SERIAL NO. **SSC-73**

SSC-73

A REVIEW

of the

INFLUENCE OF COMPOSITION AND DEOXIDATION on the PROPERTIES OF SHIP PLATE STEELS

by
ADVISORY COMMITTEE
for
SHIP STRUCTURE COMMITTEE PROJECT SR-110
at Battelle Memorial Institute

Transmitted through

NATIONAL RESEARCH COUNCIL'S
COMMITTEE ON SHIP STEEL

Advisory to

SHIP STRUCTURE COMMITTEE

SERIAL NO. **SSC-73**
BuShips Project NS-011-078

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

November 16, 1953

SHIP STRUCTURE COMMITTEE

MEMBER AGENCIES:

BUREAU OF SHIPS, DEPT. OF NAVY
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AMERICAN BUREAU OF SHIPPING

ADDRESS CORRESPONDENCE TO:

SECRETARY
SHIP STRUCTURE COMMITTEE
U. S. COAST GUARD HEADQUARTERS
WASHINGTON 25, D. C.

November 16, 1953

Dear Sir:

As part of its research program related to the improvement of hull structures of ships, the Ship Structure Committee is sponsoring an investigation on the influence of chemical composition and deoxidation on the properties of semikilled ship steel at the Battelle Memorial Institute. This project is being conducted with the advisory assistance of the Committee on Ship Steel of the National Academy of Sciences-National Research Council.

Herewith is a copy of a report prepared by the advisory group for this project, entitled "A Review of the Influence of Composition and Deoxidation on the Properties of Ship Plate Steels." This report summarizes and discusses some of the more important findings obtained to date on this investigation, which is still active.

This report is being distributed to those individuals and agencies associated with and interested in the work of the Ship Structure Committee.

Yours sincerely,

K K Cowart
K. K. COWART
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

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Prepared for

National Research Council's
Committee on Ship Steel

Advisory to

SHIP STRUCTURE COMMITTEE

under

Department of the Navy
Bureau of Ships Contract NObs-50148
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A REVIEW OF THE INFLUENCE OF COMPOSITION AND DEOXIDATION ON THE PROPERTIES OF SHIP PLATE STEELS

I. INTRODUCTION

Upon the recommendation of the Committee on Ship Steel of the National Academy of Sciences-National Research Council, Project SR-110 was established late in 1949 at Battelle Memorial Institute by the Ship Structure Committee. Direct guidance of the project was provided by an advisory group appointed by the Committee on Ship Steel.

The purpose of the project was to study the influence of chemical composition and deoxidation on the transition temperature and tensile properties of 200-pound laboratory melts of semikilled ship steel rolled into 3/4-inch plates. Two base compositions were investigated--one, a 0.25% C and 0.45% Mn type, similar to ABS Class A; and the other, a 0.21%C and 0.75% Mn type, similar to ABS Class B. The principal deoxidizing elements studied were silicon and aluminum. Some of the experimental heats were made with deoxidizers added in amounts above 0.10% Si or 0.010% Al. Such heats would be classified as killed rather than semikilled. Some of these conformed to the base compositions of ABS Class C steel, which is a 0.15 to 0.30% Si type made to fine-grained practice (usually containing about 0.03% acid soluble aluminum).

As the project approached completion, it was apparent that certain relations had become reasonably well established(1).

This, coupled with the interest expressed by the Ship Structure Subcommittee in exploring the possibility of using steels of lower carbon content and hence lower tensile strength to obtain lower transition temperature, prompted the Committee on Ship Steel to request the Project SR-110 Advisory Committee to review the results of the investigation and prepare this interpretive report.

II. THE RELATION OF TRANSITION TEMPERATURE CHARACTERISTICS OF HULL STEEL TO SERVICE PERFORMANCE

The transition temperature of steel may be broadly defined as a temperature in the range in which the type of failure under stress changes from a fracture with ductile characteristics to one with brittle characteristics. Ductile failures are associated with high energy absorption prior to failure as compared to relatively low energy absorption for brittle failures. This characteristic applies to fractures of steel structures as well as of steel laboratory specimens. A structure which above its transition temperature will behave in a ductile manner may fail in a brittle manner below the transition temperature.

In the case of a structure such as a welded ship, varying amounts of restraint are present, and at certain points multiaxial stress conditions may occur. Various types of laboratory specimens have been developed to test the performance of steel under multiaxial stress conditions. Transition temperatures of these specimens are the temperatures at which the rupture behavior changes from ductile to brittle and the rupture mode from shear to cleavage. These transition temperatures are not necessarily the same for different specimen types.

Transition temperatures referred to in this review are based on the Navy Tear Test and the keyhole Charpy impact test, which were used in the Battelle investigation; and the V-notch Charpy test, which was used in the investigation of steel from failed ships at the National Bureau of Standards. (Project SR-106). With all test methods, a decrease in transition temperature reflects an increase in toughness.

The most comprehensive evaluation of ship steel in terms of service performance and notched-bar transition temperatures has been performed by the National Bureau of Standards(2). Their tests were made on plate samples taken from ships built in wartime and which failed in service. Fig. 1, based on this study, indicates that the average 15 ft-lb transition temperature for 25 plates in which fractures started was 100°F in V-notch Charpy tests. The average transition temperature for 70 plates in which fractures passed through or stopped was 60°F by the same test criterion. Both groups showed a range of transition temperatures but none of the plates in which fractures passed through or stopped showed a transition temperature over 100°F. Conversely, none of the plates in which

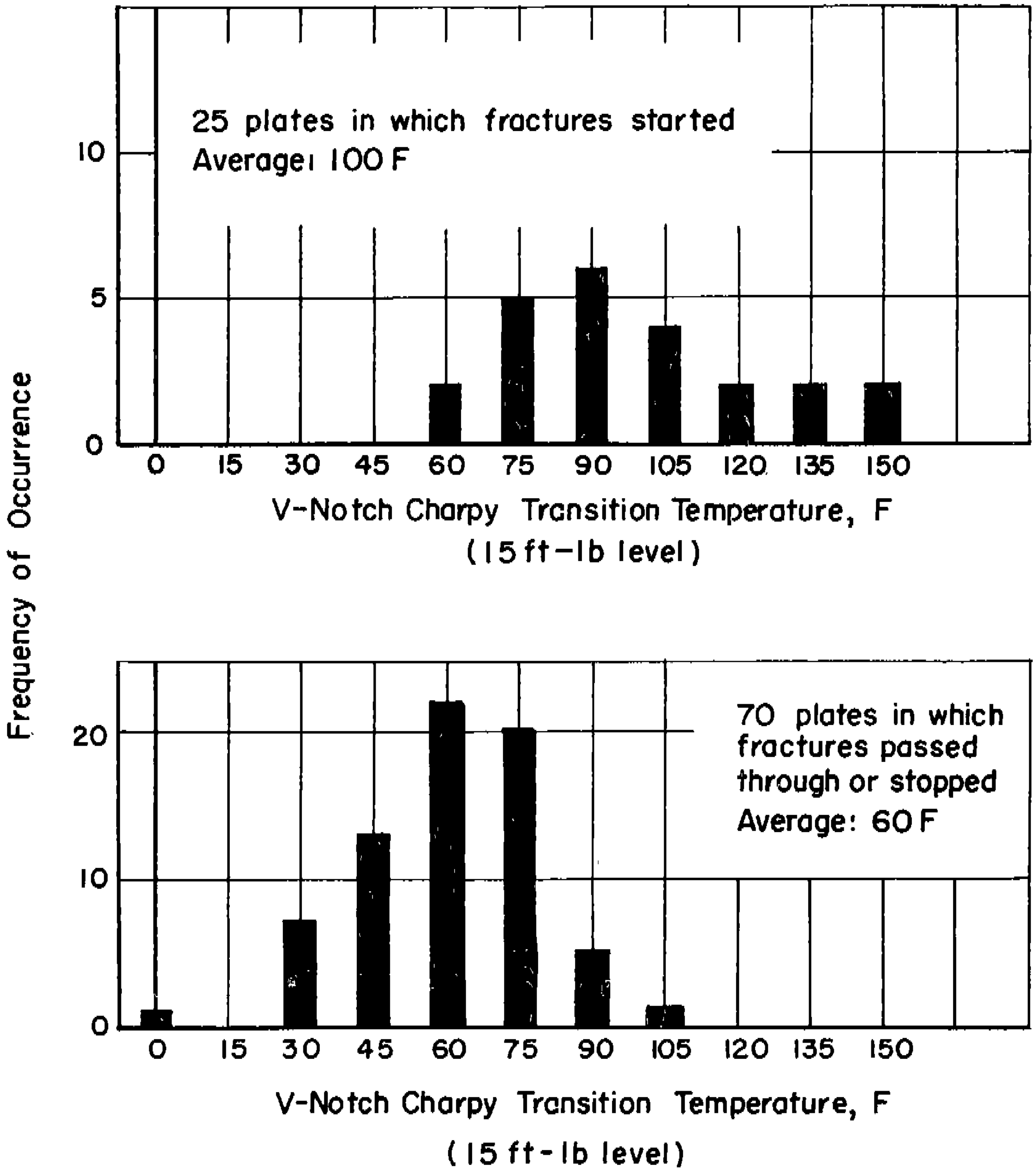

FIGURE 1. COMPARISON OF V-NOTCH CHARPY TRANSITION TEMPERATURES OF PLATES FROM FRACTURED SHIPS BUILT IN WAR TIME (Adapted from Reference 2)

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failures started had a transition temperature under 60°F. This difference in transition temperatures between the two groups is significant and classifies the quality of the steels in accordance with their known service histories. Using the generally accepted(3,4) method of subtracting 30°F from 15 ft-lb V-notch Charpy transition temperatures, the corresponding 20 ft-lb keyhole Charpy transition temperatures are 70°F and 30°F.

III. RELIABILITY OF DATA FROM LABORATORY MELTS

An important part of the Battelle investigation was to determine how closely semikilled steels made and processed in the laboratory matched commercial steels. It was established early in the work that the compositions and tensile properties of commercial plates could be reproduced consistently. Of even more importance, convincing evidence shows that the notched-bar properties of the laboratory heats agreed closely with those available on commercial ship plate. Some of this evidence is worth mentioning.

The properties of 18 laboratory heats at two manganese levels can be compared with those for 48 commercial Class A and Class B steels. The average properties of the laboratory steels are listed in Table 1. The keyhole Charpy transition temperatures of the two grades of commercial ABS ship plates are shown in Fig. 2. It should be emphasized that a particular

TABLE 1. PROPERTIES(#) OF 18 SEMIKILLED STEELS MADE AND PROCESSED IN THE LABORATORY

	Type A (10 Heats)	Type B (8 Heats)
Carbon Content, per cent	0.22 ± .01	0.20 ± .02
Manganese Content, per cent	0.45 ± .02	0.76 ± .03
Silicon Content, per cent	0.04 ± .01	0.05 ± .02
Phosphorus, per cent	0.015 ± .002	0.015 ± .002
Nitrogen, per cent	0.004 ± .0005	0.004 ± .0006
Tensile Strength, psi	61,175 ± 1300	62,150 ± 1080
Elongation in 8 inches, per cent	29.2 ± 2.2	29.0 ± 2.5
Tear Test* Transition Temp., F	+80 ± 13.7	+70 ± 7.1
Keyhole Charpy** Transition Temp., F	+21 ± 13.6	-15 ± 8.0

(#) Data are shown as averages plus or minus the standard deviation.

* Highest temperature at which at least one specimen broke with less than 50% shear texture. Not more than four specimens were tested at any temperature.

** Based on 20 ft-lb level. This criterion is used throughout this report.

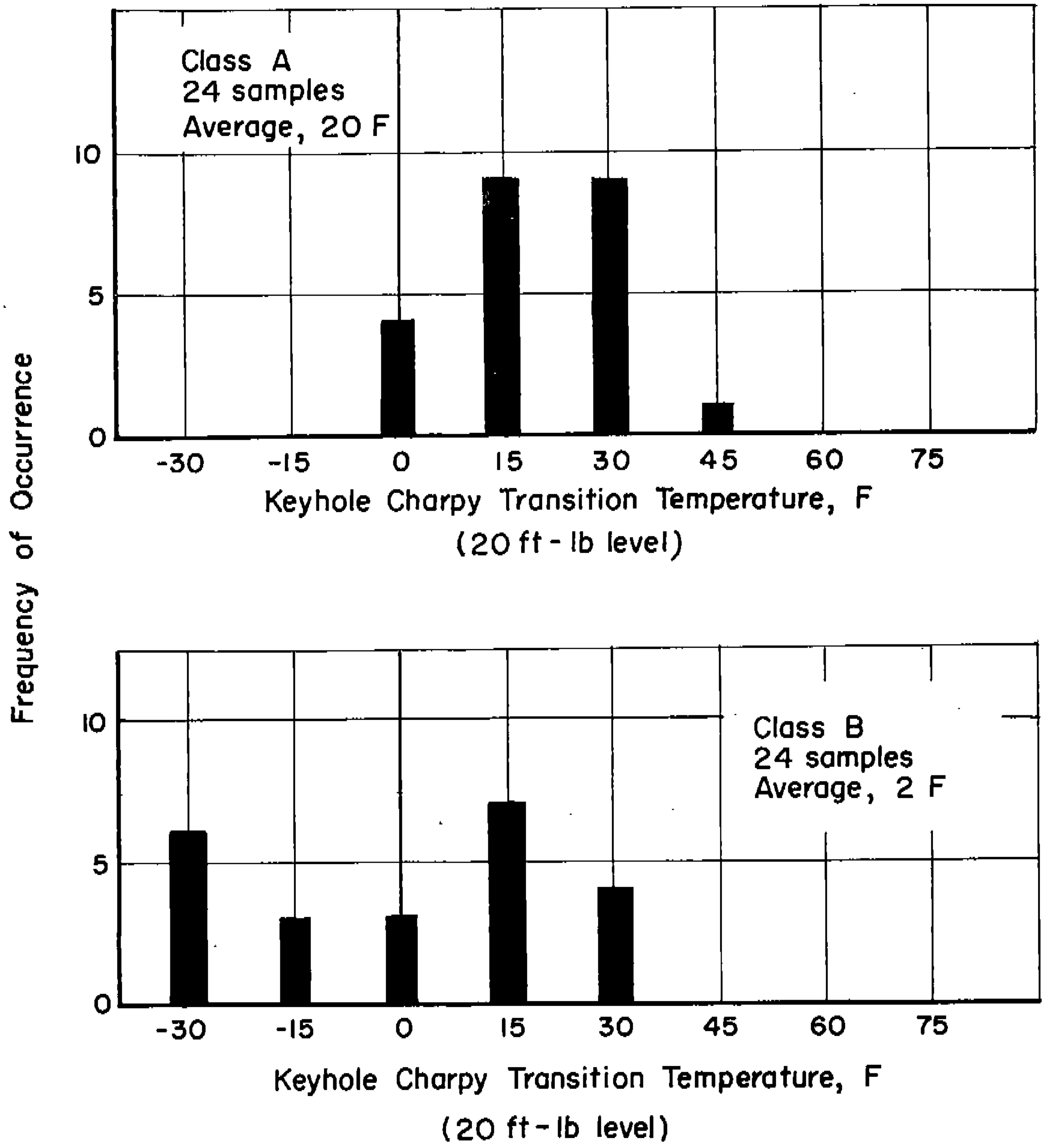

FIGURE 2. COMPARISON OF KEYHOLE CHARPY TRANSITION TEMPERATURES OF $^3/_4$ - INCH ABS STEELS
(Adapted from Reference 3)

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grade of steel is characterized by a certain range in transition temperatures rather than a certain temperature. The data in Figs. 1 and 2 illustrate this point.

The average Charpy transition temperatures of the Class A steels and the comparable laboratory steels are almost identical, +20°F and +21°F, respectively.

The agreement between the commercial Class B steels and the comparable laboratory steel is poorer. This is not surprising because the flat distribution curve for the Class B steels in Fig. 2 indicates that the samples in this group varied appreciably in quality, and 2°F may not be typical of the average transition temperature of Class B steels. The average transition temperature of the comparable laboratory steels was -15°F. The discrepancy between -15°F and +2°F is not serious because of the limits of precision of Charpy tests and the lack of information on the composition and rolling temperatures for the Class B steels in Fig. 2.

The formulas in Table 2 show the effects of carbon and manganese on the properties of semikilled steels as determined in the Battelle investigation. The equations are based on data from twenty-five steels made and rolled in the laboratory, using a finishing temperature of 1850°F. The formula for tensile strength permits another check on the similarity of laboratory and commercial plates. The Battelle formula for laboratory steels and others published for commercial

TABLE 2. EQUATIONS FOR CALCULATING THE EFFECTS OF CARBON AND MANGANESE ON THE PROPERTIES OF HOT-ROLLED, SEMIKILLED STEELS(A)

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(1) Tensile Strength, psi = 30,800 + (104,000 x % C) + (13,000 x % Mn)
Standard error of estimate = 2200 psi

(2) Tear Test Transition Temperature, F = 17 + (330 x % C) - (23 x % Mn)
Standard error of estimate = 10 F

(3) Keyhole Charpy Transition Temperature, F = K* - 19 + (349 x % C) - (74 x % Mn)
Standard error of estimate = 12 F

(A) The formulas are based on laboratory 3/4-inch plates finished at 1850 F. The steels contained approximately 0.015% P, 0.004% N, 0.05% Si, and less than 0.01% Al.

* K is a factor that varies with the manganese content, as shown below:

% Mn.	"K"	% Mn.	"K"
0.20	+6 F	0.90	-8 F
0.30	+3 F	1.00	-5 F
0.40	+1 F	1.10	-2 F
0.50	-1 F	1.20	+2 F
0.60	-3 F	1.30	+5 F
0.70	-6 F	1.40	+8 F
0.80	-8 F	1.50	+12 F

steels can be used to calculate the tensile strengths expected for the average compositions listed in Table 1. This leads to the comparison in Table 3, which shows that the strengths predicted by Equation 1 of Table 2 agree quite well with actual values given in Table 1. Furthermore, actual tests and estimates based on the laboratory formula both give tensile strengths intermediate between the strengths predicted by formulas developed and used for commercial hot-rolled plates.

In this report the tensile strength of laboratory steels containing 0.25% carbon and 0.45% manganese or 0.21% carbon and 0.75% manganese is considered to be 62,500 psi. This value for tensile strength agrees quite well with the formula in Table 2 and with experimental data in Table 1 corrected for the small differences in composition. In later sections of this report, the formulas in Table 2 will be used to adjust for small differences in carbon or manganese contents in some experimental steels so that comparisons can be made between steels with the same strength--62,500 psi.

In any long-term investigation it is important to check the constancy of experimental procedures. For this reason, it should be noted that the steels summarized in Table 1 were made and processed at intervals over a three-year period. The standard deviations for data on steels intended to be alike are quite small. This indicates that experimental

TABLE 3. COMPARISON OF TENSILE STRENGTHS ESTIMATED BY FORMULAS WITH AVERAGE VALUES FOR SEMI-KILLED LABORATORY STEELS*

Source of Formula or Estimate	Type A*	Type B*
Commercial Steels, Quest and Washburn(5)	58,100	61,100
Commercial Steels, Washburn**	61,600**	63,400**
Laboratory Steels, Battelle	59,600	62,400
Laboratory Steels, Experimental Values	61,200	62,200

* Compositions used for the comparisons are given in Table 1. The Battelle formula and the experimental data are for laboratory steels rolled with a finishing temperature of 1850°F.

** Revised formula given in a private communication.

conditions were controlled well enough that data obtained at different periods of the study can be compared safely.

The tear test transition temperature appears to be more sensitive to the influence of nitrogen and less sensitive to the effect of manganese than the Charpy transition temperature.

The effect of mangasese can be illustrated by an example using the data in Table 1 of this report.

	0.45% Mn Steel	0.75% Mn Steel
Average Transition Temperature in Tear Tests, F	80	70
Average Transition Temperature in keyhole Charpy Tests, F	+21	-15
Average Difference in Transition Temperature, F	59	85

These data and the formulas in Table 2 show that the differences in transition temperatures as determined by the two types of tests depend more on manganese than on carbon.

Data to be discussed later (Figs. 7 and 8) show that nitrogen must also be taken into account in any effort to convert between Charpy and tear test transition temperatures. This complicating influence of nitrogen has also been noted in attempts to convert data from fast and slow notched bend tests.

For these reasons estimating tear test transition temperatures from Charpy data is not justified.

IV. EFFECT OF FINISHING TEMPERATURE AND FERRITIC GRAIN SIZE ON TRANSITION TEMPERATURE

The temperature at which hot rolling is completed was found to have an important effect on the transition temperatures of steel plates. Tests on laboratory steels and on open-hearth plates re-rolled in the laboratory established the beneficial effects of lower rolling temperatures. Data on both types of laboratory steel, illustrated by Fig. 3, indicate that decreasing the finishing temperature below 1850°F improved the transition temperature. Fig. 3 is based on Charpy data. Tear tests also showed similar relations among transition temperature, grain size and finishing temperature. Qualitatively two re-rolled commercial plates responded similarly; increasing the finishing temperature above 1850°F increased their transition temperatures.

The ferritic (as-rolled) grain size of a particular steel is largely governed by the minimum temperature at which it was hot worked and the rate of cooling through the transformation range. The numbers near the points in Fig. 3 show the number of ferrite grains per unit area in the various plates. Obviously, a significant increase in ferritic grain size resulted from the increases in finishing temperatures. Consequently, a correlation exists between finer ferritic grain sizes and lower (better) transition temperatures. Although ferritic grain size is important, it does not outweigh

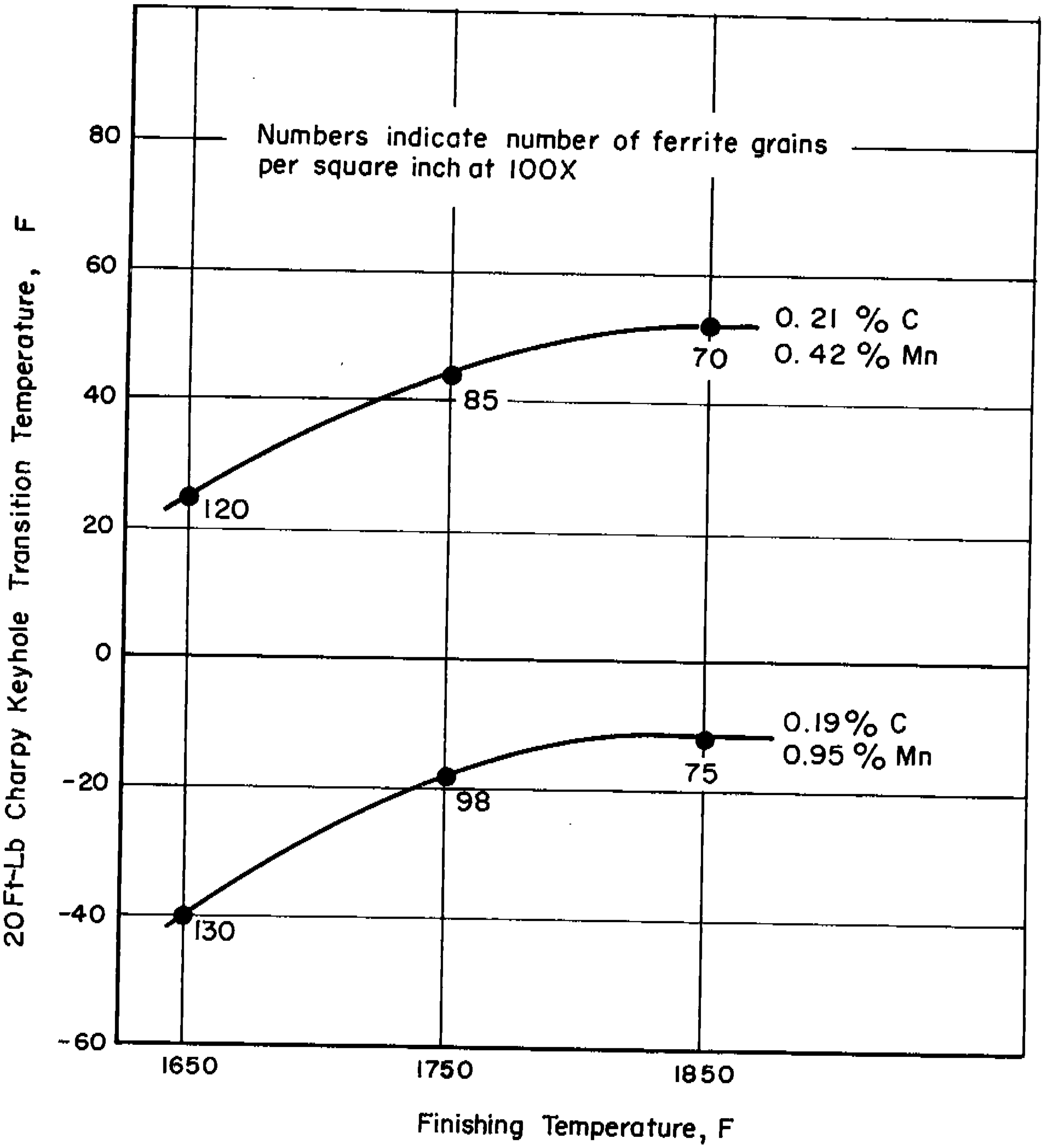

FIGURE 3. EFFECT OF FINISHING TEMPERATURE ON TRANSITION TEMPERATURE AND FERRITE GRAIN SIZE ON TWO LABORATORY SEMIKILLED STEELS

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the other effects of composition. Almost all of the differences shown in Fig. 3 between the transition temperatures of the two types of steel are attributable to their differences in carbon and manganese contents.

Under the Battelle contract, it was not feasible to vary rolling temperatures for a large number of laboratory heats. Therefore, this method of altering grain size could not be used to establish the effect of as-rolled grain size on transition temperatures quantitatively.

It would be difficult to lower finishing temperatures in rolling mills in order to improve the transition temperatures of ship plate. Plate and strip mills are designed to roll and finish at relatively high temperatures, with 1850°F as an example for 3/4-inch plates. A reduction of 200°F in finishing temperature might result in lower production rates, increased power requirements, greater roll wear, and more difficulty in maintaining gauge.

One alternative to controlling ferritic grain size by rolling temperatures is to normalize ship plates. Normalizing from 1650°F can refine the grain size and improve the notch bar toughness. At the present time normalizing is not feasible as a means of controlling the grain size on large tonnages of ship steel because of limitations in production facilities and capacities.

V. EFFECT OF COMPOSITION ON TRANSITION TEMPERATURE

a. Carbon and Manganese

Carbon raises and manganese lowers the transition temperature as illustrated by the data for laboratory steels plotted in Fig. 4. Because of the importance of these elements, Battelle produced and tested a series of twenty-five compositions in which carbon and manganese varied independently. The formulas given in Table 2 were obtained from the data for these laboratory melts. In addition to the twenty-five melts from which the equations were calculated, it was found that these equations agree quite well with experimental data for 3/4-inch plates finished from the other laboratory melts of semikilled steel.

Figs. 5 and 6 show the relationship between manganese and carbon ratio and transition temperatures in the Navy tear test and the Charpy keyhole test. This is a convenient way of demonstrating the influence of carbon and manganese on notch toughness of steels with the same tensile strength. The data are for actual determinations on laboratory melts segregated according to tensile strength. There is a correlation between strength and transition temperature because both are influenced by carbon and manganese.

Increases in carbon and manganese contents which raise the tensile strength without changing the manganese and carbon ratio will have the net result of increasing the transition

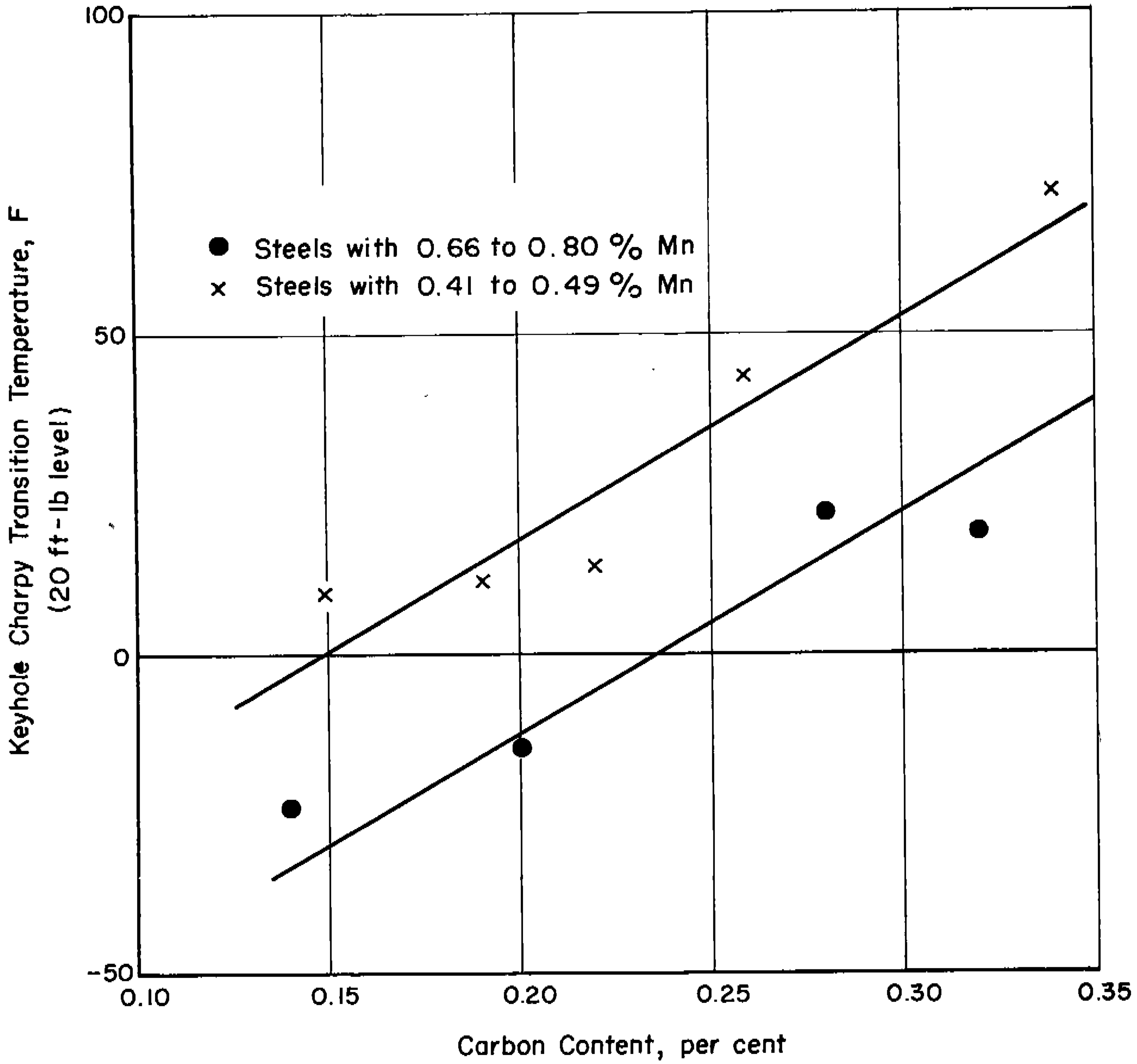

FIGURE 4. INFLUENCE OF CARBON ON CHARPY TRANSITION TEMPERATURE OF SEMIKILLED STEELS WITH TWO MANGANESE LEVELS

Trend lines from formula in Table 2 for steels with 0.45 or 0.75 % Mn.

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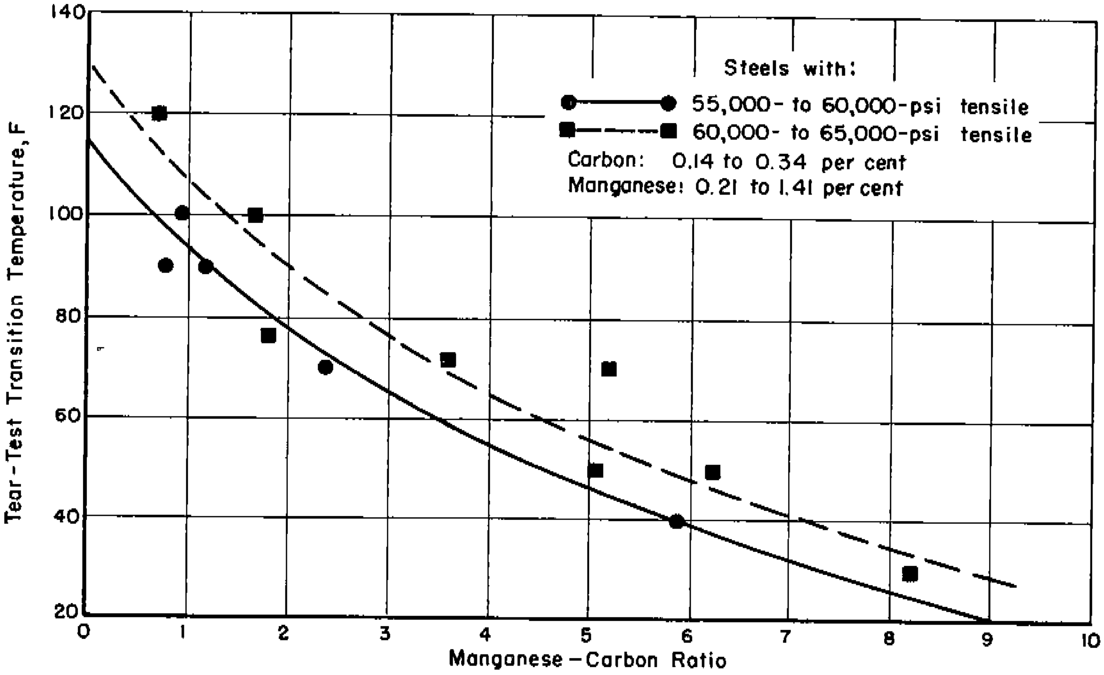

FIGURE 5. RELATIONSHIP BETWEEN MANGANESE-CARBON RATIO AND TEAR-TEST TRANSITION TEMPERATURE FOR EXPERIMENTAL SEMIKILLED STEELS WITH VARIOUS TENSILE STRENGTHS

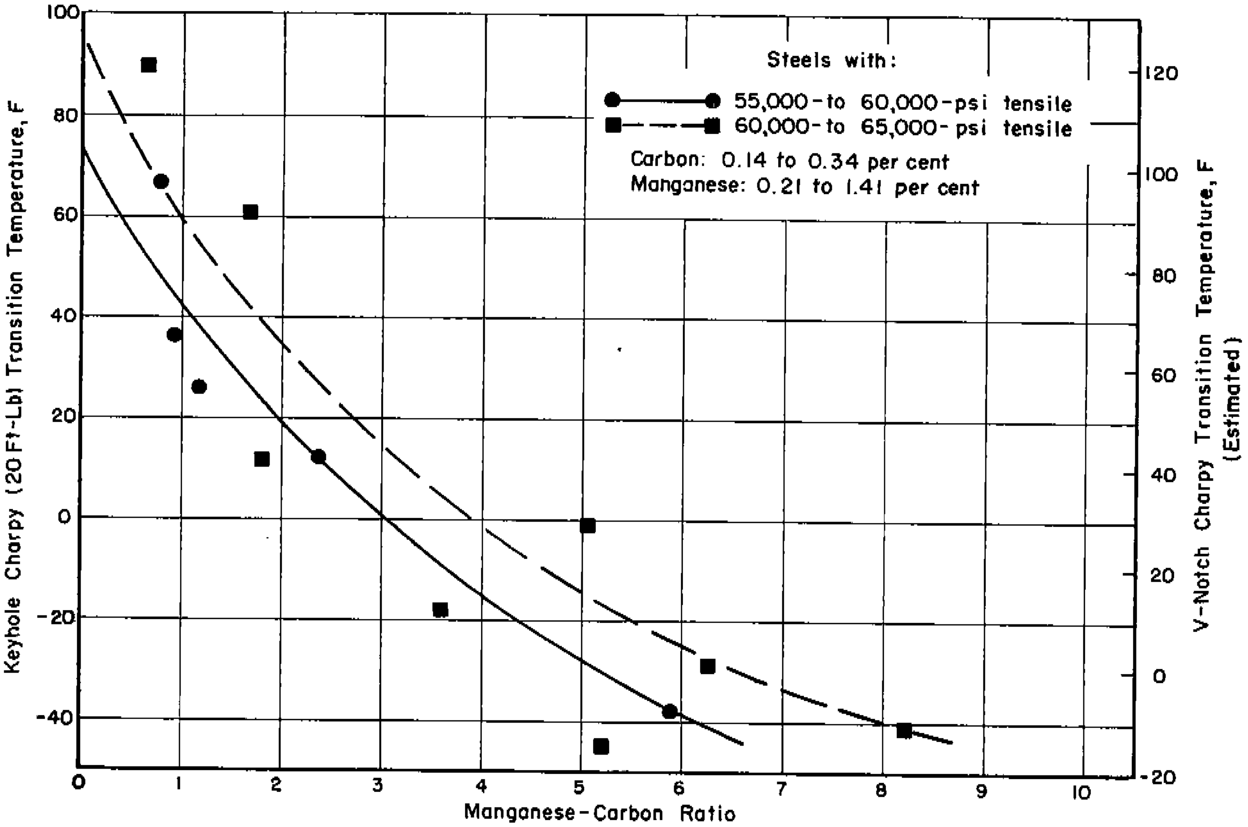

FIGURE 6. RELATIONSHIP BETWEEN MANGANESE-CARBON RATIO AND KEYHOLE CHARPY TRANSITION TEMPERATURE FOR EXPERIMENTAL SEMIKILLED STEELS WITH VARIOUS TENSILE STRENGTHS

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temperature. The formulas, based on twenty-five melts, confirm this relationship for manganese and carbon ratios below 5.

Table 4 shows that carbon and manganese also differ in their effects on the energy values for Charpy tests at temperatures above the transition temperature. The data indicate that strengthening hot-rolled semikilled steels by increasing the carbon content is detrimental from the standpoint of the effect on the Charpy energy value. On the other hand, Table 4 shows that raising the manganese content at a constant carbon level improves the Charpy values for specimens tested above the transition temperature.

b. Phosphorus and Nitrogen

The effects of phosphorus and nitrogen on the transition temperatures of semikilled steels with tensile strengths of 62,500 psi are shown in Figs. 7 and 8. Fig. 7 refers to steels containing 0.45% manganese; Figure 8 to steels with 0.75% manganese. Both phosphorus and nitrogen strengthen steel. Consequently, appropriate calculations were made to maintain a constant tensile strength for these comparisons. These adjustments were made by taking into consideration the effect of carbon on strength and transition temperature.

The charts indicate that substituting nitrogen or phosphorus for carbon, while maintaining a constant tensile strength, results in a higher transition temperature. At a

TABLE 4. KEYHOLE CHARPY VALUES IN FOOT-POUNDS OF HOT-ROLLED SEMIKILLED STEELS, DIFFERING IN CARBON OR MANGANESE CONTENTS, TESTED AT 75 to 80 F*

Manganese Content, per cent	Carbon Content, per cent				
	0.14/0.17	0.18/0.20	0.21/0.25	0.26/0.28	0.31/0.34
0.20/0.25	44	33	28	23	19
0.40/0.50	38	36	32	24	20
0.65/0.85	55	38	38	28	24
0.86/1.05	--	42	--	31	30
1.06/1.25	57	56	--	--	--
1.26/1.50	--	50	46	--	34

* Most of the values quoted are averages for tests on four specimens. All data were obtained on samples taken from 3/4-inch plates rolled at 1850 F from laboratory melts of semikilled steel.

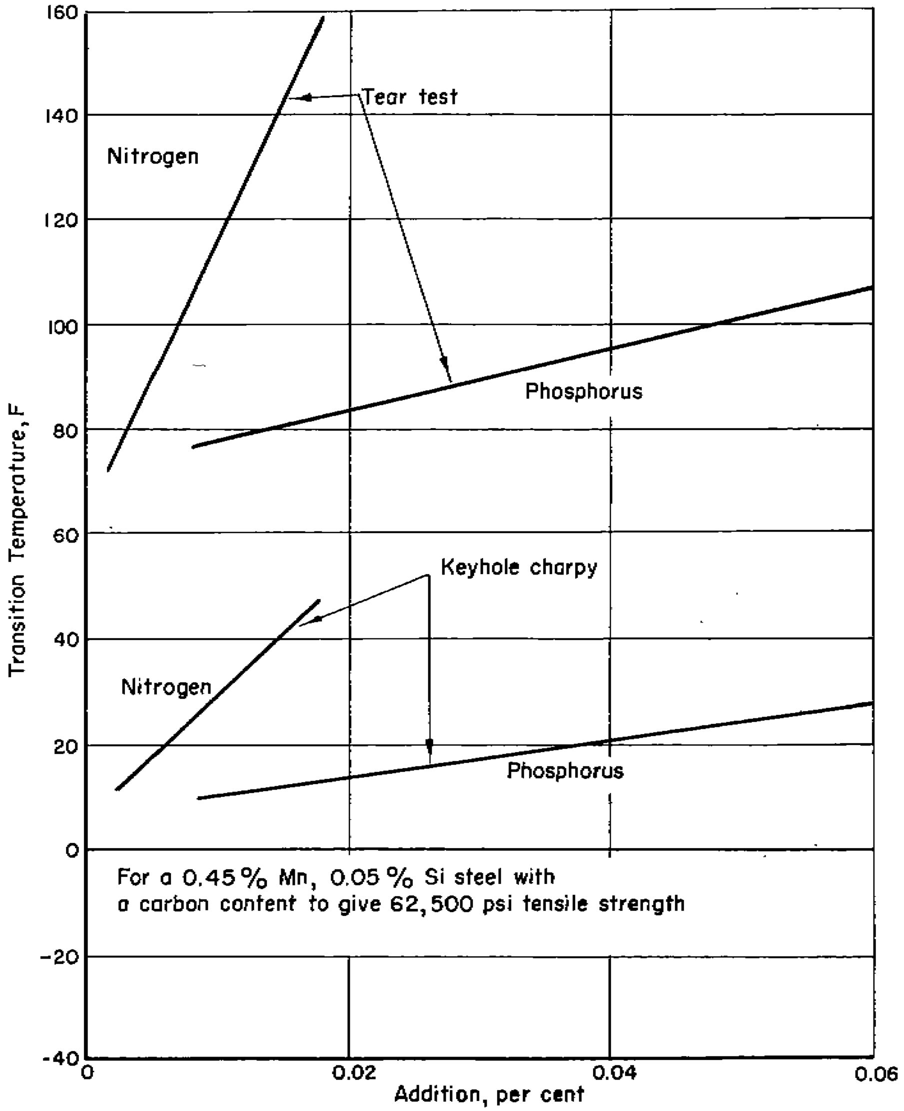

FIGURE 7. EFFECT OF PHOSPHORUS AND NITROGEN ON CHARPY AND TEAR-TEST TRANSITION TEMPERATURES AT 0.45 % MANGANESE STEELS CORRECTED TO 62,500-PSI TENSILE STRENGTH

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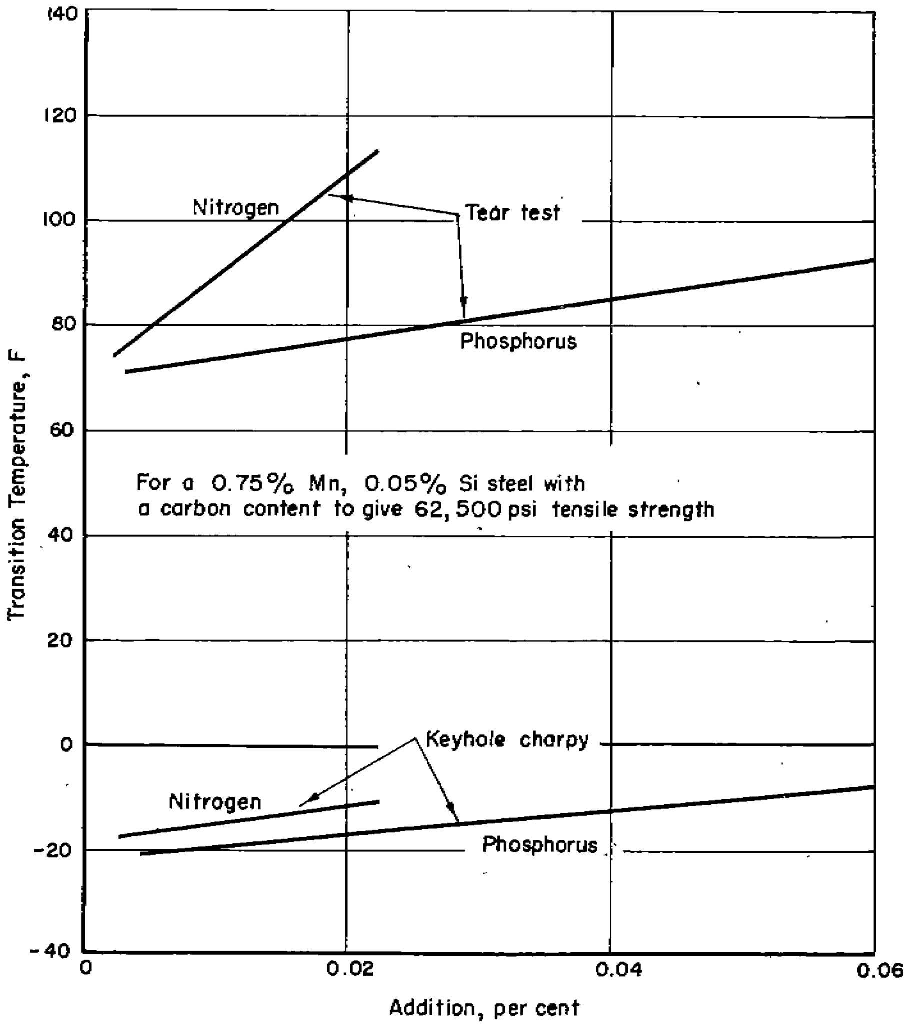

FIGURE 8. EFFECT OF PHOSPHORUS AND NITROGEN ON CHARPY AND TEAR-TEST TRANSITION TEMPERATURES IN 0.75 % MANGANESE STEELS CORRECTED TO 62,500-PSI TENSILE STRENGTH

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strength level of 62,500 psi, the harmful effects of phosphorus and nitrogen appear to be less marked in steels with the higher manganese level. This effect of the manganese level is less apparent if the steels are compared on the basis of constant carbon content rather than constant tensile strength.

Another important conclusion from the Battelle investigation is that the tear test is more sensitive to the effects of nitrogen than the Charpy test. This is shown by variations in slopes of the trend lines in Figs. 7 and 8. The charts for steels of equal tensile strengths show striking quantitative differences in the effect of nitrogen on transition temperatures determined in the two types of tests. The change in transition temperature is three to eight times as large in tear tests as the change in Charpy tests. This is attributed to strain aging which might occur during the greater duration of the tear test. The tear test, like the Charpy test, indicates that the lower-manganese steels are more susceptible to embrittlement by nitrogen.

c. Silicon

The evaluation of the effect of silicon is complicated by the fact that silicon functions both as a deoxidizer and as an alloying element. Figs. 9 and 10 show the effect of silicon on transition temperatures for Type A and Type B steels. It should be noted that the curves represent the

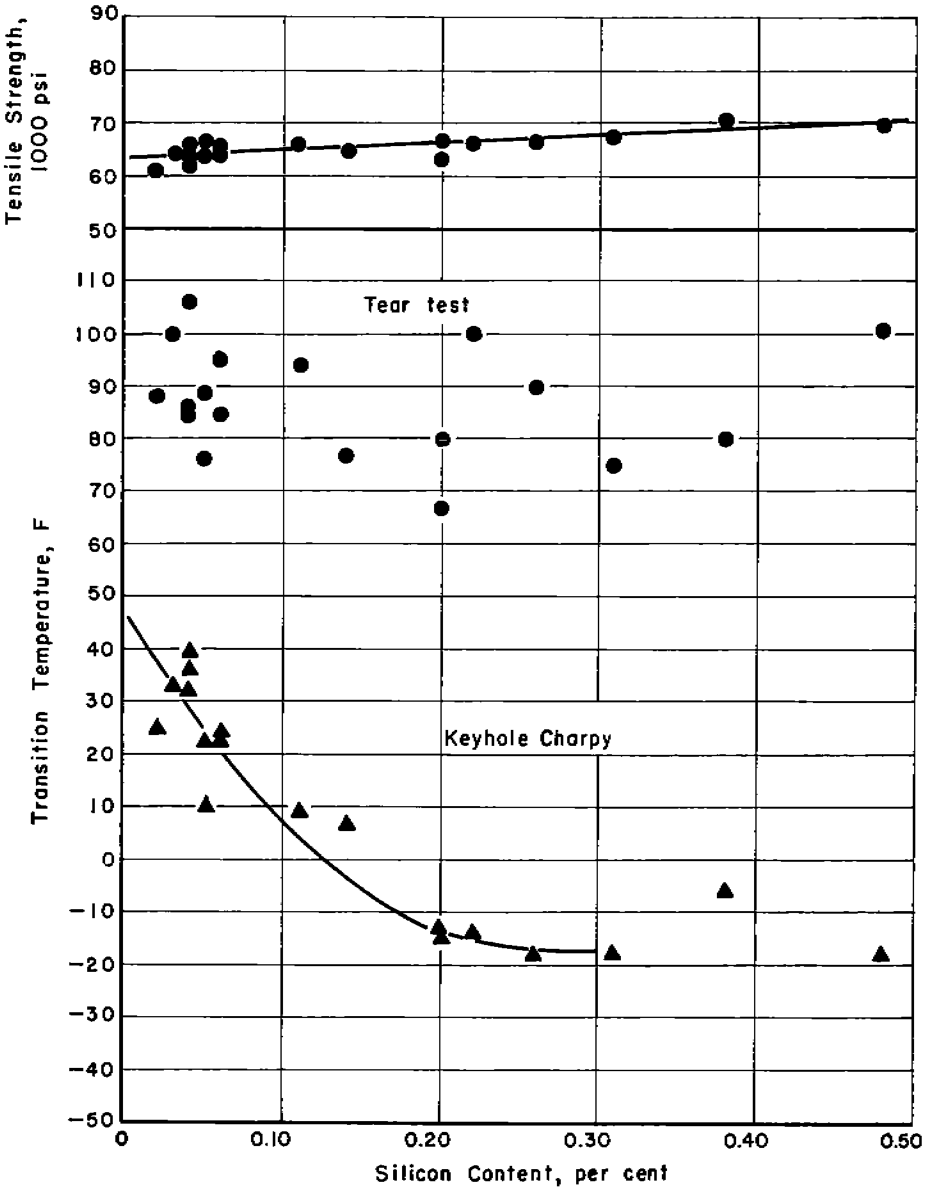

FIGURE 9. EFFECT OF SILICON CONTENT ON TENSILE STRENGTH AND TRANSITION TEMPERATURE; PROPERTIES CORRECTED TO CORRESPOND TO A STEEL CONTAINING 0.25 % C AND 0.45 % Mn

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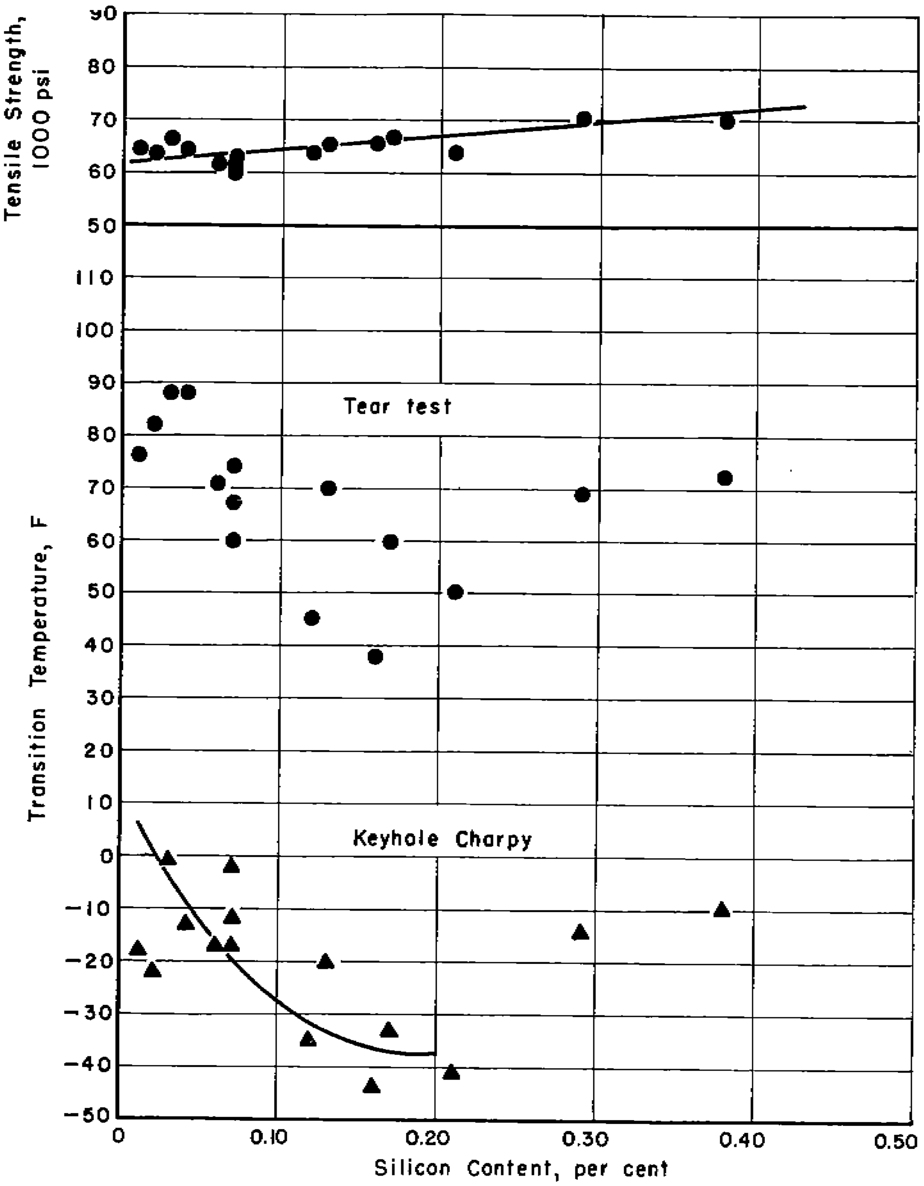

FIGURE 10. EFFECT OF SILICON CONTENT ON TENSILE STRENGTH AND TRANSITION TEMPERATURE; PROPERTIES CORRECTED TO CORRESPOND TO A STEEL CONTAINING 0.21 % C AND 0.75 % Mn

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properties of steels which differ in tensile strengths because of the variations in silicon content. All data points were adjusted for minor differences in carbon and manganese contents to the base analyses indicated. It was not feasible to make similar corrections for silicon in order to make comparisons at a constant strength level. The formulas previously cited were determined from steels with 0.05% silicon and might not be applicable for higher silicon steels. It should be recognized, however, that correcting for strength by lowering the carbon content would result in some lowering of the transition temperature curves with increasing silicon.

The Battelle data indicate that the Charpy transition temperature decreases with increases in silicon up to a certain amount, above which this effect may be reversed. The tear test data lend some support to the opinion that there is an optimum silicon content above which this element is deleterious. However, Fig. 9 shows that the tear test was not so convincing as the Charpy data in establishing the existence of a reversal. The agreement between testing methods is better in Fig. 10 for steels containing 0.75% manganese. There is evidence that the reversal occurs at a lower silicon content when the manganese content is high, but the available data are insufficient to confirm this point.

The initial effect of silicon in lowering the Charpy transition temperature may be a result of deoxidation by the first increments of silicon. In larger quantities silicon apparently functions as an alloying element and in this role raises the transition temperature. The earlier investigation by Rinebolt and Harris(6) on fully killed steels showed that silicon in the range from 0.2 to 1.0% increases the transition temperature. Other studies(7) indicated that silicon as an alloying element lowers the Charpy values of aluminum killed cast steels tested at 75°F and -25°F.

In considering silicon as a means for lowering the transition temperature of ship steel, it must be recognized that only a limited amount can be used in semikilled steels. Steel containing more than about 0.10% silicon is usually considered a killed steel.

Fig. 11 shows the effect of silicon on the transition temperatures of 0.75% manganese laboratory steels made with and without aluminum. An acid soluble aluminum content of 0.03% is approximately the amount necessary to produce "fine-grained" fully killed steels. The Charpy tests indicate that the fine-grained, aluminum-treated steels have lower transition temperatures than those free of aluminum.

d. Aluminum

The effect of aluminum on the Charpy and tear test transition temperatures is shown in Figs. 12 through 15. The heats plotted in these graphs were produced with silicon contents of .01%, .05%, and .10%.

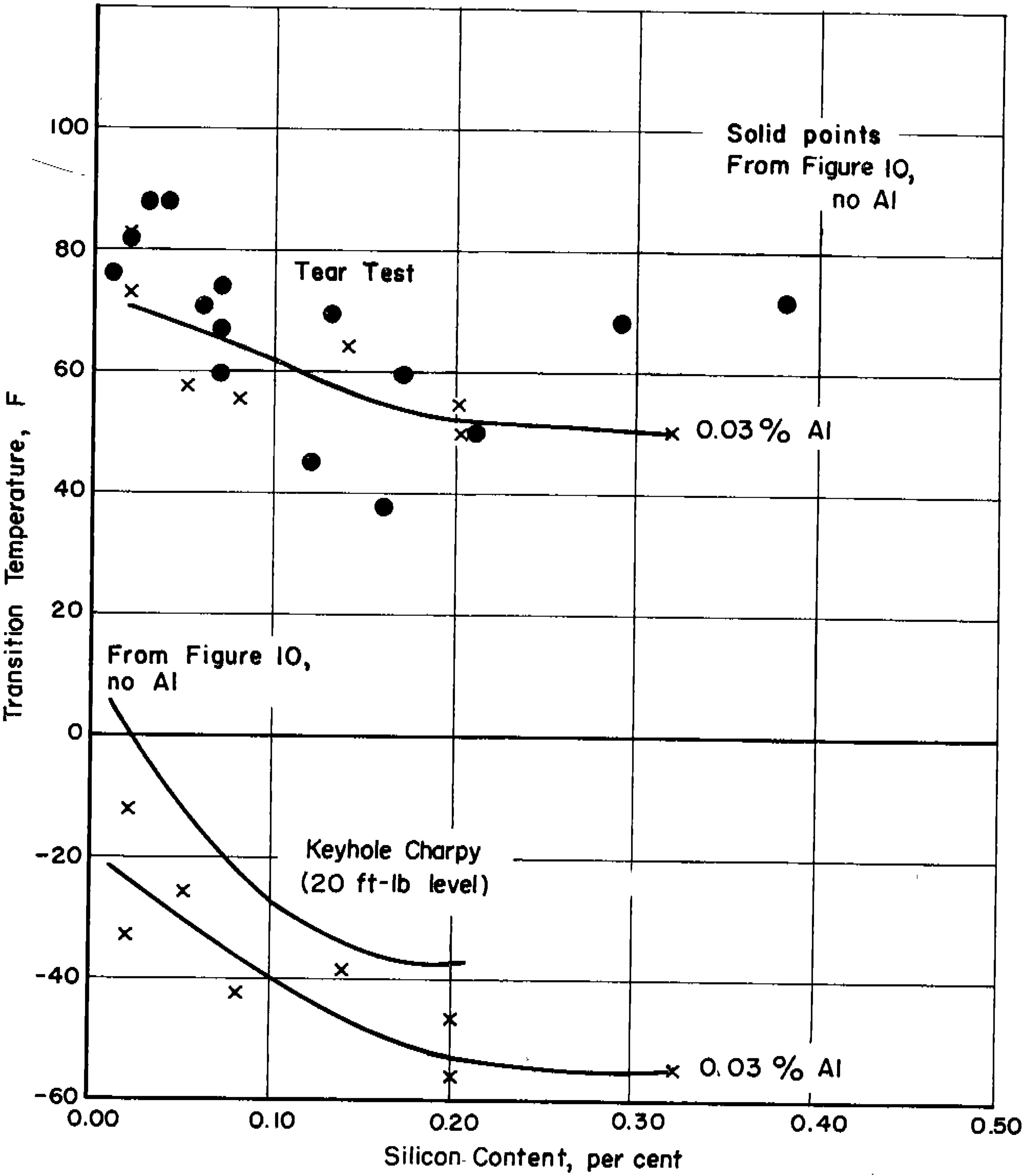

FIGURE 11. EFFECT OF SILICON IN STEELS CONTAINING 0.75 PER CENT MANGANESE, WITH AND WITHOUT ALUMINUM, ON KEYHOLE CHARPY AND TEAR-TEST TRANSITION TEMPERATURE

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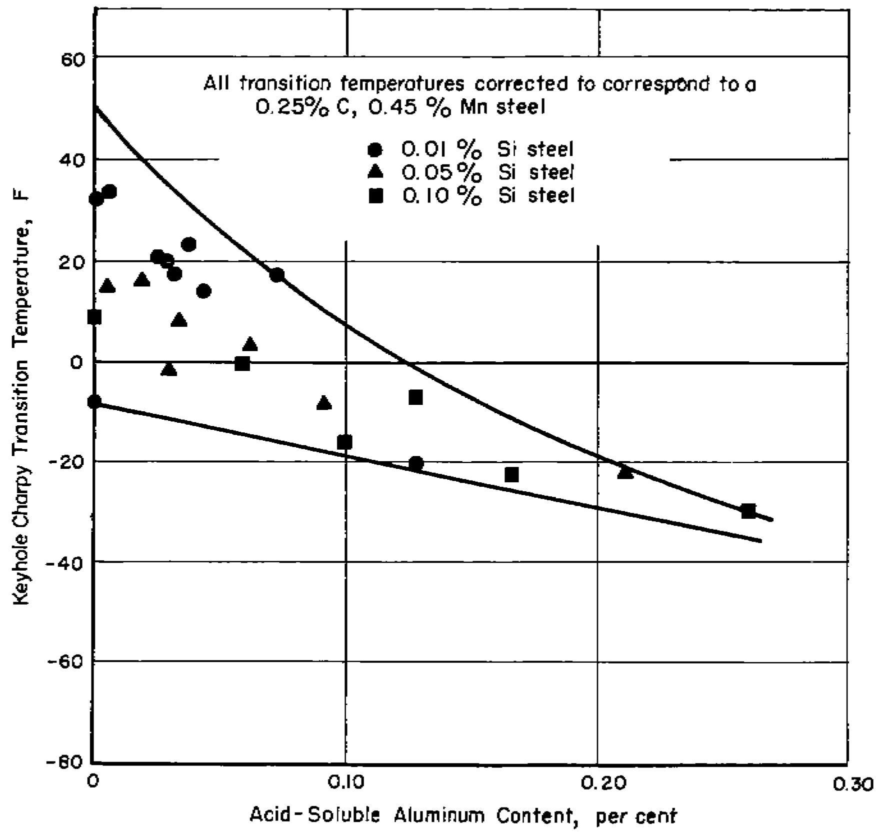

FIGURE 12. EFFECT OF ALUMINUM ON KEYHOLE CHARPY TRANSITION TEMPERATURE IN STEELS CONTAINING 0.25 % CARBON AND 0.45 % MANGANESE WITH 0.01 %, 0.05 %, AND 0.10 % SILICON

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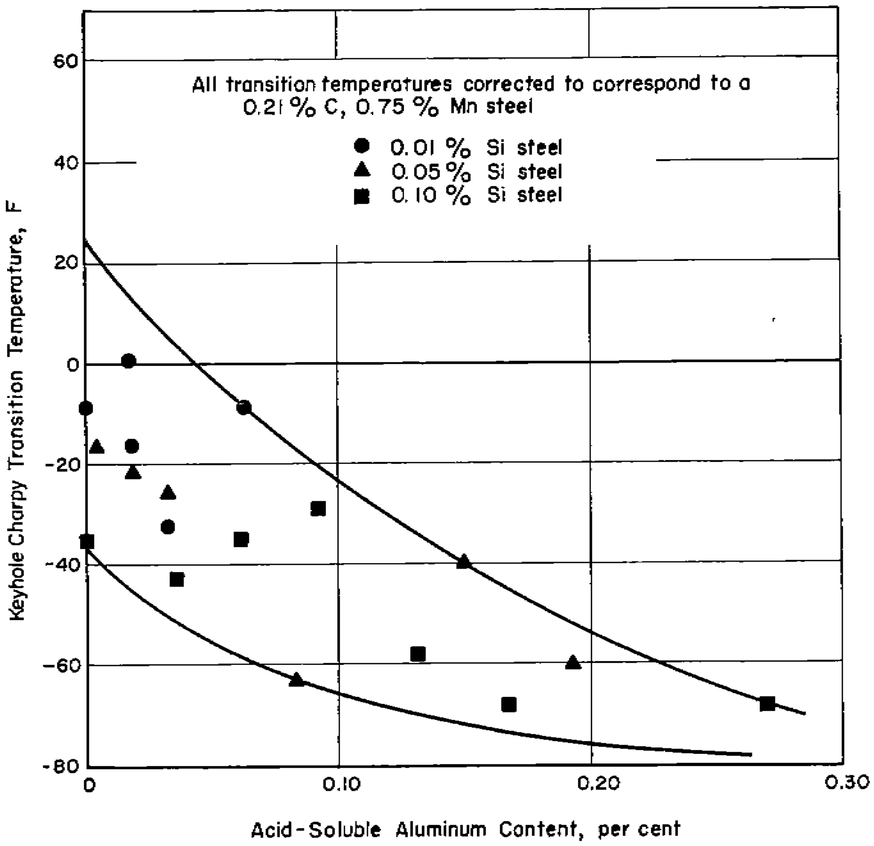

FIGURE 13. EFFECT OF ALUMINUM ON KEYHOLE CHARPY TRANSITION TEMPERATURE IN STEELS CONTAINING 0.21 % CARBON AND 0.75 % MANGANESE WITH 0.01 %, 0.05 %, AND 0.10 % SILICON

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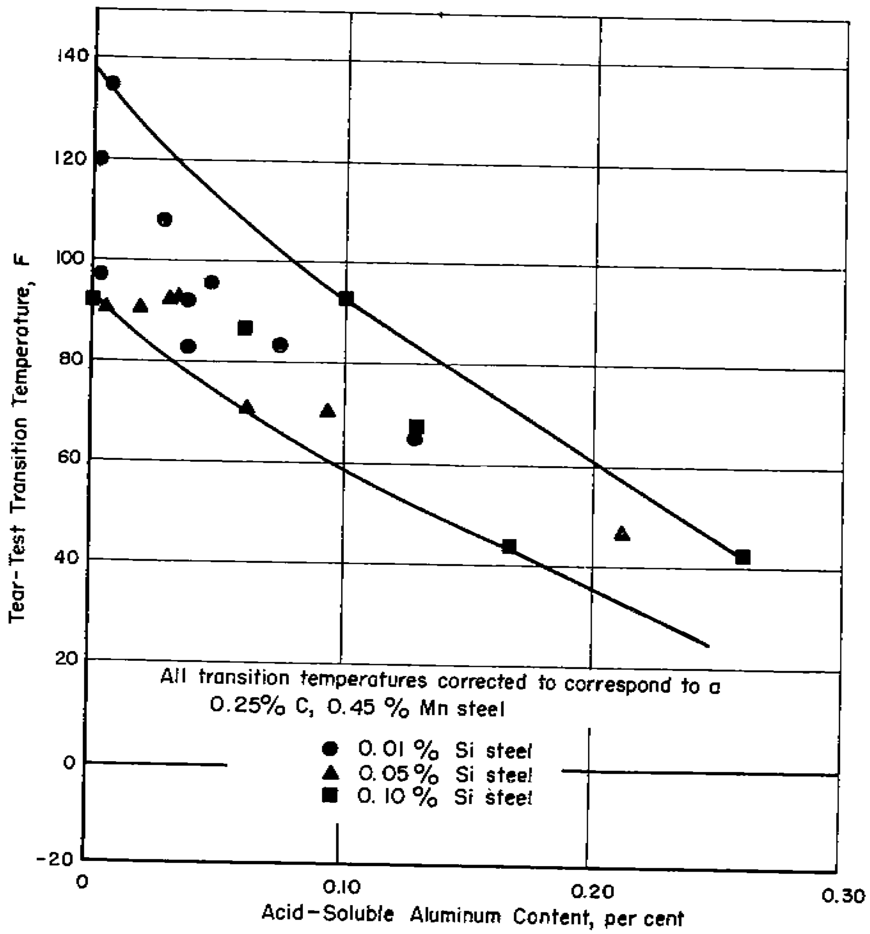

FIGURE 14. EFFECT OF ALUMINUM ON TEAR-TEST TRANSITION TEMPERATURE IN STEELS CONTAINING 0.25 % CARBON AND 0.45 % MANGANESE WITH 0.01 %, 0.05 %, AND 0.10 % SILICON

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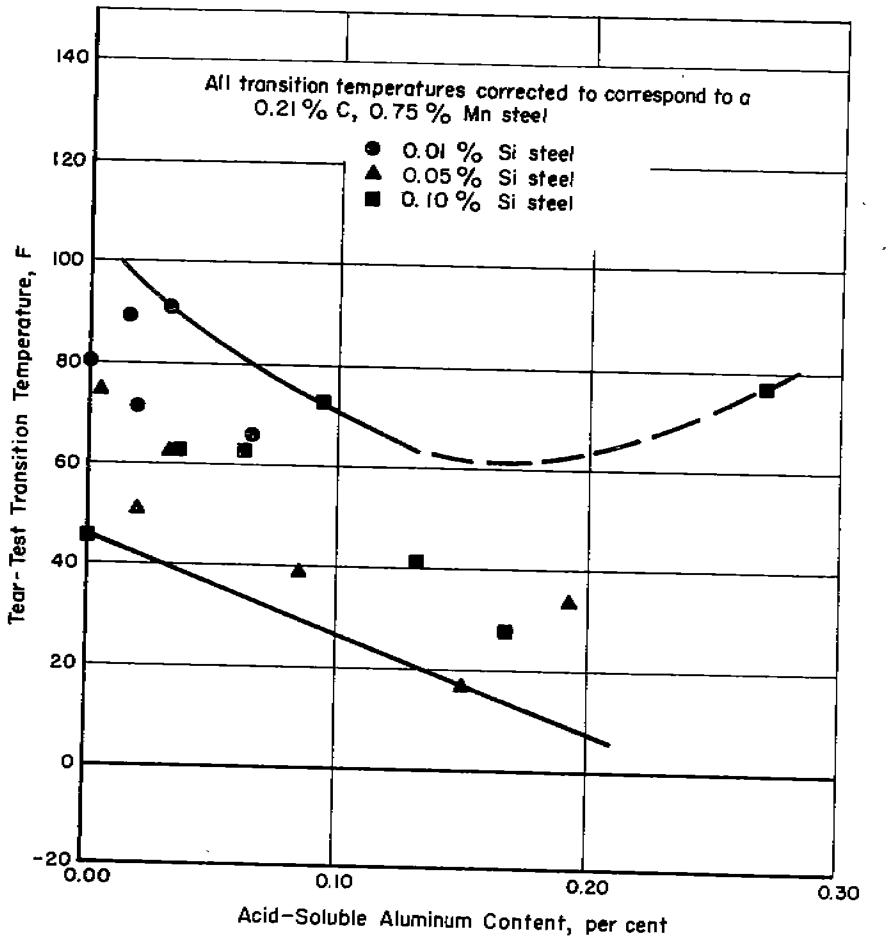

FIGURE 15. EFFECT OF ALUMINUM ON TEAR-TEST TRANSITION TEMPERATURE IN STEELS CONTAINING 0.21 % CARBON AND 0.75 % MANGANESE WITH 0.01 %, 0.05 %, AND 0.10 % SILICON

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As in the case of the silicon series, it should be recognized that the steel cannot be considered in the semikilled class if the acid soluble aluminum content is over .010%. This limiting value is less if silicon is also present. A study of the relation between aluminum and transition temperature indicates that in the range feasible in semikilled steels aluminum has no significant effect on either the keyhole or tear test transition temperatures.

With increasing amounts above .010%, which would result in the production of fully killed steel, aluminum decreases the transition temperature up to 0.20% aluminum and possibly higher.

e. Other Alloying and Deoxidizing Elements

The Battelle investigation also included heats deoxidized with titanium and zirconium. Within the range permissible for semikilled steel, neither element significantly affected the transition temperatures determined in Charpy or tear tests. Consideration was also given to other deoxidizers that might be used in producing semikilled steel. There was no evidence that such additions would improve transition temperatures.

Vanadium was also investigated. It was concluded that small amounts of vanadium had no effect and large amounts raised the transition temperature.

No significant effect of sulfur on tear test or Charpy transition temperatures was noticed in laboratory steels containing up to 0.060%.

VI. SUMMARY

Battelle Project SR-110 was established to investigate the effect of the type and degree of deoxidation and the content of elements other than those used for deoxidation on the transition temperature characteristics of ship steel. The object was to determine whether modifications might be made in deoxidation or composition which would lower the transition temperature of hull plates and thus decrease their susceptibility to brittle failure in service.

The degree of deoxidation of steel varies and in general is indicated by classifying the steelmaking practice as rimmed, semikilled, or killed. The rimmed and semikilled steels are normally made in open top ingots, and killed steel in hot top ingots. Rimmed steel is only used to a limited extent for the production of hull plates because of difficulties in producing the higher manganese ranges and maintaining uniform tensile properties. Killed steel has the disadvantage that hot topped molds are necessary, and this type of mold establishes limitations on tonnages and production rates. As a consequence of the limitations on other types, semikilled steel would have to be extensively used in the production of hull plates for any expanded shipbuilding program. The Battelle investigation was therefore primarily directed towards the study of variables affecting the transition temperatures of semikilled steel.

The Battelle investigation has demonstrated that reproducible results can be obtained on semikilled steel made and processed in the laboratory at different times. Properties of such steel are similar to those of ship plate made and processed in steel plants. Therefore, it is believed that laboratory prototype steels can be used to estimate the effects of changes in composition or processing on the characteristics of commercial ship plate.

Carbon and manganese are the most important elements in hull steel composition from the standpoint of establishing tensile strengths specified for hull plates. The effects of carbon, manganese and the manganese/carbon ratio on the transition temperature were determined. It appears that most of the improvement in the transition temperature characteristics of semikilled hull steel that can be accomplished by modifying the carbon and manganese content has already been obtained as a result of the recent changes in ship steel specifications. The Battelle work and other data on ship plate indicate that a significant decrease in transition temperature was accomplished by establishing a 0.60%--0.90% manganese range for plates over 1/2 inch to 1 inch, inclusive, in the American Bureau of Shipping specification, and 0.90% manganese maximum for hull plates over 3/16 inch to 7/8 inch, exclusive, in the Navy (Mil-S-16113 A) specification. Further improvements could be made by establishing a minimum manganese content in the Navy specification, or by raising the manganese ranges in both specifications. The latter alternative has the disadvantage of increasing the amount of ferromanganese that would be used for the production of hull plate steel in periods when this alloy might be in short supply.

An improvement in the transition temperature of semikilled steel could also be obtained by lowering the tensile range specified. Such a change would make it possible to produce a steel with a lower carbon content which is one of the most important variables affecting the transition temperature. The Battelle data indicate that an average decrease of 3000 psi in tensile strength through reduction in carbon content results in an average lowering in transition temperature of about 10°F.

The Battelle studies on the deoxidation of semikilled steel covered the effect of most of the elements which might be used as deoxidizers. Since silicon and aluminum are the deoxidizers normally used in commercial steelmaking practice, the most extensive work was done on the effect of these elements. It was concluded that within the ranges of deoxidizers feasible for the production of semikilled steel there is no controllable silicon or aluminum deoxidation practice which will result in a significant decrease in transition temperature characteristics of hull plates. This conclusion does not apply to killed steel, whether of the coarse or fine grained type, the transition temperatures of which are definitely affected by the amounts of silicon or aluminum present.

The effects of nitrogen and phosphorus were also studied. Both of these elements raised the transition temperature--particularly nitrogen. In the case of phosphorus the maximum amounts specified in current hull steel specifications appear to establish a satisfactory limitation of this element. Nitrogen is not currently incorporated in specifications. Since the nitrogen content of open hearth steelmaking by conventional practice normally will not be over .005%, this element likewise appears to be under satisfactory control in open hearth steel. Consideration might be given to establish a maximum nitrogen content for semikilled hull steel plates rolled from electric furnace steel or open hearth steel made with Bessemer blown metal used in the charges. It should be noted that the above conclusions with respect to the detrimental effect of nitrogen on the transition temperature does not apply to fully killed fine grained steel as nitrogen might even be beneficial in this grade.

The effects of titanium and vanadium on the transition temperature were also studied, and it was found that the small amounts that could be present in semikilled steel did not significantly influence the transition temperature. The amounts of sulphur present within the limitations of ship steel specification are also without influence.

The Battelle investigation included studies of ferritic grain size. It was found that grain size had a very important effect on the transition temperature of semikilled steel--the smaller the grain size, the lower the transition temperature. The grain size, insofar as it is established by the finishing temperature, does not appear to be a controllable variable since it is not feasible to establish rolling temperature ranges in ship steel specifications. The alternative of refining the grain size by normalizing hull plates appears to be the most satisfactory means of controlling this variable. As pointed out in the discussion of grain size, it is not feasible to take advantage of this beneficial effect of normalizing except on a limited tonnage basis because of the lack of adequate normalizing furnace facilities and capacities.

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