NRL REPORT M-3343

THE EFFECT OF TITANIUM AND VANADIUM ON THE MECHANICAL PROPERTIES AND WELDABILITY OF EXPERIMENTAL LOW-ALLOY HIGH-TENSILE STEEL

George G. Luther
Carl E. Hartbower
Donald B. Roach

November 23, 1948

Approved by:

Dr. O. T. Marzke, Superintendent, Metallurgy Division

NAVAL RESEARCH LABORATORY
CAPTAIN H. A. SCHADE, USN, DIRECTOR
WASHINGTON, D.C.

DISTRIBUTION

BuShips	5
BuAer	2
BuOrd	2
ONR Attn: Code N-482	2
Cdr., Boston Naval Shipyard	2
Cdr., Brooklyn Naval Shipyard	2
Cdr., Charleston Naval Shipyard	2
Cdr., Pearl Harbor Naval Shipyard	2
Cdr., Long Beach Naval Shipyard	2
Cdr., Mare Island Naval Shipyard	2
Cdr., Norfolk Naval Shipyard	2
Cdr., Philadelphia Naval Shipyard	2
Cdr., Portsmouth Naval Shipyard	2
Cdr., Puget Sound Naval Shipyard	2
Cdr., San Francisco Naval Shipyard	2
Dir., USNEL	2
Cdr., USNOTS Attn: Reports Unit	2
Dir., USNEES, Annapolis, Md.	1
Dir., USNML, Munhall, Pa.	1
Cdr., USNOL, Silver Spring, Md.	1
Supt., USNGF, Wash., D. C.	1
Dir., NBS, Wash., D. C.	1

CO, NTS, Newport, R. I.	1
OCSigO	
Attn: Ch. Eng. & Tech. Div., SIGTM-S	1
CO, SCEL	
Attn: Dir. of Engineering	2
BAGR, CD, Wright-Patterson Air Force Base	
Attn: BAU-ADD	1
RDB	
Attn: Library	2
Attn: Navy Secretary	1
Science and Technology Project	
Attn: Mr. J. H. Heald	2

PROBLEM STATUS

This report concludes the work on this problem, and unless otherwise advised by the Bureau, the problem will be closed one month from the mailing date of this report.

AUTHORIZATION

NRL Problem M03-08R (BuShips ltr. JJ46-1-(27) (334) 31 Jan. 1944).

CONTENTS

ABSTRACT

It was the purpose of this investigation to determine the mechanical properties and weldability of experimental manganese-titanium and manganese-vanadium high-tensile low-alloy steels which met the physical requirements of Navy Specification 48S5 (BuShips). Fifty-nine 80-pound fully-killed laboratory heats were prepared with ranges of composition of 0.12 to 0.20 percent carbon, 1.00 to 1.50 percent manganese, and 0.01 to 0.05 percent titanium or 0.05 to 0.15 percent vanadium. Tensile properties, maximum underbead hardness, underbead cracking, weldability according to the nick-bend specimen, and notch sensitivity as determined by the V-notch Charpy bar were the means of evaluating the relative performance of the steels in both the as-rolled and normalized conditions.

Of the above data, the most noteworthy were those provided by the nick-bend specimen and V-notch Charpy bar. These data showed that small variations in the amount of titanium or vanadium produced a marked effect on the temperature of transition from ductile to brittle behavior. The nick-bend specimen showed that welding adversely affected both the titanium- and the vanadium-alloyed steels, this effect being most pronounced for the higher percentages of titanium or vanadium. Normalizing produced a marked improvement in the ductility of welded titanium-alloyed steels, but there was little improvement in welded vanadium steels. In regard to notch sensitivity as determined by the V-notch Charpy bar, high percentages of titanium and vanadium resulted in high transition temperatures in the as-rolled condition. Normalizing produced a marked improvement in the titanium-alloyed steels while in the case of the vanadium steels the improvement was neither marked nor consistent. Carbon exerted a marked influence on mechanical properties and weldability, while manganese had no effect on notch sensitivity. It was found that to minimize notch sensitivity, carbon and titanium in combination should not exceed 0.15 and 0.025 percent, respectively; and carbon and vanadium, 0.15 to 0.10 percent, respectively.

Explanation was sought for the persistent differences in mechanical performance between the titanium- and vanadium-alloyed steels. A study of the microstructure revealed that the titanium-alloyed steels contained visible nitride crystals while the vanadium steels did not. Chemical analyses for acid-soluble and acid-insoluble nitrogen indicated that increasing titanium content was accompanied by an increase in the amount of acid-insoluble nitrogen while no appreciable change was observed in the vanadium-alloyed steels. A study of the acid-soluble amounts of titanium and vanadium before and after normalizing again disclosed a difference in the action of titanium and vanadium. In the case of titanium, acid soluble amounts decreased after normalizing, while in the case of vanadium, acid soluble amounts increased after normalizing.

THE EFFECT OF TITANIUM AND VANADIUM ON THE MECHANICAL PROPERTIES AND WELDABILITY OF EXPERIMENTAL LOW-ALLOY HIGH-TENSILE STEEL

PURPOSE OF INVESTIGATION

The object of this investigation was to determine the mechanical properties and weldability of experimental manganese-titanium and manganese-vanadium high-tensile steels which met the physical requirements of BuShips Specification 48S5 (INT), 15 July 1943. The approximate ranges of composition investigated were 0.12 to 0.22 percent carbon, 1.00 to 1.50 percent manganese, 0.01 to 0.05 percent titanium, and 0.05 to 0.15 percent vanadium.

"High Tensile Steel Plate" has been used in ship hull construction for many years. At first, the desired strengths were obtained by increasing the manganese content and adding vanadium. During the war when the supplies of vanadium became critical, titanium was substituted for vanadium. The question has repreatedly arisen as to how much titanium or vanadium should be added in combination with carbon and manganese to get optimum physical properties before and after welding.

MELTING AND ROLLING PROCEDURE

Eighty-pound laboratory heats were prepared for each of twenty-seven manganese-titanium and thirty-two manganese-vanadium steels. These heats were prepared in a three-hundred-pound capacity, basic-lined, induction furnace. The furnace was initially charged with Armco iron, electrolytic nickel, and copper bar stock. The nickel and copper and subsequent additions of molybdenum and chromium were to adjust for the residual elements usually existing in commercial steels.

The more important details of the melting procedure follow: Ferrosilicon (95 percent) was added to the heat at regular intervals to quiet the steel in the process of melting and to keep the heat from rimming. The molten charge was allowed to condition for ten minutes before adjusting the composition of the heat with the remaining alloys. Carbon as wash metal (4 percent) was then added, followed at one-half minute intervals by ferrosilicon (95 percent), electrolytic manganese, and ferrochromium (71 percent). These were followed two minutes later by an aluminum addition equivalent to one pound per ton, and finally, a few seconds later, by the titanium or vanadium addition for the first eighty-pound split. Immediately after the first split was poured, additional aluminum to the equivalent of 3/4 pound per ton was introduced, and then the titanium or vanadium for the second split was added. The aluminum was added in two parts to keep the residual aluminum reasonably constant, i.e. to compensate for losses between the first and last splits. The time elapsing between the pouring of the first and second splits was approximately two minutes. The final titanium or vanadium addition was then made and the third split was poured one and one-half to two minutes after the second split. The pouring temperature was approximately 2900°F. Big-end-up cast iron chill molds provided with hot tops and pouring gates were used to cast the steel. The chemical compositions of all heats are presented in Table I.*

After removing the piped section, the ingots were soaked at 2200°F, forged into two-inch-thick slabs and air cooled. The slabs were then heated to 2100°F and hot rolled to plates 1-1/8 to 1-1/4 inches thick. To eliminate the effects of differences in finishing temperature, a portion of each plate was normalized from 1675°F, thus providing as-rolled and normalized samples for investigation.

TENSILE PROPERTIES

Standard 0.505-inch-diameter tensile specimens were prepared from each plate of steel in both the as-rolled and the normalized condition. The specimens were taken parallel to the direction of rolling. Average tensile and hardness results for duplicate specimens are presented in Table II.

In general, for the range of chemical compositions investigated, the as-rolled and normalized manganese-vanadium steels had higher yield and tensile strengths, higher yield-to-tensile-strength ratios, and slightly lower elongation and reduction of area than the manganese-titanium steels. This difference between the titanium- and vanadium-alloyed steels was most notable when the carbon was on the high side of the range investigated. With increasing amounts of titanium and vanadium, the as-rolled steels showed a general trend toward increase in yield and ultimate strength and decrease in elongation.

Normalizing was found to raise slightly the yield strength of steels containing low titanium, while it lowered the yield strength of steels containing higher titanium. Comstock[1] also observed this trend and attributed it to grain refinement in the lower titanium steels and change in mode of titanium carbide dispersion in the case of the higher titanium steels. Normalizing had no appreciable effect on the ultimate strength of steels containing low titanium but it lowered the ultimate when the titanium content was high. In general, normalizing a vanadium-alloyed steel lowered both the yield and the ultimate strength regardless of whether the vanadium content was high or low.

V-NOTCHED CHARPY BAR TEST

Standard V-notched Charpy bars were prepared from the experimental steels of this investigation with the notch transverse to the direction of rolling and parallel to the surface of the plate. Approximately fifteen specimens were used in establishing the transition temperature curve of each heat of steel in both the as-rolled and the normalized condition. In general, single test specimens were broken at temperatures above and below the transition zone, while in the transition zone, two or three specimens were broken at a single temperature. The desired range of temperature was obtained by means of baths of alcohol and dry ice and of water heated electrically. The bars were immersed for at least 15 minutes at the desired temperature, removed, immediately placed in position on the anvil of the testing machine and broken. A pendulum-type impact testing machine of 220 ft-lb capacity was used at a striking velocity of 17.4 ft/sec.

[1] Comstock, George F., METAL PROGRESS, 47, 510-520, March 1945.

* All tables appear at end of report on pp. 23-38.

The data were plotted as "energy absorbed vs temperature" for all steels, with each plot on a separate sheet. Curves were then "faired-in" and, finally, curves from splits of the same heat were superimposed on a single sheet to facilitate analysis of results (Figures 1-6). The original 59 separate plots are not included here and the plotted points are not shown on the curve sheets because of the overlapping of scattered points. All the data, however, are presented in Tables III and IV. Curves for steels 466A, B, and C (as-rolled) and 466 AN, BN, and CN (normalized) are plotted from these data as typical examples of the scatter encountered (Figure 3).

Work[2] at this Laboratory using the Charpy bar indicated that an expedient method of representing the transition temperature phenomenon was to note the highest temperature at which there occurred the first visual evidence of brittleness. The trace of brittleness consisted of tiny facet-like surfaces in an otherwise dull fibrous fracture. To establish the transition temperature with any degree of certainty by this method, it was considered desirable to have at least three completely ductile specimens at temperatures above that of the specimen containing the first trace of brittleness. This procedure was carried out whenever there were sufficient specimens to permit doing so. When there were insufficient specimens, the temperature reported (Table V) is accompanied by the symbol for "greater than" (>). Data representing the first sign of brittleness are encircled in Tables III and IV and the transition temperatures are summarized in Table V.

The more obvious conclusions from an examination of the transition temperature curves and the onset of brittleness follow.

(a) For all combinations of carbon and manganese in the as-rolled condition, there was a detrimental effect on the impact-temperature relationship as the titanium or vanadium content was increased. There was a tendency toward erratic behavior in the vanadium-alloyed steels that was not present in the titanium steels.

(b) For a given manganese and titanium or vanadium content in the as-rolled condition, an increase of 6 points of carbon produced a marked shift in the Charpy curves toward higher temperatures. This may be observed by comparing the curves for titanium steels 464 with 459, and 466 with 460; and by comparing the curves for vanadium steels 467 with 461, and 458 with 463.

(c) With a given carbon and titanium or vanadium content in the as-rolled condition, an increase of as much as 45 points of manganese had no appreciable effect on the impact-temperature relationship. This may be observed by comparing the curves for titanium steels 464, 465, and 466 and also 428, 429, and 430. An exception is seen, however, by comparing curves 459B and C with 460B and C. In the case of vanadium, the effect of manganese may be observed by comparing the curves for steels 467, 434, 458; also 461, 462, 463; and by noting the curves for steel 433.

(d) In the case of the titanium-alloyed steels, normalizing produced a marked improvement in the impact-temperature relationship. In general the improvement was greatest when the titanium was on the high side of the range investigated. As in the case of the as-rolled steels, when the titanium content was increased, the Charpy curves (of the normalized steels) were shifted to higher temperatures. However, after normalizing, the difference between the steels of high and low titanium content was much less than it

---

[2] Luther, George G., Hartbower, Carl E., Metius, Richard E., and Laxar, Frank H., THE WELDING JOURNAL, 25, 634-s-645-s, October 1946.

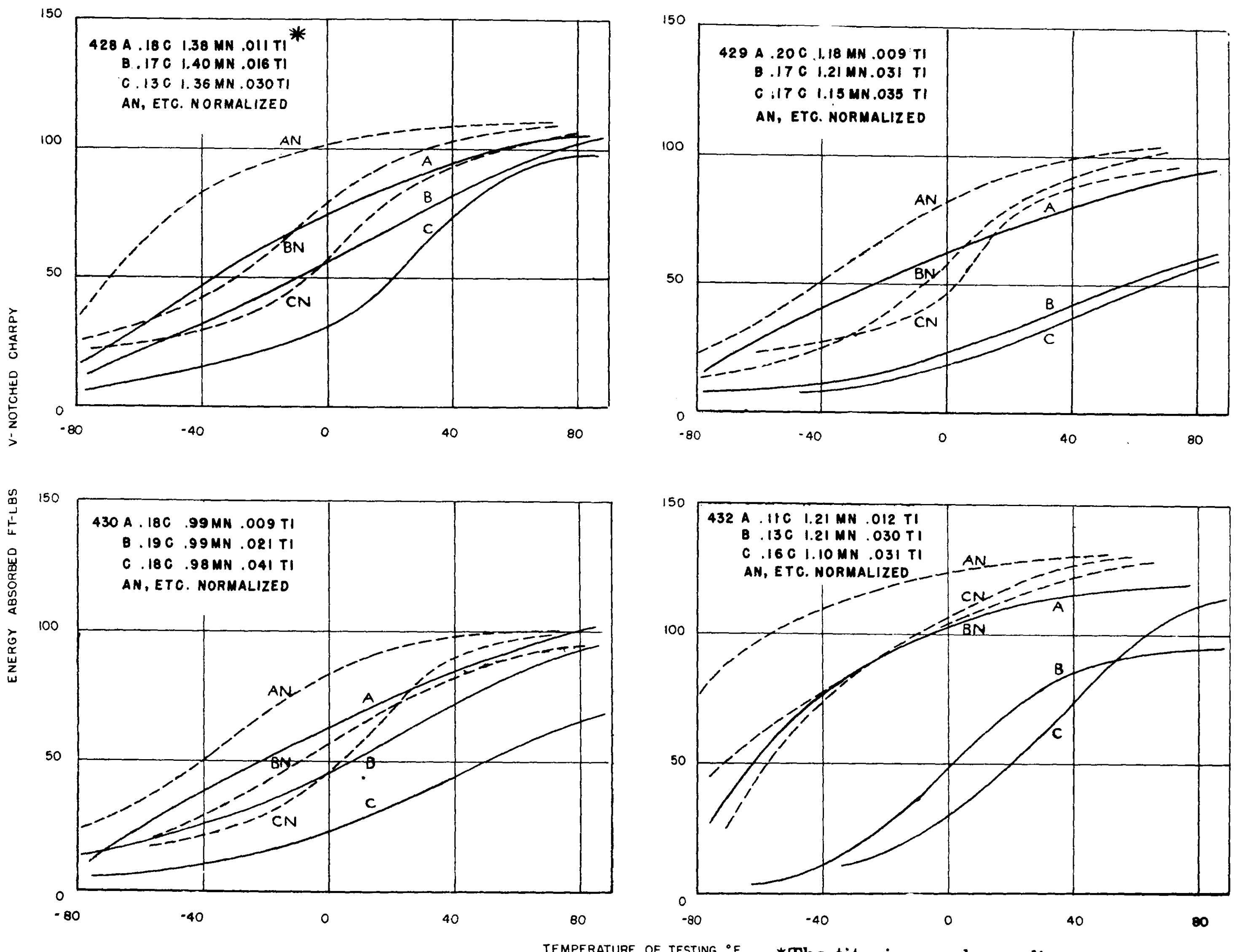


Fig. 1 - Transition temperature curves for titanium-alloyed steels 428, 429, 430 and 432

*The titanium and vanadium contents reported on this and the following figures are total amounts.

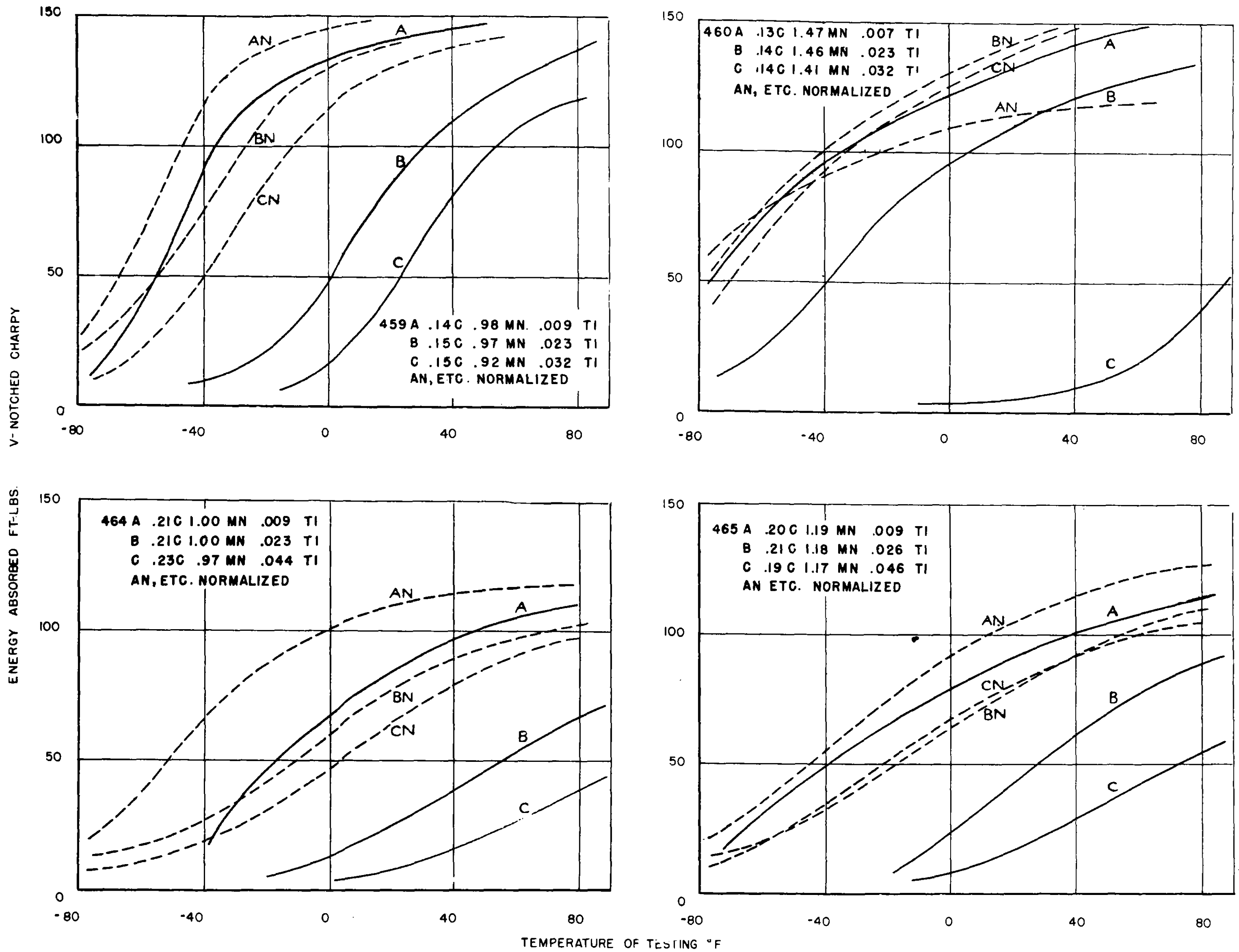


Fig. 2 - Transition temperature curves for titanium-alloyed steels 459, 460, 464 and 465

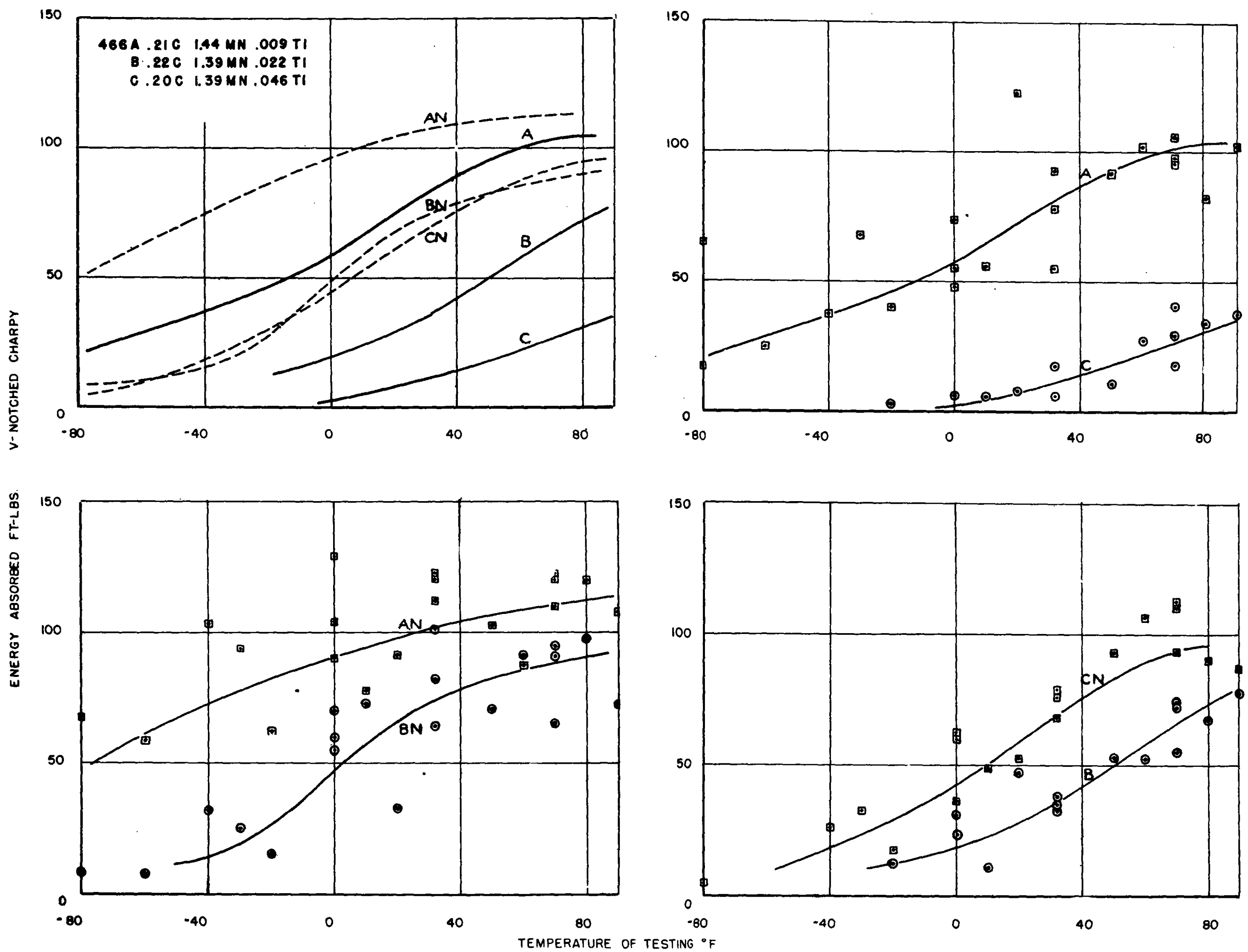


Fig. 3 - Sample plot of Charpy bar data - steel 466

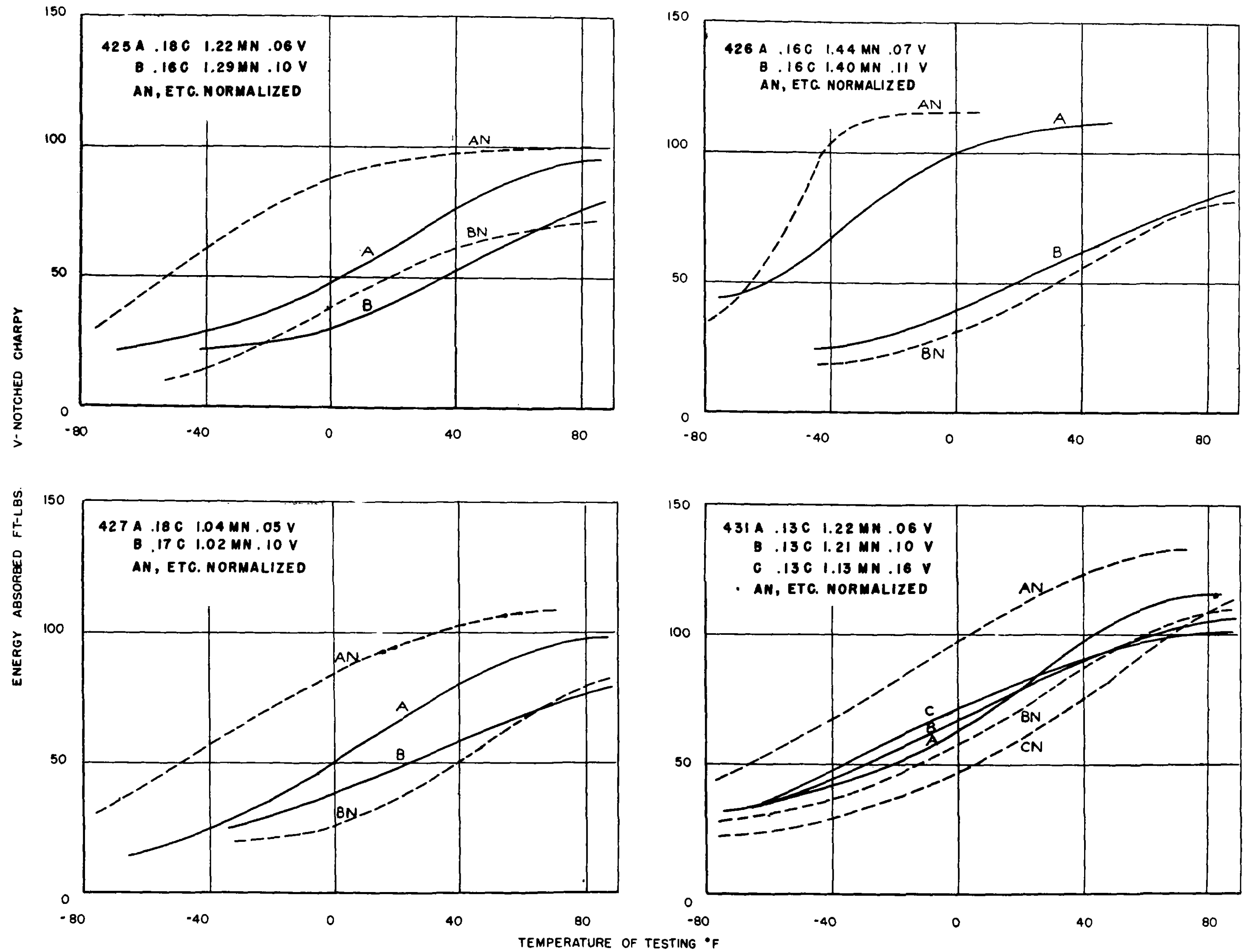


Fig. 4 - Transition temperature curves for vanadium-alloyed steels 425, 426, 427 and 431

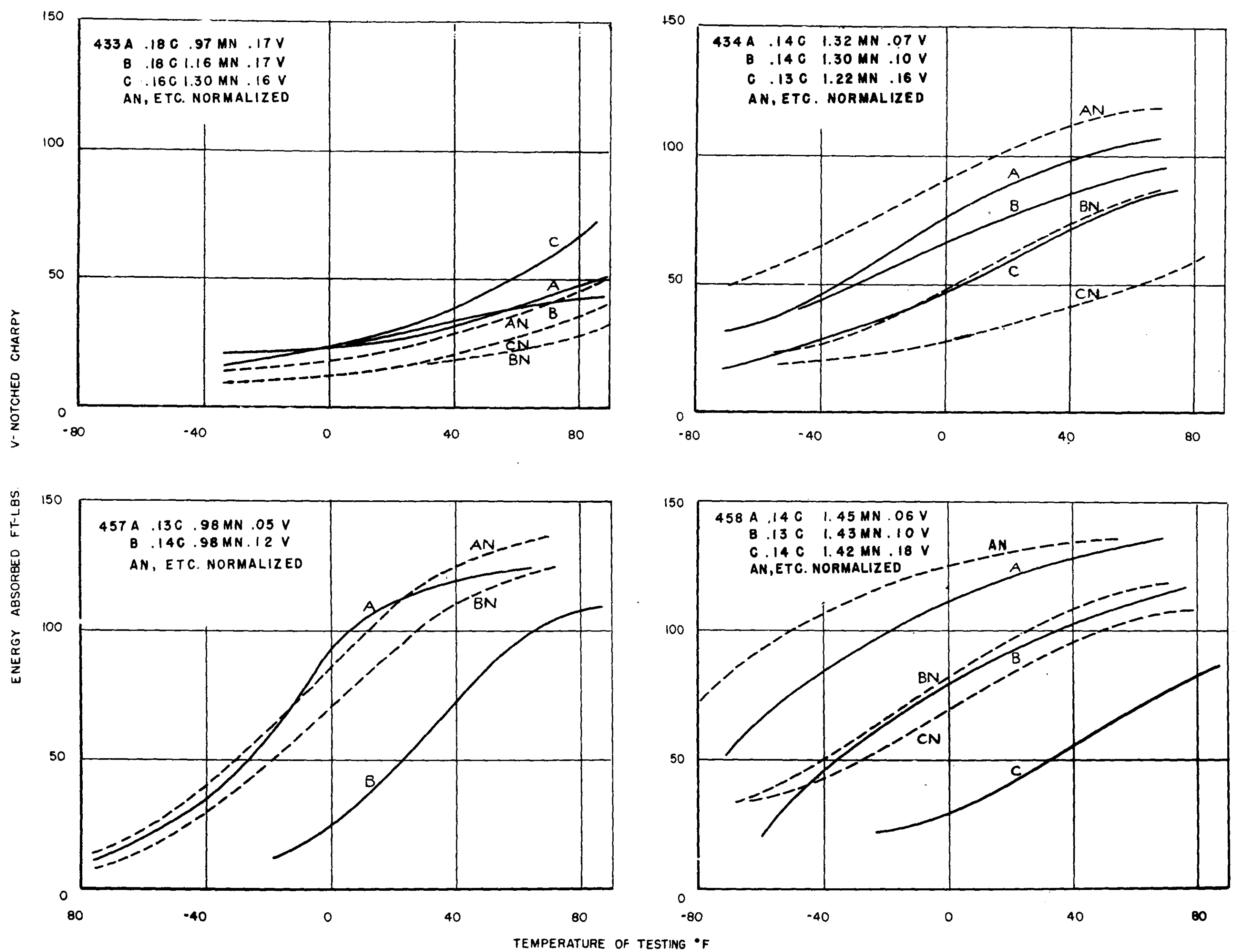


Fig. 5 - Transition temperature curves for vanadium-alloyed steels 433, 434, 457 and 458

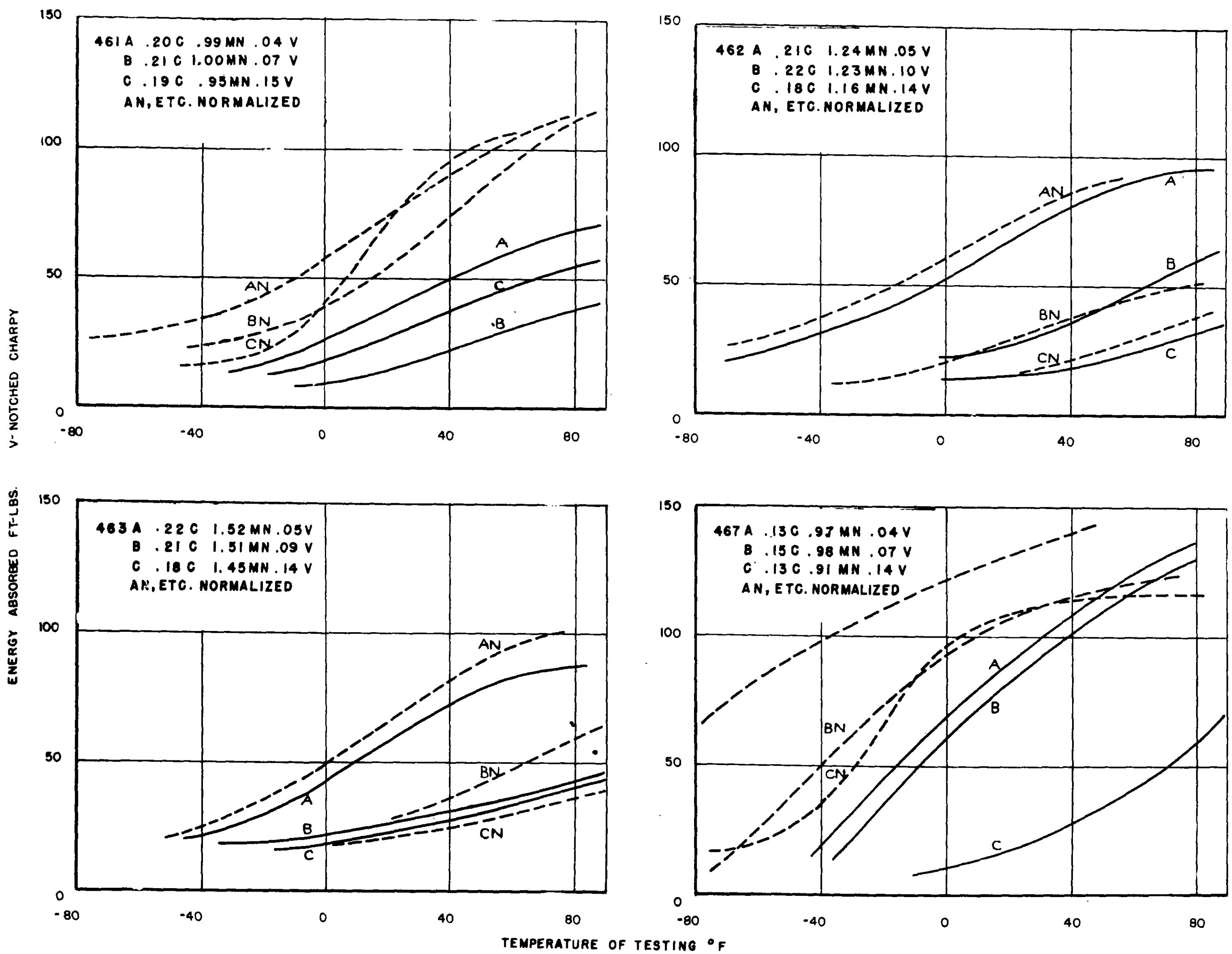


Fig. 6 - Transition temperature curves for vanadium-alloyed steels 461, 462, 463 and 467

was in the as-rolled condition, especially with carbon on the low side of the range investigated. In the case of the vanadium-alloyed steels, the effect of normalizing was not consistent and the improvement, if any, was not as marked as in the case of the titanium-alloyed steels. In some cases, normalizing was found to be detrimental (notably 433 and 434). In many instances, normalizing was found to have no effect on the impact-temperature relationship. Thus, there was a marked tendency toward erratic behavior and a lack of significant trends after normalizing the vanadium steels.

The combined effect of carbon and titanium, and carbon and vanadium, in altering the transition temperature curves makes it difficult to determine the optimum combinations of carbon and titanium or vanadium for minimizing notch sensitivity. A detailed examination of the temperature-impact curves indicated that carbon and titanium in combination should not exceed 0.15 and 0.025 percent, respectively, and carbon and vanadium should not exceed 0.15 and 0.10 percent, respectively (Figures 7 and 8).

BEAD-WELD NICK-BEND TEST

The nick-bend specimen was employed for measuring the effect of welding on ductility. Longitudinal specimens for both the as-rolled and normalized conditions were prepared in accordance with Figure 9. For the welded specimen, both welded and unwelded specimens were tested. Bead welds were deposited automatically in the flat position using 3/16-inch E6010 electrode with 175 amperes, 26 volts, and 6 inches-per-minute travel. Steels 425A through 434C were inadvertently tested in the original as-rolled thickness (1-1/8 to 1-1/4 inches). All other plates were shaped to a thickness of 1 inch to provide a uniform surface for welding and a constant beam thickness. Two days after welding, duplicate specimens were bent at 80°F in a 9-inch-span jig using a 1-inch-radius plunger. Load-deflection diagrams were automatically recorded and the maximum load and angle of bend at maximum load were noted. The results are presented in Table VI.

A detailed examination of the nick-bend angles for the various possible combinations of carbon, manganese, and titanium or vanadium in both the as-rolled and normalized conditions revealed no marked or consistent trends except where a major increase in carbon decreased the bend angle.

From automatically recorded load-deflection diagrams, a standard has been devised for the purpose of qualitatively classifying the amount of energy expended in fracturing a specimen after maximum load (Figure 10).[3] This was found to provide a useful index of weldability. The standard consisted of three major categories of load-deflection diagram. The "A-type" signified progressive failure until the load had dropped over 50 percent; "B-type" signified progressive failure followed by an appreciable drop in load after maximum with negligible increase in angle of bend; and "C-type" signified an appreciable drop in load with negligible increase in angle, the failure occurring at maximum load (brittle failure). It is to be noted that there are three energy measurements which can be made from the load-deflection diagram: (1) The work done before maximum load, i.e., the energy required to initiate failure, (2) the work done after maximum load, i.e., the energy required to propagate failure, and (3) the total work, i.e., the energy required to rupture the specimen. The temperature at which there occurred a transition from B- to C-type failure, i.e., the temperature which minimized the energy required to propagate failure, was taken as the index of weldability. A comparison between the titanium and

---

[3] Luther, George G., Jackson, Clarence E., and Hartbower, Carl E., THE WELDING JOURNAL, 25, 376-s-396-s, July 1946.

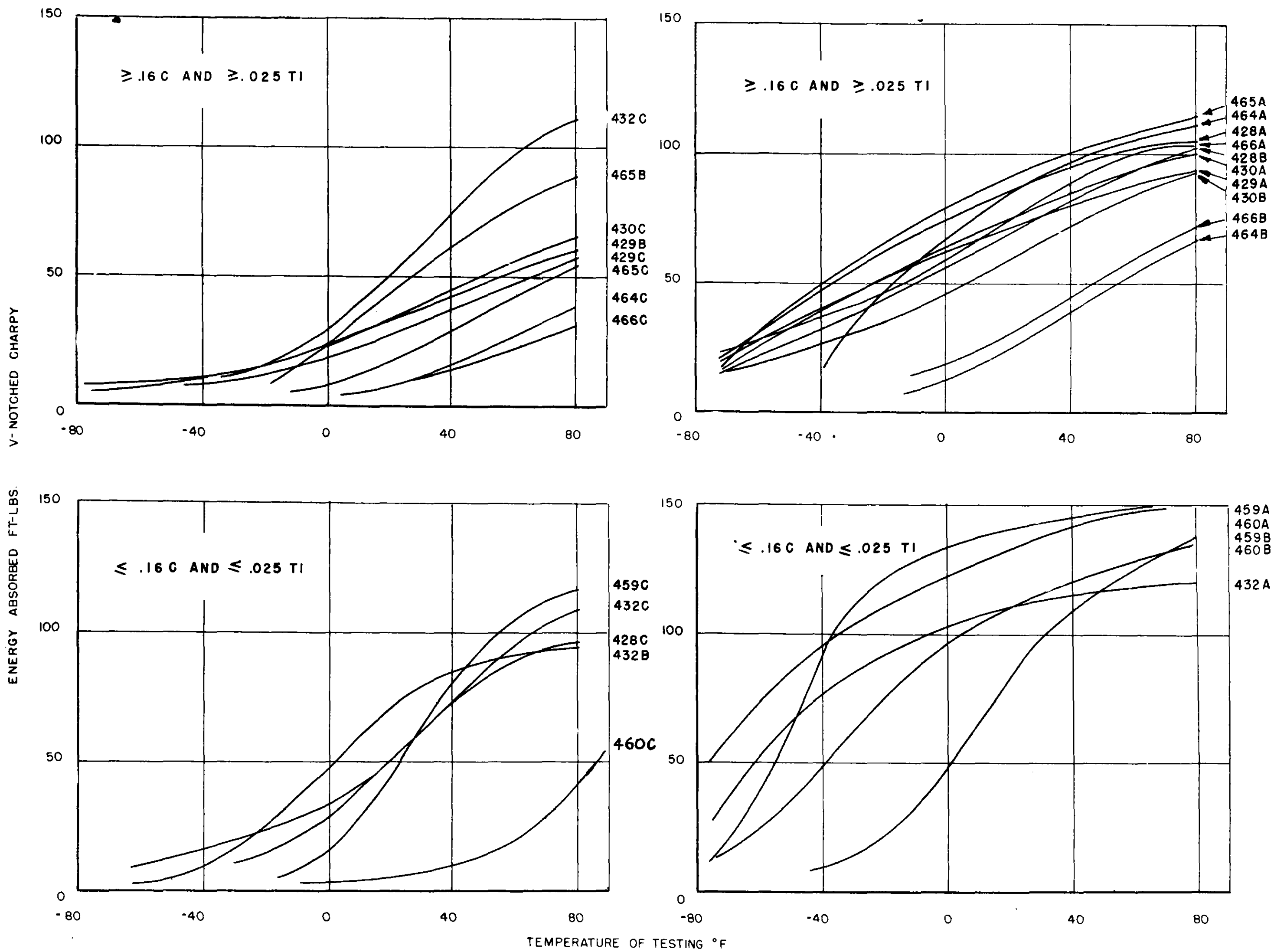


Fig. 7 - Summary of transition temperature curves for titanium-alloyed steels

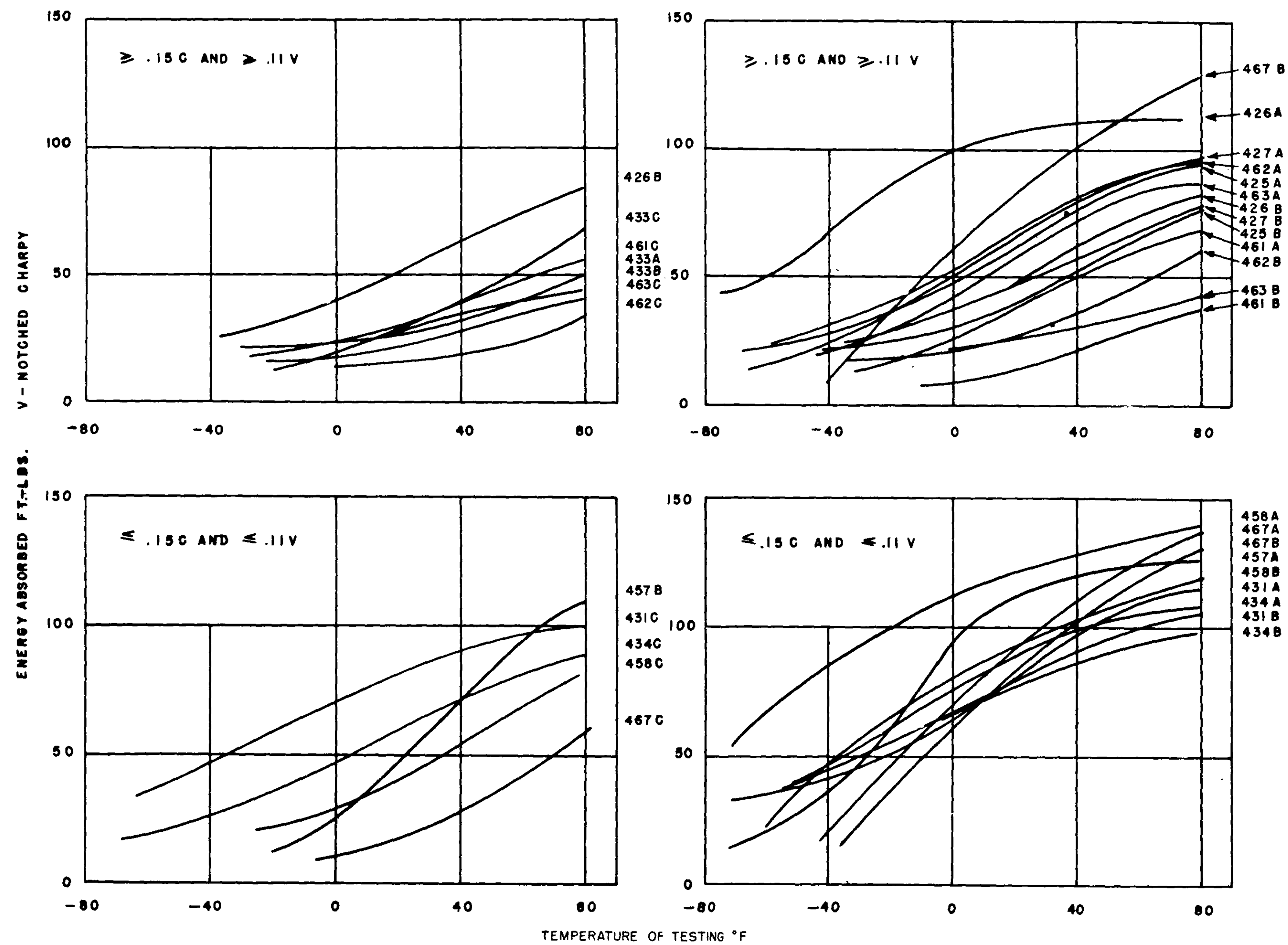


Fig. 8 - Summary of transition temperature curves for vanadium-alloyed steels.

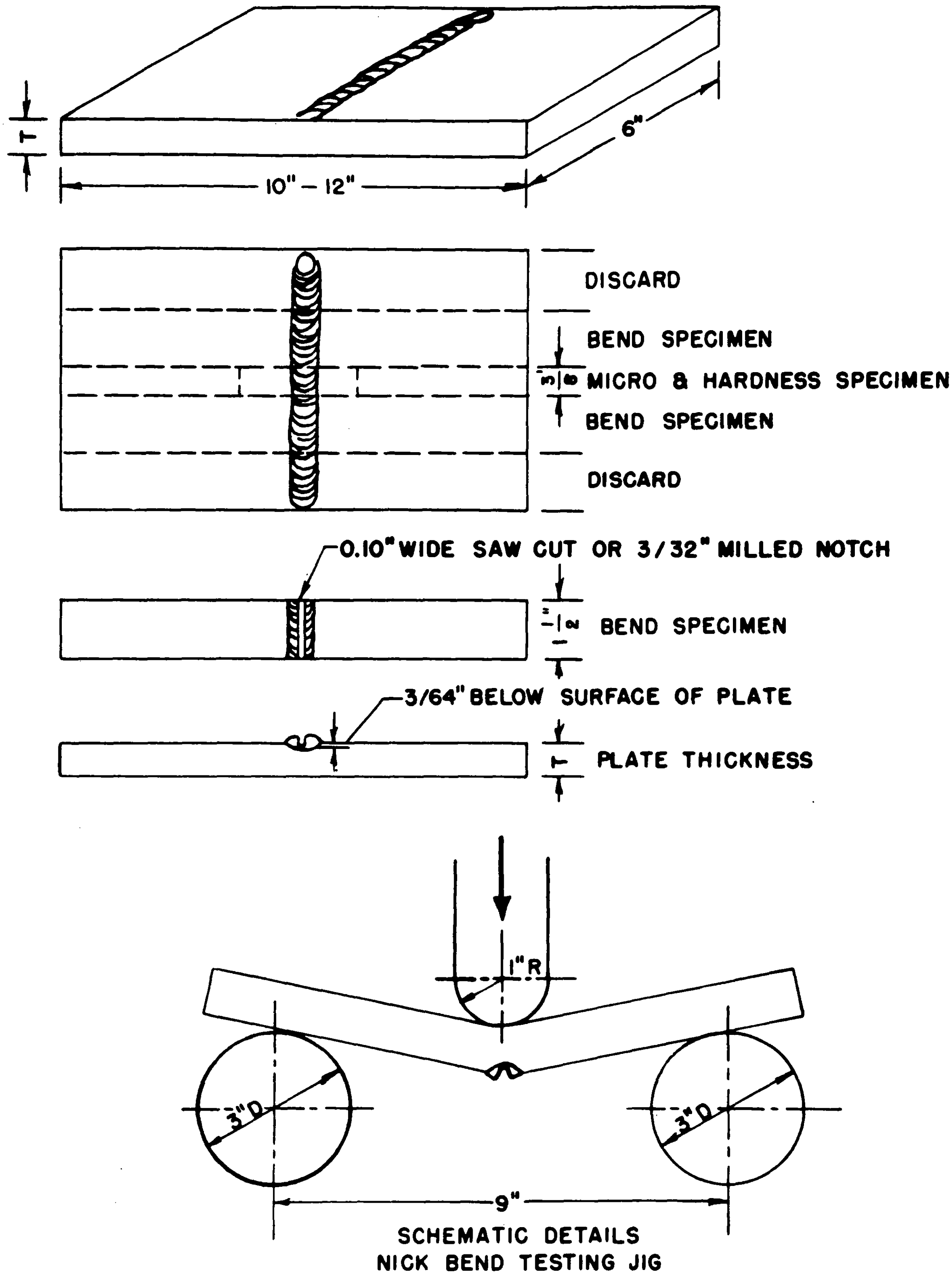


Fig. 9 - Bead weld nick-bend details

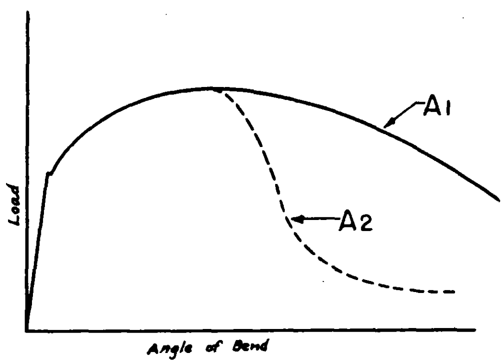
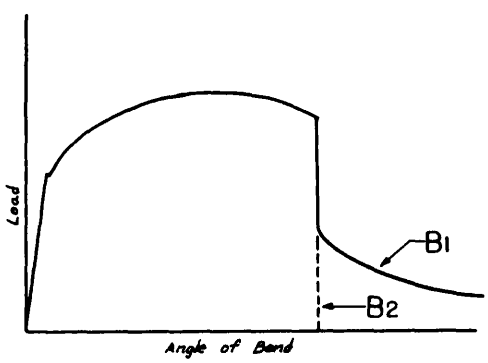
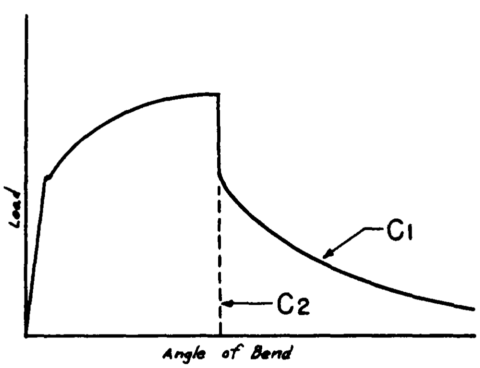
<table>
<tr><th>TYPE</th><th>SUB TYPE</th><th>DESCRIPTION</th><th>TYPICAL STRESS STRAIN CURVES</th></tr>
<tr><td>A</td><td></td><td>PROGRESSIVE FAILURE UNTIL LOAD DROPS TO LESS THAN 50%.</td><td rowspan="3">
</td></tr>
<tr><td></td><td>1</td><td>GRADUAL DECREASE IN LOAD AS ANGLE IS INCREASED.</td></tr>
<tr><td></td><td>2</td><td>RAPID PROGRESSIVE FAILURE. LOAD DROPS AT LEAST 50% BEFORE ANGLE HAS INCREASED 10° BEYOND MAXIMUM LOAD.</td></tr>
<tr><td>B</td><td></td><td>PROGRESSIVE FAILURE FOLLOWED BY INSTANTANEOUS* FAILURE BEFORE LOAD DROPS 50%.</td><td rowspan="3">
</td></tr>
<tr><td></td><td>1</td><td>INSTANTANEOUS* FAILURE CAUSES LOAD TO DROP TO NO LESS THAN 500 POUNDS.</td></tr>
<tr><td></td><td>2</td><td>INSTANTANEOUS* FAILURE CAUSES LOAD TO DROP TO LESS THAN 500 POUNDS.</td></tr>
<tr><td>C</td><td></td><td>INSTANTANEOUS * FAILURE AT MAXIMUM LOAD. LOAD DROPS AT LEAST 10%.</td><td rowspan="3">
</td></tr>
<tr><td></td><td>1</td><td>INSTANTANEOUS* FAILURE CAUSES LOAD TO DROP TO NO LESS THAN 500 POUNDS.</td></tr>
<tr><td></td><td>2</td><td>INSTANTANEOUS* FAILURE CAUSES LOAD TO DROP TO LESS THAN 500 POUNDS.</td></tr>
<tr><td colspan="4">* APPRECIABLE DROP IN LOAD WITH NEGLIGIBLE INCREASE IN ANGLE (USUALLY AUDIBLE)</td></tr>
</table>

Fig. 10 - Types of nick-bend failures

vanadium steels using this index of weldability disclosed the following: In the as-rolled condition both the titanium and vanadium steels were adversely affected by welding in that their transition temperatures were raised. In general, as the titanium or vanadium content was increased with a given carbon and manganese content, welding reduced the amount of energy required to propagate failure at a given temperature level. However, the titanium steels were less affected by welding than the vanadium steels, particularly when the carbon and the titanium or vanadium were on the high side of the ranges investigated. Normalizing the titanium-alloyed steels produced a substantial improvement. B- and C-type failures became A-type failures with but two exceptions. Thus, after normalizing, the weldability of the titanium steels was markedly improved. Normalizing the vanadium-alloyed steels was somewhat beneficial but the effect was not nearly so marked as in the case of the titanium steels.

UNDERBEAD CRACKING

The cracking specimen used in this investigation consisted of a short string weld bead 1-1/4 inches long deposited on a small block 4 inches long by 2 inches wide. The specimens were welded at two temperatures, $10^{\circ}F$ and $80^{\circ}F$, using 1/8-inch-diameter E6010 electrodes with 100 amperes, 25 volts, and 8-inches-per-minute travel speed. The method of crack detection consisted of taking transverse sections of the weld and polishing, etching, and examining the heat-affected zone at a magnification of 150 diameters. The amount of cracking present was noted according to the following index: "OK" indicates no visible cracking; "X" only one small crack; "XX" one or more large cracks; and "XXX" cracking completely around the heat-affected zone. The steels were found to have little tendency toward cracking in the heat-affected zone (Table VII). Only 9 of the 59 steels exhibited cracking, none of which were completely cracked, and of these, 7 contained 0.18 percent or more carbon.

MAXIMUM UNDERBEAD HARDNESS

Strips 3/8-inch thick were cut from the center of the as-rolled nick-bend weldments transverse to the weld bead. The sections were surface ground and polished through 3/0 grit emery paper and then electrolytically polished with a mixture of perchloric acid and acetic anhydride followed by etching with a nital-picral reagent to bring out the fusion line and heat-affected zone. Six rows of Knoop indents (0.5-kg load) were then made perpendicular to and across the fusion line of each weld, and at a later time a series of Vickers indents (10-kg load) were made in the heat-affected zone adjacent to the fusion line. For purposes of comparison, the maximum quench hardness was determined for each steel and the percent of maximum quench hardness to maximum underbead hardness was determined.

An examination of both the Vickers and Knoop maximum underbead hardness (Table VII) for a given carbon and manganese content showed that there was no consistent relationship between titanium or vanadium content and maximum underbead hardness. The expected relationship between carbon content and maximum underbead hardness was found, however, and as the manganese was increased from low, to intermediate, to the high side of the range investigated, the maximum underbead hardness increased. It has been shown previously in this report that as the titanium or vanadium was increased with a given carbon and manganese content (1) the as-rolled steels showed a general trend toward increase in yield and ultimate tensile strength and a decrease in elongation, (2) the nick-bend ductility before and after welding decreased, and (3) the notched-bar transition from ductile to brittle behavior was shifted to increasingly higher temperatures. In spite of these trends in mechanical properties, maximum underbead hardness showed no significant differences between A, B, C splits where carbon and manganese were held constant and the titanium or vanadium varied.

MICROSTRUCTURE

Microexamination of representative steels (458, 460, 462, and 465) in the polished but unetched condition disclosed visible nitride crystals in the titanium-alloyed steels while there were none in the vanadium steels. It was noted in the case of the titanium-alloyed steels that as the titanium content increased, the presence of titanium-nitride became increasingly evident. In steels 460A and 465A where the titanium content was low (0.007 and 0.009 percent, respectively), nitrides were not observed at 1500 diameters; in steels 460B and 465B where the titanium content was intermediate (0.023 and 0.026 percent, respectively), there was an occasional large angular crystal; and in steels 460C and 465C where the titanium content was high (0.032 and 0.046 percent, respectively), large pink angular crystals of the nitride occurred relatively frequently and the matrix contained numerous small crystals often associated with other inclusions (Figure 11). Typical

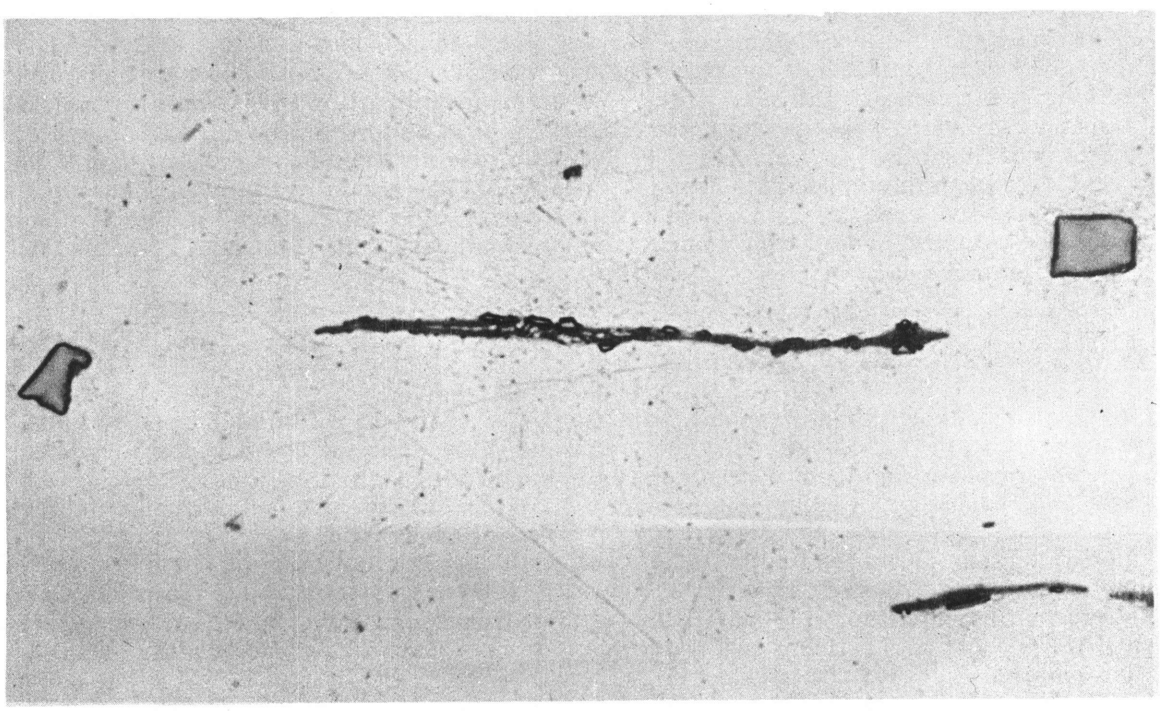


Fig. 11 - Titanium-cyano-nitride in steel 465 C (specimen unetched - 1500 X)

microstructures of the titanium and vanadium steels (etched with 1 percent nital and 4 percent picral) are shown in Figures 12 and 13.

Grain size determinations were made on 24 steels in both the as-rolled and normalized conditions. The as-rolled grain sizes were predominantly 6 and 7 while after normalizing they were 7 and 8. No relationship was found between grain size and nick-bend ductility or notched-bar transition temperature. A comparison of the as-rolled grain sizes of a group of steels of progressively poorer impact-temperature relationships

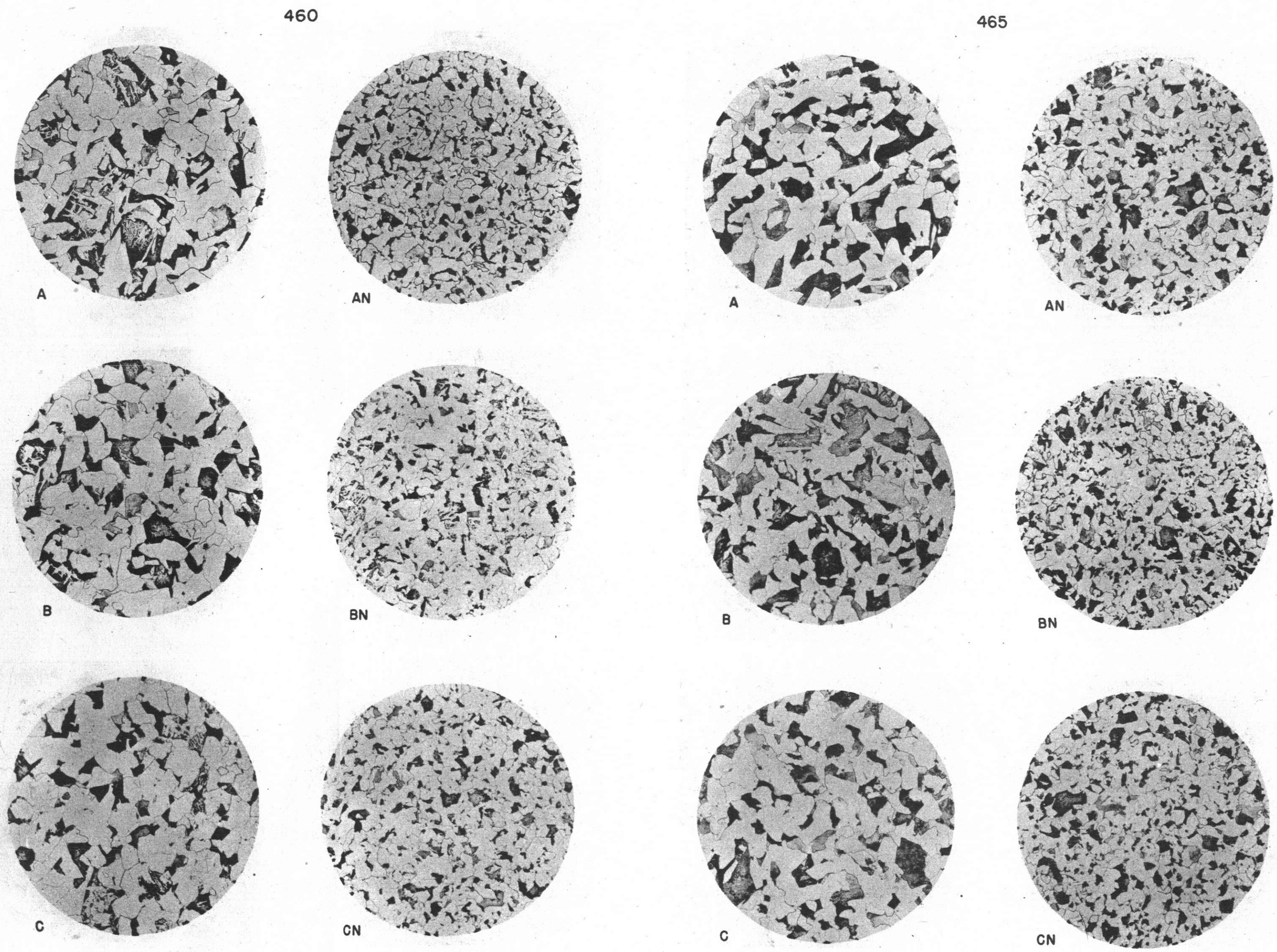


Fig. 12 - Microstructure of titanium-alloyed steels. (Magnified 125 times)

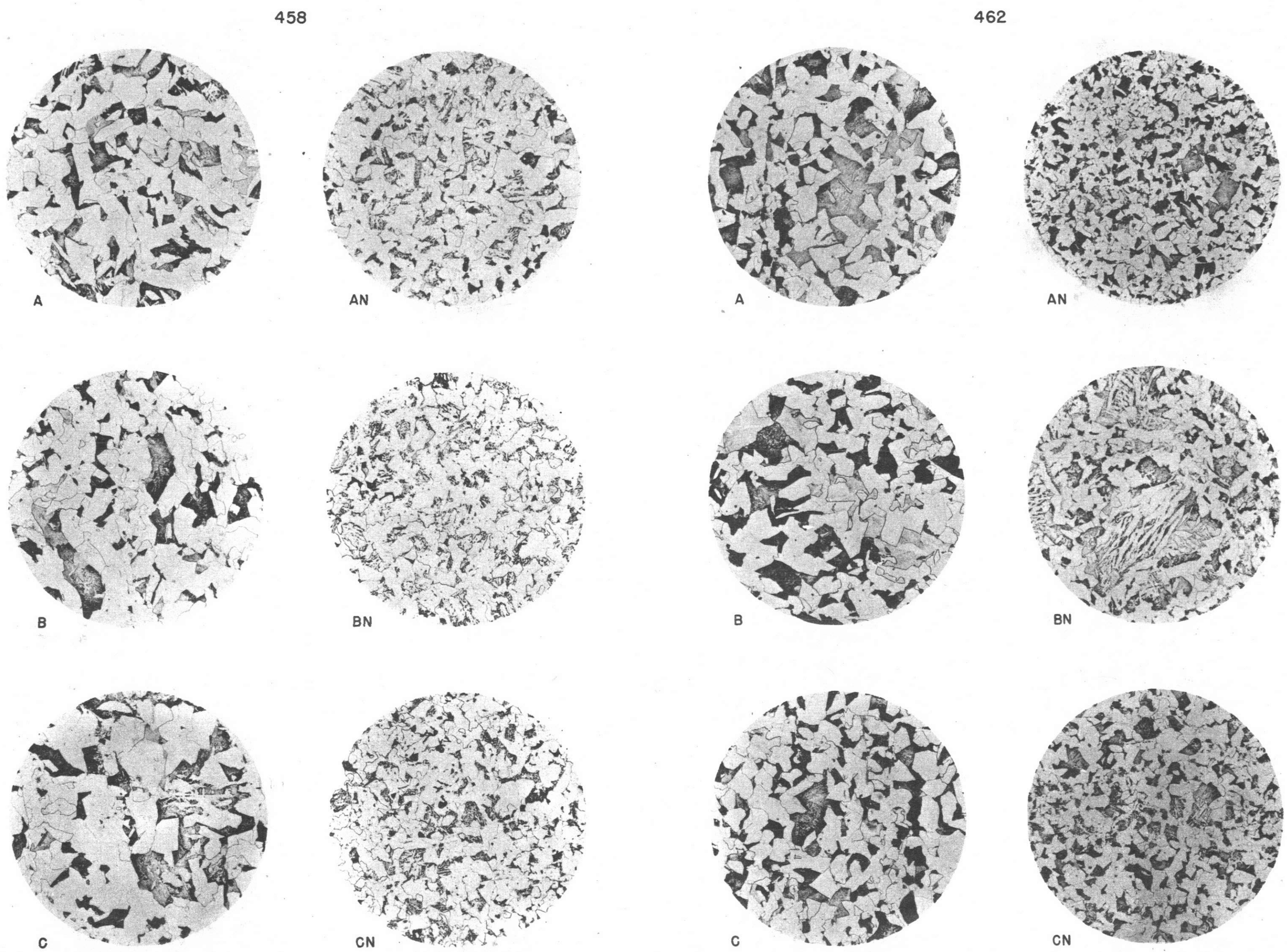


Fig. 13 - Microstructure of vanadium-alloyed steels. (Magnified 125 times)

(Figure 8: Steels 426A, 425A, 467B, 425B and 462B) showed the best steel of the group (426A) to be particularly fine-grained but there were no significant or consistent differences between the grain sizes of the other steels. An examination of steel 458A, whose impact-temperature relationship was best of all the vanadium-alloyed steels, did not reveal any difference between its grain size and that of the majority of the other as-rolled steels examined.

Since titanium and vanadium are both strong carbide formers, and size and distribution of the carbides are generally considered to have an effect on the mechanical properties, a study of the carbides was undertaken. At high magnification (1000 X) a peppering of fine carbides was revealed throughout the pearlite and at the grain boundaries of the pearlite (Figure 14). There were none of the fine carbides in the ferrite or at the ferrite grain boundaries except occasionally immediately adjacent to the pearlite. After normalizing, the pearlite areas were smaller and more generally distributed and the fine carbides were generally more prevalent at the pearlite grain boundaries. No marked differences in the size and distribution of the carbides were noted between the A-, B-, or C-splits or between the titanium and vanadium steels in general.

CHEMICAL ANALYSIS FOR NITROGEN

Acid-soluble and acid-insoluble determinations of nitrogen were made on a number of representative steels by dissolving the samples in 1-1 HCl acid and treating the insoluble material with perchloric acid. The analysis for acid-insoluble nitrogen was taken to indicate the amount of titanium or vanadium combined as the nitride and the acid-soluble amount was taken to indicate both the nitrogen in solid solution and the nitrogen combined as aluminum-nitride, manganese-nitride, etc. The total nitrogen was taken as the sum of the acid-soluble and the acid-insoluble amounts. Table VIII records the results of these analyses.

The chemical analyses for nitrogen disclosed a difference between the titanium- and the vanadium-alloyed steels. In the case of the titanium-alloyed steels both as-rolled and normalized, the acid-soluble nitrogen decreased and the acid-insoluble nitrogen (titanium nitride) increased as the titanium content was increased but the total nitrogen content remained practically constant. In general, normalizing had no effect on either the acid soluble and insoluble amounts or the total nitrogen content. For vanadium-alloyed steels both as-rolled and normalized, the nitrogen determinations were relatively constant for any one group of steels regardless of the vanadium content. No explanation is offered for the rather large differences in nitrogen content between the as-rolled and the normalized condition of steels 425A and 425B.

CHEMICAL ANALYSIS FOR ACID-SOLUBLE TITANIUM AND VANADIUM

Comstock,[4] in an investigation of steels alloyed with titanium and made under conditions of actual steel mill practice, noted an appreciable increase in impact value brought about by normalizing and attributed the improvement to the decrease of titanium in solid solution in the ferrite as the result of normalizing. To determine whether there was a decrease in solid solution of titanium and vanadium on normalizing, six samples of both titanium- and vanadium-alloyed steels were analyzed for acid-soluble titanium or vanadium before and after normalizing, Table IX. Once again a basic difference between the

[4] Comstock, loc. cit.

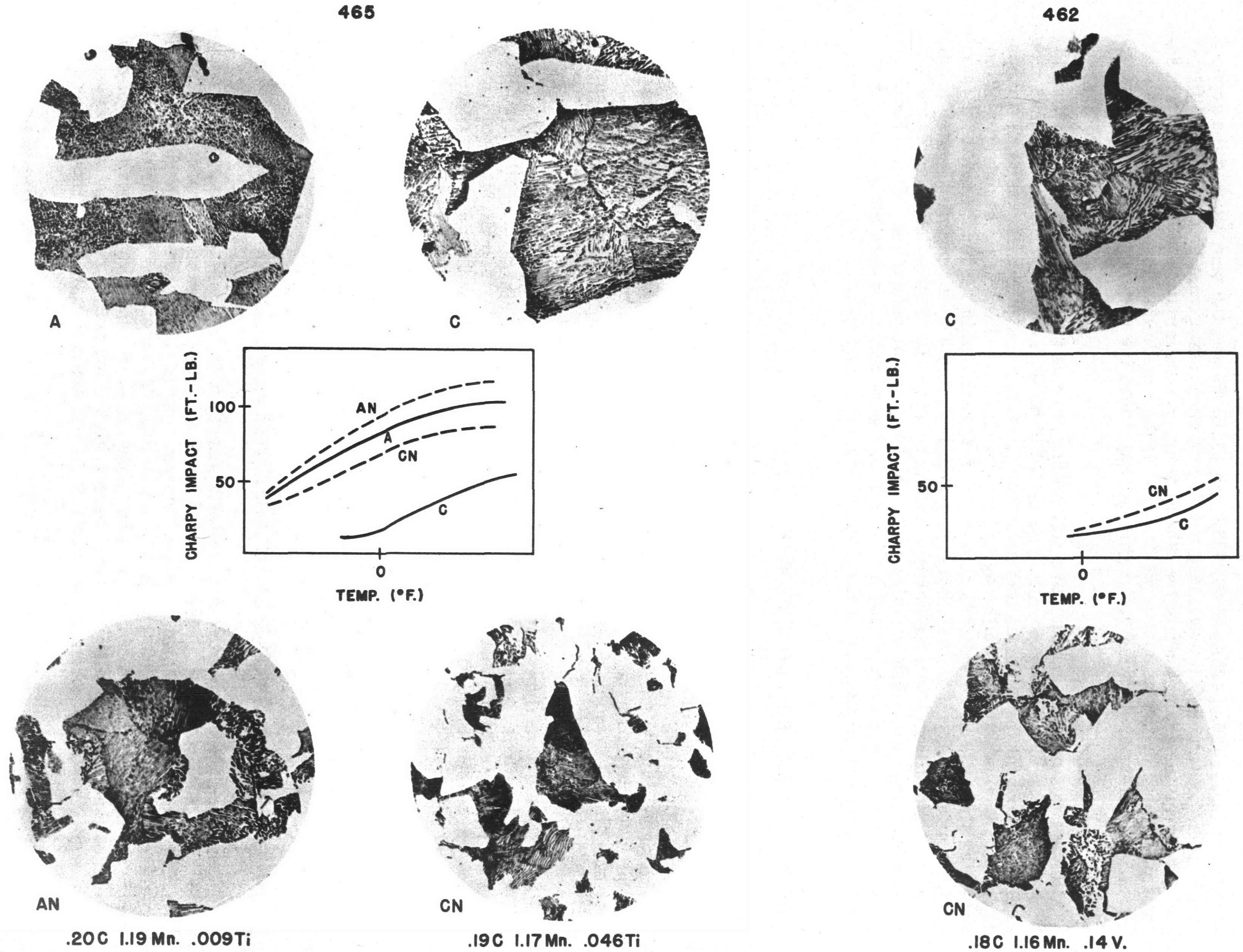


Fig. 14 - Pearlite magnified 650 times

titanium- and vanadium-alloyed steels was disclosed. In the case of the titanium-alloyed steels, the samples containing low titanium were relatively unaffected by normalizing (a difference between values of 0.003 is not considered significant) while those containing titanium on the high side of the range investigated were affected in that the acid-soluble amount was decreased by normalizing. In the case of the vanadium-alloyed steels, two of the three heats containing low vanadium were unaffected while the third containing high carbon, showed a decrease in the acid-soluble amount after normalizing. The three steels containing vanadium on the high side were affected to varying extents, but in all cases the acid-soluble amounts increased. In regard to the latter three steels, it is to be noted that the steel whose notch sensitivity was unaffected by normalizing showed the least increase in the acid-soluble amount while the two steels whose transition temperatures were materially improved by normalizing showed a substantial increase in acid-soluble vanadium as the result of normalizing.

CONCLUSIONS

Small variations in the amount of titanium or vanadium present in the high-tensile low-alloy experimental steels investigated, had a marked effect on the temperature transition from ductile to brittle behavior as indicated by the V-notch Charpy bar and the nick-bend specimen. The latter showed that welding adversely affected both the titanium- and vanadium-alloyed steels; the effect was most pronounced when the titanium or vanadium was on the high side of the ranges of composition investigated. Normalizing produced a marked improvement in the weldability of the titanium-alloyed steels, but there was little improvement in the vanadium steels. In regard to notch sensitivity as indicated by the Charpy bar, titanium and vanadium on the high side of the ranges investigated resulted in undesirably high transition temperatures in the as-rolled condition. Normalizing, however, produced a marked improvement in the transition temperatures of the titanium-alloyed steels, but the improvement was neither marked nor consistent in the vanadium steels. To minimize notch sensitivity in the experimental heats of steel, it was found that carbon and titanium in combination could not exceed 0.15 and 0.025 percent, respectively, and carbon and vanadium, 0.15 and 0.10 percent,respectively.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the keen interest and co-operation of Mr. C. M. Bible and Mr. D. I. Walter of the Analytical Chemistry Section in making the chemical analyses, the assistance of Mr. A. R. Donaldson and Miss Florence Wiley of the Metallography Group, and Messrs. J. Davenport, E. Eschbacher, and J. Rinebolt of the Welding Section in preparing specimens for microexamination. The authors also wish to express their thanks to the members of the Metallurgy Division of the National Bureau of Standards who assisted in the rolling of the steels, to Mr. C. E. Jackson, former head of the Welding Section at Naval Research Laboratory, who supervised the early work of this investigation, and to Messrs. J. Darby and J. Willkie of the Naval Research Laboratory Foundry for assistance in preparing the steels.

* * *

This page intentionally left blank.

TABLE I

CHEMICAL ANALYSES

Titanium-alloyed Steels — Elements (Percent)

Steel No.	C	Mn	Si	S	P	Ni	Cu	Mo	Cr	Al*	Ti*
428 A	0.18	1.38	0.16	0.028	0.014	0.14	0.31	0.049	0.069	0.033	0.011
428 B	0.17	1.40	0.16	0.028	0.007	0.14	0.32	0.047	0.064	0.052	0.016
428 C	0.13	1.36	0.16	0.028	0.013	0.14	0.32	0.047	0.064	0.039	0.030
429 A	0.20	1.18	0.17	0.027	0.012	0.14	0.32	0.042	0.066	0.036	0.009
429 B	0.17	1.21	0.20	0.027	0.012	0.14	0.32	0.044	0.068	0.036	0.031
429 C	0.17	1.15	0.17	0.026	0.011	0.14	0.32	0.045	0.068	0.028	0.035
430 A	0.18	0.99	0.18	0.028	0.016	0.14	0.31	0.037	0.068	0.034	0.009
430 B	0.19	0.99	0.16	0.029	0.009	0.14	0.34	0.045	0.074	0.037	0.021
430 C	0.18	0.98	0.16	0.027	0.015	0.14	0.33	0.039	0.074	0.028	0.041
432 A	0.11	1.21	0.27	0.028	0.009	0.13	0.33	0.044	0.069	0.048	0.012
432 B	0.13	1.21	0.27	0.028	0.019	0.13	0.33	0.039	0.064	0.044	0.030
432 C	0.16	1.10	0.26	0.028	0.019	0.13	0.32	0.040	0.062	0.036	0.031
459 A	0.14	0.98	0.16	0.020	0.012	0.11	0.27	0.038	0.039	0.025	0.009
459 B	0.15	0.97	0.15	0.020	0.012	0.11	0.28	0.035	0.041	0.021	0.023
459 C	0.15	0.92	0.13	0.020	0.012	0.11	0.26	0.035	0.041	0.019	0.032
460 A	0.13	1.47	0.22	0.015	0.013	0.11	0.26	0.033	0.036	0.026	0.007
460 B	0.14	1.46	0.23	0.015	0.013	0.11	0.26	0.034	0.035	0.025	0.023
460 C	0.14	1.41	0.21	0.015	0.013	0.10	0.26	0.036	0.035	0.020	0.032
464 A	0.21	1.00	0.13	0.020	0.017	0.11	0.25	0.035	0.038	0.021	0.009
464 B	0.21	1.00	0.13	0.020	0.017	0.10	0.26	0.038	0.037	0.020	0.023
464 C	0.23	0.97	0.13	0.020	0.017	0.10	0.27	0.034	0.039	0.019	0.044
465 A	0.20	1.19	0.14	0.020	0.011	0.11	0.27	0.034	0.040	0.024	0.009
465 B	0.21	1.18	0.15	0.020	0.011	0.11	0.27	0.034	0.041	0.026	0.026
465 C	0.19	1.17	0.14	0.020	0.011	0.11	0.26	0.039	0.054	0.022	0.046
466 A	0.21	1.44	0.18	0.024	0.017	0.10	0.27	0.026	0.036	0.027	0.009
466 B	0.22	1.39	0.18	0.025	0.017	0.11	0.26	0.026	0.035	0.025	0.022
466 C	0.20	1.39	0.18	0.026	0.017	0.10	0.26	0.036	0.035	0.021	0.046

Vanadium-alloyed Steels — Elements (Percent)

Steel No.	C	Mn	Si	S	P	Ni	Cu	Mo	Cr	Al*	V*
425 A	0.18	1.22	0.16	0.028	0.008	0.22	0.39	0.049	0.066	0.036	0.06
425 B	0.16	1.29	0.16	0.023	0.009	0.17	0.40	0.045	0.066	0.045	0.10
426 A	0.16	1.44	0.17	0.027	0.013	0.14	0.33	0.046	0.062	0.030	0.07
426 B	0.16	1.40	0.17	0.026	0.006	0.14	0.34	0.042	0.061	0.045	0.11
427 A	0.18	1.04	0.16	0.028	0.007	0.15	0.31	0.042	0.072	0.032	0.06
427 B	0.17	1.02	0.17	0.026	0.004	0.14	0.32	0.043	0.068	0.045	0.10
431 A	0.13	1.22	0.18	0.027	0.011	0.14	0.33	0.041	0.069	0.037	0.06
431 B	0.13	1.21	0.18	0.027	0.013	0.14	0.33	0.042	0.063	0.054	0.10
431 C	0.13	1.13	0.16	0.027	0.016	0.14	0.32	0.047	0.063	0.060	0.16
433 A	0.18	0.97	0.25	0.027	0.015	0.14	0.30	0.056	0.066	0.043	0.17
433 B	0.18	1.16	0.26	0.027	0.015	0.14	0.31	0.046	0.063	0.054	0.17
433 C	0.16	1.30	0.24	0.027	0.015	0.13	0.30	0.041	0.062	0.040	0.16
434 A	0.14	1.32	0.26	0.027	0.018	0.13	0.31	0.047	0.061	0.042	0.07
434 B	0.14	1.30	0.27	0.027	0.015	0.14	0.31	0.049	0.064	0.063	0.10
434 C	0.13	1.22	0.27	0.027	0.011	0.13	0.31	0.043	0.065	0.047	0.16
457 A	0.13	0.98	0.08	0.020	0.010	0.11	0.34	0.037	0.051	0.028	0.06
457 B	0.14	0.98	0.08	0.020	0.010	0.11	0.34	0.037	0.051	0.028	0.12
458 A	0.14	1.45	0.18	0.021	0.012	0.11	0.28	0.038	0.041	0.033	0.06
458 B	0.13	1.43	0.15	0.021	0.012	0.11	0.28	0.036	0.040	0.034	0.10
458 C	0.14	1.42	0.14	0.021	0.013	0.11	0.27	0.036	0.040	0.026	0.18
461 A	0.20	0.99	0.15	0.017	0.013	0.10	0.27	0.034	0.035	0.022	0.04
461 B	0.21	1.00	0.14	0.017	0.013	0.10	0.28	0.034	0.034	0.030	0.07
461 C	0.19	0.95	0.15	0.017	0.013	0.11	0.26	0.035	0.035	0.027	0.15
462 A	0.21	1.24	0.18	0.018	0.011	0.11	0.28	0.035	0.038	0.025	0.05
462 B	0.22	1.23	0.20	0.018	0.011	0.11	0.25	0.036	0.040	0.034	0.10
462 C	0.18	1.16	0.14	0.018	0.011	0.11	0.27	0.036	0.038	0.025	0.14
463 A	0.22	1.52	0.15	0.021	0.016	0.10	0.28	0.034	0.034	0.030	0.05
463 B	0.21	1.51	0.16	0.021	0.016	0.11	0.26	0.037	0.035	0.036	0.09
463 C	0.18	1.45	0.15	0.023	0.016	0.10	0.27	0.034	0.036	0.029	0.14
467 A	0.13	0.97	0.17	0.017	0.011	0.10	0.26	0.036	0.035	0.021	0.04
467 B	0.15	0.98	0.15	0.017	0.011	0.10	0.24	0.037	0.033	0.032	0.07
467 C	0.13	0.91	0.15	0.017	0.011	0.11	0.25	0.035	0.034	0.026	0.14

*Total amounts

TABLE II

TENSILE PROPERTIES AND PLATE HARDNESS

Titanium-alloyed Steels

Steel No.	As-rolled: Yield Point psi	As-rolled: Ultimate Strength psi	As-rolled: Yield Ratio percent	As-rolled: Elon. in 2-in. percent	As-rolled: Red. of Area percent	As-rolled: Hardness BHN	Normalized: Yield Point psi	Normalized: Ultimate Strength psi	Normalized: Yield Ratio percent	Normalized: Elon. in 2-in. percent	Normalized: Red. of Area percent	Normalized: Hardness BHN
428 A	51,000	75,000	67.9	35.5	71.0	141	54,000	74,750	72.3	36.0	70.5	143
428 B	48,500	72,750	66.6	35.0	70.0	141	52,250	74,750	70.0	37.0	71.5	144
428 C	51,000	75,250	67.7	34.0	68.5	150	51,000	76,250	66.9	35.0	71.0	145
429 A	50,250	74,250	67.8	35.5	68.0	142	51,500	74,750	69.0	35.5	69.5	145
429 B	52,750	77,750	67.9	31.5	65.0	149	52,250	74,000	70.6	36.5	70.5	142
429 C	58,000	81,000	71.5	33.0	63.0	147	50,750	73,750	68.9	37.0	68.0	142
430 A	46,750	69,000	67.8	36.5	66.0	128	47,750	69,250	69.0	39.0	68.0	137
430 B	43,750	68,750	63.7	35.0	65.5	137	46,750	70,500	66.4	36.0	68.0	131
430 C	48,500	72,000	67.4	31.0	63.5	143	47,250	70,000	67.5	37.0	67.5	135
432 A	45,500	66,250	68.7	38.5	68.5	127	50,750	69,250	73.3	39.0	72.5	135
432 B	49,500	69,000	71.6	36.5	71.5	140	51,500	68,750	74.9	39.0	74.0	130
432 C	50,250	71,250	70.5	33.5	71.5	134	48,500	68,000	71.3	40.0	71.0	135
459 A	39,000	63,000	61.0	46.0	72.0	121	39,750	62,000	64.2	41.0	74.5	115
459 B	40,750	63,000	64.7	39.5	71.0	126	39,250	62,500	62.8	41.0	73.5	118
459 C	43,250	65,500	66.0	36.5	64.0	128	39,750	61,500	64.6	39.5	72.5	114
460 A	44,000	68,500	64.3	38.5	76.0	134	47,250	70,000	67.5	39.5	79.0	126
460 B	50,500	72,750	69.4	36.5	74.0	149	45,250	68,750	65.7	38.5	78.0	131
460 C	57,000	84,250	67.6	31.5	70.5	156	48,000	69,500	69.0	38.5	78.5	131
464 A	42,750	67,250	63.5	38.5	64.5	137	44,000	69,000	63.8	37.5	68.0	135
464 B	47,250	74,250	63.7	35.0	65.0	146	43,000	68,000	63.3	36.0	67.0	126
464 C	52,000	78,750	66.0	30.0	59.5	149	46,250	70,000	66.1	37.0	66.5	124
465 A	46,750	64,250	72.8	37.0	68.5	143	47,750	73,750	64.8	36.5	70.5	132
465 B	50,500	78,250	64.6	33.0	68.0	156	46,500	73,250	63.5	35.0	68.5	131
465 C	54,000	81,500	66.3	32.5	65.5	156	46,500	71,250	65.3	36.0	65.5	133
466 A	49,250	78,500	62.8	35.0	68.0	146	51,750	78,500	65.9	34.5	70.5	-
466 B	53,250	83,250	64.0	33.5	64.5	163	52,500	78,750	66.7	33.5	68.5	152
466 C	53,250	84,750	62.9	31.0	66.5	170	49,500	74,750	66.3	35.0	69.0	137

TABLE II (cont.)

Vanadium-alloyed Steels

Steel No.	As-rolled Yield Point psi	As-rolled Ultimate Strength psi	As-rolled Yield Ratio percent	As-rolled Elon. in 2-in. percent	As-rolled Red. of Area percent	As-rolled Hardness BHN	Normalized Yield Point psi	Normalized Ultimate Strength psi	Normalized Yield Ratio percent	Normalized Elon. in 2-in. percent	Normalized Red. of Area percent	Normalized Hardness BHN
425 A	55,500	79,250	70.0	32.5	68.0	160	53,500	76,750	69.7	34.5	68.5	146
425 B	54,000	79,000	68.4	31.0	66.0	169	58,750	86,750	67.7	29.0	63.5	167
426 A	53,500	76,750	69.8	33.0	71.5	157	52,000	76,750	67.7	35.0	72.0	149
426 B	56,000	80,000	70.0	29.0	64.5	169	57,500	85,000	67.7	28.5	66.0	163
427 A	51,250	71,750	71.5	33.0	67.0	136	48,750	69,750	70.0	35.5	71.0	137
427 B	54,000	75,500	71.5	32.5	67.0	144	52,750	76,000	69.5	34.0	66.0	144
431 A	52,000	72,500	71.8	36.0	71.5	134	46,750	68,250	68.5	38.5	73.5	137
431 B	51,500	71,000	72.5	35.0	68.5	143	50,000	73,750	67.8	33.5	69.5	140
431 C	55,000	71,750	76.6	34.0	69.0	147	49,000	71,750	68.4	34.5	66.0	144
433 A	66,000	83,250	79.4	27.5	60.0	169	55,750	79,000	70.6	31.5	66.5	161
433 B	61,000	85,250	71.6	26.0	62.0	171	66,500	93,500	71.2	24.5	62.5	183
433 C	61,250	85,000	72.0	27.5	64.0	157	50,250	82,250	61.1	31.5	65.0	169
434 A	52,500	73,500	71.5	34.0	71.5	146	50,250	72,250	69.5	36.0	72.5	142
434 B	49,750	73,000	68.0	35.0	71.5	149	49,750	75,250	66.2	34.0	71.0	148
434 C	53,000	73,250	72.4	35.0	68.0	140	50,250	76,250	65.9	33.5	67.0	149
457 A	45,000	67,000	67.2	37.0	70.0	131	41,250	62,750	65.9	39.0	71.0	116
457 B	47,250	66,000	71.6	33.0	68.0	146	44,750	64,750	69.1	39.5	72.0	125
458 A	53,500	74,750	71.5	34.5	73.0	152	47,250	72,000	65.7	35.0	70.0	139
458 B	55,000	78,250	70.4	32.0	68.5	156	49,500	76,500	64.7	33.0	68.0	144
458 C	61,000	87,500	69.7	29.0	65.5	170	55,250	78,500	70.4	31.0	68.0	153
461 A	51,000	78,750	64.7	32.0	64.0	156	48,250	73,250	66.0	35.5	68.5	128
461 B	56,750	83,000	68.5	32.0	66.5	167	52,250	75,750	69.0	35.0	66.0	138
461 C	59,250	83,250	71.2	30.0	61.0	170	53,750	79,500	67.7	31.5	62.5	156
462 A	57,750	85,500	67.6	32.0	66.5	174	53,750	80,000	67.2	33.0	67.5	153
462 B	61,750	89,750	68.9	27.5	66.0	183	57,000	83,750	68.2	28.0	60.0	179
462 C	57,250	93,500	61.3	25.5	59.0	187	62,250	89,750	69.4	27.5	60.5	163
463 A	60,250	94,000	67.8	30.0	66.0	179	55,750	83,250	67.0	30.0	67.0	161
463 B	67,000	94,250	71.1	29.5	65.5	197	60,250	90,000	67.0	26.5	62.0	180
463 C	73,250	100,750	72.7	25.5	59.5	192	66,250	92,500	71.6	26.5	62.0	176
467 A	44,750	67,000	66.9	37.0	70.5	131	42,250	63,000	67.0	37.5	73.0	116
467 B	44,500	66,250	67.3	34.9	69.0	134	41,000	64,750	63.4	37.0	71.5	122
467 C	49,750	75,250	66.2	29.5	66.0	149	46,750	66,250	70.6	37.0	70.0	131

TABLE III

CHARPY BAR DATA FOR THE AS-ROLLED STEELS

(Ft-lbs of Energy Absorbed)

STEEL No.	TESTING TEMPERATURE °F.																				
	-80	-60	-40	-30	-20	0°	10	20	32	50	60	70	80	90	100	120	140	160	180	200	220
425A	16	32	18		33	88	51	58	47 49 77 73	89	67	77 84 102 77	101	101	88		88				
B	5	24	20		28	27	35	70	51 50 49 53	49	76	58 69 65 75	69	82	81		88			96	
426A	41	50	95		117	77	125	119	122 93 132 80	111	112	113 106 106 81	123	111	111		115				
B			27		29	40	67		60 47 69 45	56		85 63 67	80								
427A	7	13	34		28	54	71	103	69 63 77 58	73	106	106 104 89 74	98	95	90		90				
B	7	9	31		37	42	51	40	50 47 71 58	59	90	87 87 87 77	64	88	95	91	97	102			
428A	39	10	48		74	91	94	96	90 77 78 54	105	96	85 98 126 88	114	97	102		102				
B	5	31	40		34	74	42	80	69 85 68 87	94	82	113 107 96 97	112	98	101		121				
C	3	5	65		27	22	47	40	50 38 97 40	89	118	85 69 101 88	91	81	97	112					
429A	9	30	38		54	69	56	55	85 64 92 64	79	98	85 80 84 74	89	102	94	97	100				
B	4	35	8		7	26	36	47	31 22 32 33	59	89	69 48 50 55	62	65	61	88	69	84			
C			5		77	45	22	30	22 22 36 31	30	50	43 47 60 48	88	78	46	90	90				
430A	6	23	75		45	68	56	71	102 59 64 96	76	98	92 98 108 96	103	92	99	96	93				
B	7	17	36		35	33	47	80	62 58 104 50	98	83	67 75 82 126	86	84	111	86	104				
C	6	3	3		40	80	64	17	15 12 79 14	80	88	48 40 36 39	37	114	41	115 99					
431A		104	42		56	65	132	87	110 127 151 88	80	170	112 115 113 116	94	97	102	111	95				
B	31	42	52		84	63	46	79	92 93 90 68	92	110	94 98 107 94	111	104	93	109 105 110	113				
C	22		66		70	58	117	133	61 63 62 72	72	103	95 96 124 94	101								
432A	11	110	50		121	138	119	118	96 94 133 78	124	117	135 101 129 113	117	107	114	143	95				
B	3	5	25		9	133	130	66	53 50 83 51	81	83	68 87 110 77	108	110	95	91 116	109 114				
C			8		91	8	83	36	29 33 55 33	103	120	53 75 123 73	108	131	118						
433A			13		20	22	31	24	37 31 21 25	40	57	51 38 45 52	49	41	37	56	72 70	90 85 87			
B			4		17	22	20	26	42 36 39 39	29	21	52 68 23 49	38	46	45	53	54				
C			22		24	25	30	30	37 38 32 29	56	95	46 63 66 48	103	86	83	97					
434A	34	27	80		50	107	94	68	99 69 90 85	138	95	110 110 115 82	119	97	113	118	103				
B	30	30	68		83	72	73	73	65 60 90 88	78	81	114 87 117 75	121	116	89	117 116					
C	10	22	35		34	62	57	42	45 56 79 53	110	70	95 80 119 83	77	70	98						
457A	4	5	32	17	30	102 98 48	18	61	111 97 91	112	116	119 127 111	130	126	106						
B					12	15 13 3	43	64	69 88 26	108	90	62 98 95	101	104	110 127	121	103				
458A	28 85	23	108	103	100	88 125 97	88	121	123 105 143	125	124	138 130 147	123	110	127						
B	22	13	53	63	100	73 114 63	94	74	106 78 101	110	118	98 109 105	122	109	106						
C					30	7 34 27	42	39	90 38 53	93	76	75 80 75	90	63	67	99	109 99	93			

TABLE III (cont.)

STEEL No.	TESTING TEMPERATURE °F.																				
	-80	-60	-40	-30	-20	0	10	20	32	50	60	70	80	90	100	120	140	160	180	200	220
459 A	9 6	13	109	109	150	139 (110) 130 145	133	123	149 167 152 150	150	142	129 161 140	159	146	145						
B	2		12	73	34	82 57 9	61	21	88 167 82 155 152	118	(106)	114 130 129	137	133	136						
C					10	6 46 9	13	63	32 81 81	96	95	93 118 109	97	(106)	133	133	125	118			
460 A	52 118	114	120	142	141	150 165 135	143	(151)	171 176 164	176	170	159 174 136	156	174	159						
B	6 4	6	95	95	85	104 88 89	120	55	107 124 89	149	128	133 122 125	159	(104)	159	180					
C					4	5	5	7	10 7	11	45	15 20 49	19	49	63	89	95	118		(110)	121 118 129
461 A			7		31	17 8	43	43	33 34 64	77	73	68 68 67	58	69	79	(73)	98 95	100 98			
B					7	10	9	11	24 22	31	28	32 40 32	30	41	33	45	61	72	81	(68)	92 94 90 90
C					7	19 22	30	18	52 30 34	50	60	60 61 57	58	36	50	75	(73)	97 86	93 93 97	91	
462 A	7 22	19	34	32 37	37	69 43	68	56	78 57 89	87	83	86 88 91	100	97	(97)	100	100	103			
B	10			8	10	39 23	25	33	31 31 23	53	52	42 51 71	38	76	64	84	86	(78)	97	97	
C					8	18	16	25	19 24	30	21	22 22 35	25	31	36	64	62	73	(67)	88 95 92	
463 A	20	9	33	32	40	47 48 27	41	60	72 81 72	85	75	75 90 85	88	90	(91)	95	101	102			
B			21		19	29	33	19	39 27	50	30	46 46 34	48	54	46	58	78	(50)	83 80	83	
C					11	26 73	23	21	34 38	42	24	25 27 39	48	42	30	56	57	60	79 (59) 82	81 75 84 84	
464 A	3		11	51	40	60 79	106	88	98 108 93	114	(95)	103 104 102	107	115	100						
B				6	4	36 6	15	39	39 27 31	57	55	60 60 52	59	84	78	64	(90)	105 93	105		
C					3	5	7	12	19 7	39	38	11 26 35	58	53	44	60	59	73	88 (77) 96	88 94 94 90	
465 A	5 20	35	51	17	73	70 80 97	85	90	101 61 102	(100)	118	112 116 115	109	116	110						
B	3			29	5	37 27 10	19	50	82 62 59	68	90	84 61 70	96	98	98	(93)	112	101			
C					5	7 8 13	7	13	48 46 36	32	48	59 51 39	53	42	63	85	65	85		(94)	
466 A	65 18	25	38	68	40	55 48 74	56	123	55 78 93	(92)	102	96 98 106	83	102	92						
B					13	24 31	11	48	35 32 38	53	53	55 74 72	67	77	(85)	101	93	86			
C					3	5	5	7	6 17	11	27	41 18 29	34	38	23	57	58	85	91	(84)	99 92 96
467 A	5		17	46	57	49 90 78	73	77	104 92 87	143	129	129 136 123	140	136	(126)						
B	4		7	78	43	95 26 63	94	86	98 100 75	108	106	130 102 129	130	(118)	120						
C					6	5	16	10	38 17 32	43	32	80 32 41	75	55	91	76	109	(102)	99	122	

Note: The encircled values correspond to the temperature at which there occurred the first visual evidence of brittleness in the fracture.

TABLE IV

CHARPY BAR DATA FOR THE NORMALIZED STEELS

(Ft-lbs of Energy Absorbed)

STEEL No.	TESTING TEMPERATURE °F.																					
	-100	-80	-60	-40	-30	-20	0	10	20	32	50	60	70	80	90	100	120	140	160	180	200	220
425 AN	28	29	40	70	78	91	81 96 102	74	87	106 94 114	95	96	100 105 91	93	88							
BN				21		17	50	40	52	50 33 71	95	73	34 61 95	57	77	87	105 103 98	103				
426 AN	27		40	124		107	126 115 117	117	110	108 117 112	116	115	119 119 108	105	108							
BN		24		21	40		52 32		19	66 60 19			101 87	54	44		116					
427 AN	16	35	65	50	72	81	78 84 91	94	103	96 107 94	107	109	110 117 89	98	99							
BN				26		25	21	27	32	42 40 64	81	46	92 89 38	43	82		100	101 88 71	100 88	102	90	
428 AN	25	87	23	108	97	92	113 109 99	84	103	123 117 105	107	103	115 113 92	118	110							
BN	7	30	27	56	94	41	75 98 61	70	90	118 96 99	93	99	117 118 100	86	104							
CN		28	21	37	49	29	90 97 36	75	73	98 100 92	90	104	104 99 98	112 113 108	102	107						
429 AN	12	32	28	71	86	58	95 105 72	84	97	91 110 83	92	105	103 110 100	105	97							
BN		11	21	13	74	33	84 123 49	78	66	113 96 84	84	90	104 109 89	94	101							
CN		21		27	63	28	81 72 32	56	44	108 108 87	87	81	95 108 88	92	90							
430 AN	11	29	34	75	80	46	120 117 87	91	79	110 112 94	98	94	106 107 92	103	94							
BN		11	19	25	39	44	48 123 102	73	56	66 63 99	89	85	95 80 91	98	96							
CN		16		10	76	28	63 66 30	77	54	85 98 93	83	105	101 108 90	86	90							
431 AN	28	50	86	62	142	76	135 138 76	103	125	155 129 101	103	129	132 146 115	113	100							
BN		50	20	53	80	21	85 103 35	72	56	80 96 71	113	84	132 108 107	93	102	110	108					
CN		19		18	50	25	70 58 68		38	96 90 57	61	75	89 116 114	117	79		116					
432 AN	16	92	111	109	138	95	133 114 128	128	120	147 117 124	114	114	148 145 158	93	118							
BN		29	23	105	104	72	113 112 110	111	117	158 148 108	128	98	148 143 122	121	126							
CN	16	61	56	65	98	86	126 137 93	95	113	128 115 108	112	118	132 117 116	101	100							
433 AN				16			28	15	26	40 42 33	38	46	75 76 26	45	29	53	66	73	98	96	75	
BN				9			9	17	19	21 12	22	24	30 31 5	26	23	33	26	39			56	88
CN				7			7	7	29	47 32	23	33	36 90 28	25	48	36	77	35	97	93	91	
434 AN	35	69	37	56	78	55	109 112 100	75	106	117 143 109	108	96	125 136 112	122	111							
BN		30		29	52	18	90 52 22	34	41	107 119 57	49	46	98 115 73	87	74		89	62	109	123	114	
CN		12	27	23	18		59 38 20	33	30	64 61 25	25	52	49 90 22	73	38	58	52					
457 AN	5	6	30	30	95	100	116 118 72	108	128	165 148 113	106	101	158 145 133	107	122							
BN		8	9	75	77	36	78 70 57	97	105	105 103 137	106	117	133 110 101	131	122	135	132					
458 AN	77	100	34	136	121	134	113 101 102	137	130	145 138 101	100	111	137 134 144	110	134							
BN		43	19	31	73	65	45 57 88	96	104	118 120 108	116	79	121 109 110	95	123							
CN		9		42	38	62	79 55 97	96	108	87 81 96	96	114	84 113 89	115	94	108	127					

TABLE IV (cont.)

STEEL No.	-100	-80	-60	-40	-30	-20	0	10	20	32	50	60	70	80	90	100	120	140	160	180	200	220
							TESTING TEMPERATURE °F.															
459 AN	13	12	(58)	126	152	137	165 154 148	144	139	181 70 142	143	137	173 162 143	154	142							
BN	2	95	35	110	118	58	138 151 128	15	(123)	145 132 135	144	145	150 156 139	153	138							
CN		7	14	67	122	71	141 128 119	107	(118)	150 172 136	137	135	155 152 145	140	142							
460 AN	(124)	165	166	152	162	165	183 178 157	161	161	185 201 159	170	160	183 197 168	172	177							
BN	5	7	100	123	92	128	166 152 142	117	134	191 142 (136)	172	167	182 186 145	151	170							
CN	6	68	47	128	137	94	166 142 123	(125)	155	164 150 137	144	155	175 179 150	153	164							
461 AN	8	38	22	64	39	30	89 82 73	46	95	83 97 (59)	105	89	105 104 118	118	97							
BN		26		32	21	29	40 42 35	64	44	59 53 84	(72)	102	69 56 108	114	112							
CN		6		40	8	5	10 24 86	79	107	76 78 94	98	98	47 106 24	31	110	41	43		109	77	(73)	78 108
462 AN	13	27	37	25	46	80	49 56 40	45	92	87 82 66	97	92	85 83 (80)	94	109	126						
BN		9	18	9	12	7	30 37	17	46	31 32	33	42	33 41 33	59	49	40	70	73		(73)		
CN		5		11	12	11	26 44 6	14	32	27 76 6	20	35	29 44 23	33	80	47	62	57	(78)		93	
463 AN		25		20	46	32	45 44	79	52	81 68	(43)	96	90 98 101	103	100							
BN		18		17	18	21	23 18	35	26	25 71	28	66	30 30 43	68	62	87	(70)	86 86	85			
CN		20		20	13	14	26 15	20	22	22 32	37	27	45 25 31	35	59	28	31	82 79	(78)		72	
464 AN	12	30	23	90	88	95	97 91 97	112	(99)	113 115 110	93	117	100 118 118	117	124							
BN		13	15	38	13	56	63 68 92	44	81	92 92 83	103	91	104 86 (90)	107	105	120	113					
CN		8	11	25	31	28	58 58 51	56	69	80 86 80	85	(88)	91 102 100	117 100	97	115	111					
465 AN	5	20	40	45	74	81	81 92 (105)	116	110	110 115 117	112	115	126 113 117	114	102							
BN		16	23	31	30	52	74 80 56	56	102	86 80 77	103	102	98 120 111	(105)	108	131	116					
CN		8	14	52	37	65	88 81 61	58	77	90 97 74	92	88	117 103 90	91	(98)		103 116	106	117			
466 AN	28	67	58	103	94	61	104 128 90	(77)	91	120 122 112	103	87	122 120 110	120	108							
BN		9	8	33	25	15	55 60 70	72	33	101 64 83	71	93	95 91 65	98	73	(71)	121	80	102			
CN		5		26	33	17	60 63 36	49	52	79 76 68	93	105	110 112 94	90	87	(110)	110	102	106			
467 AN	7	89	98	102	90	115	144 138 101	120	(124)	158 150 145	135	142	147 162 117	142	149							
BN		7	14	85	53	50	105 86 120	138	83	101 110 111	139	138	139 102 126	97	103	(145)	132	157	106			
CN		25	9	31	43	93	91 89 106	104	75	123 103 112	118	110	134 115 (115)	120	115	141	135					

Note: The encircled values correspond to the temperature at which there occurred the first visual evidence of brittleness in the fracture.

This page intentionally left blank.

TABLE V

TRANSITION TEMPERATURE ACCORDING TO THE FIRST SIGN OF BRITTLENESS

TITANIUM-ALLOYED

Steel	A	B	C	AN	BN	CN
428	32	70	$>90^{+2}$*	-60	32	80
429	80	$>160^{+0}$	$>140^{+0}$	0	50	60
430	90	80	$>100^{+2}$	20	50	50
432	10	120	50	-20	32	32
459	0	60	90	-60	20	20
460	20	$>90^{+2}$	$>200^{+2}$	-80	32	10
464	60	140	180	20	70	60
465	50	120	$>200^{+0}$	0	80	90
466	50	100	$>200^{+2}$	10	100	100

VANADIUM-ALLOYED

Steel	A	B	C	AN	BN	CN
425	60	$>140^{+1}$	—	20	100	—
426	0	$>80^{+0}$	—	-40	$>90^{+1}$	—
427	50	$>120^{+2}$	—	-20	140	—
431	50	100	$>80^{+0}$	0	80	$>90^{+1}$
433	140	$>140^{+0}$	$>100^{+1}$	140	$>200^{+1}$	140
434	60	$>100^{+2}$	$>100^{+0}$	60	140	$>120^{+0}$
457	60	$>140^{+0}$	—	32	70	—
458	20	32	120	50	60	70
461	120	$>200^{+2}$	140	32	50	$>200^{+2}$
462	100	$>160^{+2}$	180	70	$>180^{+0}$	$>160^{+1}$
463	100	160	180	50	120	$>160^{+1}$
467	$>100^{+0}$	$>90^{+1}$	$>160^{+2}$	20	100	70

*The notation $>90^{+2}$ signifies that the onset of brittleness may occur at a higher temperature than 90°F ($+2$ indicates that two completely ductile fractures occurred at 90° or higher temperatures — at least $+3$ are desirable in establishing the first sign of brittleness).

TABLE VI

NICK-BEND TEST DATA

Titanium-alloyed Steels

	As-rolled							Normalized					
	PLATE			WELDED				PLATE			WELDED		
Steel No.	Degrees* of Bend	Maximum Load-lb	Type of Failure	Degrees* of Bend	Maximum Load-lb	Type of Failure	Steel No.	Degrees* of Bend	Maximum Load-lb	Type of Failure	Degrees* of Bend	Maximum Load-lb	Type of Failure
428 A	68	21,400	No curves run	26	18,600	A1	428 A	66	21,400	A1	36	20,300	A
428 B	64	21,600		26	18,800	B1	428 B	63	21,300	A1	28	18,400	A1
428 C	64	21,800		33	20,800	B1	428 C	68	21,500	A1	47	21,300	A1
429 A	64	20,800		26	17,300	A1	429 A	64	22,100	A1	38	20,500	A1
429 B	58	22,400		28	21,200	B2	429 B	65	21,300	A1	31	17,700	A1
429 C	47	22,300		26	20,800	B2	429 C	62	22,000	A1	41	20,200	A1
430 A	66	20,900		40	18,900	A1	430 A	74	19,200	A1	46	19,600	A1
430 B	61	21,700		35	19,100	A1	430 B	63	21,500	A1	40	19,500	A1
430 C	46	20,700		34	19,600	B2	430 C	62	20,300	A1	46	19,700	A1
432 A	76	21,100		46	20,100	A1	432 A	65	20,000	A1	53	19,000	A1
432 B	70	20,650		41	19,400	B1	432 B	66	19,150	A1	43	17,800	
432 C	62	19,750		40	20,200	B2	432 C	66	20,000	A1	49	19,900	A1
459 A	74	13,750	A1	61	14,300	A1	459 A	79	14,100	A1	66	14,600	A1
459 B	75	15,000	A1	63	15,400	A1	459 B	83	14,300	A1	57	15,200	A1
459 C	71	15,150	A1	67	16,300	B2	459 C	83	14,200	A1	64	14,300	A1
460 A	72	15,700	A1	48	16,200	B1	460 A	76	14,900	A1	65	16,800	A1
460 B	71	16,850	A1	52	17,600	B2	460 B	72	15,500	A1	57	16,400	B1
460 C	68	18,700	B2	40	19,400	C2	460 C	75	16,200	A1	46	15,300	A1
464 A	69	15,700	B2	43	15,300	A2	464 A	76	15,900	A1	47	16,000	A1
464 B	67	17,100	B2	41	16,400	B2	464 B	75	15,600	A1	41	16,000	A1
464 C	52	18,100	B2	43	17,600	B2	464 C	67	16,100	A1	41	15,300	A1
465 A	72	16,700	A1	36	16,000	A2	465 A	73	17,000	A1	38	15,500	A1
465 B	67	17,600	A1	37	17,300	B2	465 B	81	16,600	A1	30	15,200	A1
465 C	58	18,400	B2	35	17,400	C2	465 C	72	16,700	A1	36	14,800	A1
466 A	64	18,150	A1	23	14,800	B1	466 A	67	17,100	A1	37	17,200	A2
466 B	64	19,800	B2	19	16,300	C1	466 B	69	18,000	A1	22	16,150	B1
466 C	57	20,700	B2	19	18,200	C2	466 C	69	17,200	A1	18	13,400	A1

*Angle at maximum load.

TABLE VI (cont.)

Vanadium-alloyed Steels

Steel No.	As-rolled PLATE Degrees* of Bend	As-rolled PLATE Maximum Load-lb	As-rolled PLATE Type of Failure	As-rolled BEAD WELD Degrees* of Bend	As-rolled BEAD WELD Maximum Load-lb	As-rolled BEAD WELD Type of Failure	Steel No.	Normalized PLATE Degrees* of Bend	Normalized PLATE Maximum Load-lb	Normalized PLATE Type of Failure	Normalized BEAD WELD Degrees* of Bend	Normalized BEAD WELD Maximum Load-lb	Normalized BEAD WELD Type of Failure
425 A	63	23,100	No curves run	29	21,700	B1	425 A	63	20,700	A1	38	19,400	A1
425 B	56	23,500		19	21,500	C2	425 B	61	23,600	A1	16	17,400	B1
426 A	62	23,000		27	21,500	B1	426 A	73	22,300	A1	27	19,300	B2
426 B	63	26,100		26	21,500	A1	426 B	50	23,800	A1	22	19,300	C1
427 A	66	21,000		35	19,200	B1	427 A	73	20,200	A1	53	19,000	A1
427 B	54	22,100		26	20,000	B1	427 B	75	24,200	A1			
431 A	70	20,500		40	20,300	B1	431 A	63	20,800	A1	54	19,400	A1
431 B	69	22,800		30	19,600	B2	431 B	60	19,400	A1	39	17,800	B1
431 C	63	21,500		35	20,500	B1	431 C	65	21,700	A1	37	19,700	B2
433 A	53	24,700		25	21,800	B2	433 A	62	23,200	B2	39	21,300	B2
433 B	36	24,400		14	22,000	C2	433 B	59	25,500	B2	26	22,000	C2
433 C	50	25,800		20	21,200	C1	433 C	62	23,900	B2	33	22,000	B2
434 A	63	21,500		35	20,900	B1	434 A	65	20,000	A1	48	18,900	A1
434 B	63	22,400		30	20,300	B2	434 B	70	19,700	A1	38	19,900	B1
434 C	58	21,700		43	21,800	B2	434 C	63	21,700	A1	46	21,700	B2
457 A	75	15,500	A1	55	15,500	B2	457 A	73	14,000	A1	64	15,600	A1
457 B	68	16,900	A1	46	16,700	B2	457 B	73	14,900	A1	49	15,200	A1
458 A	68	17,600	A1	38	17,600	B2	458 A	67	16,700	A1	43	17,400	B2
458 B	76	18,350	A1	41	18,000	B2	458 B	68	16,500	A2	37	17,700	B2
458 C	63	20,800	B1	30	19,800	B2	458 C	63	18,600	B2	28	16,600	B2
461 A	59	18,900		15	14,600	B1	461 A	68	16,800	A1	26	14,700	A1
461 B	53	17,800	B2	21	17,600	C2	461 B	56	17,100	A1	19	14,700	B1
461 C	43	19,200	B2	28	15,600	C2	461 C	43	17,500	B2	16	14,100	B1
462 A	62	19,900	B2	16	16,500	C1	462 A	61	18,400	A1	17	14,400	B1
462 B	51	20,400	B2	21	18,800	C2	462 B	48	19,400	B2	9	13,800	C1
462 C	44	21,400	B2	9	16,900	C2	462 C	43	21,200	B2	9	15,500	C1
463 A	52	20,600	B2	13	16,700	C1	463 A	57	19,800	A1	14	14,700	C1
463 B	51	21,800	B2	14	18,000	C2	463 B	42	19,800	B2	8	15,600	B1
463 C	42	22,600	B2	8	16,900	C2	463 C	40	20,100	B2	10	17,000	C1
467 A	73	15,000	A1	50	15,900	B1	467 A	78	14,700	A1	61	15,100	A1
467 B	68	15,500	A1	53	16,900	A1	467 B	76	15,200	A1	60	15,700	B2
467 C	63	17,500	B2	49	18,000	B2	467 C	75	15,700	A1	53	15,900	A1

*Angle at maximum load.

TABLE VII

UNDERBEAD CRACKING RESULTS AND MAXIMUM UNDERBEAD HARDNESS

Titanium-alloyed Steels

Steel No.	Max. Underbead Hardness			Max. Quench Hardness VHN	Percent Max. Hardness	Underbead Cracking Results †	
	Knoop	VHN	VHN*			10°F	80°F
428 A	363	366		495	74.0	OK	OK
428 B	363	297	292	482	61.6	OK	OK
428 C	412	308	304	436	70.7	OK	OK
429 A	363	326	320	519	62.9	XX	X
429 B	363	292	287	482	60.6	OK	OK
429 C	363	307	292	482	63.7	OK	OK
430 A	363	293	285	495	59.2	OK	OK
430 B	363	284	278	507	56.0	OK	OK
430 C	341	273	263	495	55.2	OK	OK
432 A	287	253		400	63.6	OK	OK
432 B	323	255		436	58.5	OK	OK
432 C	287	243	240	470	51.6	OK	OK
459 A	285	228	227	443	51.5	OK	OK
459 B	268	226	227	450	50.2	OK	OK
459 C	300	224	221	450	49.7	OK	OK
460 A	310	304	304	436	69.7	OK	OK
460 B	368	319	303	443	72.0	OK	OK
460 C	358	289	279	443	65.4	OK	OK
464 A	408	325	312	510	63.7	OK	OK
464 B	368	306	301	510	60.0	OK	OK
464 C	408	302	295	526	57.4	XX	OK
465 A	408	357	350	496	72.0	OK	OK
465 B	434	330	325	510	64.9	XX	OK
465 C	455	342	340	492	69.5	OK	OK
466 A	408	373	363	510	73.1	OK	OK
466 B	434	370	368	526	70.4	OK	OK
466 C	434	373	363	496	75.1	OK	XX

† "OK" - indicates no visible cracking
"X" - one small crack
"XX" - one or more large cracks
"XXX"- cracking completely around the heat-affected zone.

*Hardness based upon the average of 5 highest Vickers Hardness Numbers.

TABLE VII (cont.)

Vanadium-alloyed Steels

Steel No.	Max. Underbead Hardness			Max. Quench Hardness	Percent Max. Hardness	Underbead Cracking Results †	
	Knoop	VHN	VHN*	VHN		10°F	80°F
425 A	474	378	376	495	75.9	OK	OK
425 B	474	401	393	470	85.4	OK	OK
426 A	412	388	376	470	82.5	OK	OK
426 B	412	381	377	470	81.0	OK	OK
427 A	443	345	339	495	69.7	XX	OK
427 B	412	366	353	482	75.9	OK	OK
431 A	363	327	324	436	75.0	OK	OK
431 B	363	327		436	75.0	XX	OK
431 C	341	305	302	436	70.0	OK	OK
433 A	363	342	319	495	69.1	OK	OK
433 B	412	373	369	470	79.4	OK	OK
433 C	397	350	336	470	74.4	OK	X
434 A	341	333	327	443	75.2	OK	OK
434 B	363	328	322	436	75.2	OK	OK
434 C	341	314	309	436	72.0	OK	OK
457 A	396	299	290	436	68.6	OK	OK
457 B	348	306	304	443	69.0	OK	OK
458 A	408	370	365	443	83.5	OK	OK
458 B	396	370	365	436	84.9	OK	OK
458 C	408	354	352	443	80.0	OK	OK
461 A	455	409	401	496	82.4	OK	XX
461 B	486	401	397	510	78.7	OK	OK
461 C	470	387	384	492	78.7	OK	OK
462 A	503	433	429	510	85.0	OK	OK
462 B	470	433	419	526	82.4	OK	OK
462 C	520	446	439	495	90.2	OK	OK
463 A	486	446	445	526	80.2	OK	OK
463 B	470	446	425	510	87.5	OK	OK
463 C	486	470	425	495	74.8	OK	XX
467 A	338	289	289	436	66.3	OK	OK
467 B	325	303	297	460	65.9	OK	OK
467 C	338	299	296	436	68.5	OK	OK

† "OK" - indicates no visible cracking
"X" - one small crack
"XX" - one or more large cracks
"XXX"- cracking completely around the heat-affected zone.

*Hardness based upon the average of 5 highest Vickers Hardness Numbers.

TABLE VIII

CHEMICAL ANALYSIS FOR NITROGEN

Nitrogen Determinations - Titanium-alloyed

STEEL NO.	CHEMICAL ANALYSIS	NITROGEN* ACID-SOLUBLE	NITROGEN* ACID-INSOLUBLE	NITROGEN* TOTAL
466 A	.21C 1.40Mn .009Ti	.0030	.0020	.0050
B	.022Ti	.0005	.0035	.0040
C	.046Ti	.0000	.0040	.0040
AN	Normalized	.0037	.0012	.0049
BN		.0005	.0045	.0050
CN		.0005 .0015	.0025 .0035	.0030 .0050
465 A	.20C 1.18Mn .009Ti	.0045	.0010	.0055
B	.026Ti	.0000 .0010	.0015 .0030	.0015 .0040
C	.046Ti	.0020	.0045	.0065
AN	Normalized	.0050	.0000	.0050
BN		.0012	.0035	.0047
CN		.0015	.0035	.0050
460 A	.14C 1.45Mn .007Ti	.0050	.0000	.0050
B	.023Ti	.0010 .0015	.0010 .0035	.0020 .0050
C	.032Ti	.0015 .0020	.0013 .0050	.0025 .0070
AN	Normalized	.0050	.0000	.0050
BN		.0020	.0033	.0053
CN		.0015	.0035	.0050
459 A	.15C .96Mn .009Ti	.0040	.0025	.0065
C	.032Ti	.0010	.0040	.0050
AN	Normalized	.0033	.0017	.005
CN		.0010	.0035	.0045

*Values reported are estimated to be ±0.0005. Wherever two values are reported, the left-hand value is the original determination and the right-hand value is the result of a check on an entirely new sample.

TABLE VIII (cont.)

Nitrogen Determinations - Vanadium-alloyed

STEEL NO.	CHEMICAL ANALYSIS	NITROGEN*		
		ACID-SOLUBLE	ACID-INSOLUBLE	TOTAL
467 A	.14C .96Mn .04V	.0035	.0030	.0065
C	.14V	.0023 .0030	.0022 .0020	.0045 .0050
AN	Normalized	.0035	.0025	.0060
CN		.0012 .0020	.0035 .0030	.0047 .0050
462 A	.20C 1.20Mn .05V	.0030	.0010	.0040
B	.10V	.0030	.0010	.0040
C	.14V	.0025	.0010	.0035
AN	Normalized	.0017	.0020	.0037
BN		.0030	.0005	.0035
CN		.0020	.0015	.0035
458 A	.14C 1.43Mn .06V	.0030	.0010	.0040
B	.10V	.0035	.0005	.0040
C	.18V	.0030	.0017	.0047
AN	Normalized	.0040	.0000	.0040
BN		.0040	.0005	.0050
CN		.0025	.0020	.0045
425 A	.17C 1.25Mn .06V	.0033	.0025	.0058
B	.10V	.0040 .0040	.0030 .0030	.0070 .0070
AN	Normalized	.0055	.0005	.0060
BN		.0055 .0055	.0005 .0010	.0060 .0065

*Values reported are estimated to be ±0.0005. Wherever two values are reported, the left-hand value is the original determination and the right-hand value is the result of a check on an entirely new sample.

TABLE IX

CHEMICAL ANALYSIS FOR ACID-SOLUBLE TITANIUM AND VANADIUM

Steel No.	Acid-soluble Titanium		
	Composition	Acid-soluble	Condition
460 A	.14C 1.45Mn .007Ti	.003	as-rolled
AN	(Total)	.003	normalized
C	.032Ti	.014	as-rolled
CN		.002	normalized
466 A	.21C 1.40Mn .009Ti	.004	as-rolled
AN		.004	normalized
C	.046Ti	.005	as-rolled
CN		.000	normalized
459 A	.15C .96Mn .009Ti	.009	as-rolled
AN		.006	normalized
C	.032Ti	.007	as-rolled
CN		.000	normalized

Steel No.	Acid-soluble Vanadium		
	Composition	Acid-soluble	Condition
462 A	.20C 1.20Mn .05V	.070	as-rolled
AN	(Total)	.062	normalized
C	.14V	.132	as-rolled
CN		.138	normalized
467 A	.14C .97Mn .04V	.064	as-rolled
AN		.065	normalized
C	.14V	.126	as-rolled
CN		.139	normalized
458 A	.14C 1.43Mn .06V	.072	as-rolled
AN		.074	normalized
C	.18V	.142	as-rolled
CN		.153	normalized

PRNC-9093-1-28-49-200