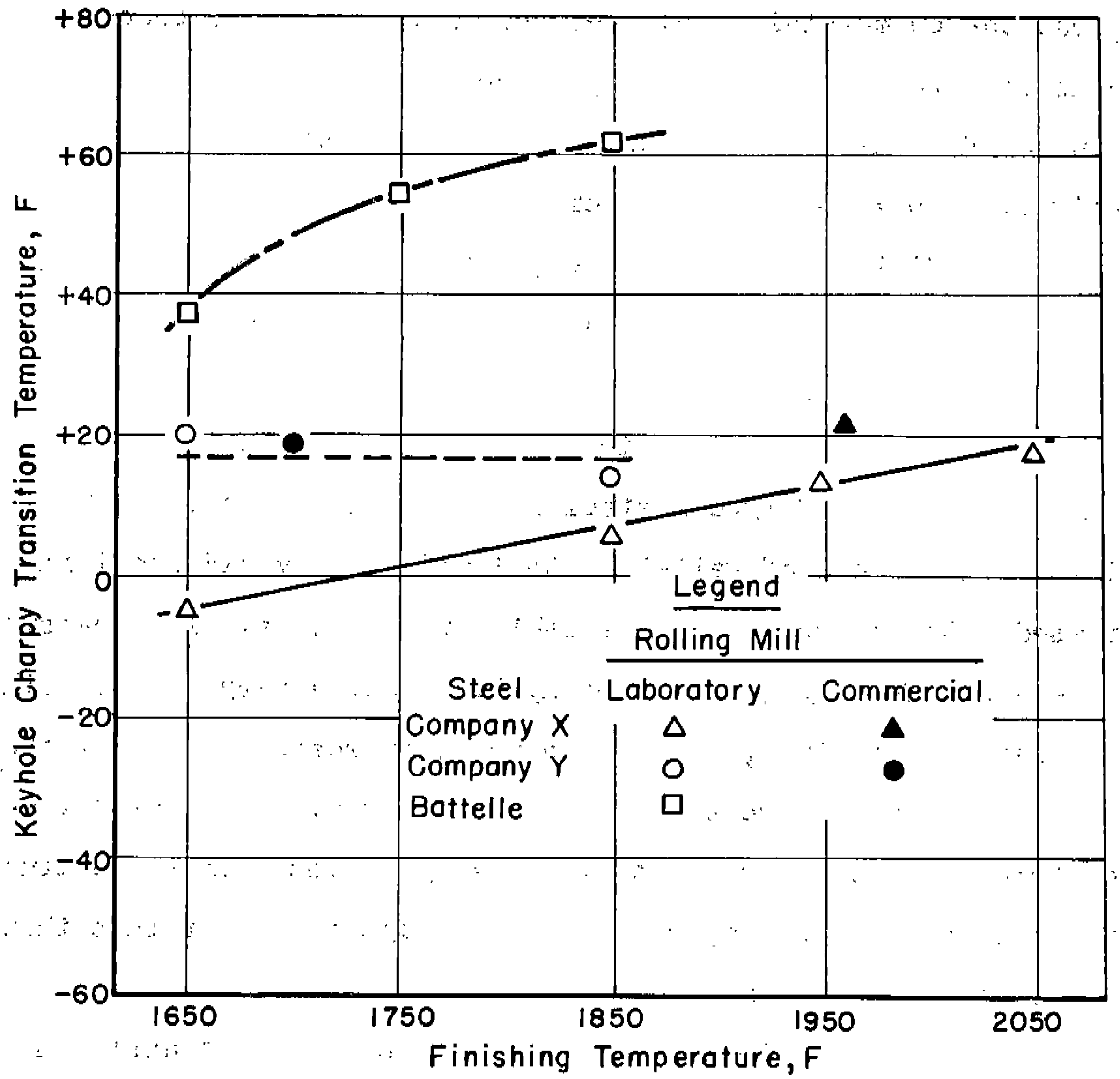

FIGURE 21. INFLUENCE OF FINISHING TEMPERATURE UPON KEYHOLE CHARPY TRANSITION TEMPERATURE OF $\frac{3}{4}$-INCH STEEL PLATE

Transition temperatures corrected to a 0.25% C, 0.45% Mn steel

A-1405

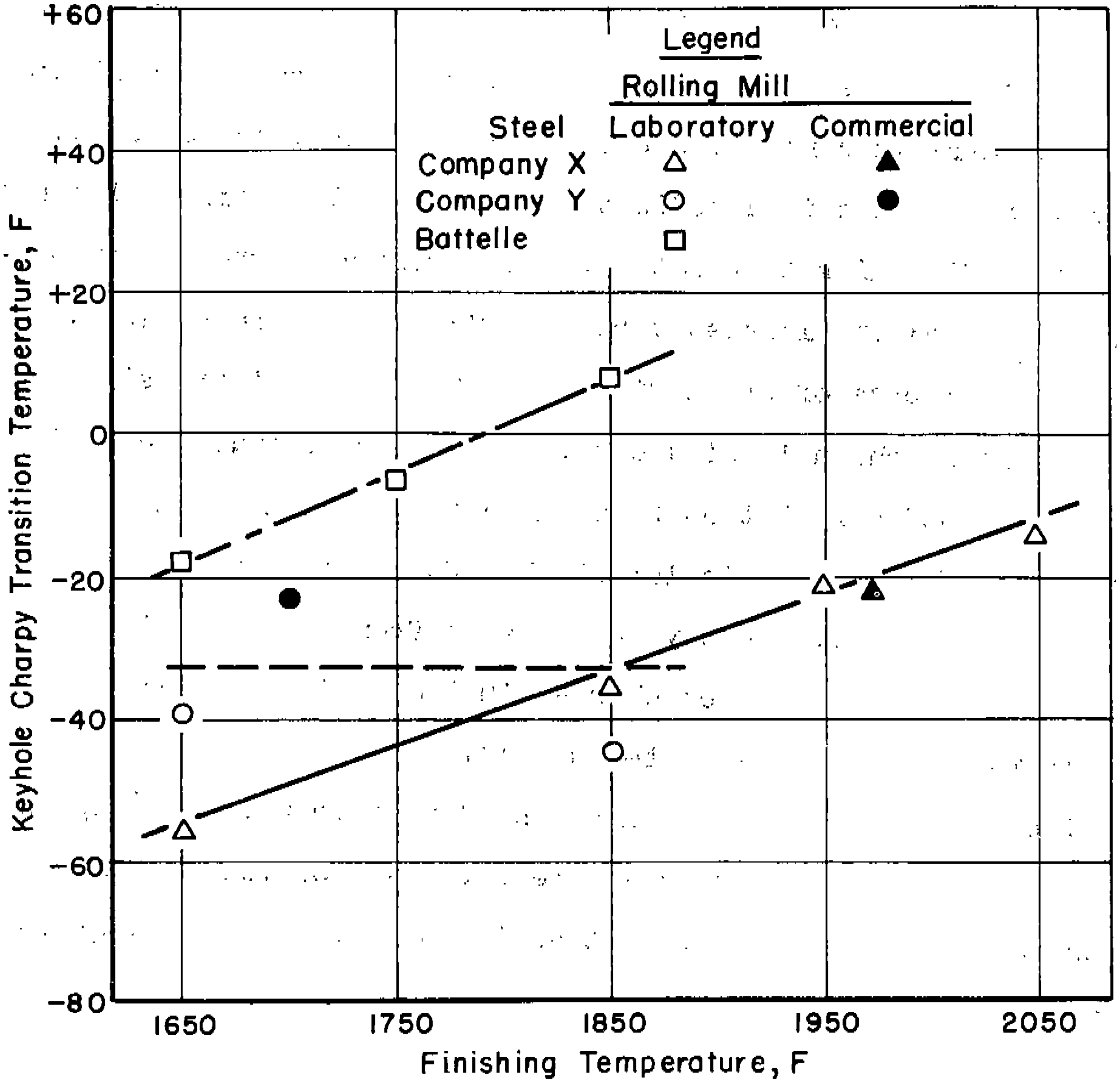

FIGURE 22. INFLUENCE OF FINISHING TEMPERATURE UPON THE KEYHOLE CHARPY TRANSITION TEMPERATURE OF $\frac{3}{4}$-INCH STEEL PLATE

Transition temperatures corrected to a 0.21% C, 0.75% Mn steel

A-1406

photomicrograph taken at 100 magnification. This count was divided by four to give the number of ferrite grains per square inch at 100 magnifications. The results of this experiment are listed in Table 17 and are shown plotted against finishing temperature in Figure 23. Although there is considerable scatter from the average curve, nevertheless, there is a definite trend of smaller grain size with decreasing finishing temperature. The commercial steel from Company "Y" showed the largest variation from the average curve.

The influence of grain size upon the tear-test transition temperature is shown in Figure 24. These curves indicate that there is a good correlation between grain size and transition temperature for any particular steel. Steels from Company "X" behaved somewhat differently than steels from Company "Y", the former showing much greater changes in transition temperature with grain size than the latter steels.

The effect of grain size upon the Charpy transition temperature is shown graphically in Figure 25. Both of the Type A steels show the same change in transition temperature and grain size.

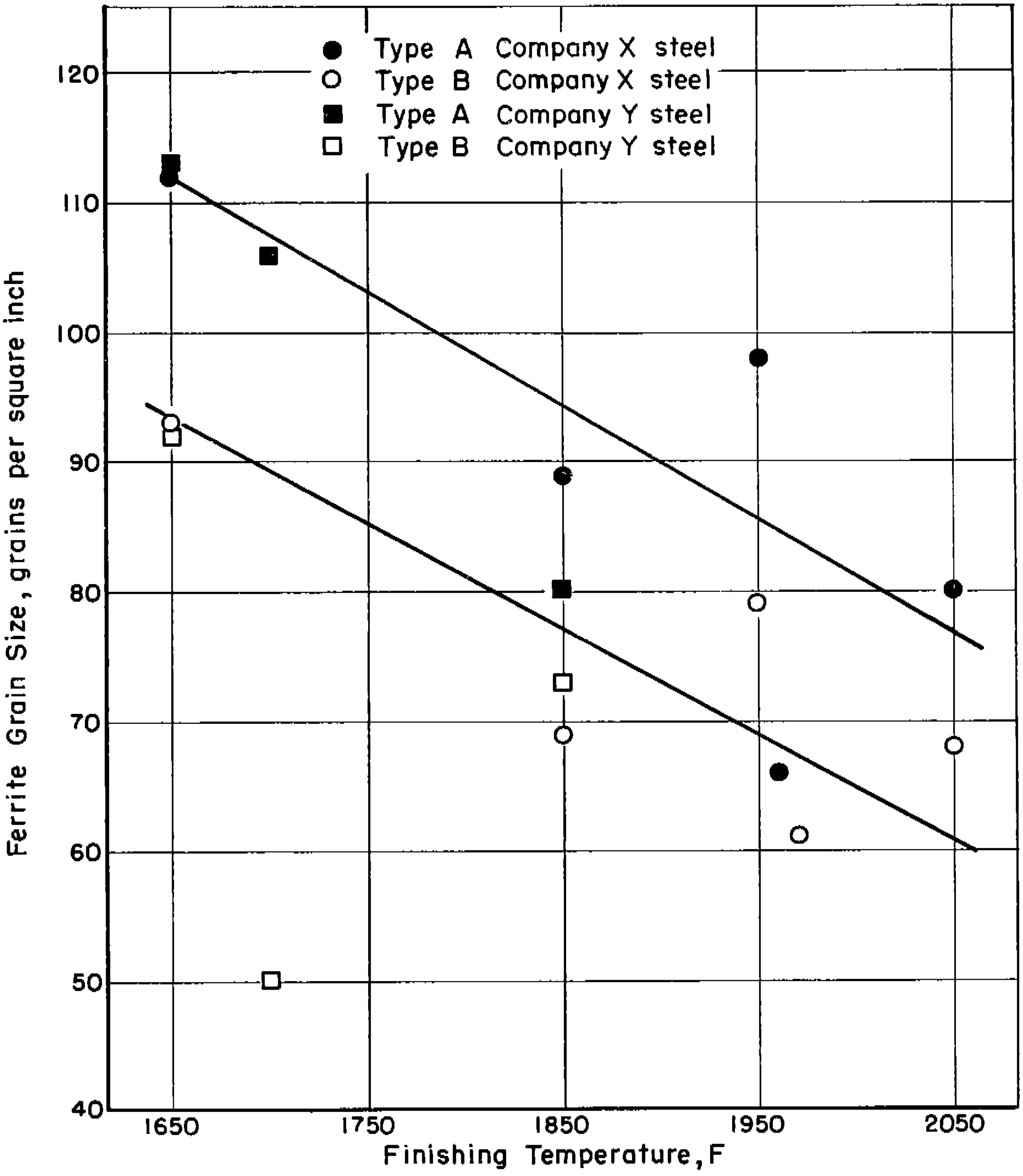

FIGURE 23. INFLUENCE OF FINISHING TEMPERATURE UPON FERRITE GRAIN SIZE OF COMMERCIAL AND LABORATORY ROLLED $\frac{3}{4}$-INCH STEEL PLATE

A-1407

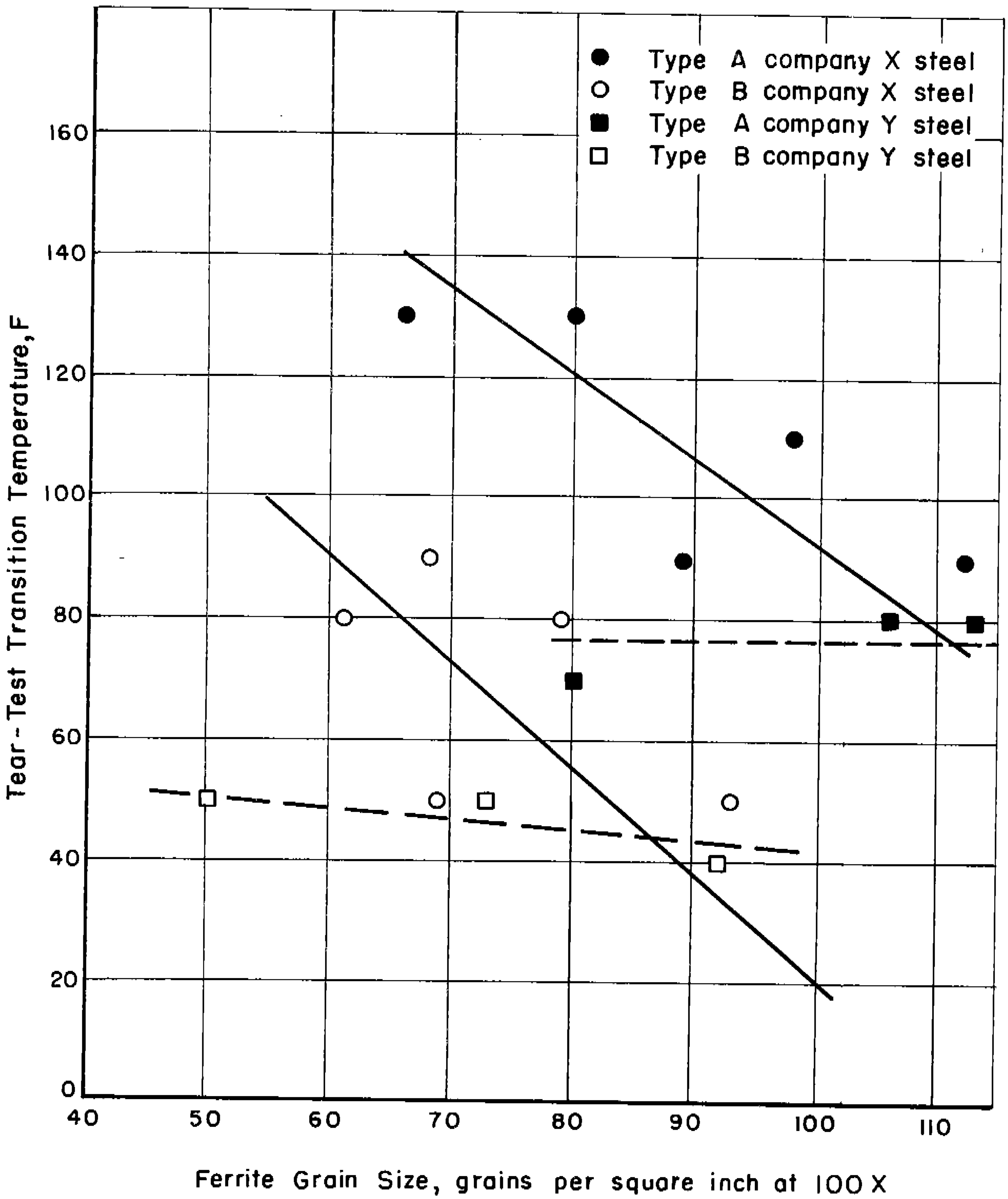

FIGURE 24. INFLUENCE OF FERRITE GRAIN SIZE UPON TEAR-TEST TRANSITION TEMPERATURE OF COMMERCIAL AND LABORATORY ROLLED $\frac{3}{4}$-INCH STEEL PLATE

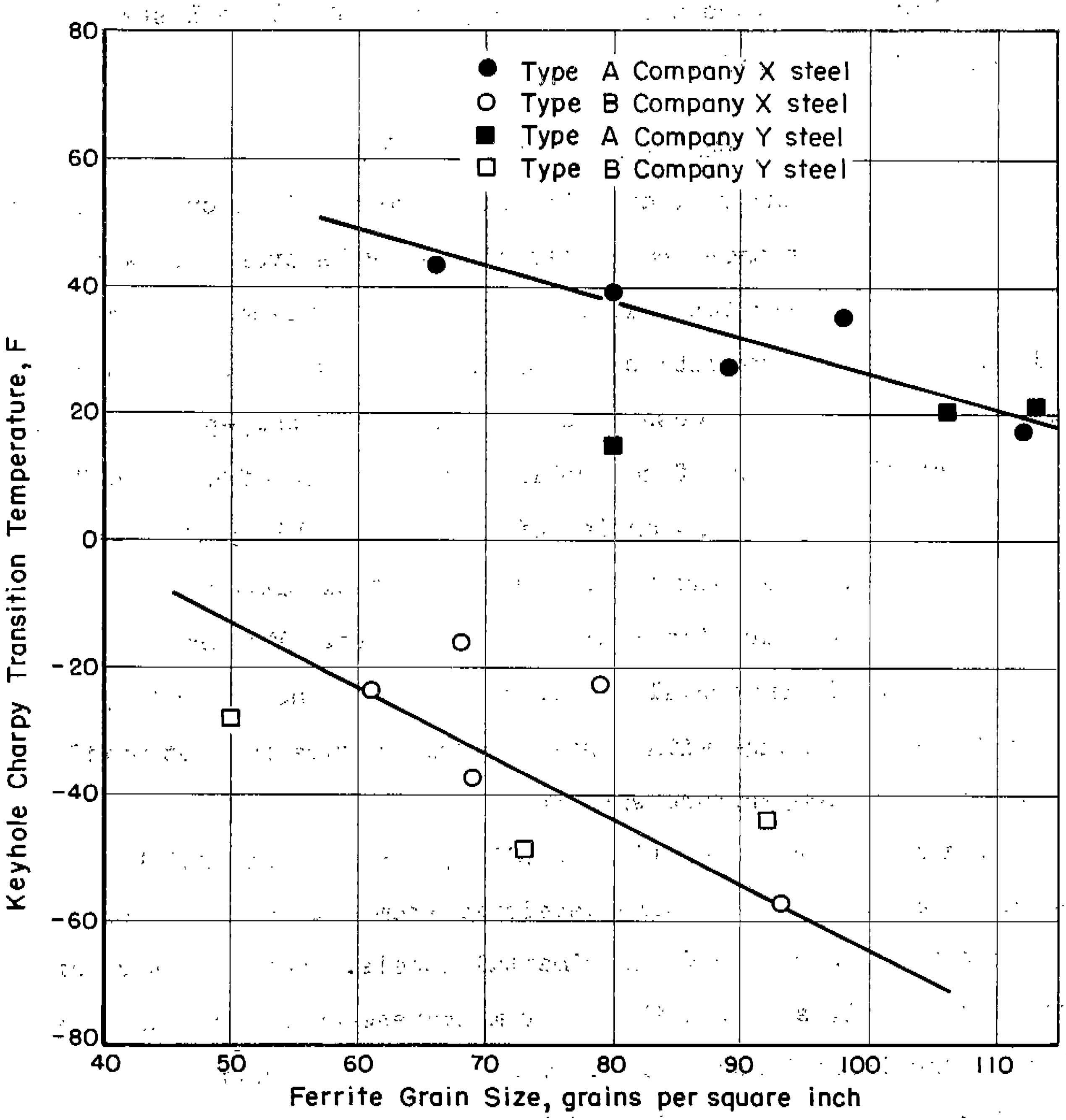

FIGURE 25. INFLUENCE OF FERRITE GRAIN SIZE UPON CHARPY TRANSITION TEMPERATURE OF COMMERCIAL AND LABORATORY ROLLED $\frac{3}{4}$-INCH STEEL PLATE

A-1409

The indications were that the effect of grain size variation on transition temperature was slightly greater for Type B steels than for Type A steels.

SUMMARY AND CONCLUSIONS

Consistent and reproducible data were obtained on semikilled laboratory steels made and tested at intervals over a two-year period. This indicates that considerable confidence can be placed on laboratory data showning the effects of variations in composition and processing on properties of ship-plate steels.

Variations in the final rolling temperature affect the Navy tear-test and Charpy properties of semikilled ship plate. In general, lower finishing temperatures on steel prepared in the laboratory give lower transition temperatures. The transition temperatures of commercial plates rerolled in the laboratory also tended to change with finishing temperature but not until the finishing temperature was above 1850 F.

Formulas for calculating tensile properties and notched-bar transition temperatures were developed from data obtained on a comprehensive series of experimental steels. For a particular strength level, steels with higher manganese-carbon ratios have lower transition temperatures. The influence of nitrogen in raising the strength and transition temperature of semikilled steel was studied. Increasing the nitrogen of both Type A and Type B steels from 0.004 to 0.02 per cent increased the tensile strength about 10,000 psi and raised the tear-test transition temperature about 80 F and the Charpy transition temperature about 40 F.

Heats treated with zirconium in amounts ranging from 0.06 to 0.10 per cent were made and tested. Results of Navy tear tests and Charpy tests do not justify conclusions on the effect of this element. In this respect, they agree with unofficial reports from the steel industry, that the effect of zirconium is not established.

Small additions of aluminum to steels with low silicon contents usually lowered the tear-test and Charpy transition temperatures. The effect of a specific addition varied with the composition of the base metal, the effect being greater in steels of Type B than in steels of Type A.

The presence of titanium in excess of 0.02 per cent seems to increase the transition temperature of both Type A and Type B type ship plate. In the range up to 0.02 per cent titanium, the transition temperature of Type B steel appears to be lowered by titanium.

Increasing the ferritic grain size of a particular steel by austenitizing at increasingly higher temperatures raises the transition temperature. The ferrite grain size was also increased by decreasing the rate of cooling from the austenitizing temperature. No correlation was found between transition temperatures and ferritic grain sizes determined by a counting method of ship steels which varied in composition over a fairly wide range. This is particularly true when both manganese and carbon contents are varied. Both elements affect the amount of pearlite in the microstructure. As the amount of pearlite changes, the number of ferrite grains in a given volume of metal change, though the size of the individual ferrite grains may remain unchanged. For that reason the effect of ferritic grain size on transition temperature is often out-weighed by effects from changes in composition.

This investigation is being continued under Contract NObs 53239, Index NS-011-078. The influence of grain size and interrelated effects of deoxidizing elements will be given continued attention.

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APPENDIX

TABLE 1A. TENSILE-TEST DATA FOR CLASS A AND CLASS B STEELS IN THE REPRODUCIBILITY STUDY

Heat Number	Specimen Number	Yield Strength, psi Upper	Yield Strength, psi Lower	Tensile Strength, psi	Elongation in 8 In., %
A-6650	1	35,300	34,100	60,200	27.0
	2	35,900	34,400	60,900	29.5
A-6705	1	36,700	35,800	62,500	22.0
	2	37,400	36,000	63,500	27.0
A-7663	1	35,100	34,600	60,800	29.0
	2	35,000	34,400	61,400	33.5
A-6651	1	36,200	35,700	62,000	28.0
	2	38,200	35,700	62,600	29.5
A-7664	1	36,100	34,600	62,100	27.5
	2	36,100	35,000	62,500	32.0

TABLE 1B. NAVY TEAR-TEST DATA FOR TYPE A AND TYPE B STEELS IN THE REPRODUCIBILITY STUDY

Heat Number	Specimen Number	Testing Temperature, °F	Maximum Load, Pounds	Energy to Start Fracture, Ft -Lb	Energy to Propagate Fracture, Ft -Lb	% Shear in Fracture
A-6650	N1	70	37,550	917	133	5
	Q2	80	35,800	858	592	100
	S1	80	37,200	842	750	100
	M2	80	36,600	767	575	100
	P1	80	36,550	800	650	100
A-6705	P2	60	36,100	817	66	5
	L1	70	35,600	783	616	100
	R1	70	37,000	817	600	100
	Q2	70	37,000	750	733	100
	M2	70	36,000	700	383	100
A-7663	N2	60	37,950	790	75	5
	N1	70	37,500	775	650	100
	P1	70	37,700	766	142	10
	P2	80	37,150	790	50	15
	Q1	90	37,250	824	633	100
	Q2	90	37,500	885	133	15
	R1	100	37,500	910	885	100
	R2	100	37,600	800	842	100
	S1	100	37,900	842	665	100
	S2	100	37,750	915	757	100
A-6651	M1	60	39,550	833	616	100
	P2	60	38,700	892	725	95
	R1	60	38,300	842	158	5
	S2	70	38,500	858	125	10
	N1	80	38,200	757	807	100
	Q2	80	38,700	891	757	100
	R2	80	37,700	867	741	100
	N2	80	39,100	992	600	100
A-7664	N2	60	39,250	1,020	216	10
	N1	70	39,150	935	740	100
	P1	70	39,250	1,020	815	100
	P2	70	38,750	950	58	15
	Q1	80	39,300	925	275	25
	Q2	90	39,400	961	784	100
	R1	90	38,700	950	734	100
	R2	90	38,950	875	734	100
	S1	90	39,100	958	707	100

TABLE 1C. CHARPY IMPACT-TEST DATA FOR TYPE A AND TYPE B STEELS IN THE REPRODUCIBILITY STUDY

Heat Number	Testing Temperature, F	Charpy Impact Strength, Ft -Lb 1st Test	2nd Test	3rd Test	4th Test
A-6650	120	33	35	37	35
	75	31	32	31	29
	40	27	28	24	28
	20	21	6	21	22
	0	11	5	9	18
	-40	3	3	3	3
A-6705	75	32	30	32	31
	40	22	27	27	25
	0	18	20	19	19
	-40	2	2	2	3
A-7663	80	31	22	—	—
	50	27	27	—	—
	40	11	25	29	25
	30	24	23	24	20
	20	24	20	6	18
	10	19	21	10	21
	0	16	6	4	14
A-6651	75	38	37	39	39
	40	38	36	35	37
	20	33	34	35	35
	0	31	33	32	31
	-40	3	4	10	17
	-80	2	2	2	2
A-7664	80	31	37	—	—
	40	34	33	—	—
	30	33	26	—	—
	20	30	28	—	—
	10	25	31	25	27
	0	26	20	25	30
	-10	5	26	10	20
	-20	16	10	—	—
	-40	4	5	—	—

TABLE 2A. TENSILE-TEST DATA FOR STEELS IN THE CARBON-MANGANESE SERIES

Heat Number	Specimen Number	Yield Strength, psi Upper	Lower	Tensile Strength, psi	Elongation in 8 In., %
0.15% Carbon Series					
A-7448	1	33,600	28,600	50,700	34.0
	2	33,000	28,800	50,700	36.0
A-6539	1	31,600	30,900	53,400	31.0
	2	32,100	30,600	53,200	30.0
A-6586	1	32,300	31,300	53,800	28.5
	2	33,700	32,700	55,000	28.0
A-7516	1	35,600	34,800	59,600	31.0
	2	36,800	34,600	59,600	32.5
A-7517	1	37,500	36,100	61,400	29.0
	2	36,800	35,900	61,400	30.0
0.20% Carbon Series					
A-6590	1	33,100	32,000	55,200	30.0
	2	33,100	30,900	55,000	31.0
A-7532	1	31,600	31,400	56,400	32.0
	2	31,800	31,500	55,700	33.0
A-7518	1	36,400	35,400	61,700	33.5
	2	36,000	35,300	61,700	32.5
A-7519	1	37,800	37,100	64,400	28.0
	2	37,600	36,900	64,000	30.0
A-6599	1	44,000	43,500	72,400	24.0
	2	43,700	43,300	72,300	25.0
0.25% Carbon Series					
A-6589	1	33,900	33,100	58,100	29.0
	2	34,200	32,500	58,700	30.0
A-6547	1	36,200	35,600	65,200	27.5
	2	37,500	36,300	65,600	25.5
A-6554	1	39,100	37,300	64,700	30.0
	2	38,000	36,900	65,100	29.0
A-6598	1	43,200	42,600	75,100	23.0
	2	42,500	41,700	73,300	23.0
0.30% Carbon Series					
A-7520	1	34,000	31,400	58,200	29.0
	2	34,500	32,600	59,000	29.5
A-7521	1	36,500	34,000	62,600	32.0
	2	36,400	33,800	62,000	28.0
A-7522	1	38,400	37,000	68,400	26.5
	2	38,500	36,900	68,500	25.0
A-7533	1	41,600	39,400	73,900	28.0
	2	42,200	39,100	73,300	27.0
A-7524	1	45,300	44,900	81,000	27.0
	2	46,300	46,000	80,600	26.0
0.35% Carbon Series					
A-7527	1	34,800	34,000	62,900	29.0
	2	34,500	33,600	63,000	31.0
A-6596	1	43,600	40,000	75,000	20.5
	2	39,000	37,100	70,800	22.0
A-6597	1	41,900	41,200	75,600	24.5
	2	39,900	39,000	74,600	25.0
A-7525	1	40,500	40,200	76,500	26.0
	2	40,500	40,000	76,000	27.5

TABLE 2B. NAVY TEAR-TEST DATA FOR STEELS IN THE CARBON-MANGANESE SERIES

Heat Number	Specimen Number	Testing Temperature, F	Maximum Load, Pounds	Energy to Start Fracture, Ft -Lb	Energy to Propagate Fracture, Ft -Lb	% Shear in Fracture
		0.15% Carbon Series				
A-7448	P1	40	34,350	1035	91	10
	P2	50	34,050	1050	715	80
	Q1	50	33,750	984	325	35
	Q2	60	33,100	958	750	95
	R1	60	33,600	975	666	80
	R2	60	33,000	925	616	90
	S1	60	32,750	950	659	85
A-6539	B1	30	38,850	1150	108	15
	T2	40	36,000	1018	666	100
	L2	40	35,300	866	133	5
	D1	50	35,300	833	116	5
	M2	60	34,900	875	650	100
	C1	60	36,100	950	666	100
	T1	60	35,850	1008	542	70
	D2	60	36,350	892	158	10
	A1	70	34,900	925	584	85
	M1	70	35,400	983	675	100
	S1	70	35,750	950	650	100
	L1	70	35,050	858	866	100
	S2	80	33,700	892	666	100
A-6586	M1	20	39,250	1283	567	75
	P1	20	39,600	1408	208	10
	R2	30	38,900	1350	292	25
	Q1	40	37,900	1250	108	5
	N1	50	37,500	1225	933	100
	P2	50	38,150	1225	992	100
	L1	50	38,400	1375	1918	100
	R1	50	38,200	1250	683	95
A-7516	M1	30	41,050	1170	833	95
	M2	30	41,150	1190	550	55
	N1	40	41,100	1250	850	100
	N2	40	40,400	1100	325	25
	P1	50	40,500	1225	735	90
	P2	50	40,300	1150	809	100
	Q1	50	40,950	1260	875	100
	Q2	50	40,850	1240	940	100
A-7517	N1	20	43,350	1280	142	10
	N2	30	42,800	1240	875	100
	P1	30	42,600	1175	910	100
	P2	30	42,500	1170	150	10
	Q1	40	42,300	1130	915	100
	Q2	40	42,400	1170	850	100
	R1	40	42,300	1180	860	100
	R2	40	42,300	1220	850	100
		0.20% Carbon Series				
A-6590	R1	90	34,150	800	742	100
	S2	90	34,700	825	750	100
	H1	90	34,750	807	758	100
	F2	90	34,800	875	83	15
	S1	100	33,150	807	650	100
	R2	100	32,600	775	866	100
	F1	100	34,900	950	850	100
	G1	100	33,800	815	600	100
A-7532	N1	60	37,600	990	900	100
	N2	60	37,850	950	58	5
	M2	70	36,850	900	683	100
	P1	70	37,750	940	724	100
	P2	70	37,850	940	842	100
	Q1	70	37,750	825	917	10
	M1	80	36,600	900	842	100
	Q2	80	36,450	850	775	100
	R1	80	35,150	825	842	100
	R2	80	35,450	892	633	100
A-7518	N1	50	40,600	1040	675	100
	N2	50	40,250	958	133	10
	P1	60	39,700	975	800	100
	P2	60	39,750	940	734	95
	Q1	60	39,900	984	1025	100
	Q2	60	40,250	958	734	95
A-7519	Q1	50	45,000	1220	416	55
	P1	60	43,000	915	868	100
	Q2	60	43,200	1000	800	100
	R1	60	44,250	1025	775	100
	R2	60	43,600	990	809	100
	P2	70	43,350	1000	860	100
A-6599	M1	20	49,000	1292	125	2
	N2	30	46,850	1183	183	10
	S2	40	46,850	1108	92	3
	Q2	50	46,700	925	258	8
	R2	60	46,700	1058	333	20
	P1	60	46,900	1118	550	50
	N1	70	45,550	842	900	100
	Q1	70	45,750	842	858	100
	R1	70	45,950	1042	758	100
	M2	70	47,950	1150	892	100
		0.25% Carbon Series				
A-6589	A2	90	36,250	800	692	100
	C2	90	36,600	858	707	100
	N1	90	35,500	741	650	100
	M1	90	34,400	666	100	10
	B2	100	33,900	700	708	100
	M2	100	34,600	683	100	10
	C1	110	34,800	972	725	100
	D2	110	34,700	725	733	100
	A1	110	35,650	791	625	100
	N2	110	35,450	775	616	100
A-6547	N1	60	40,350	910	117	10
	N2	70	40,250	900	692	95
	P1	70	39,050	875	125	15
	P2	80	38,800	740	700	95
	Q1	80	39,450	784	642	100
	Q2	80	38,700	775	108	20
	R1	90	39,150	809	700	100
	R2	90	39,250	784	692	100
	S1	90	38,700	734	715	100
	S2	90	38,600	715	815	100
A-6554	M1	70	40,300	866	150	10
	M2	80	41,350	935	833	100
	N1	80	41,150	910	1110	100
	N2	80	40,150	790	665	100
	P1	80	41,650	935	590	70
A-6598	M2	50	45,900	1083	492	40
	L1	60	46,450	1142	75	5
	Q1	70	46,800	925	925	100
	R2	70	46,000	875	783	95
	L2	70	43,500	892	400	30

TABLE 2B. (Continued)

Heat Number	Specimen Number	Testing Temperature, F	Maximum Load, Pounds	Energy to Start Fracture, Ft -Lb	Energy to Propagate Fracture, Ft -Lb	% Shear in Fracture
	P2	80	44,700	900	817	100
	Q2	80	46,150	1183	817	100
	R1	80	44,950	817	892	100
	N1	80	45,000	917	800	100
		0.30% Carbon Series				
A-7520	N1	80	34,800	650	175	15
	R1	90	35,750	815	484	85
	N2	90	34,800	715	535	65
	S1	90	36,100	815	133	7
	P1	100	34,500	675	809	100
	P2	100	34,500	635	675	100
	Q1	100	34,900	692	575	100
	Q2	100	34,300	666	784	100
A-7521	M2	80	36,350	666	75	10
	N1	90	36,650	700	125	15
	M1	100	35,650	600	566	100
	N2	100	37,100	765	541	100
	P1	100	37,850	765	566	90
	P2	100	36,400	642	416	45
	Q1	110	37,000	709	709	95
	Q2	110	37,000	734	584	100
	R1	110	36,650	700	700	100
	R2	110	37,400	740	840	100
A-7522	M1	90	37,750	584	150	20
	M2	100	37,750	592	592	100
	N1	100	37,200	560	550	100
	N2	100	38,400	616	550	100
	P1	100	37,800	616	560	100
A-7533	P2	70	44,100	683	100	<5
	Q1	80	43,450	715	583	95
	Q2	80	41,850	633	659	95
	R1	80	43,000	716	358	45
	P1	90	43,600	692	675	100
	R2	90	42,800	633	608	100
	S1	90	42,550	650	591	100
	S2	90	44,600	817	666	100
A-7524	N1	70	47,950	725	150	30
	N2	80	47,050	675	117	10
	P1	90	47,900	700	300	15
	P2	100	47,200	775	225	15
	Q1	110	45,900	734	-	100
	Q2	110	46,900	675	685	95
	R1	110	47,300	759	659	100
	R2	110	47,800	775	642	100
		0.35% Carbon Series				
A-7527	L1	100	35,450	634	283	40
	L2	110	35,700	576	250	30
	M1	120	35,050	576	500	100
	M2	120	36,100	592	500	100
	N1	120	36,000	592	516	100
	N2	120	36,150	616	117	25
	P1	130	35,600	565	708	100
	P2	130	36,050	616	650	100
	Q1	130	35,500	616	526	100
	Q2	130	35,350	558	692	100
A-6596	Q2	90	37,700	608	100	10
	N1	100	37,350	542	50	10
	N2	110	36,600	558	183	15
	L2	120	36,650	500	308	40
	R1	130	35,250	525	533	100
	M2	130	35,650	466	525	100
	L1	130	35,900	508	567	100
	R2	130	36,700	583	667	100
A-6597	M1	80	39,150	542	33	3
	N2	90	40,350	566	300	45
	H1	100	42,350	617	575	100
	J2	100	42,550	700	558	100
	M2	100	40,500	600	658	100
	K2	100	40,950	650	633	100
A-7525	M1	70	44,750	650	83	5
	M2	80	44,500	733	242	25
	L2	90	43,600	576	517	95
	N1	90	42,750	634	133	15
	N2	100	43,350	625	592	100
	P1	100	43,450	608	584	100
	P2	100	44,800	782	508	87
	Q1	100	44,300	675	458	75
	L1	120	42,650	616	542	100

TABLE 20. CHARPY IMPACT DATA FOR STEELS IN THE CARBON-MANGANESE SERIES

Heat Number	Testing Temperature, F	Charpy Impact Strength, Ft -Lb			
		1st Test	2nd Test	3rd Test	4th Test
		0.15% Carbon Series			
A-7448	80	50	38	—	—
	40	34	32	—	—
	30	9	29	29	24
	20	20	29	13	20
	10	22	6	6	24
	0	6	27	6	6
	-20	3	5	4	4
A-6539	73	42	32	37	39
	40	34	26	34	34
	20	27	7	26	25
	0	6	19	21	8
	-20	5	5	4	4
	-40	3	3	3	3
A-6586	75	54	55	56	56
	40	46	50	57	62
	0	49	44	51	56
	-20	37	7	39	38
	-40	4	6	5	5
	-80	2	2	2	2
A-7516	80	57	55	—	—
	40	47	46	—	—
	0	10	46	—	—
	-20	39	35	38	35
	-30	34	6	41	34
	-40	32	4	—	—
	-50	4	4	33	4
	-60	3	38	3	3
A-7517	80	58	56	—	—
	40	48	55	—	—
	0	40	42	—	—
	-10	43	20	40	41
	-20	9	35	6	37
	-30	5	40	6	37
	-40	6	5	5	43
	-50	33	4	—	—
		0.20% Carbon Series			
A-6590	75	33	32	35	30
	60	28	31	30	30
	40	28	21	29	26
	20	6	22	5	25
	0	4	13	5	5
	-40	3	3	3	3
A-7532	80	38	34	—	—
	40	31	27	—	—
	30	29	27	12	19
	20	28	28	27	25
	10	19	26	17	7
	0	5	20	5	19
	-10	17	10	—	—
	-20	7	4	—	—
A-7518	80	43	41	—	—
	40	39	36	—	—
	0	32	32	33	31
	-10	28	30	30	28
	-20	24	24	5	6
	-30	5	5	—	—
	-40	21	4	—	—
	-60	2	3	3	3
A-7519	80	51	50	—	—
	40	40	43	—	—
	0	37	35	—	—
	-20	5	32	—	—
	-30	25	28	5	28
	-40	30	20	4	6
	-50	5	5	3	3
	-60	3	3	3	3
A-6599	75	51	47	49	53
	40	41	45	50	49
	0	39	35	41	38
	-40	5	31	5	32
	-80	2	2	2	2
		0.25% Carbon Series			
A-6589	75	29	25	28	30
	60	23	24	24	26
	40	17	24	22	22
	20	17	19	5	18
	00	4	4	4	5
	-40	2	2	2	2
A-6547	80	38	38	—	—
	40	34	34	—	—
	0	28	28	—	—
	-10	28	25	—	—
	-20	24	26	24	22
	-30	19	17	19	23
	-40	7	4	17	3
	-50	4	6	4	3
A-6554	80	41	41	—	—
	40	38	39	—	—
	0	34	30	—	—
	-40	24	28	5	28
	-50	4	21	26	27
	-60	3	22	3	3
	-70	3	3	3	3
	-80	2	3	—	—
A-6598	75	41	42	41	41
	40	37	38	38	37
	0	33	31	33	31
	-40	27	25	28	27
	-80	15	3	2	22
		0.30% Carbon Series			
A-7520	100	27	26	—	—
	80	21	27	24	22
	70	22	18	21	20
	60	19	17	19	8
	50	23	15	18	21
	40	14	6	17	5
	30	5	9	—	—
A-7521	80	23	22	23	27
	60	24	23	—	—
	50	19	20	9	24
	40	20	20	23	19
	30	20	16	19	21
	20	17	9	6	17
	0	3	11	—	—
A-7522	80	28	28	—	—
	40	24	24	17	24
	30	22	20	23	17
	20	22	22	22	26
	10	13	15	18	11
	0	13	17	10	11
	-10	15	5	—	—
A-7533	80	30	32	—	—
	40	27	28	—	—
	10	25	25	21	24
	0	20	25	23	23
	-10	6	22	23	6
	-20	7	18	5	8
	-30	16	19	—	—
	-40	8	9	—	—
A-7524	80	36	32	—	—
	40	41	29	—	—
	20	28	27	30	27
	10	23	29	16	25
	0	7	5	22	26
	-10	25	4	26	26
	-20	25	20	4	24
		0.35 Carbon Series			
A-7527	120	25	24	24	25
	110	23	23	21	22
	100	21	20	19	19
	90	22	20	21	21
	80	19	21	19	16
	70	16	18	—	—
	40	11	4	—	—
A-6596	75	20	20	20	19
	40	14	16	14	16
	0	9	3	6	4
	-40	2	2	2	2
A-6597	75	27	26	25	26
	40	23	22	25	25
	20	22	20	20	20
	0	5	10	19	7
	-40	3	3	3	3
A-7525	80	28	32	—	—
	40	22	26	—	—
	20	23	24	21	22
	10	22	20	23	19
	0	20	19	6	8
	-10	11	6	18	14
	-20	15	4	4	7

TABLE 3A. TENSILE-TEST DATA FOR STEELS IN THE SILICON SERIES

Heat Number	Specimen Number	Yield Strength, psi Upper	Yield Strength, psi Lower	Tensile Strength, psi	Elongation in 8 In., %
A-7526	1	37,100	34,400	65,000	29.0
	2	36,800	35,400	65,000	29.0
A-7528	1	36,300	35,900	63,500	31.0
	2	36,400	36,000	63,800	34.0

TABLE 3B. NAVY TEAR-TEST DATA FOR STEELS IN THE SILICON SERIES

Heat Number	Specimen Number	Testing Temperature, F.	Maximum Load, Pounds	Energy to Start Fracture, Ft -Lb	Energy to Propagate Fracture, Ft.-Lb	% Shear in Fracture
A-7526	L1	70	40,450	782	100	10
	N1	80	39,700	700	624	100
	N2	80	40,400	774	750	100
	P1	80	40,100	733	566	90
	P2	80	40,800	766	566	100
	M2	90	38,800	716	641	100
	L2	90	38,650	675	782	100
	L1	100	38,200	733	566	100
A-7528	M2	40	42,000	961	193	10
	N1	50	42,800	1000	725	100
	N2	50	41,600	920	150	10
	M1	60	41,400	990	824	100
	P2	60	41,450	920	725	100
	Q1	60	43,300	1090	692	100
	Q2	60	41,050	915	766	100

TABLE 3C. CHARPY IMPACT-TEST DATA FOR STEELS IN THE SILICON SERIES

Heat Number	Testing Temperature, F	Charpy Impact Strength, Ft -Lb 1st Test	2nd Test	3rd Test	4th Test
A-7526	80	33	31	--	--
	40	28	27	--	--
	0	24	21	22	21
	-10	24	21	21	20
	-20	20	18	19	19
	-30	4	19	17	7
	-40	4	3	12	—
A-7528	80	43	45	--	—
	40	35	40	--	--
	0	33	30	—	—
	-40	27	24	26	4
	-50	25	3	12	23
	-60	22	5	3	4
	-70	4	4	3	4
	-80	5	2	--	--

TABLE 4A. TENSILE-TEST DATA FOR STEELS IN THE NITROGEN SERIES

Heat Number	Specimen Number	Yield Strength, psi Upper	Yield Strength, psi Lower	Tensile Strength, psi	Elongation in 8 In., %
		TYPE A Steels			
A-6600	1	36,200	35,400	62,600	25.0
	2	37,100	34,600	61,600	24.0
A-7440	1	40,800	37,800	67,200	28.0
	2	39,700	37,700	67,300	29.0
A-7441	1	41,600	39,400	69,400	26.0
	2	42,800	39,300	69,300	27.0
		TYPE B Steels			
A-6601	1	40,100	37,100	63,300	26.5
	2	39,200	36,800	63,200	25.5
A-7439	1	42,400	40,200	70,700	29.0
	2	43,000	41,100	70,700	29.5
A-7437	1	44,600	42,300	73,400	21.0
	2	45,900	42,500	72,600	19.5

TABLE 4B. NAVY TEAR-TEST DATA FOR STEELS IN THE NITROGEN SERIES

Heat Number	Specimen Number	Testing Temperature F	Maximum Load, Pounds	Energy to Start Fracture, Ft Lb	Energy to Propagate Fracture, Ft -Lb	% Shear in Fracture
A-6600	R2	50	38,950	933	67	3
	Q2	60	37,700	842	125	8
	L2	70	38,400	875	800	100
	N2	70	36,650	863	533	100
	P1	70	37,750	900	825	100
	R1	70	36,750	783	683	100
A-7440	M1	110	37,950	708	833	20
	M2	120	36,800	591	242	30
	N1	130	37,400	650	300	40
	N2	140	37,500	641	534	100
	P1	140	37,100	659	525	100
	P2	140	37,200	591	516	100
	Q1	140	37,000	641	534	95
A-7441	M1	130	38,600	625	167	20
	M2	140	38,450	600	192	20
	N1	150	39,400	642	650	75
	N2	150	38,050	642	266	30
	P1	160	38,750	609	350	45
	P2	170	39,350	609	1060	100
	Q1	170	37,600	484	1090	100
	Q2	170	38,500	459	541	100
	R1	170	37,950	541	425	70
A-6601	P2	70	38,200	883	833	100
	N1	70	39,550	800	175	15
	S2	80	38,900	958	100	12
	M1	90	40,050	917	258	30
	Q1	100	38,000	892	858	100
	S1	100	37,950	858	683	100
	M2	100	37,500	858	625	100
	P1	100	37,600	908	625	100
A-7439	E1	100	41,200	861	50	5
	E2	110	41,250	895	133	20
	F1	120	40,600	759	266	20
	F2	130	40,000	784	1300	100
	G1	130	40,800	855	1150	100
	G2	130	40,250	765	741	100
	H1	130	40,200	765	366	45
	H2	140	39,950	710	666	100
	J1	140	40,500	734	825	100
	J2	140	40,500	700	710	100
	K1	140	40,200	691	650	100
A-7437	E2	120	41,800	725	148	15
	E1	130	40,750	734	216	20
	F1	140	41,300	775	534	95
	F2	140	41,100	675	367	35
	G1	150	39,750	665	759	100
	G2	150	41,750	691	584	80
	H1	150	42,000	775	1175	75
	H2	150	39,400	684	550	100

TABLE 4C. CHARPY IMPACT-TEST DATA FOR STEELS IN THE NITROGEN SERIES

Heat Number	Testing Temperature, F	Charpy Impact Strength, Ft -Lb			
		1st Test	2nd Test	3rd Test	4th Test
A-6600	75	33	32	33	33
	40	28	29	29	29
	0	22	23	25	25
	-20	16	16	8	4
	-40	3	4	3	8
A-7440	80	30	25	--	--
	40	25	7	23	23
	30	22	22	19	23
	20	20	23	20	22
	10	20	20	4	21
	0	14	6	4	21
	-10	14	--	--	--
A-7441	80	23	24	--	--
	60	24	23	22	23
	50	24	21	24	24
	40	19	20	20	23
	30	5	18	21	19
	20	9	5	18	19
A-6601	75	40	38	40	42
	40	36	39	37	38
	0	34	34	31	31
	-20	27	23	26	29
	-40	22	8	15	3
	-80	2	2	2	2
A-7439	80	34	35	--	--
	40	27	28	--	--
	20	28	27	25	26
	10	26	24	23	6
	0	5	25	23	26
	-10	4	4	--	--
	-20	3	3	21	4
	-30	3	3	--	--
A-7437	80	28	30	--	--
	40	26	25	25	21
	30	22	26	22	23
	20	24	13	21	23
	10	23	20	4	4
	0	18	19	--	--
	-20	2	4	3	2

TABLE 5A. TENSILE-TEST DATA FOR STEELS IN THE TITANIUM, ZIRCONIUM, AND ALUMINUM SERIES

Heat Number	Specimen Number	Yield Strength, psi Upper	Yield Strength, psi Lower	Tensile Strength, psi	Elongation in 8 In., %
Titanium Series - Type A					
A-7667	1	40,400	38,600	66,300	28.0
	2	40,700	39,400	66,500	27.0
A-7668	1	39,400	37,400	66,400	27.0
	2	39,600	37,400	67,400	27.0
A-7665	1	42,700	40,900	70,200	24.0
	2	43,800	40,700	69,100	23.0
Titanium Series - Type B					
A-7669	1	37,500	35,600	62,300	31.0
	2	37,500	36,100	61,800	29.5
A-7670	1	37,500	36,200	62,000	29.0
	2	36,700	35,000	60,800	27.5
A-7671	1	46,300	44,600	70,000	25.5
	2	45,800	44,400	70,000	26.0
Zirconium Series - Type A					
A-7431	1	34,500	31,100	63,000	30.0
	2	34.600	31,600	63,500	27.5
A-6699	1	30,800	30,600	64,500	26.5
	2	30,300	30,000	63,900	25.0
A-7432	1	29,700	29,700	63,200	26.0
	2	29,700	29,600	64,700	29.0
Zirconium Series - Type B					
A-7433	1	31,800	31,200	62,900	29.0
	2	31,600	30,800	62,800	30.0
A-7434	1	35,200	33,400	64,700	31.5
	2	34,500	33,000	64,400	31.5
A-7435	1	31,500	31,300	65,100	29.5
	2	31,500	31,300	65,000	29.5
Aluminum Series - Low Silicon - Type A					
A-6648	1	38,200	37,500	65,300	30.0
	2	37,800	36,900	66,300	24.5
A-6707	1	35,600	33,200	58,800	29.0
	2	35,200	33,600	59,200	28.5
A-6708	1	38,200	35,100	61,500	30.0
	2	38,500	35,800	61,600	31.5
A-6709	1	35,400	34,300	59,600	32.0
	2	36,100	34,000	60,100	34.0
Aluminum Series - Low Silicon - Type B					
A-6649	1	38,100	37,100	64,800	23.0
	2	37,300	36,600	64,600	25.5
A-7319	1	35,100	33,900	58,900	30.0
	2	35,300	33,800	59,600	30.0
A-7320	1	34,600	33,500	60,200	32.0
	2	34,200	33,300	59,700	31.5

TABLE 5A. (Continued)

Heat Number	Specimen Number	Yield Strength, psi Upper	Yield Strength, psi Lower	Tensile Strength, psi	Elongation in 8 In., %
Aluminum Series - 0.05 % Silicon - Type A					
A-7531	1	35,700	33,300	60,500	32.5
	2	35,400	34,600	60,600	32.5
A-7661	1	33,200	32,600	59,800	31.5
	2	33.500	33,000	59,800	31.0
A-7529	1	36,500	36,200	62,900	31.5
	2	39,000	33,400	62,000	31.5
Aluminum Series - 0.05 % Silicon - Type B					
A-7660	1	35,900	34,200	61,300	30.0
	2	36,200	35,000	61.500	32.5
A-7662	1	36,000	34,500	62,600	29.0
	2	36,600	34,400	62,300	28.0
A-7530	1	36,400	35,400	62,600	30.5
	2	36,800	35,400	62,500	31.5
Aluminum - 0.05 % Silicon - 0.010 % Nitrogen - Type B Steel					
A-7659	1	37,700	36,400	66,000	29.0
	2	38,400	37,000	66,200	28.0

TABLE 5B. NAVY TEAR-TEST DATA FOR STLELS IN THE TITANIUM, ZIRCONIUM, AND ALUMINUM SERIES

Heat Number	Specimen Number	Testing Temperature °F.	Maximum Load, Pounds	Energy to Start Fracture Ft Lb	Energy to Propagate Fracture, Ft Lb	% Shear in Fracture
Titanium Series - Type A						
A-7667	N1	60	39,800	910	92	5
	N2	70	39,850	790	83	5
	Q1	80	38,500	842	83	5
	P1	90	39,500	824	650	100
	P2	90	38,850	766	625	100
	Q2	90	39,350	860	108	10
	R1	100	40,000	766	92	10
	R2	110	39,250	842	92	15
	S1	120	38,900	784	800	100
	S2	120	38,650	784	633	100
	T1	120	39,750	757	665	100
	T2	120	38,800	757	609	95
A-7668	M1	70	40,800	866	125	5
	M2	90	41,000	975	92	5
	N1	100	41,050	1033	175	10
	N2	110	40,500	833	42	10
	R1	120	40,700	866	83	15
	P1	130	40,500	757	1020	100
	P2	130	41,350	950	665	100
	Q1	130	40,400	875	642	100
	Q2	130	40,500	891	842	100
A-7665	M1	70	42,650	900	67	1
	M2	80	42,500	833	83	1
	N1	90	42,650	833	100	1
	N2	100	43,000	961	158	5
	P1	110	43,100	815	67	5
	P2	120	41,700	750	58	5
	Q1	130	42,950	784	50	10
	Q2	150	41,750	808	234	20
	R1	160	41,650	800	808	100
	R2	160	41,650	757	665	100
	S1	160	42,800	875	715	100
	S2	160	42,100	784	242	20
	T1	170	42,600	866	784	100
	T2	170	41,000	766	885	100
	U1	170	42,400	833	684	100
	U2	170	42,650	940	715	100
Titanium Series - Type B						
A-7669	M2	40	40,550	925	67	5
	L2	50	41,450	1020	642	85
	M1	50	40,700	961	757	100
	N1	50	39,950	961	750	98
	N2	50	40,500	958	100	7
	L1	60	40,300	950	766	100
	P1	60	41,150	1077	750	100
	P2	60	40,250	950	808	100
	Q1	60	40,150	1000	700	95
	K2	80	40,100	1025	775	100
	K1	100	38,650	961	784	100
A-7670	G1	60	40,800	1077	75	10
	O2	70	40,300	1040	808	100
	H1	70	41,600	1067	800	100
	H2	70	41,200	1040	790	100
	J1	70	41,200	1050	740	100
	F2	80	40,400	1120	700	100
	F1	100	38,900	961	700	100
A-7671	K1	80	44,100	900	117	5
	K2	100	44,050	1020	92	5
	L1	120	44,700	990	92	15
	L2	140	43,300	950	800	95
	M1	140	44,900	950	642	95
	M2	140	45,350	1160	216	20
	N1	150	44,850	975	367	45
	N2	160	44,850	984	757	100
	P1	160	44,400	940	700	100
	P2	160	44,000	940	1060	100
	Q1	160	44,350	940	725	100
Zirconium Series - Type A						
A-7431	K2	40	40,900	950	150	10
	K1	50	40,450	910	675	100
	L2	50	40,600	950	208	15
	M1	60	41,150	958	500	45
	J2	70	40,600	850	815	100
	M2	70	39,650	910	835	95
	N1	70	40,600	885	750	100
	N2	70	40,450	925	760	100
	J1	90	39,950	868	750	100
A-6699	S1	30	39,650	708	92	2
	R1	40	39,700	717	33	2
	U2	50	40,200	742	100	5
	T2	60	38,550	717	83	3
	T1	70	39,250	808	675	100
	Q2	70	39,400	858	142	5
	P1	80	38,800	775	58	15
	S2	90	39,200	863	683	95
	P2	90	38,800	833	733	100
	R2	90	39,000	833	883	100
	Q1	90	38,600	900	67	20
	V2	100	38,000	700	167	15
	V1	110	37,600	750	863	100
	W1	110	38,100	767	633	100
	W2	110	38,200	767	683	100
	U1	110	39,000	850	533	100
A-7432	J2	60	39,750	900	358	45
	K1	70	38,800	809	158	15
	K2	80	38,950	740	833	100
	L1	80	38,550	750	850	100
	L2	80	39,550	850	725	100
	M1	80	39,100	765	740	100
	J1	90	39,550	784	766	100

TABLE 5B. (Continued)

Heat Number	Specimen Number	Testing Temperature, F	Maximum Load, Pounds	Energy to Start Fracture, Ft - Lb	Energy to Propagate Fracture, Ft - Lb	% Shear in Fracture
		Zirconium Series - Type B				
A-7433	K2	40	42,000	950	534	60
	K1	50	40,200	865	700	90
	L1	50	41,350	990	575	75
	L2	50	42,000	1050	860	100
	M1	50	41,650	950	434	45
	M2	60	42,800	1040	984	100
	N1	60	41,250	965	900	100
	N2	60	41,600	1025	734	95
	P1	60	41,850	1020	868	100
A-7434	L1	30	42,450	1110	409	55
	K2	40	42,750	1082	833	100
	L2	40	41,850	1100	117	10
	K1	50	41,600	1020	709	100
	M1	50	40,850	950	158	10
	J2	60	41,300	1050	709	100
	M2	60	40,450	984	725	100
	N1	60	41,300	1035	725	100
	N2	60	40,300	984	709	100
	J1	80	41,400	990	740	100
A-7435	K2	40	42,150	965	150	10
	K1	50	41,700	984	683	100
	L1	50	41,600	1000	342	45
	J2	60	41,900	1000	625	90
	L2	60	41,200	940	900	100
	M1	60	40,800	910	158	15
	M2	70	41,100	940	709	100
	N1	70	40,700	875	150	15
	J1	80	41,300	1077	958	100
	N2	80	42,050	984	875	100
	P1	80	42,800	1040	125	50
	P2	90	41,300	925	400	40
	T1	100	39,850	868	800	100
	T2	100	40,000	900	809	100
	U1	100	40,650	965	860	100
	U2	100	40,500	891	800	100
		Aluminum Series - Low Silicon - Type A				
A-6648	K2	50	39,900	925	67	3
	L2	60	39,300	825	67	3
	N1	70	37,050	750	92	3
	K1	80	36,100	580	33	5
	L1	90	37,300	670	33	5
	M2	100	36,850	675	250	20
	M1	110	36,050	616	616	100
	N2	110	36,050	675	650	100
	Q1	110	36,400	683	742	100
	P2	110	36,500	675	700	100
A-6707	Q1	70	37,000	900	117	10
	S1	80	36,500	967	67	20
	T2	90	35,500	900	616	95
	Q2	90	36,100	950	125	20
	U1	100	35,300	863	650	100
	R1	100	36,600	950	717	100
	T1	100	36,700	783	700	100
	P1	100	37,400	883	800	100

TABLE 5B. (Continued)

Heat Number	Specimen Number	Testing Temperature, F	Maximum Load, Pounds	Energy to Start Fracture, Ft. Lb	Energy to Propagate Fracture, Ft Lb	% Shear in Fracture
A-6708	Q2	60	39,100	985	0	10
	P1	70	38,200	919	601	100
	R1	70	38,500	1035	0	8
	P2	80	38,600	919	601	100
	Q1	80	38,500	1035	701	100
	R2	80	38,200	935	0	8
	S1	90	37,800	885	635	100
	S2	90	37,200	852	668	100
	T1	90	36,600	985	635	100
	T2	90	37,200	902	752	100
A-6709	N1	20	40,200	967	100	7
	R2	30	39,800	972	125	7
	P2	40	39,900	1000	824	100
	R1	40	39,050	923	708	100
	S1	40	39,000	955	92	3
	Q1	42	38,100	919	618	99
	M2	50	39,200	908	1210	100
	P1	50	38,800	969	651	100
	Q2	50	38,750	867	692	95
	S2	50	39,250	962	125	10
	N2	60	38,600	1019	635	100
	T1	60	38,500	930	675	100
	T2	60	38,450	925	716	100
	U1	60	37,750	875	1175	100
	U2	60	37,250	833	734	100
	M1	70	38,400	952	718	100
		Aluminum Series - Low Silicon - Type B				
A-6649	P1	50	42,450	1108	75	5
	L2	60	42,600	1108	175	15
	N2	70	38,900	858	67	10
	P2	80	39,000	842	683	100
	Q2	80	39,050	800	83	10
	Q1	90	38,650	883	708	100
	L1	90	38,550	842	775	100
	R1	90	37,700	708	742	100
	M1	90	38,500	758	716	100
A-7319	J1	80	38,800	940	1010	15
	J2	90	38,950	1100	1210	100
	K1	90	38,850	1040	815	100
	K2	90	38,450	1040	860	100
	L1	90	37,800	990	885	100
A-7320	J2	60	40,000	1050	208	10
	J1	70	40,350	1090	850	100
	K1	70	39,350	1000	715	85
	K2	70	40,050	1082	125	7
	L1	80	39,100	990	775	95
	L2	80	38,600	965	875	100
	M1	80	38,350	990	800	98
	M2	80	38,600	934	784	95
		Aluminum Series - 0.05 % Silicon - Type A				
A-7531	P2	60	39,100	866	117	7
	R2	80	38,750	885	625	90
	Q2	80	38,350	850	734	100
	R1	80	38,250	842	757	100
	L1	80	37,350	815	475	45

TABLE 5B. (Continued)

Heat Number	Specimen Number	Testing Temperature, F	Maximum Load Pounds	Energy to Start Fracture, Ft Lb.	Energy to Propagate Fracture, Ft. Lb	% Shear in Fracture
	L2	90	37,650	808	725	100
	M1	90	38,000	958	1210	100
	M2	90	37,150	800	757	100
	N1	90	38,100	866	707	100
A-7661	L2	60	38,750	933	92	10
	L1	70	37,100	792	658	100
	M1	70	38,700	917	117	10
	M2	80	39,050	975	83	10
	N1	90	37,850	900	817	100
	N2	90	38,500	967	758	100
	P1	90	38,200	867	758	100
	P2	90	38,450	975	775	100
A-7529	M1	60	38,600	750	83	7
	M2	70	39,350	850	50	10
	N1	80	39,200	782	158	20
	N2	90	38,550	782	838	100
	P1	90	39,000	808	775	100
	P2	90	38,550	782	658	100
	Q1	90	38,350	766	858	100
		Aluminum Series - 0.05 % Silicon - Type B				
A-7660	M1	70	39,350	867	100	10
	M2	80	39,000	891	700	100
	N1	80	39,050	891	783	100
	N2	80	39,950	965	1000	100
	P1	80	40,000	958	842	100
A-7662	N1	60	40,950	1100	183	10
	N2	70	40,700	1000	800	100
	P1	70	40,200	1050	891	100
	P2	70	40,450	1020	600	75
	Q1	70	40,700	1010	758	95
A-7530	M1	40	41,550	950	216	20
	M2	50	41,500	958	666	95
	N1	50	41,200	940	650	90
	N2	50	41,000	908	675	95
	P1	50	41,350	920	542	70
	L2	60	40,850	891	750	100
	L1	70	40,400	873	766	100
		Aluminum - 0.05 % Silicon - 0.010 % Nitrogen - TYPE B				
A-7659	M1	70	39,800	850	75	5
	M2	80	40,050	891	282	35
	N1	90	40,700	891	67	5
	P1	110	41,000	891	1330	100
	P2	110	40,350	867	1230	100
	Q1	110	40,350	883	1150	100
	Q2	110	40,900	958	683	98

TABLE 5C. CHARPY IMPACT-TEST DATA FOR STEELS IN THE TITANIUM, ZIRCONIUM, AND ALUMINUM SERIES.

Heat Number	Testing Temperature, F	Charpy Impact Strength, Ft -Lb 1st Test	2nd Test	3rd Test	4th Test
	Titanium Series - Type A				
A-7667	80	28	27	--	--
	60	25	22	22	26
	50	24	23	25	23
	40	5	20	16	14
	30	20	22	13	20
	20	4	10	8	5
	10	4	3	--	--
A-7668	80	28	27	28	27
	70	25	25	27	25
	60	25	23	24	12
	50	23	21	23	19
	40	16	6	20	12
	30	20	5	10	5
A-7665	100	24	25	26	26
	90	26	26	27	25
	80	22	22	23	24
	70	22	20	18	20
	60	15	13	16	14
	40	4	7	--	--
	Titanium Series - TYPE B				
A-7669	80	41	38	--	--
	40	34	33	--	--
	0	30	26	--	--
	-10	6	26	29	27
	-20	5	22	27	7
	-30	16	5	24	4
	-40	6	4	--	--
	-80	2	2	--	--
A-7670	80	41	41	--	--
	40	34	34	--	--
	0	28	31	--	--
	-10	24	23	25	22
	-20	16	4	5	15
	-30	5	4	4	4
	-40	5	5	4	4
	-80	3	2	--	--
A-7671	80	27	31	--	--
	50	25	27	27	29
	40	24	22	24	23
	30	5	15	12	9
	20	5	4	12	9
	10	4	5	4	4
	0	3	3	--	--
	Zirconium Series - TYPE A				
A-7431	80	37	36	--	--
	40	30	33	--	--
	20	28	27	25	27
	10	26	25	28	29
	0	16	16	25	29
	-10	18	6	24	17
	-20	5	24	5	4
A-6699	75	35	32	34	36
	40	31	31	31	31
	20	28	27	27	27
	0	21	21	8	25
	-40	4	7	8	19
	-80	2	2	3	2
A-7432	80	36	34	--	--
	40	32	31	--	--
	0	26	26	27	28
	-10	16	25	25	24
	-20	22	22	10	15
	-30	9	11	14	4
	-40	13	13	10	3
	Zirconium Series - TYPE B				
A-7433	80	4	40	--	--
	40	34	37	--	--
	20	30	33	--	--
	10	22	23	27	28
	0	26	27	19	25
	-10	6	6	5	14
	-20	9	5	4	6
	-40	5	4	--	--

TABLE 5C. (Continued)

Heat Number	Testing Temperature, F	Charpy Impact Strength, Ft -Lb 1st Test	2nd Test	3rd Test	4th Test
A-7434	80	43	43	--	--
	40	40	40	--	--
	0	35	37	--	—
	-20	34	27	--	--
	-30	30	4	29	28
	-40	27	18	29	26
	-50	8	4	8	4
	-60	7	10	11	15
A-7435	80	41	46	--	--
	40	41	41	--	--
	0	33	38	--	--
	-20	33	33	29	32
	-30	31	28	31	26
	-40	4	25	10	28
	-50	4	7	13	25
	-60	3	9	--	--
Aluminum Series - Low Silicon - TYPE A					
A-6648	75	30	28	32	29
	40	25	26	25	26
	20	21	22	18	19
	0	17	11	6	16
	-40	4	3	3	3
A-6707	75	38	35	37	36
	40	29	32	30	33
	0	25	17	19	18
	-40	2	2	3	3
A-6708	75	36	34	--	--
	40	32	30	--	--
	0	6	28	24	26
	-20	4	4	4	21
A-6709	75	45	40	--	--
	40	36	35	--	--
	0	30	30	28	32
	-20	24	25	26	28
	-40	25	23	7	[illegible]
Aluminum Series - Low Silicon - TYPE B					
A-6649	75	37	37	36	36
	40	31	33	31	29
	0	27	28	27	28
	-20	23	20	24	9
	-40	3	4	5	3
A-7319	80	42	41	--	--
	10	37	36	--	--
	0	14	35	34	32
	-10	32	8	35	31
	-20	31	6	--	--
	-40	6	25	21	6
	-50	3	3	8	--
A-7320	80	40	43	--	--
	0	32	24	--	--
	-10	33	8	--	--
	-20	7	27	31	25
	-30	6	24	11	26
	-40	28	20	7	4
	-50	10	22	3	3
	-60	3	3	--	--
Aluminum Series - 0.05 % Silicon - TYPE B					
A-7531	80	35	33	--	--
	40	34	31	--	--
	30	27	28	--	--
	20	27	22	24	27
	10	28	24	26	22
	0	6	25	23	21
	-10	5	19	5	19
	-20	4	10	--	--
A-7661	80	32	37	--	--
	40	32	26	--	--
	20	27	29	--	--
	10	24	26	29	26
	0	20	24	27	20
	-10	21	10	23	14
	-20	9	21	14	4
	-40	4	4	--	--

TABLE 5C. (Continued)

Heat Number	Testing Temperature, F	Charpy Impact Strength, Ft -Lb 1st Test	2nd Test	3rd Test	4th Test
A-7529	80	31	31	--	--
	40	27	25	--	--
	20	10	23	--	--
	10	23	23	25	26
	0	21	21	21	20
	-10	20	20	20	20
	-20	10	19	14	19
	-40	6	7	--	--
Aluminum Series - 0.05 % Silicon - TYPE B					
A-7660	80	40	40	--	--
	40	34	34	--	--
	0	30	32	--	--
	-20	14	6	--	--
	-30	9	20	5	23
	-40	4	25	4	22
	-50	18	6	7	3
	-60	5	3	--	--
	-80	2	2	--	--
A-7662	80	38	39	--	--
	50	33	36	--	--
	40	38	35	--	--
	0	32	30	--	--
	-20	30	25	--	--
	-30	21	8	20	21
	-40	25	17	22	4
	-50	12	3	11	4
	-80	2	2	--	--
A-7530	80	42	43	--	--
	40	38	35	--	--
	0	33	32	--	--
	-40	26	27	--	--
	-50	25	24	23	23
	-60	4	17	22	27
	-70	22	23	17	20
	-80	3	12	4	4
Aluminum - 0.05 % Silicon - 0.010 % Nitrogen - TYPE B					
A-7659	80	35	34	--	--
	40	32	29	--	--
	0	28	27	25	23
	-10	25	25	26	5
	-20	14	25	4	4
	-30	10	3	12	3
	-40	4	3	--	--
	-60	3	3	--	--

TABLE 6A. TENSILE-TEST DATA FOR SPECIAL STEELS

Heat Number	Specimen Number	Yield Strength, psi Upper	Yield Strength, psi Lower	Tensile Strength, psi.	Elongation in 8 In., %
			Vanadium Series		
A-7446	1	35,900	34,500	59,000	33.0
	2	36,100	35,200	59,000	33.5
A-7310	1	39,600	38,000	61,100	28.0
	2	39,400	37,500	60,100	28.5
A-7447	1	39,400	36,100	59,600	32.0
	2	37,400	35,200	59,400	32.5
A-7311	1	39,000	38,300	60,600	30.0
	2	39,200	38,400	60,600	29.0
			Phosphorus Series		
A-7312	1	38,100	35,900	59,600	26.0
	2	37,600	37,000	60,600	30.5
A-7436	1	39,400	37,900	59,100	30.0
	2	39,800	38,100	59,200	30.5
A-7442	1	38,300	36,400	58,900	32.0
	2	38,100	36,300	58,500	33.0
			Molybdenum Series		
A-7313	1	40,200	36,200	63,200	27.0
	2.	39,600	35,900	62,800	27.0
A-7314	1	38,400	37,400	64,400	25.5
	2	39,400	37,600	65,400	24.5

TABLE 6B. NAVY TEAR-TEST DATA FOR SPECIAL STEELS

Heat Number	Specimen Number	Testing Temperature, F	Maximum Load, Pounds	Energy to Start Fracture, Ft -Lb	Energy to Propagate Fracture, Ft -Lb	% Shear in Fracture
			Vanadium Series			
A-7446	E1	70	38,200	950	125	5
	E2	80	38,550	900	175	15
	F1	90	38,450	1067	690	100
	F2	90	37,450	925	700	100
	G1	90	37,150	842	665	100
	G2	90	37,700	885	707	100
A-7310	L1	60	38,350	874	133	15
	L2	70	37,800	800	75	10
	M1	80	36,350	700	757	100
	M2	80	38,350	808	733	100
	N1	80	37,350	708	692	100
	N2	80	38,400	800	766	95
A-7447	F1	50	40,900	1140	92	5
	E2	60	39,400	1080	757	95
	F2	60	39,500	1020	750	90
	G2	60	40,150	1140	125	10
	H1	70	39,250	1050	808	95
	H2	70	40,450	1100	790	95
	J1	70	39,550	990	790	90
	E1	70	39,450	1173	707	90
A-7311	K2	37	41,350	1090	193	20
	L1	40	40,750	1080	125	10
	K1	42	41,200	1100	900	100
	L2	50	40,250	1025	333	15
	M1	60	39,800	1010	166	10
	M2	70	39,250	1020	891	100
	N1	70	40,300	1000	858	100
	N2	70	40,000	1025	75	10
	P1	80	40,550	1020	817	100
	P2	80	40,050	1020	817	100
	Q1	80	40,050	916	824	100
	Q2	80	39,750	942	750	100
			Phosphorus Series			
A-7312	K1	120	38,900	1117	125	40
	J2	130	38,650	1124	807	100
	K2	130	38,650	1040	800	100
	L1	130	38,000	991	733	100
	L2	130	38,000	1040	708	100
	J1	140	40,650	1240	742	100
A-7436	K1	70	43,200	1380	392	55
	K2	80	43,500	1310	825	95
	L1	80	43,350	1530	650	70
	L2	80	41,900	1430	725	95
	M1	80	42,350	1410	100	15
	M2	90	42,200	1470	534	50
	N1	100	41,200	1390	915	5
	N2	110	40,050	1325	675	100
	P1	110	40,000	1310	683	95
	P2	110	39,900	1200	725	100
	Q1	110	39,900	1260	759	95
A-7442	F2	100	38,550	1150	833	15
	F1	110	37,750	1100	740	90
	G1	110	38,700	1210	659	95
	G2	110	38,500	1140	100	15

TABLE 6B. (Continued)

Heat Number	Specimen Number	Testing Temperature, F	Maximum Load, Pounds	Energy to Start Fracture, Ft -Lb.	Energy to Propagate Fracture, Ft -Lb.	% Shear in Fracture
	E1	120	38,200	1120	1535	100
	E2	120	38,300	1040	1820	100
	H1	120	38,550	1275	675	95
	H2	120	37,750	1090	267	25
	J1	130	38,100	1125	675	100
	J2	130	38,550	1185	616	100
	K1	130	38,000	1160	650	100
	K2	130	38,300	1070	591	100
		Molybdenum Series				
A7313	L1	70	38,200	833	50	10
	L2	80	38,750	800	17	15
	M2	90	36,350	716	683	100
	N1	90	36,900	750	168	20
	M1	100	36,900	775	633	100
	N2	100	36,800	750	642	100
	P2	100	37,000	750	225	20
	P1	110	36,050	691	650	100
	Q1	110	36,200	683	617	100
	Q2	110	36,100	650	625	100
	R1	110	36,200	633	657	100
A7314	L1	60	40,500	Pen did not record curve		10
	J1	70	40,300	908	625	95
	J2	70	40,450	942	608	90
	K1	70	40,000	967	600	95
	K2	70	39,550	900	708	100

TABLE 6C. CHARPY IMPACT-TEST DATA FOR SPECIAL STEELS

Heat No.	Testing Temp., F	Charpy Impact Strength, Ft-lb 1st Test	2nd Test	3rd Test	4th Test
		Vanadium Series			
A7446	80	34	39	-	-
	40	30	33	-	-
	20	25	28	23	26
	10	20	22	26	23
	0	10	19	22	23
	-10	5	4	11	4
	-20	5	4	9	3
A7310	80	36	34	-	-
	40	31	30	28	29
	30	28	30	-	-
	20	24	26	8	27
	10	25	26	24	23
	0	5	5	20	22
	-10	4	18	19	6
A7447	80	47	47	-	-
	40	39	39	-	-
	20	35	38	38	38
	0	38	9	-	-
	20	31	28	30	30
	30	30	9	26	7
	40	4	5	-	-
	60	3	3	-	-
	80	2	3	-	-
A7311	80	42	42	-	-
	0	31	31	-	-
	-10	32	31	-	-
	-20	4	25	34	29
	-30	25	28	-	-
	-40	25	26	23	7
	-50	4	3	3	5
	-60	3	-	-	-
		Phosphorus Series			
A7312	80	28	38	-	-
	40	34	28	30	22
	30	33	32	26	9
	20	6	7	7	7
	0	4	4	-	-
A7436	80	40	40	-	-
	40	38	37	-	-
	10	25	31	34	22
	0	27	31	4	28
	-10	3	4	3	3
	-20	3	3	3	3
	-40	3	2	-	-
A7442	80	21	40	-	-
	40	33	35	-	-
	20	28	35	8	8
	10	31	12	6	5
	0	5	30	6	26
	-10	4	20	5	4
	-20	4	3	4	4
		Molybdenum Series			
A7313	80	31	29	-	-
	40	26	24	24	26
	30	21	25	-	-
	20	19	23	21	20
	10	19	20	6	19
	0	4	7	13	13
	-15	9	7	9	5
A7314	80	35	34	-	-
	30	27	30	29	27
	20	27	10	27	28
	10	28	25	25	9
	0	15	26	7	6
	-10	15	5	6	20
	-20	12	4	-	-

TABLE 7A. TENSILE-TEST DATA FOR COMMERCIAL STEELS FINISHED AT VARIOUS TEMPERATURES

Heat Number	Finishing Temp., F	Specimen Number	Yield Strength, psi		Tensile Strength, psi	Elongation in 8 In., %
			Upper	Lower		
58x428	1650	1	40,500	39,200	69,600	27.5
		2	40,000	39,200	69,500	27.0
58x428	1850	1	40,700	38,400	69,800	26.0
		2	42.200	38,200	70,000	30.0
58x428	1950	1	39,400	37,300	69,600	26.0
		2	40,000	38,100	70,000	27.5
58x428	1960*	1	35,600	34,300	71,500	26.0
		2	35,100	34,200	71,200	26.5
58x428	2050	1	38,200	36,000	68,400	25.5
		2	38,900	35,800	69,500	25.0
50x426	1650	1	39,800	39,000	60,600	32.0
		2	39,500	38,400	61,400	31.5
50x426	1850	1	36,000	35,000	59,300	33.5
		2	35,900	34,500	59,200	33.0
50x426	1950	1	35,200	34,200	61,500	32.0
		2	35,500	34,600	61,600	28.5
50x426	1970*	1	31,800	31,100	59,000	30.5
		2	33,600	30,900	59,100	30.5
50x426	2050	1	33,800	32,900	61,300	30.0
		2	34,200	33,600	61,300	30.5
5779	1650	1	36,100	34,600	59,100	34.5
		2	35,500	34,200	59,300	33.5
5779	1700*	1	33,600	32,800	59,000	30.0
		2	33,600	32,400	59,200	30.0
5779	1850	1	36,000	33,900	59.500	31.5
		2	34,200	33,300	59,500	33.0
1046	1650	1	39,200	37,200	61,000	35.0
		2	39,500	37,700	61,500	33.0
1046	1700*	1	37,200	32,700	60,900	31.0
		2	36,700	32,900	60,900	31.0
1046	1850	1	40,600	38,800	66,500	32.5
		2	40,800	39,400	66,000	24.5
4666	1725*	1	31,300	29,200	59,700	27.0
		2	31,300	29,200	59,200	27.0

* Finished in a Commercial Mill

TABLE 7B. NAVY TEAR-TEST DATA FOR COMMERCIAL STEELS FINISHED AT VARIOUS TEMPERATURES

Heat Number	Finishing Temp., F	Specimen Number	Testing Temp., F	Maximum Load, Pounds	Energy to Start Fracture, Ft -Lb	Energy to Propagate Fracture, Ft -Lb	% Shear in Fracture
58x428	1650	J1	60	41,300	708	92	2
		J2	80	40,250	757	258	20
		K1	90	40,300	683	600	100
		L1	90	40,350	716	117	15
		K2	100	39,600	919	601	100
		L2	100	40,000	710	609	100
		M1	100	40,150	751	1101	100
		M2	100	39,550	676	576	100
58x428	1850	J1	60	40,600	808	58	2
		J2	80	39,100	674	83	5
		K1	90	37,950	625	200	20
		K2	100	39,700	642	585	100
		L1	100	39,250	609	575	100
		L2	100	40,100	635	601	100
		M1	100	39,400	617	601	100
58x428	1950	H2	70	38,400	565	58	2
		J1	80	37,500	1023	67	5
		J2	90	38,150	583	100	15
		H1	100	37,850	608	700	100
		K1	100	37,850	600	117	20
		K2	110	37,050	740	625	100
		L1	110	36,400	525	67	20
		L2	120	37,800	583	683	100
		M1	120	37,800	690	565	100
		M2	120	37,500	633	466	100
		N1	120	36,550	658	583	100
58x428	1960*	A1	70	41,100	651	0	5
		A2	80	42,400	835	0	25
		B2	90	40,400	668	0	8
		C1	100	41,000	601	0	8
		D1	110	39,700	567	83	15
		C2	120	40,400	585	484	95
		D2	120	39,750	600	125	15
		E1	130	39,550	567	567	100
		E2	130	39,600	583	258	30
		F1	140	39,800	568	585	100
		F2	140	39,400	534	576	100
		1	140	39,550	575	609	100
		2	140	40,000	600	534	95
58x428	2050	H1	80	38,350	658	50	5
		J1	120	36,600	550	150	20
		H2	130	36,750	543	565	95
		J2	130	36,450	525	300	45
		K1	140	36,150	575	575	100
		K2	140	35,000	475	600	100
		L1	140	35,500	515	591	100
		L2	140	36,600	534	515	95
50x426	1650	A2	50	42,700	1292	125	5
		A1	60	42,250	1245	818	100
		B1	60	41,100	1135	878	100
		B2	60	41,100	1278	844	100
		C1	60	41,400	1145	1748	100

TABLE 7B. (Continued)

Heat Number	Finishing Temp., F	Specimen Number	Testing Temp., F	Maximum Load, Pounds	Energy to Start Fracture, Ft -Lb	Energy to Propagate Fracture, Ft -Lb	% Shear in Fracture
50x426	1850	C1	50	39,500	1308	583	40
		A1	60	39,100	1277	1277	100
		A2	60	38,750	1244	1560	100
		B1	60	38,750	1295	960	90
		B2	60	39,100	1220	1110	100
50x426	1950	H1	80	41,550	1182	184	18
		H2	90	40,250	1075	740	100
		J1	90	39,250	950	900	100
		J2	90	40,600	1090	659	90
		K1	90	41,500	1125	750	95
50x426	1970*	B2	70	40,200	1119	0	10
		A1	76	40,900	1202	718	100
		A2	80	40,900	1069	1269	90
		B1	80	41,200	1119	818	100
		C2	80	41,200	1219	0	5
		C1	90	40,600	1202	768	100
		D1	90	40,400	1086	1152	100
		D2	90	40,000	1052	786	100
		E1	90	40,400	1069	802	100
50x426	2050	H2	60	40,600	1070	67	20
		J1	70	39,200	958	67	5
		H1	80	38,800	1010	750	100
		J2	80	39,450	1000	92	10
		K1	90	39,700	1390	67	50
		K2	100	40,200	1140	725	100
		L1	100	40,200	1167	725	100
		L2	100	40,950	1140	750	100
		M1	100	40,100	1077	750	100
5779	1650	A1	60	40,300	816	50	2
		A2	80	38,250	775	33	10
		B1	90	38,350	893	1210	100
		B2	90	39,550	951	960	100
		C1	90	37,400	835	1594	100
		C2	90	38,050	876	701	100
5779	1700*	C1	50	38,800	969	0	10
		A2	60	38,900	1019	701	90
		B1	60	39,400	935	635	100
		B2	60	39,100	952	635	100
		C2	60	38,800	919	0	5
		A1	70	38,100	768	1804	100
		D1	70	38,600	902	1386	100
		D2	70	38,800	969	0	10
		E1	80	38,100	835	1536	100
		E2	80	38,900	902	1820	100
		F1	80	38,400	885	618	50
		F2	90	37,600	919	585	100
		G1	90	37,100	818	1645	100
		G2	90	36,550	826	1570	100
		H1	90	36,950	726	667	100
5779	1850	J1	60	37,600	892	165	3
		K1	70	37,600	817	165	10
		J2	80	36,350	768	685	100
		K2	80	36,550	794	1237	90
		L1	80	37,150	860	543	90
		L2	80	35,700	802	660	100
1046	1650	K1	40	41,950	1173	108	8
		J2	50	41,300	1019	2370	100
		K2	50	41,950	1128	2490	100
		L1	50	41,700	1151	860	100
		L2	50	42,400	1228	2320	100
		J1	60	42,200	1160	1400	100

TABLE 7B. (Continued)

Heat Number	Finishing Temp., F	Specimen Number	Testing Temp., F	Maximum Load, Pounds	Energy to Start Fracture, Ft -Lb	Energy to Propagate Fracture, Ft -Lb	% Shear in Fracture
1046	1700*	C1	50	40,800	1035	0	3
		A2	60	41,400	1119	651	95
		B1	60	41,000	1035	1971	100
		B2	60	41,200	1086	835	100
		C2	60	41,400	1086	919	100
		A1	70	40,200	1035	668	100
1046	1850	F1	50	41,500	1090	100	3
		D1	60	40,600	1102	2235	100
		D2	60	40,650	960	960	100
		E1	60	41,050	1119	626	100
		E2	60	40,800	1070	844	100
24666	1725*	H1	80	34,250	559	446	85
		H2	80	33,800	466	100	10
		J1	90	33,600	559	450	95
		J2	90	34,900	459	440	100
		K1	90	33,150	484	475	98
		K2	90	34,300	408	491	100

* Finished in a Commercial Mill

TABLE 7C. CHARPY IMPACT DATA FOR COMMERCIAL STEELS FINISHED AT VARIOUS TEMPERATURES

Heat Number	Finishing Temperature, F	Testing Temperature, F	Charpy Impact Strength, Ft -Lb			
			1st Test	2nd Test	3rd Test	4th Test
58x428	1650	80	24	26	--	--
		40	22	20	22	23
		20	20	21	21	20
		10	20	23	19	--
		0	18	19	16	5
		-15	16	4	18	9
		-30	3	3	3	--
58x428	1850	80	24	26	--	--
		40	23	23	20	20
		30	21	21	21	21
		20	20	20	16	21
		10	18	20	20	13
		0	16	9	--	--
		-15	16	8	11	5
58x428	1950	80	26	25	--	--
		50	22	23	24	23
		40	24	22	17	20
		30	20	20	20	12
		20	16	19	16	21
		10	8	15	17	8
		0	11	10	--	--
58x428	1960*	75	23	22	20	21
		60	21	22	23	27
		50	25	24	23	24
		40	19	18	19	20
		30	21	22	7	--
		20	9	22	7	4
58x428	2050	80	27	23	--	--
		60	22	25	22	25
		50	24	22	17	24
		40	23	20	20	19
		30	20	17	20	19
		20	15	17	4	20
		0	4	5	--	--
50x426	1650	80	50	49	--	--
		0	40	38	--	--
		-40	36	26	28	31
		-50	30	31	27	22
		-60	6	14	3	29
		-60	5	30	--	--
		-70	8	3	7	3
50x426	1850	80	46	49	--	--
		0	38	33	--	--
		-20	33	29	5	25
		-30	19	27	28	5
		-40	31	29	4	5
		-50	5	4	8	4
		-60	3	4	3	3
50x426	1950	80	48	44	--	--
		40	41	38	--	--
		0	32	31	34	27
		-10	25	31	26	27
		-20	4	21	5	5
		-30	23	18	9	23
		-40	3	4	4	7
50x426	1970*	75	48	49	--	--
		40	41	43	--	--
		0	37	28	34	9
		-10	27	5	28	--
		-20	12	31	29	33
		-30	7	5	13	15
		-40	4	12	14	26
50x426	2050	80	39	41	--	--
		40	40	37	--	--
		0	33	31	--	--
		-10	33	29	23	12
		-20	20	6	27	11
		-30	9	4	4	5
		-40	13	14	6	9
		-50	3	3	--	--

TABLE 7C. (Continued)

Heat Number	Finishing Temperature, F	Testing Temperature, F	Charpy Impact Strength, Ft -Lb			
			1st Test	2nd Test	3rd Test	4th Test
5779	1650	80	36	33	--	--
		20	23	22	7	--
		10	5	6	20	5
		0	18	21	19	19
		0	9	6	--	--
		-10	18	20	16	5
		-20	5	9	3	4
		-30	14	7	--	--
5779	1700*	80	29	31	--	--
		60	26	26	--	--
		40	27	28	28	27
		30	20	22	24	25
		20	23	23	9	25
		10	14	21	19	21
		0	14	18	--	--
5779	1850	80	35	34	--	--
		20	23	20	--	--
		10	19	21	22	6
		0	5	16	14	18
		0	20	19	--	--
		-10	5	4	13	19
		-20	5	4	4	4
		-30	3	4	--	--
1046	1650	80	50	50	--	--
		0	36	36	--	--
		-30	33	32	32	32
		-40	27	7	19	6
		-50	28	5	22	4
		-60	5	23	5	16
		-70	3	3	2	5
1046	1700*	75	47	49	--	--
		40	41	40	--	--
		0	30	35	31	34
		-10	34	30	36	--
		-20	34	6	28	30
		-30	34	26	6	13
		-40	4	4	8	28
1046	1850	80	50	52	--	--
		0	35	33	--	--
		-30	33	28	37	37
		-40	28	25	27	27
		-50	14	6	25	24
		-60	25	15	5	9
4666	1725*	100	23	21	20	20
		90	22	20	19	20
		75	20	19	17	20
		70	18	19	21	19
		60	19	18	20	17
		40	14	8	--	--
		0	3	3	--	--

* Finished in a Commercial Mill