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THE EFFECTS OF INTERSTITIAL CONTAMINANTS ON THE NOTCH-TENSILE PROPERTIES OF TITANIUM AND TITANIUM ALLOYS

Part II. Alloy Titanium

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FOREWORD

This report was prepared by Syracuse University, under USAF Contract No. AF 33(616)-2281. The contract was initiated under Project No. 7351, "Metallic Materials", Task No. 73510, "Titanium Metal and Alloys", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Lt. H. Burte as project engineer. This report covers research performed from November 15, 1953 to October 1, 1955.

ABSTRACT

The notch-tensile properties of alloy titanium contaminated with oxygen, nitrogen and carbon have been determined. In all six alloys have been studied and the effects of the various contaminants on the notch sensitivity have been presented in discussion of the results for each alloy.

Notch sensitivity has been shown to depend on the tensile strength, and becomes potentially severe as the strength exceeds about 150,000 psi. Metallographic structure and alloy content also profoundly affect notch sensitivity in these alloys.

The effects of testing temperature, contamination level, and strain rate on promoting notch sensitivity in the respective alloys are also discussed.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
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INTRODUCTION

The interstitial contamination limits in unalloyed titanium which may be tolerated without the development of severe notch embrittlement as determined in the notch tensile test have been established in Phase I of the present research program and are reported in WADC Technical Report 55-325 Part I. Comparable data obtained for alloyed titanium are presented in this report, which constitutes the presentation and analysis of the data obtained under Phase II of the contract.

SCOPE OF THE PROGRAM

The notch tensile properties at room and lower temperatures were to be determined at controlled levels of contamination with carbon, oxygen and nitrogen for the materials listed in Phase II, as follows:

Phase II

1. Selected Alpha Alloys

   A. 5 Al - 2-1/2 Sn

   B. 6 Al

2. Selected Alpha-Beta Alloys

   A. 7 Al - 3 Mo

   B. 4 Al - 4 Mn

   C. 8 Mn

3. A selected Beta Alloy

   A. 15 Cr

EXPERIMENTAL PROCEDURE

Introduction:

The titanium sponge and required alloy additions were compacted into 2 in. x 2 in. x 10 in. bars which were welded together under an atmosphere of helium and argon. The resulting titanium electrodes were then melted as previously described (WADC Technical Report 55-325 Part I) with approximately 30 poind ingots being obtained. The ingots were forged to 1-inch square bars. The 1-inch square stock was cleaned by grinding, contaminated and then remelted into ingots which weighed from 3 to 5 pounds and these were forged to 1/2-inch-square stock.

During the remelting of the small ingots occasional additional contamination with nitrogen was experienced. Because of the properties modifications resulting from the nitrogen pick-up experienced for the doubly melted stock, additional tests were completed on the singly melted material. All base material properties, therefore, were completed on singly melted stock.

Materials:

Sponge titanium was obtained from E. I. DuPont de Nemours Company in two lots as sponge with a specified BHN of 120 max. The oxygen content of both lots of sponge was determined as $\sim$ 0.05 percent.

The alloying additions are listed in Table I. The contaminating additions were obtained in the form of "Acheson" graphite, TiO_2 and TiN. The compositions of these materials and the compositions of the gases under which melting was accomplished are given in Table I.

Preparation of Compacts:

The required weight of the respective alloying additions for each 2 in. x 2 in. x 10 in. compact bar was weighed and added in the compacting die to insure uniform distribution along the length of the compact. The additions were concentrated in the center of the compact, for the Al, Al-Mo and Mn alloys. For the Al-Sn, Al-Mn and Cr alloys the alloying additions were intimately mixed before compacting. For the Al-Sn, Al-Mn and Cr alloys homogeneity after first melting is expected to be high.

Melting Procedure:

Melting was completed as has been described in WADC Technical Report 55-325 Part I. However, the furnace in the course of the many melting operations developed leaks which were not detected immediately and some of the ingots were contaminated with atmospheric nitrogen and oxygen. As many as possible of the ingots were replaced; however, the number of nitrogen bearing ingots of titanium is relatively high and for some of the alloys it has not been possible to establish the tolerable limits of carbon contamination in the absence of nitrogen contamination.

Forging and Annealing:

The forging and annealing temperatures are listed in Table II. The forging was completed as described in WADC Technical Report 55-325 Part I.

Contamination of the Titanium:

The following nominal contaminant levels were to be studied for the sponge material:

a) Contamination free,
b) 0.1% C,
c) 0.2% C,
d) 0.1% N_2,
e) 0.2% N_2,
f) 0.2% O_2,
g) 0.1% N_2 + 0.2% C, and,
h) 0.1% N_2 + 0.1% O_2.

Contamination was effected by addition of the contaminant in the form of a weld bead along the four sides of the 1-inch square bar stock that was obtained from the first melting process. The contaminant ("Acheson" graphite, TiN, and/or TiO_2) was uniformly distributed along the side of the melting stock and a weld was run down the bar. This operation was performed in the controlled-atmosphere chamber presented in Figure 1.

Specimen Preparation:

Specimens according to Figure 2 were prepared from 1/2 inch-square bar stock. The notches were machined with a suitably-sharpened cutting tool. The dimensions of the specimens were measured on an optical comparator with the notch root radius being estimated by projection on a polar net equipped with latitude increments of 0.002 inch, i.e. to radius increments of 0.001 inch. A notch root radius of 0.002 inch or less was consistently obtained.

Surface Contamination:

A limited number of tests were completed on surface contaminated specimens. However, in the attainment of a surface contaminated condition metallurgical structural changes were induced, and the data obtained are as a consequence difficult to evaluate. Testing was completed on the surface contaminated specimens at -100°F.

Testing Procedure:

Two notched and one smooth specimen were tested at 75, -65, -100 and -320°F. Testing was performed on a 60,000-pound universal testing machine. For each of the three highest temperatures, specimens were tested at two loading rates. The fast loading rate led to failure of notched specimens within 3 to 6 seconds. The slow loading rate was adjusted to give failure after a time about 100 times that for the fast test. The two loading rates were obtained by established valve settings on the machine. Limited additional tests were completed in sustained loading.

Specimens were loaded to fracture in concentric loading fixtures, one of which was adapted for testing in a liquid environment at low temperatures.

Metallographic Inspection:

All materials were examined metallographically after electropolishing. Polishing and etching conditions were adjusted as required for the different materials. Etching solutions used were:

Keller's Etch		2nd Etchant
HF	1 ml	60 ml glycerine
HCl	1.5 ml	20 ml HF
HNO_3	2.5 ml	20 ml HNO_3
H_2O	95 ml	

Chemical Analyses:

The carbon and alloy analyses of the present materials were determined by Kimmann and Wheeler, Syracuse, New York. The oxygen and hydrogen analyses were determined by the National Research Corporation, Cambridge, Massachusetts. The nitrogen analyses were determined as described in WADC Technical Report 55-325 Part I.

Compositions of the Titanium Alloys

Nominal. %	By Analysis: %
2-1/2 Sn - 5 Al - Ti	2.42 Sn; 5.70 Al; 0.02 C; 0.015 N; 0.052 O; 0.0033H
6 Al - Ti	5.38 Al; 0.02 C; 0.018 N; 0.095 O; 0.011 H
3 Mo - 7 Al - Ti	2.4 Mo; 6.2 Al; 0.01 C; 0.008 N; 0.081 O; 0.014 H
4 Al - 4 Mn - Ti	4.5 Al; 4.16 Mn; 0.015 C; 0.008 N; 0.10 O; 0.0016 H
8 Mn - Ti	8.3 Mn; 0.25 C; 0.25 N; 0.228 O; 0.028 H
15 Cr - Ti	15 Cr; 0.02 C; 0.017 N; 0.04 O; 0.0183 H

Representation of the Test Data:

All data are presented in both tabular and suitable graphical form. Typical photomicrographs are included.

EXPERIMENTAL RESULTS

The Alpha Alloys

A. The 5Al-2-1/2 Sn-Ti Alloys

A.1. Introduction:

Both aluminum and tin stabilize the α titanium phase and restrict the β -phase. However, the tin addition is less effective in this action than is aluminum, and thus when added promotes an improvement in forging behavior compared to that obtained in the high aluminum titanium alloys. The alloy at testing temperatures is essentially an alpha alloy.

A.2. Chemical Analyses of the 5Al-2-1/2 Sn-Ti Alloys:

The chemical analyses of the alloys melted are given in Table III. The base analysis of the alloy was 5.70% Al, 2.42% Sn, 0.02% C, 0.015% N_2, 0.052% O_2, and 0.0033% H_2. The carbon content was closely controlled at about 0.02% for all alloys except those intentionally contaminated with carbpn. Nitrogen contamination has in some instances been large due to contamination in the melting furnace.

Representation of the alloys studied in ternary coordinates is presented in Figure 3. Indicated also are the sections taken for determining the embrittling ranges as a function of contaminant level.

A.3. Microstructures:

The Al-Sn-Ti alloy is nominally alpha at ambient temperatures. However, due to the composition limits in the present alloy, mixed crystal structures are obtained. The distribution of the microconstituents and the distribution of the interstitial contaminants between the microconstituents then becomes highly important. The distribution of the microconstituents in some measure may be determined from the microstructures of the various contaminated materials, such as are presented in Figures 4 to 12.

Where the volume of the precipate phase is small, Figures 4 and 5, the structure is, for the most part, a matrix of α-phase in which the precipitate structure is dispersed. As the volume of the α -phase is reduced, the precipitate structure forms an intergranular network which becomes first partially, Figures 6 and 7, and finally fully continuous,

Figure 12. It is to be expected that the fully continuous network structure would adversely affect ductility and potentially lead to notch sensitivity.

A.4. Tensile Properties:

The minimum tensile strength for the uncontaminated and annealed 5Al-2-1/2 Sn-Ti alloy was 115,000 psi; the maximum tensile strength after contamination was over 175,000 psi--both measured at room temperature. As the temperature is reduced, the tensile strength at low strength levels rises rapidly. The percentage increase as a function of tensile strength at room temperature is given in Figure 13. For tensile strengths above about 175,000 psi, however, the strength at -100°F is extrapolated as equal to that at room temperature. The indicated trend cannot be adequately evaluated with the relatively few data which have been obtained, but it probably signifies the incidence of extreme embrittlement with temperature reduction as the tensile strength rises to the value of about 175,000 psi. As the tensile strength exceeded 170,000 psi at room temperature, head breaks for the smooth specimen became frequent due to the incidence of high notch sensitivity.

A.5. Notch Tensile Properties:

The inert atmosphere arc-melting procedure used in the preparation of titanium alloys does not insure removal of hydrogen which is introduced into the metal due to the decomposition of absorbed water. Since hydrogen pick-up potentially leads to material having strain rate sensitive tensile properties, the strain rate sensitivity of the 5Al-2-1/2 Sn-Ti alloy was checked under sustained loading conditions. The results presented in Figure 14 indicate that strain rate sensitive tensile properties as produced by hydrogen presence are not present in this alloy.

The tensile and notch-tensile properties of the uncontaminated Al-Sn-Ti alloy, as forged and forged and annealed are presented in Figures 15 and 16. The notch strength increases continuously with reduction in temperature, although there is little increase as the temperature is lowered from -100 to -320°F. The minimum notch strength ratio measured at -320°F, Figure 15, is 1.2. This alloy, therefore, does not embrittle over the temperature range studied.

A.6. Nitrogen Contamination:

Nitrogen contamination in the Al-Sn-Ti alloy leads to embrittlement as indicated in Figures 17 and 18. While 0.1% N_2 does not yield an adverse notch strength ratio of < 1., this amount of nitrogen leads to apparent strain rate sensitivity indicating brittle behavior in dynamic load applications. A nitrogen content of 0.2 percent leads to severe embrittlement and cannot be tolerated.

A.7. Carbon Contamination:

The effects of carbon contamination cannot be evaluated in the absence of nitrogen pick-up. The high carbon alloy contained a large amount of nitrogen.

The effect of carbon additions, in so far as it has been determined, however, rather closely parallels that of nitrogen additions Figures 19 and 20. Less than 0.1% C may be tolerated if full notch toughness (i.e. notch strength ratio = 1.5) is to be obtained at room temperature. The addition of carbon also promotes velocity sensitivity, and this would be objectionable under velocity or impact loading conditions.

A.8. Oxygen Contamination:

Oxygen contamination to about 0.25 percent may be tolerated in Al-Sn-Ti alloys without the development of objectionable notch sensitivity, Figure 21. The one alloy examined became notch brittle only at temperatures below -100°F.

A.9. Carbon and Nitrogen Contamination:

The addition of carbon above the base level of the alloy studied in combination with nitrogen leads to high notch sensitivity, Figure 22.

A.10. Oxygen and Nitrogen Contamination:

The alloy prepared for this study contained sufficient nitrogen to cause embrittlement. The added oxygen led to little if any increased deterioration of properties, Figure 23.

A.11. Notch Toughness vs. Interstitial Content:

The contaminants have not been introduced into the base Al-Sn-Ti alloy independently except for the nitrogen alloys. Some nitrogen has been picked up for most of the alloys, requiring that this element be suitably weighed in the evaluation of the toleration limits for the respective interstitial contaminants. The required limits have been established by the use of the ternary sections designated in Figure 3. In all , five ternary sections are obtained and the tensile properties for these sections are plotted in Figures 24 to 28.

In Figures 24 to 28 the curve corresponding to 1.5 x tensile strength is drawn in. From the early departure of the notch strength curve from this limiting curve, it is evident that only low levels of contamination with carbon and with nitrogen can be tolerated if full notch toughness is to be obtained.

The limits of contamination for a notch strength ratio of 1. as established at the various testing temperatures are given in Figures 29 to 32.

A.12. Notch Toughness vs. Strength Level:

The notch strength vs. tensile strength for the series of Al-Sn-Ti alloys is plotted in Figure 33. As the contaminant level is raised the tensile strength is raised and this, in general, leads to a notch strength increase over the reference value of the base alloy. As the tensile strength is raised above about 160,000 psi at room temperature in this way, the alloy becomes notch sensitive.

A.13. Notch Toughness vs. Tensile Strength vs. Temperature:

Notch sensitivity is generally considered as favored by reduction in temperature. For titanium alloys the reduction of the testing temperature from 75° to -100°F promotes about a 20 percent increase in the tensile strength and this makes essential the examination of notch strength ratios determined at testing temperature for transition temperature effects. Suitable data for the comparison for the Al-Sn-Ti alloys are presented in Figure 34. From this Figure it is seen that no well defined transition temperature is indicated for any alloy with strength level at 75° of 160,000 psi or less. By increasing the tensile strength to about 170,000 psi, however, the transition temperature is displaced from less than -320°F to higher than 75°F.

B. The 6 Al-Ti Alloys

B.1. Introduction:

Aluminum additions rapidly raise the $\alpha + \beta$ phase field in titanium, Figure 35. The alloy 6 percent Al-Ti should be essentially α -phase under equilibrium conditions.

B. 2. Chemical Analyses of the 6 Al-Ti Alloys:

The chemical analyses of the alloys are given in Table V. The base analysis of the alloy was 5.38% Al; 0.02% C; 0.018% N_2; .095% O_2 and 0.011% H_2.

Representation in ternary coordinates of the alloys studied is presented in Figure 36. Indicated also are the sections taken for determining contamination limits.

B.3. Microstructures:

The 6 Al-Ti alloy is an α -phase alloy under equilibrium conditions. Due to the composition limits of the present alloy, microstructures of mixed crystals are obtained. The microstructures observed are presented in Figures 37 to 43.

B.4. Tensile Properties:

The minimum tensile strength measured for the 6 Al-Ti alloy was 130,000 psi; the maximum was 160,000 psi. The change in the tensile strength with reduction in testing temperature as a function of the tensile strength at 75°F is given in Figure 44.

B.5. Notch Tensile Properties:

The annealed 6 Al-Ti alloy did not become embrittled as the testing temperature was lowered from 75° to -320°F, Figure 45.

B.6. Carbon Contamination:

As the carbon content is raised to 0.15 percent, embrittlement results as indicated in Figure 46. Further increase in carbon content has little additional effect if any, Figure 47.

B.7. Nitrogen Contamination:

Nitrogen additions to the 6 Al-Ti alloy lead to notch sensitivity as indicated in Figure 48. Somewhat less than .1% N_2 leads to notch embrittlement at -100°F.

B.8. Carbon and Nitrogen Contamination:

The addition of carbon and nitrogen does not in these tests lead to an additive embrittling effect, Figure 49. The embrittlement indicated in Figure 50 is about that due to either the carbon or nitrogen content.

B.9. Nitrogen and Oxygen Contamination:

The combination of oxygen and nitrogen, Figure 51, leads to a highly notch sensitive condition.

B.10. Notch Toughness vs. Interstitial Content:

Tensile and notch strengths are plotted in Figures 52 to 55, for the sections indicated in Figure 36. The limits of tolerable interstitial contamination determined from these figures which yield a notch strength ratio of 1. are plotted in Figures 56 to 59.

B.11. Notch Toughness vs. Strength Level:

The notch strength versus the tensile strength is plotted in Figure 60. As the tensile strength increases above 150,000 psi, due to contamination increases, the notch strength is sharply reduced.

B.12. Notch Toughness vs. Tensile Strength vs. Temperature:

The notch strength ratio as a function of the testing temperature is plotted for the several strength levels measured at 75°F. As the tensile strength passes above 155,000 psi at 75°F, the transition temperature as indicated by an appropriate reduction in the notch strength ratio is displaced from about -320°F to about 75°F, Figure 61.

The Alpha-Beta Alloys

C. The 7% Al-3% Mo-Ti Alloys

C.1. Introduction:

Aluminum additions to titanium stabilize the α -phase; molybdenum additions stabilize the β-phase. The two elements added together yield an expanded $\alpha + \beta$ phase field and potentially give rise to a series of $\alpha + \beta$ alloys. The 7 Al-3 Mo-Ti alloy is such an $\alpha + \beta$ alloy, Figure 62.

C.2. Chemical Analyses of the 7 Al-3 Mo-Ti Alloys:

The chemical analyses of the alloys studied are given in Table VII. The base analysis of the alloy was 6.2% Al-2.4% Mo; 0.01% C; 0.008% N_2; 0.08% O_2 and 170 ppm H_2. For restricted alloys nitrogen pick-up from the atmosphere was observed, but oxygen contamination from this source was minor.

Representation in ternary coordinates of the alloys studied is presented in Figure 63. Indicated also are the sections taken for determining the embrittling ranges as a function of contaminant level.

C.3. Microstructures:

Several types of microstructures were observed for the Al-Mo titanium materials, despite the fact that all materials received ostensibly the same heat treatment, cf. Table II. The variations in microstructures complicate the interpretations of the data, but, it is emphasized, no clear correlation between microstructure and tendency to embrittle has been observed.

Thus the one ductile material to temperatures less than -100°F possessed transus structure, Figure 64. However, other materials possessing this structure were brittle or partially so, Figures 67 and 70.

Additional structural modifications were observed, Figures 66, 68 and 69, but it has not been possible to interpret the properties of these materials from a consideration of the microstructures.

C.4. Tensile Properties:

The minimum tensile strength (R.T.) for the Al-Mo titanium alloy was 150,000 psi, while the maximum was nearly 200,000 psi. As the testing temperature was lowered, the tensile strength increased as a function of strength level as indicated in Figure 72. The tensile strength is indicated to become temperature independent at the extrapolated value of 205,000 psi.

C.5. Notch Tensile Properties:

The tensile and notch strengths of the 7 Al-3 Mo-Ti alloy as annealed are presented in Figure 73. This alloy is mildly notch sensitive in this condition, but does not become notch brittle until the testing temperature is reduced to less than -100°F. The data are not sufficient to establish the transition temperature with precision, but it is estimated to lie at about -250°F.

C.6. Nitrogen Contamination:

The addition of nitrogen to the 7 Al-3 Mo-Ti alloy leads to a pronounced tensile strength increase, and with this strength increase there is a rapid increase in embrittlement tendency, Figures 74 and 75.

C.7. Carbon Contamination:

Relatively low carbon additions lead to pronounced embrittlement, Figures 76 and 77.

C.8. Oxygen Contamination:

In Figure 78 it is indicated that relatively large amounts of oxygen may be tolerated without causing excessive embrittlement.

C.9. Carbon and Nitrogen Contamination:

Carbon and nitrogen contamination in combination promote embrittlement, Figures 79 and 80.

C.10. Notch Toughness vs. Interstitial Content:

The tensile strength-notch strength curves for the sections given in Figure 63 are presented in Figures 81 to 84. Only slight increases in the interstitial levels for carbon and nitrogen can be tolerated without the development of serious notch brittleness as is represented in Figures 85 to 87.

C.11. Notch Toughness vs. Strength Level:

The notch strength as a function of the tensile strength is presented in Figure 88. As the tensile strength rises above 150,000 psi, pronounced embrittlement develops.

C.12. Notch Toughness vs. Tensile Strength vs. Temperature:

The notch strength ratio as a function of testing temperature with the tensile strength at 75°F as a parameter is presented in Figure 89. As the tensile strength (75°F) rises above 150,000 psi, the transition temperature changes from about -250°F for this strength level to about 75°F for a tensile strength (75°) of 170,000 psi.

D. The 4 Al - 4 Mn - Ti Alloys

D.1. Introduction:

Manganese additions to titanium tend to stabilize the β-phase and thus off-set the effect of aluminum additions. As indicated earlier, the addition of two alloying elements which function in this opposed manner promotes an expanded $\alpha + \beta$ -phase field. A suitable binary section for the Al - Mn - Ti system which, however, does not indicate the proportions of the phases is given in Figure 90. Due to stabilization of the final β-phase remaining after furnace cooling is completed, the $\alpha + \beta$ structure may be retained at room temperature.

D.2. Chemical Analyses:

The alloys prepared and tested are listed in Table IX, with the chemical analyses. The ternary representation of these alloys is given in Figure 91.

D.3. Microstructures:

The Al - Mn alloy is subcritically annealed to develop a finely divided dispersion of β -phase in α-phase. The α - phase is then the continuous phase in the microstructure. However, at the annealing temperature the α-phase is present as small isolated equiaxed grains in a matrix of β-phase and it is only by very slow cooling that the inversion of the matrix structure can be fully achieved* The cooling rate through the upper-critical range for the Al - Mn - Ti alloy studied has, in general, led to the retention of α-phase equiaxed grains set in a matrix of β-phase in which finely divided α phase is precipitated, Figures 92, 93, and 94. The geometrical distribution of the microconstituents is the same as for commercial material but the roles of the cooperative phases have been inverted, as may be seen from Figure 96.

The range of microstructures possible in the Al - Mn - Ti series is a function of the equilibrium phase boundaries and as these shift to higher or lower temperatures the amount of untransformed α-phase is changed during the high temperature annealing of this alloy. When the α -phase is fully dissolved a coarse-grained β-structure results and the transformation product on cooling is, in part, lamellar, Figure 95. In ad-

*See Ref. 2, for description if this inversion effect in Cu - Al alloys.

dition, much of the specimen is transformed to a structure resembling the bainite structures in steels.

The microstructures of the materials tested are presented in Figures 92 to 103.

The interstitial contaminants have not been identified in the form of characteristic precipitate structures in the specimens examined.

D.4. Tensile Properties:

The minimum tensile strength was measured as 85,000 psi for the annealed bar in the longitudinal direction. The maximum strength was about 175,000 psi. For indicated higher strength levels, head breaks were common indicating excessive notch sensitivity at the higher strengths.

The tensile strength increases with decreasing temperature are given in Figure 104 as a function of strength level.

D.5. Notch Tensile Properties:

The sustained-load data for the Al-Mn-Ti alloy as forged are presented in Figure 105 in comparison with data taken from WADC TR 54-616, (January 1955). The behavior of the alloy in this test is in accord with the measured hydrogen content.

The notch tensile strength of the Al-Mn alloy, as forged, Figure 106, drops rapidly with temperature decrease and it is embrittled at -100°F. Annealing does not affect the tensile strength and raises the low-temperature notch strength leading to an elimination of the pronounced transition temperature effect observed in the as-forged alloy, Figure 107.

Annealing to produce a reduction in the tensile strength leads to improved ductile-brittle transition behavior, Figure 108, and if the tensile strength is sufficiently lowered no ductile-brittle transition effect is observed, Figure 109. It is to be noted that the data in Figure 109 were obtained from specimens from the same bar as were the specimens reported in Figure 108. The difference in properties thus results from metallographic differences alone.

Transverse and longitudinal specimens taken from the annealed bar give nearly identical notch properties, cf. Figures 109 and 110. These data do not indicate an adverse orientation effect, but the investigation has not been sufficiently extensive to be definitive of the properties to be expected.

A lot of commercial C-130-AM was available as 5/8 in. rd. and specimens were prepared from this stock and tested. The results are presented in Figure 111. The microstructural differences between the laboratory and commercial alloys are thus seen to lead to no adverse notch properties for the laboratory lots of metal.

D.6. Carbon Contamination:

Carbon contamination severely embrittles the Al-Mn-Ti alloy, and leads to strain rate sensitivity, Figures 112 and 113.

D.7. Nitrogen Contamination:

Nitrogen contamination promotes notch sensitivity, Figures 114 and 115.

D.8. Oxygen Contamination:

The oxygen analysis of the alloy to which oxygen was added was somewhat low and probably did not contribute to the embrittlement of the alloy prepared, Figure 116, as much as did the increase in nitrogen contamination experienced in the preparation of this alloy.

D.9. Additional Contaminated Materials:

Alloys designed to possess controlled carbon plus nitrogen and oxygen plus nitrogen contaminants were not successfully melted due to apparent errors in the addition of the contaminants. The off-analyses of these materials were not discovered until after testing has been completed. The results of these tests, Figures 117 and 118, support the results reported in the foregoing sections.

D.10. Notch Toughness vs. Interstitial Content:

Very little interstitial contamination in this alloy as prepared in this investigation may be tolerated if notch toughness is to be expected at strengths of 140,000 and over. Notch and tensile strength curves obtained for the ternary section, Figure 93, are presented in Figures 119 to 121. For this alloy, heat treated as recommended,* additional contamination over the base level leads to rapid embrittlement, Figures 122 to 124.

D.11. Notch Toughness vs. Strength Level:

With increasing tensile strength beyond about 150,000 psi the 4 Al-4 Mn-Ti alloy becomes notch sensitive, Figure 125.

D.12. Notch Toughness vs. Tensile Strength vs. Temperature:

The notch strength ratio for the 4 Al-4 Mn-Ti alloy as a function of strength level and testing temperature is presented in Figure 126. As

* A combined furnace-air cooling treatment is generally recommended.

the tensile strength increases from 145,000 psi to 165,000 psi the transition temperature, defined as that temperature at which the notch strength ratio is equal to 1, is displaced from about -300°F to about 0°F.

E. The 8 Mn-Ti Alloys

E.1. Introduction:

Manganese additions stabilize the β-phase in titanium. However, the Ti-Mn system forms a eutectoid at 20% Mn, Figure 127. With sufficiently high manganese addition the metastable β-phase can be retained at room temperature. However, the 8% Mn alloy is normally an $\alpha + \beta$ -phase alloy.

E.2. Chemical Analyses:

The alloys prepared and tested are listed in Table XI with the chemical analyses. The ternary representation of these alloys is presented in Figure 128.

E.3. Microstructures:

The characteristic microstructure of the 8 Mn-Ti alloy is coarsely lamellar, Figure 129. This structure is not derived from an eutectoid reaction, but is a product of the proeutectoid precipitation of the α-phase. Typical photomicrographs are presented in Figures 129 to 136. It has recently been demonstrated that the β-phase can in some measure be stabilized (3), and perhaps this phenomenon is responsible for the β-phase structure in Figure 131.

E.4. Tensile Properties:

The tensile strength for the 8 Mn-Ti alloys varied from a minimum of 145,000 psi to a maximum of slightly greater than 175,000 psi. The change in the tensile strength with reduction in testing temperature is indicated in Figure 137.

E.5. Notch Tensile Properties:

The 8% Mn-Ti alloy in the uncontaminated condition was mildly notch brittle at 75°F, Figure 138. With decreasing temperature the notch brittleness became severe at testing temperatures of -65 and -100°F. The large amounts of hydrogen found in this alloy render all the data questionable.

The longitudinal and transverse properties measured for 2 in. x 1/2 in. stock are presented in Figures 139 and 140. These data, in agreement with the data obtained for the annealed bar, indicate severe notch embrittlement at -65 and -100°F.

E.6. Carbon Contamination:

The addition of carbon to the 8 Mn-Ti alloy leads to increasingly severe embrittlement, Figures 141, 142 and 143.

E.7. Nitrogen Contamination:

The introduction of nitrogen into the 8 Mn-Ti alloy leads to increasingly severe embrittlement, Figures 144, 145, and 146.

E.8. Nitrogen and Oxygen Contamination:

The combination of oxygen and nitrogen in this alloy leads to severe embrittlement at all testing temperatures, Figure 147.

E.9. Notch Toughness vs. Interstitial Content:

The 8 Mn-Ti alloy in the uncontaminated condition is notch brittle at slightly lowered temperatures so that any contamination which increases notch sensitivity cannot be tolerated. This is emphasized from the curves presented in Figures 148 to 150. Since the alloy is notch sensitive at -65°F under all contamination conditions examined, no contamination limits can be established.

E.10. Notch Toughness vs. Strength Level:

With reduction in tensile strength it is to be expected that the 8 Mn-Ti alloy would become decreasingly notch sensitive, and this is verified from examination of Figure 151.

E.11. Notch Toughness vs. Tensile Strength vs. Temperature:

The notch strength ratio for the 8 Mn-Ti alloy as a function of strength level and testing temperature as a parameter is presented in Figure 152. This alloy is subject to severe embrittlement with reduction in testing temperature at all strength levels examined.

F. The 15 Cr - Ti Alloys

F.1. Introduction:

Chromium additions stabilize the β -phase in titanium. However, the Ti-Cr system forms a eutectoid at 15% Cr, Figure 153, and only metastable β -phase can, as a consequence, be retained at room temperature. Only limited testing was completed on the 15% Cr alloy.

F.2. Chemical Analyses:

The alloys prepared and tested are listed in Table XIII along with the chemical analyses.

F.3. Microstructures:

The 15% Cr-Ti alloy as forged is essentially retained β -phase, Figure 154. Annealing effects the decomposition of the β -phase with the development of a finely divided lamellar structure, Figure 155. Because of the poor properties obtained for this condition the contaminated ingots were examined as forged.

For the carbon-bearing alloy the structure was β -phase with apparent carbide particles dispersed through the β -phase matrix, Figure 156. For the nitrogen bearing alloy general precipitation along the grain boundaries and through the grains was experienced, Figure 157.

F.4. Tensile Properties:

The minimum tensile strength measured at 75°F was 140,000 psi. As the strength rose above this value at 75°F, severe notch embrittlement was encountered, and head breaks were frequently experienced.

With decreasing temperature the tensile strength rose rapidly at the lower strength levels examined. As the tensile strength (75°F) rose to about 170,000 psi the rate of increase of the tensile strength with decreasing temperature rapidly fell and became zero at about 170,000 psi tensile strength, Figure 158.

F.5. Notch Tensile Properties:

The sustained-load test data, Figure 159, show that delayed failures are not to be expected in the alloy tested.

The notch properties of the β-phase alloy are excellent to -100°F for the as-forged uncontaminated alloy, Figure 160. However, a transition to brittle behavior is indicated between -100°F and -320°F.

The annealing treatment producing the finely divided lamellar structure has led to serious deterioration in notch properties, Figure 161. Since it is probable that annealing treatments, in general, must be used for titanium alloys this drop in notch properties for the β-phase alloy constitutes a serious short-coming.

The addition of 0.1% C to this alloy leads to the development of notch sensitivity at -65°F and lower temperatures, Figure 162. In addition strain rate sensitivity is indicated so that this alloy would probably have poor notch toughness under impact loads.

The addition of 0.2% N_2 to the 15% Cr alloy leads to severe embrittlement, Figure 163.

F.6. Interstitial Contaminant Limits:

The present alloy is metastable (4) and the addition of both carbon and nitrogen exaggerates this metastability. Only limited testing was completed and the results are not adequate to establish the embrittling effects of the interstitial contaminants being studied.

F.7. Notch Toughness vs. Tensile Strength:

For the alloys which have received comparable thermal treatment the notch strength varies with tensile strength as given in Figure 164. The importance of the 150,000 psi tensile strength limit is again emphasized.

F.8. Notch Toughness vs. Tensile Strength vs. Temperature:

Tensile strength alone is not an adequate criterion of transition temperature behavior to be expected in Ti-15% Cr alloys. Due to structural modifications the transition temperature in one material may vary from less than -100°F to greater than 100°F without a significant tensile strength change, Figure 165.

DISCUSSION AND CONCLUSIONS

The ductile-brittle phenomena in titanium alloys as measured in the notch tensile test have been found to depend on the following factors:

1. Metallographic structure
2. Strength level
3. Testing temperature
4. Alloy content
5. Contamination limits
6. Miscellaneous
   a) Strain rate

For the data which have been obtained in this investigation the above factors cannot be examined independently. This results from the fact that relatively few data have been obtained for any one alloy condition, and these correspond to the properties to be expected after an acceptable commercial heat treatment. Limited data, however, as obtained for the 4 Al-4 Mn-Ti alloy and which indicate the effects of metallographic structural change are presented in Figure 166.

In Figures 94 and 95 the structures obtained for the two test conditions may be compared.

The notch tensile results obtained for the indicated metallographic changes are not of interest from a quantitative point of view. However, they emphasize the very important role that metallographic structure plays in determining the ductile-brittle response in titanium alloys, and suggest that improved ductile-brittle behavior is to be expected from suitable metallographic control.

The metallographic structures of the numerous alloys which have been investigated fall into the following categories:

1. Equiaxed alpha (with dispersed spheroids of beta phase)
2. Equiaxed beta
3. Equiaxed alpha with grain boundary precipitate

4. Equiaxed beta with grain boundary alpha precipitate

5. Basketweave alpha and beta precipitate

For all structures where one of the micro-constituents is continuous, brittle behavior is to be expected when this continuous phase is notch sensitive. On the other hand for the basketweave and lamellar structures brittle response is to be expected if either micro-constituent is brittle. Detailed examination of the hardness* of the micro-constituents for the several alloys has not been possible in this investigation so the reasons for the appearance of brittleness in the various alloys cannot without question be ascribed to a simple effect of matrix embrittlement. However, if embrittlement is due to this source improved properties are indicated as possible through refinements in heat treatment.

As the tensile strength of the respective alloys has increased, the notch strength has increased and after passing through a maximum value then decreased. All titanium alloy systems investigated have responded in comparable manner, Figure 167. For the various alloys studied the strength level of 140,000 to 150,000 psi is clearly of major significance and corresponds to the strength level of 180,000 to 200,000 psi in steels. In steels it is now recognized that with suitable precautions strengths in the 200,000 to 300,000 psi range can be used. This probably signifies that titanium alloys at strengths above 160,000 psi can also be obtained, but that the alloy content and heat treatment must be carefully controlled if satisfactory service performance is to be obtained.

It is expected that limiting strength conditions will be influenced by both metallographic structure and alloy content. Limited data, Figure 168, indicate this to be so. Here the Al-Sn and Al-Mo alloys are seen to possess good ductility to low testing temperatures at high strength levels. On the other hand, the 8 Mn alloy, under all conditions of preparation, is notch sensitive at low temperatures. (The high hydrogen content of the 8 Mn alloy may contribute seriously to its low notch toughness.)

It is evident in this figure that the strength level for the alloys compared is very important in determining the transition temperature which is here defined as that temperature at which the notch strength ratio is equal to 1. Thus as the tensile strength increases above 150,000 to 160,000 psi the transition temperature is rapidly shifted from $<$ -100°F to about 75°F. It should be emphasized, however, that while the tensile strength is important in indicating susceptibility to notch embrittlement, it is not a fully definitive criterion. Thus the data compared in Figure 169 indicate possible improvements in properties through metallographic structures control and/or alloying.

*Hardness is here taken as an index of brittleness susceptibility.

A reduction of the testing temperature is expected to lead to increased notch sensitivity. This is indicated by observance of the ductile-brittle transition phenomena. A second embrittling tendency has also been observed in the smooth test bar with reduction in the test temperature. Thus the change in the rate of increase of the tensile strength with reduction in temperature indicates that as the tensile strength at 75°F increases above a value that is seemingly characteristic for the respective alloys, the low temperature tensile strength becomes relatively reduced. This is interpreted as signifying a ductile-brittle transition with reduction in temperature for the smooth specimen as the characteristic tensile strength is exceeded.

The limits to which the interstitial contaminants, oxygen, carbon and nitrogen, can be tolerated for certain of the alloy systems can be clearly established. For systems in which the relative volumes of alpha and beta phase can be altered and consequently for which the partitioning of the interstitial contaminants can be altered some question may be raised as to the maximum contamination limits that may be tolerated. Indeed if full ductility as signified by a notch strength ratio of 1.5 is required it appears that no increase in interstitial contamination over the base level in the sponge is admissible for any but the alpha-phase alloys, if these alloys are to be given the conventional heat treatment. The possibility does exist, however, that by suitable heat treatment alloys containing maximum levels of interstitial contamination may be rendered suitably notch tough for service applications.

For high strength titanium alloys there is a seeming strain rate effect as the strain rate is either increased or decreased. Embrittlement due to decreasing strain rate is attributable to the action of hydrogen while that due to increasing strain rate is of the kind expected in notch sensitive materials.

SUMMARY

1. In Phase II of the present research program six alloys of titanium have been prepared and contaminated variously with carbon, nitrogen and oxygen. The respective materials were then examined in the tensile and notch-tensile tests at temperatures from 75 to -320°F. Notch sensitivity was then established by calculation of the notch strength ratio. For values of the notch strength ratio greater than one notch-insensitive titanium is obtained. Conversely, a value of the notch strength ratio less than one designates notch sensitive titanium.

2. As the carbon, nitrogen and/or oxygen contents of the various alloys were allowed to increase either singly or in combination, notch sensitivity was induced at a contaminant level which depended on the alloy and testing temperature. The base contaminant levels of the respectivealloys as given except for the 8% Mn alloy insure notch insensitive alloys after conventional heat treatment. The oxygen, carbon and nitrogen contents of the respective alloys other than 8% Mn can be increased with notch insensitive material still being obtained. Possible limits vary for the different alloys.

3. Notch sensitivity in the various titanium alloys in the notch-tensile test has been observed to depend on the strength level with the critical strength level falling in the 140,000 to 160,000 psi range. For those alloys which have good low temperature toughness the transition temperature in the notch-tensile test is also dependent on the tensile strength.

4. Alloy content and metallurgical structure have also been found to play important roles in the determining of the notch sensitivity of the titanium alloys investigated.

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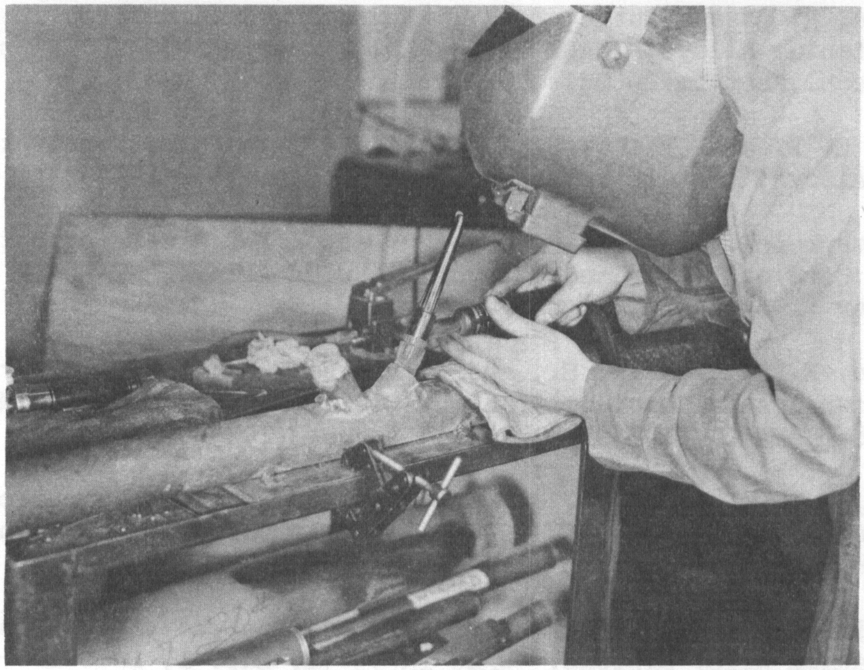


FIG. 1 PHOTOGRAPH OF THE ENCLOSED CHAMBER AND HELI-ARC TORCH USED TO CONTAMINATE TITANIUM WITH NITROGEN, CARBON, AND/OR OXYGEN.

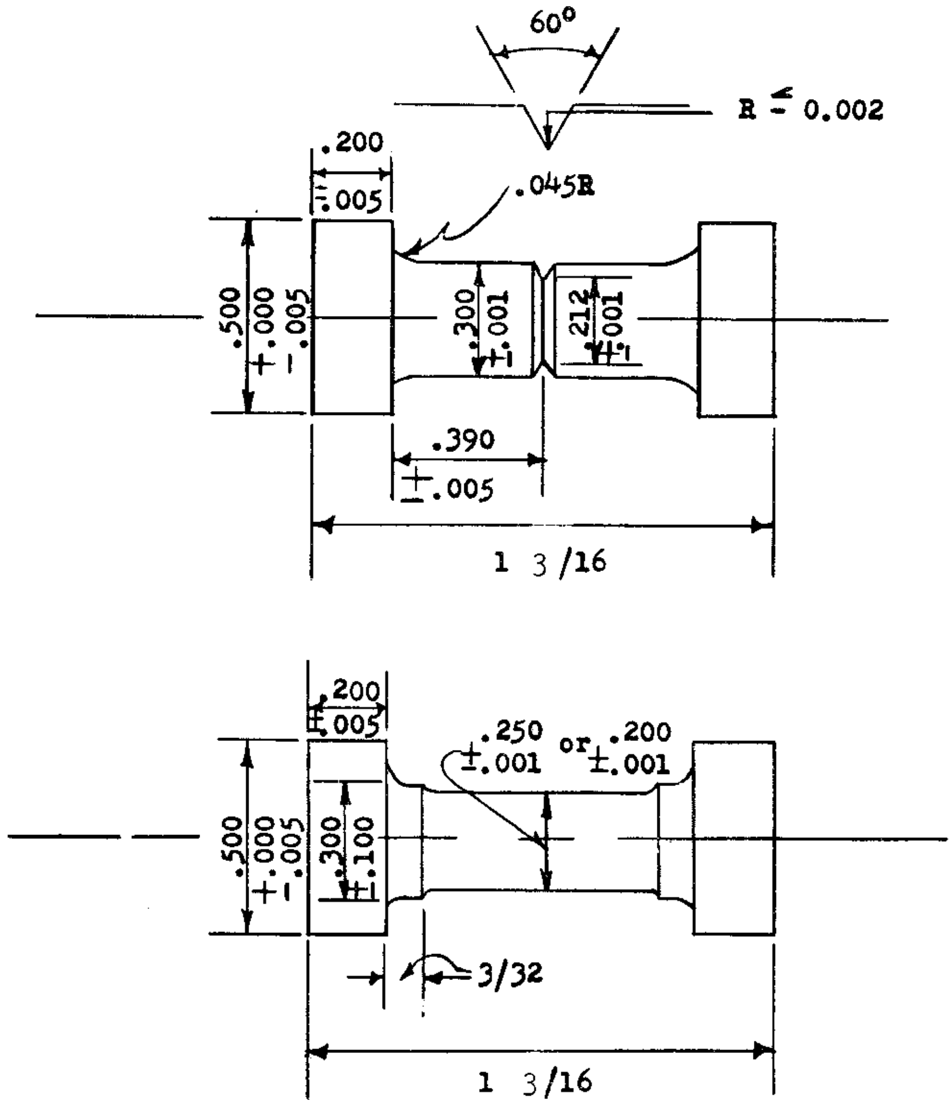


FIG. 2 SPECIMENS TESTED.

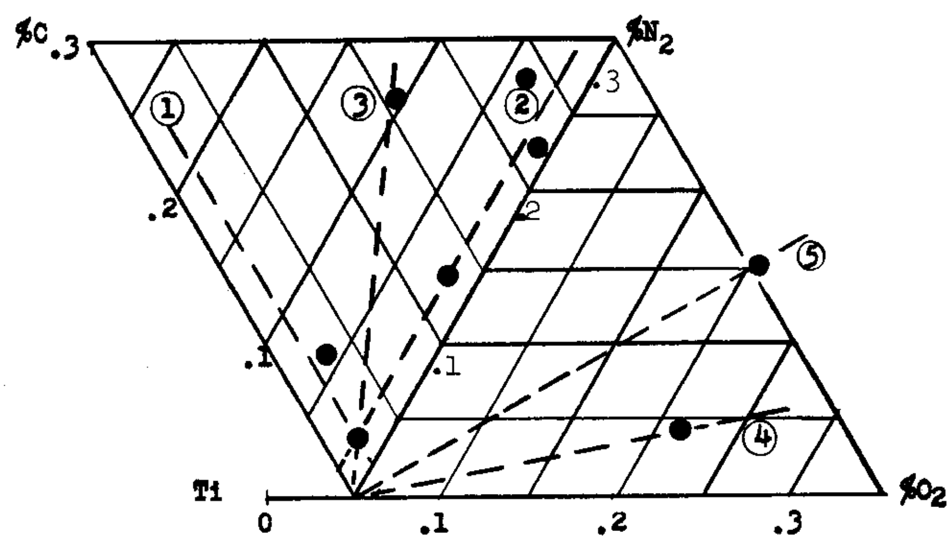
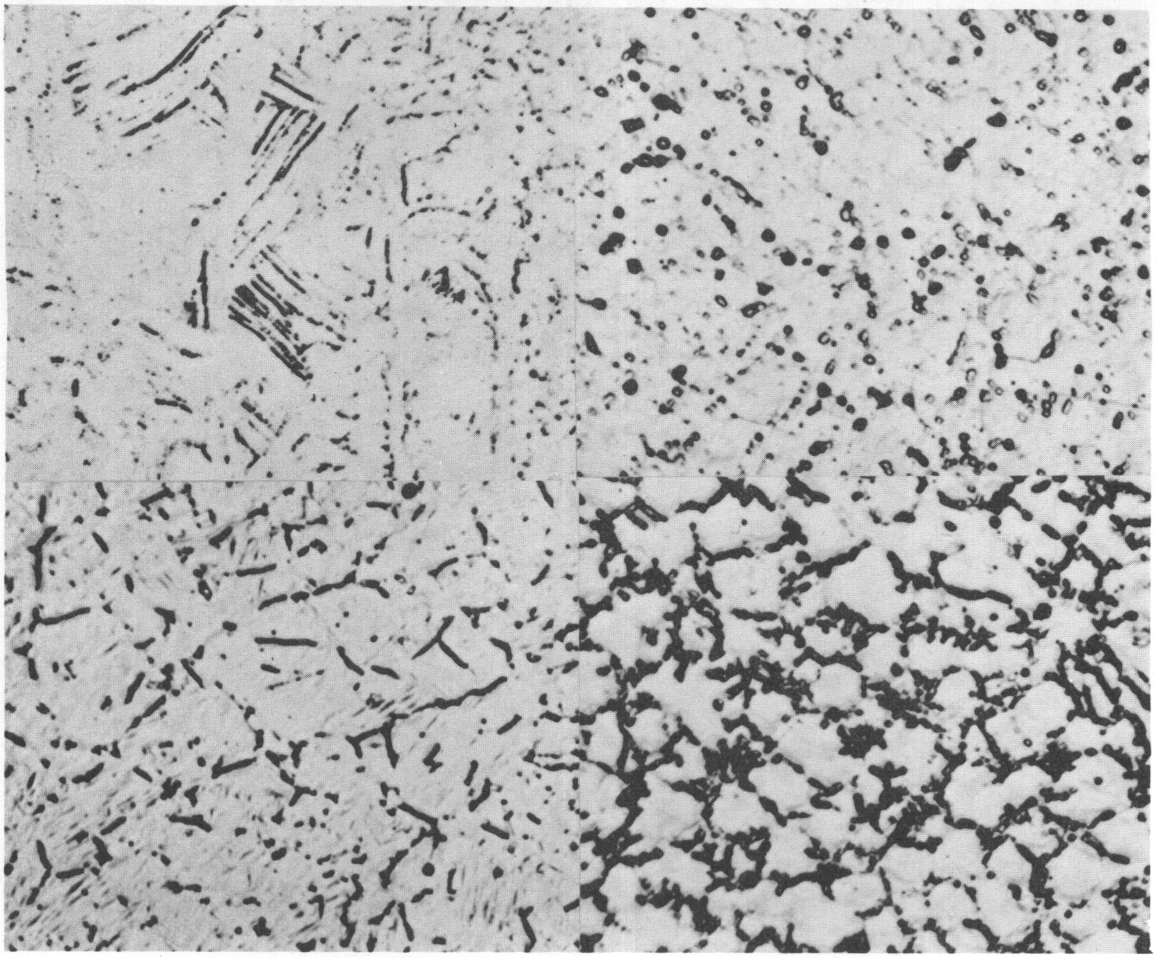


FIG. 3 COMPOSITIONS OF THE 5 Al - 2½ Sn - Ti INGOTS STUDIED, AND TERNARY SECTIONS INVESTIGATED.

4 5



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FIGS. 4 TO 7 MICROSTRUCTURES OF THE INDICATED 5Al - 2½Sn - Ti ALLOYS. ELECTROPOLISHED, KELLER'S ETCH x 500.

FIG. 4 UNCONTAMINATED - AS FORGED
FIG. 5 UNCONTAMINATED - AS ANNEALED
FIG. 6 +.125% NITROGEN - AS FORGED
FIG. 7 +.0.22% NITROGEN - AS FORGED

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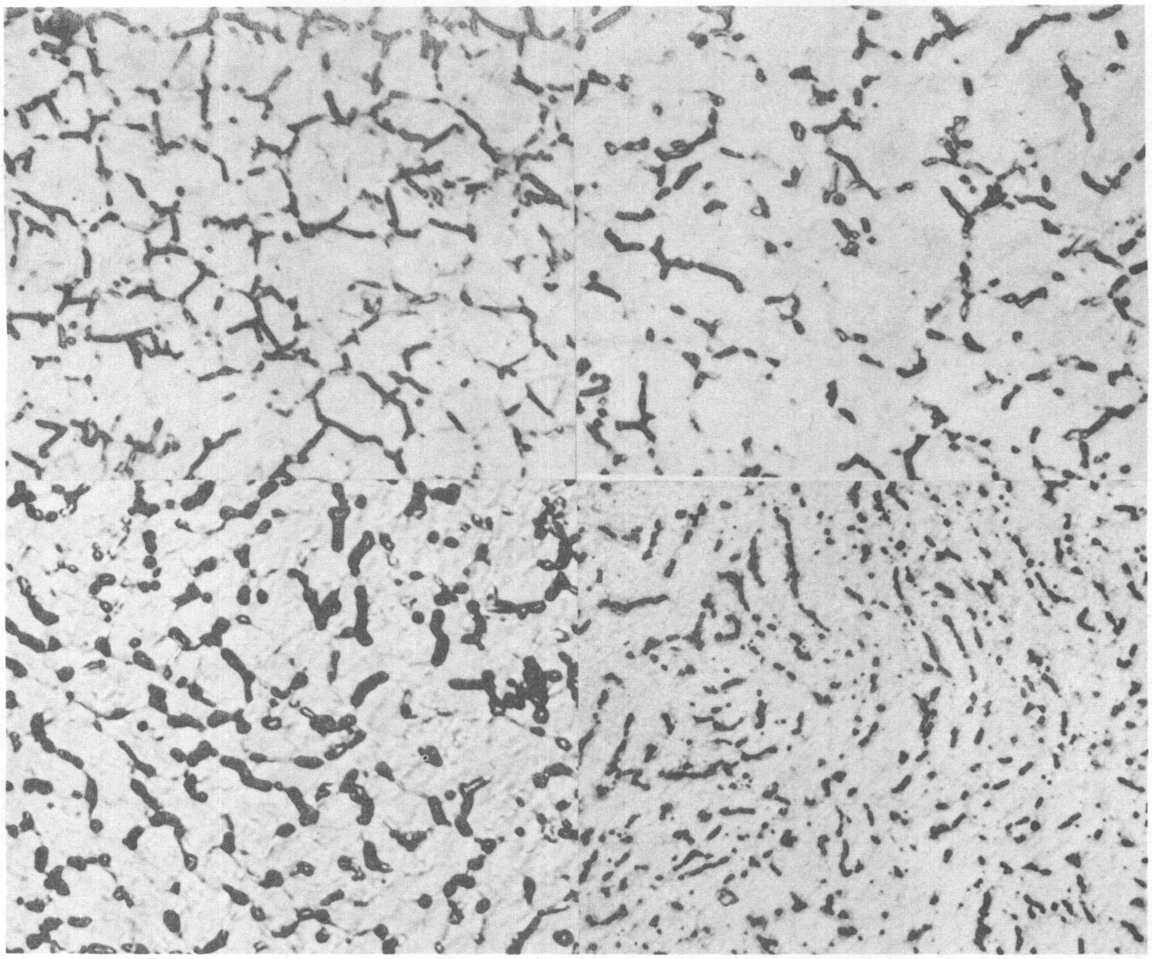

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FIGS. 8 TO 11 MICROSTRUCTURES OF THE INDICATED 5Al - 2½ Sn - Ti ALLOYS. ELECTROPOLISHED, KELLER'S ETCH x 500.

FIG. 8 +0.065% CARBON - AS FORGED
FIG. 9 +0.105% CARBON +0.155% NITROGEN - AS FORGED
FIG. 10 +0.230% OXYGEN - AS FORGED
FIG. 11 +0.04% CARBON + 0.135% NITROGEN - AS FORGED

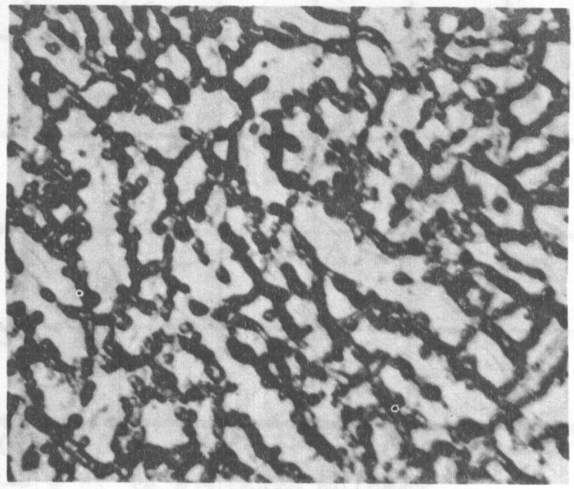
12 

FIG. 12 MICROSTRUCTURE OF THE INDICATED 5 Al - 2½Sn - Ti ALLOY. ELECTROPOLISHED, KELLER'S ETCH x 500.

FIG. 12 0.214% OXYGEN + 0.155% NITROGEN - AS FORGED

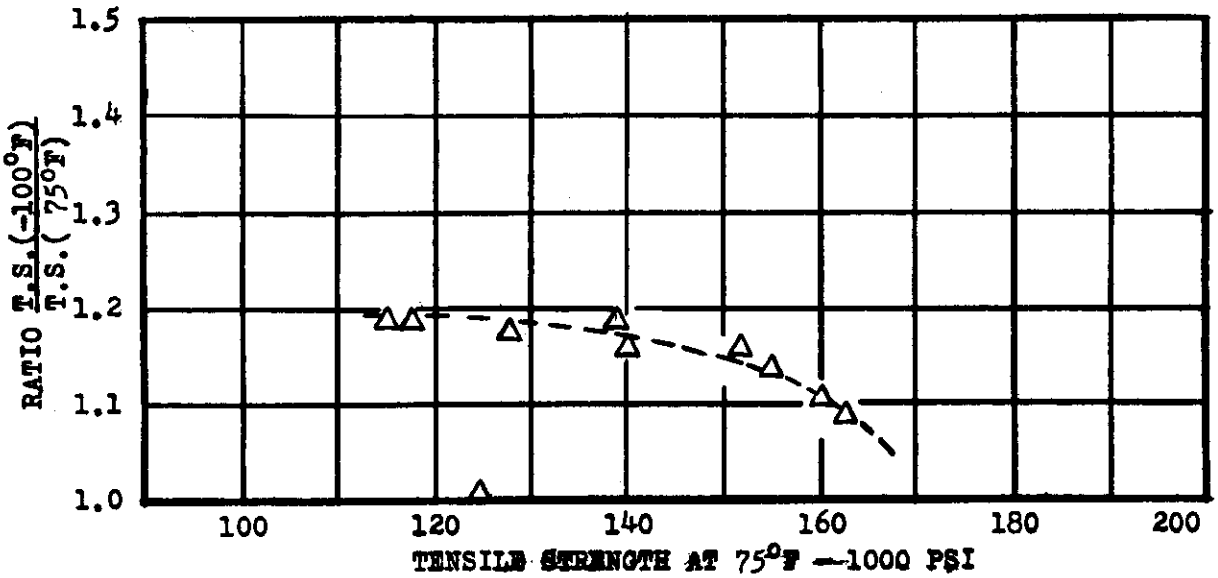


FIG. 13 THE TENSILE STRENGTH AT -100°F AS A FUNCTION OF THE TENSILE STRENGTH AT 75°F. 5Al - 2½ Sn - Ti ALLOY.

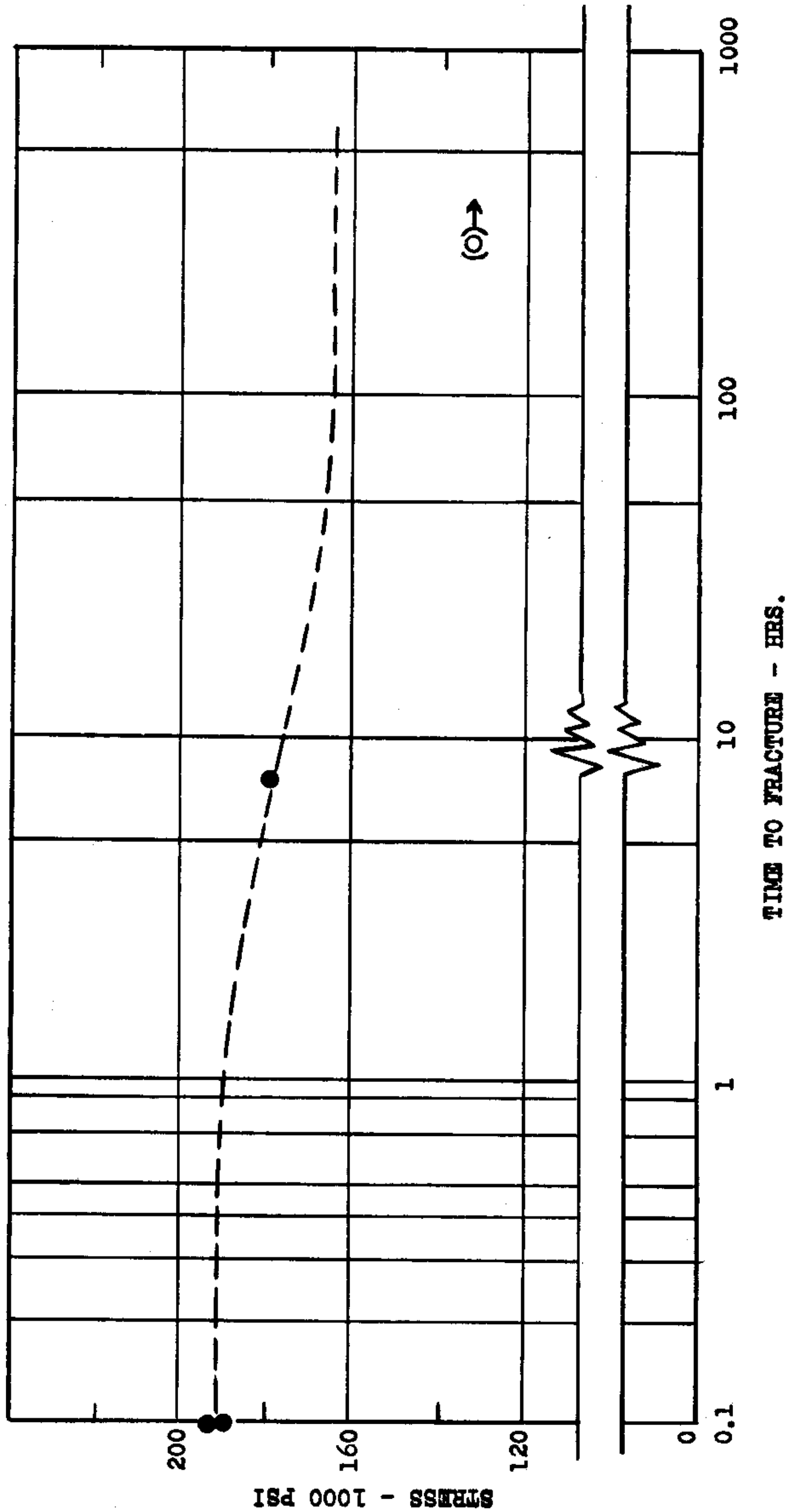


FIG. 14 THE NOTCH STRENGTH AS A FUNCTION OF THE TIME OF SUSTAINED LOAD TO FRACTURE AT 75°F. 5½ Al - 2½ Sn - Ti ALLOY.

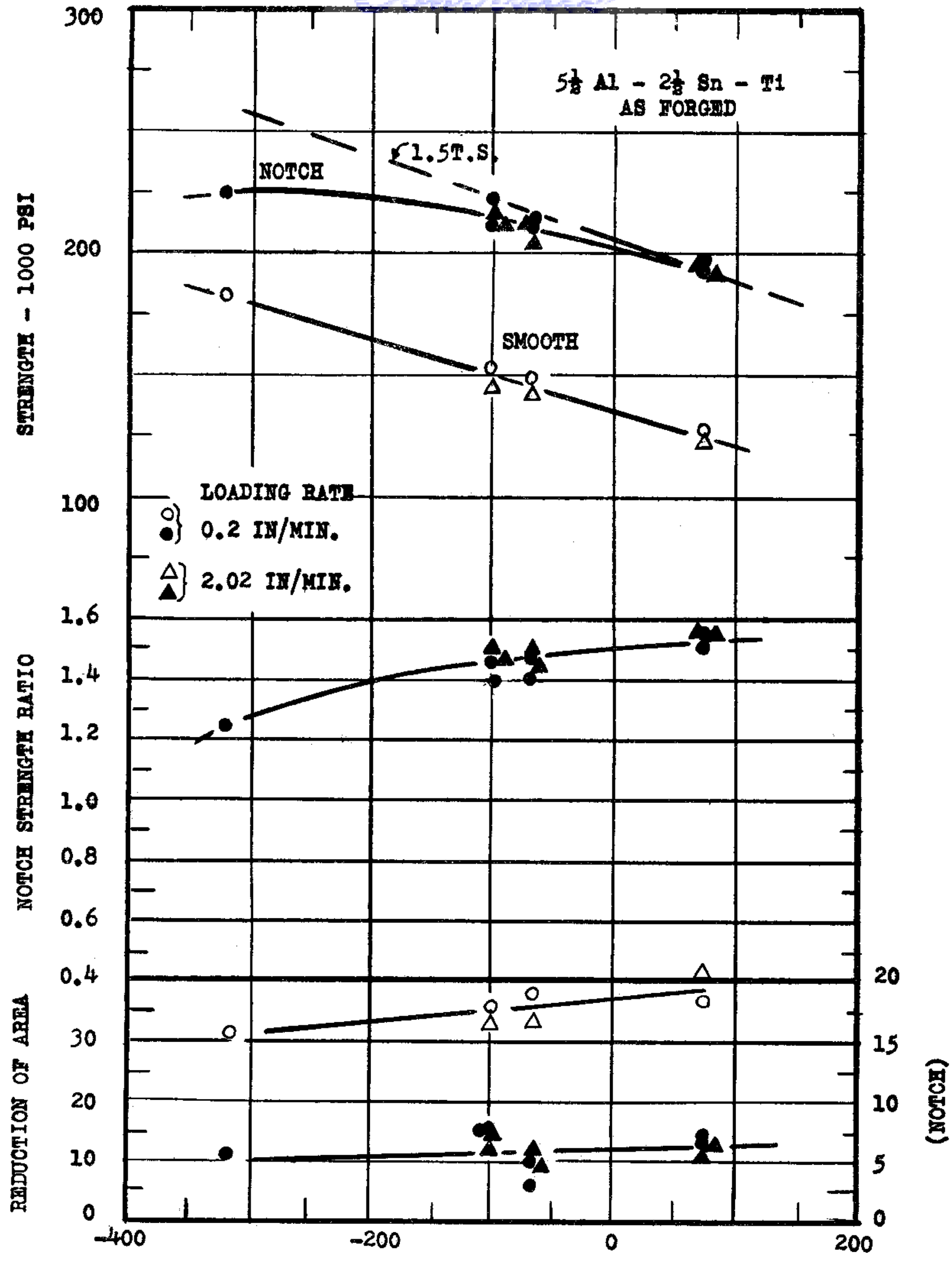


FIG. 15 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 5Al - 2½ Sn - Ti - AS FORGED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

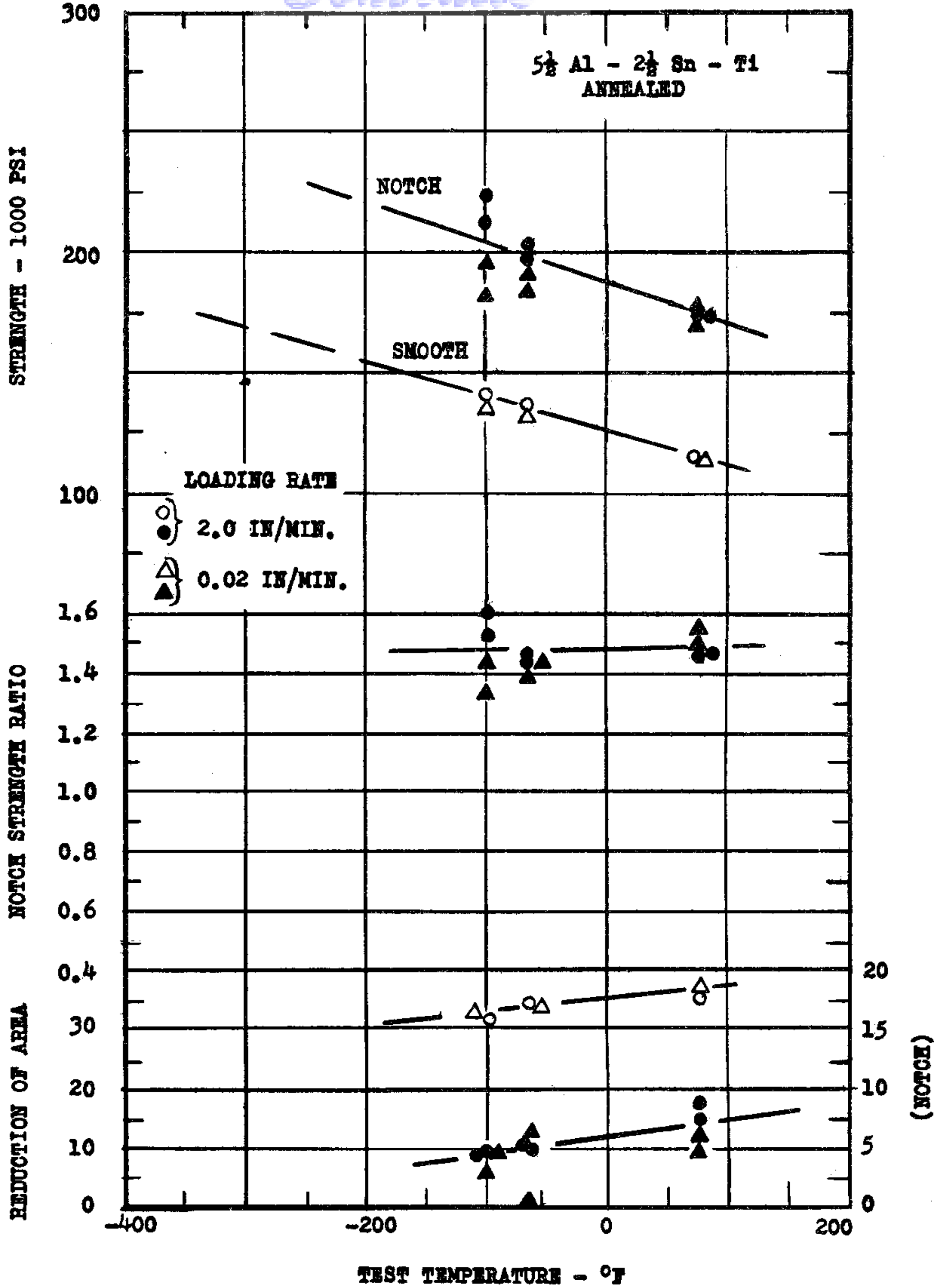


FIG. 16 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 5 Al - 2½ Sn - Ti - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

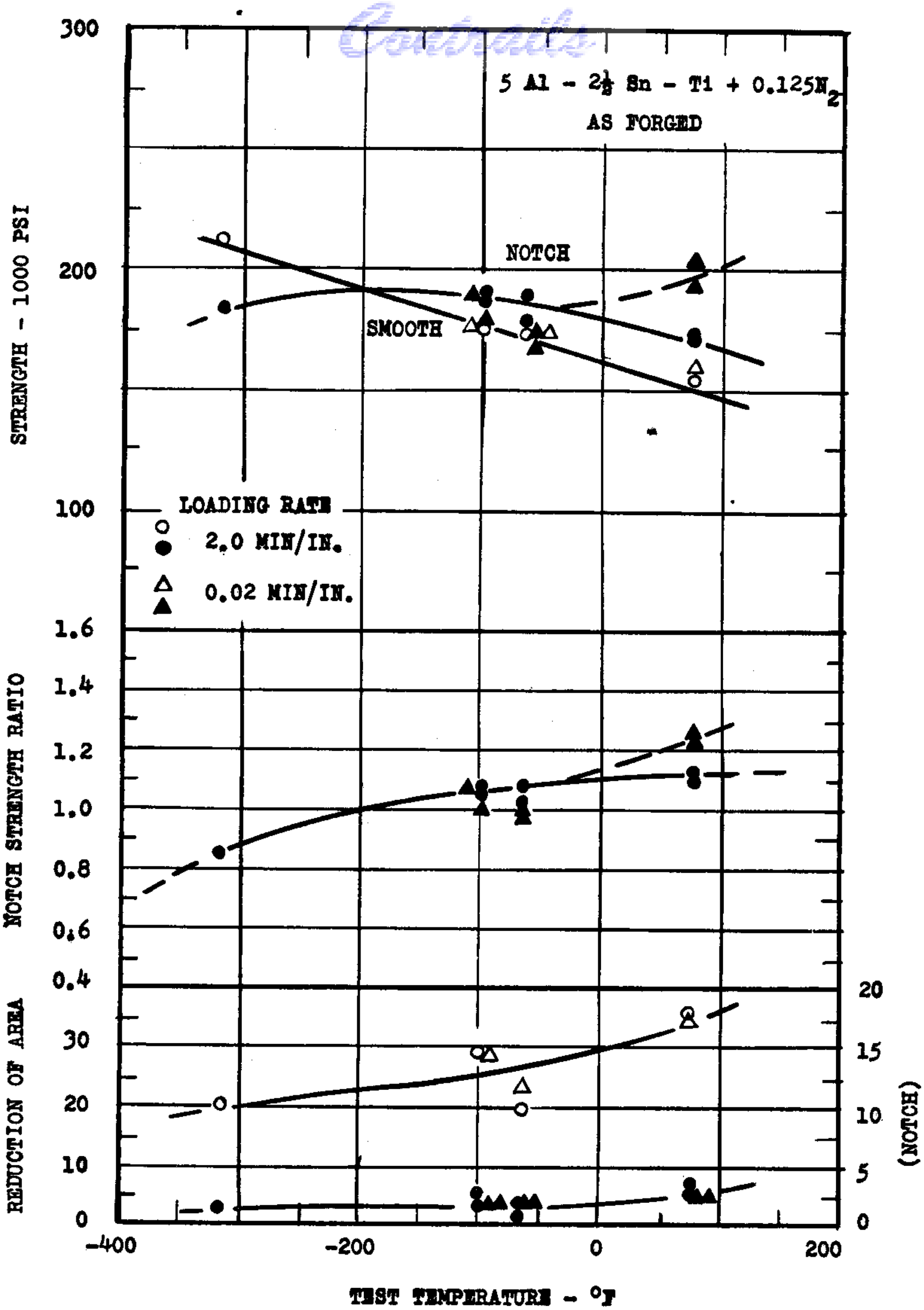


FIG. 17 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 5 Al - 2½ Sn - Ti + 0.125 N_2 - AS FORGED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

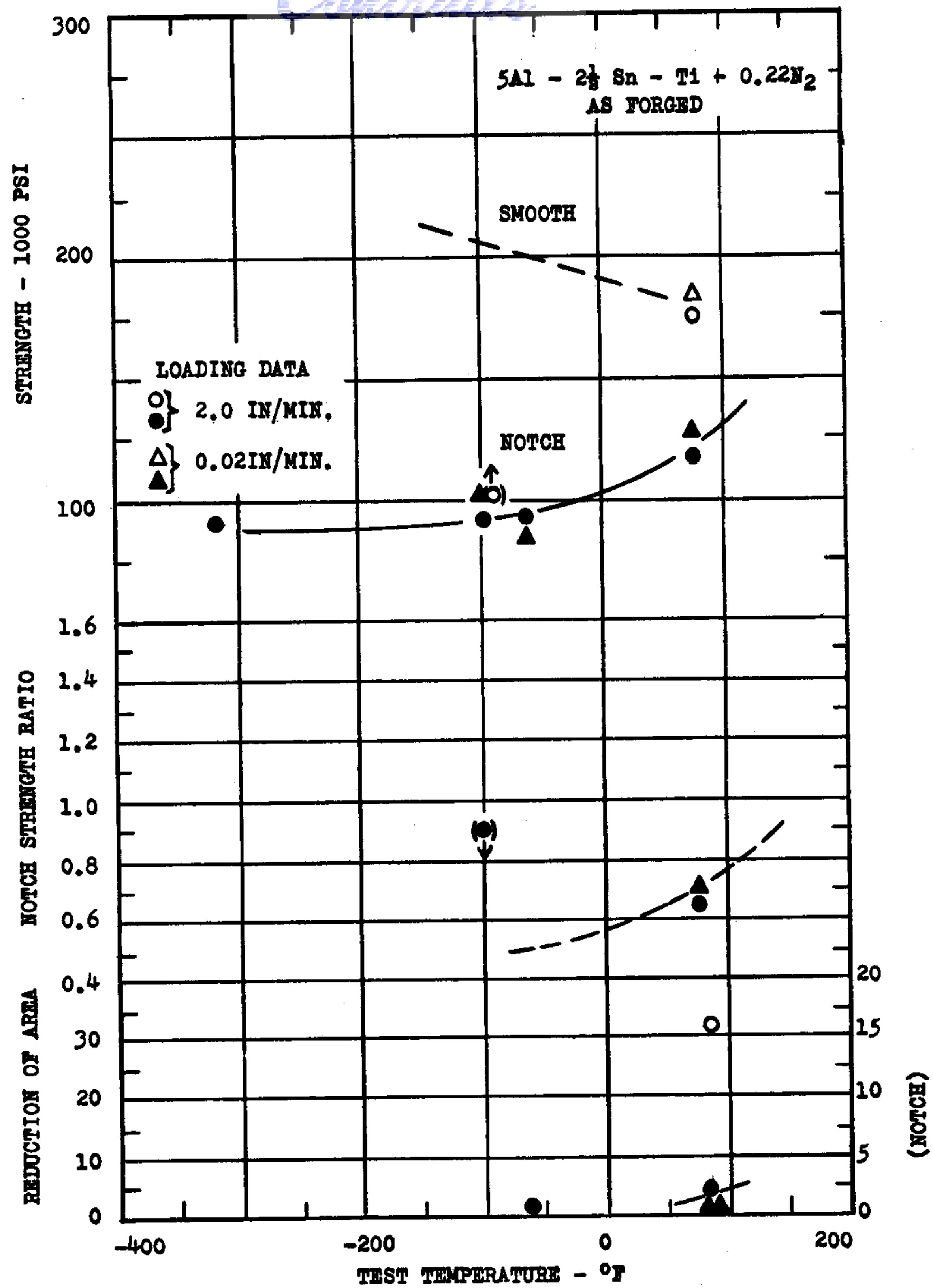


FIG. 18 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 5Al - $2\frac{1}{2}$Sn - Ti + $0.22N_2$ - AS FORGED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

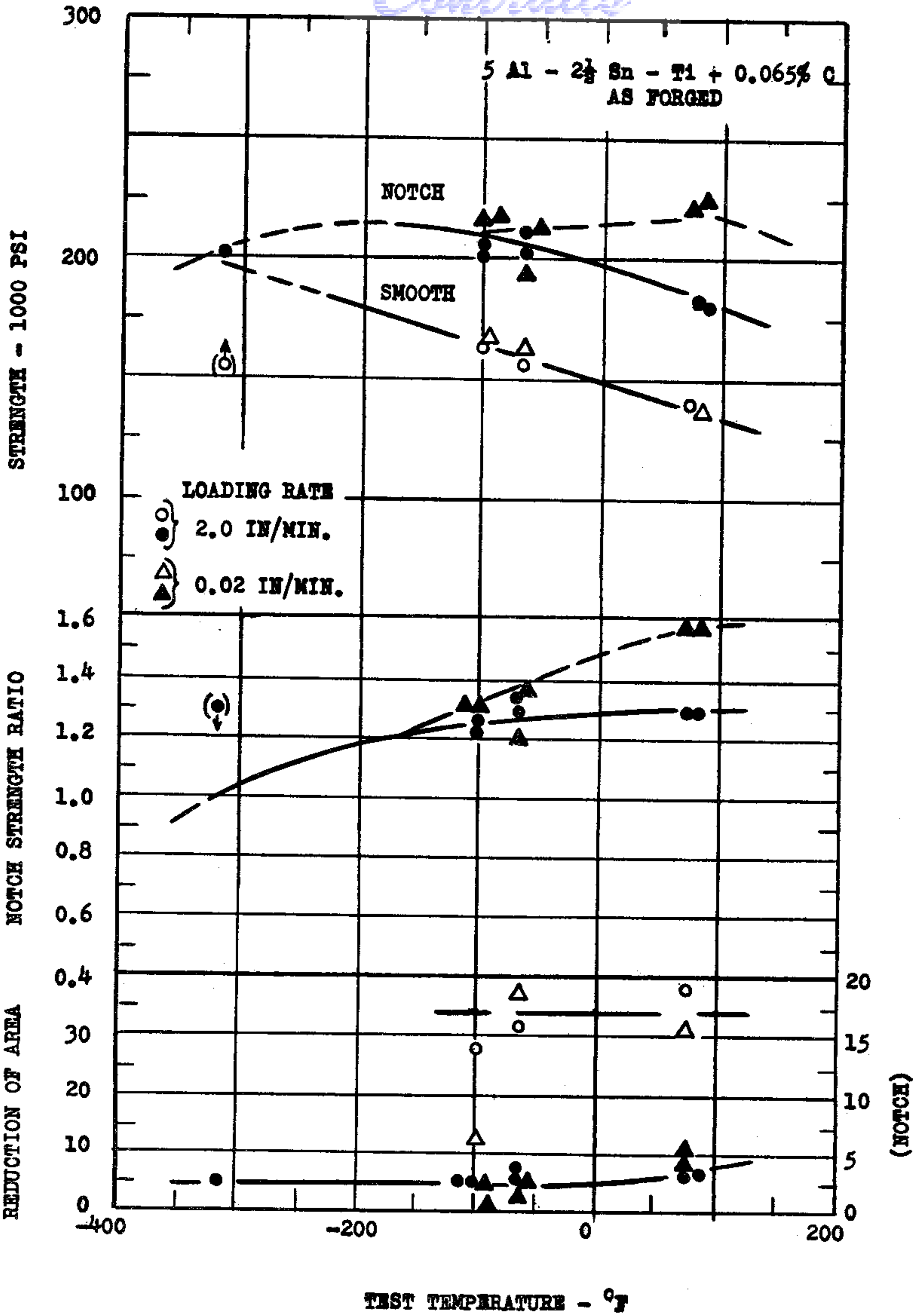


FIG. 19 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 5 Al - 2½ Sn - Ti + 0.065% CARBON - AS FORGED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

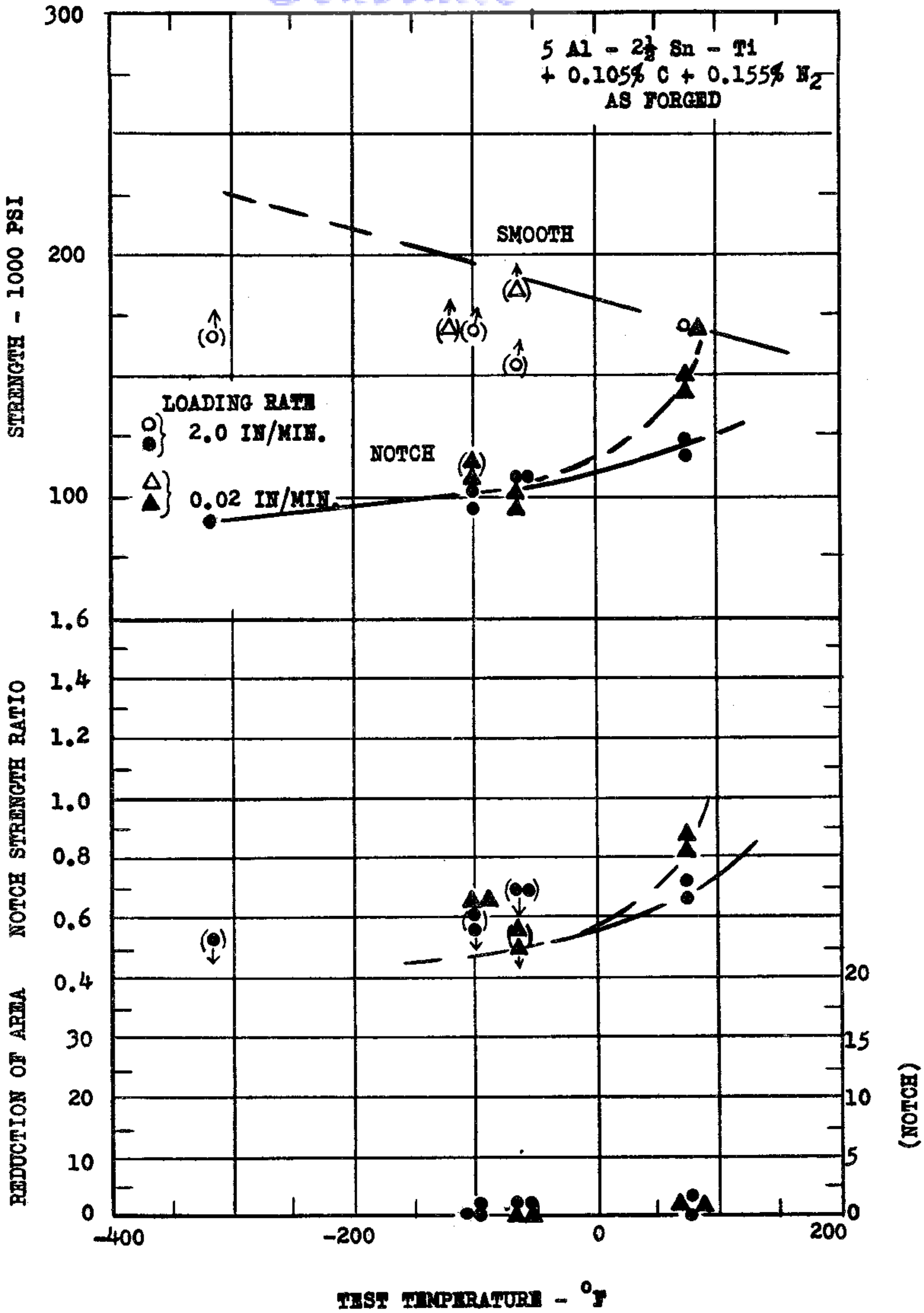


FIG. 20 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 5 Al - 2½ Sn - Ti + 0.105% CARBON + 0.155% NITROGEN - AS FORGED. SPECIMEN: 0.3 IN. DIAM. 50 % NOTCH. r ≤ 0.002 IN.

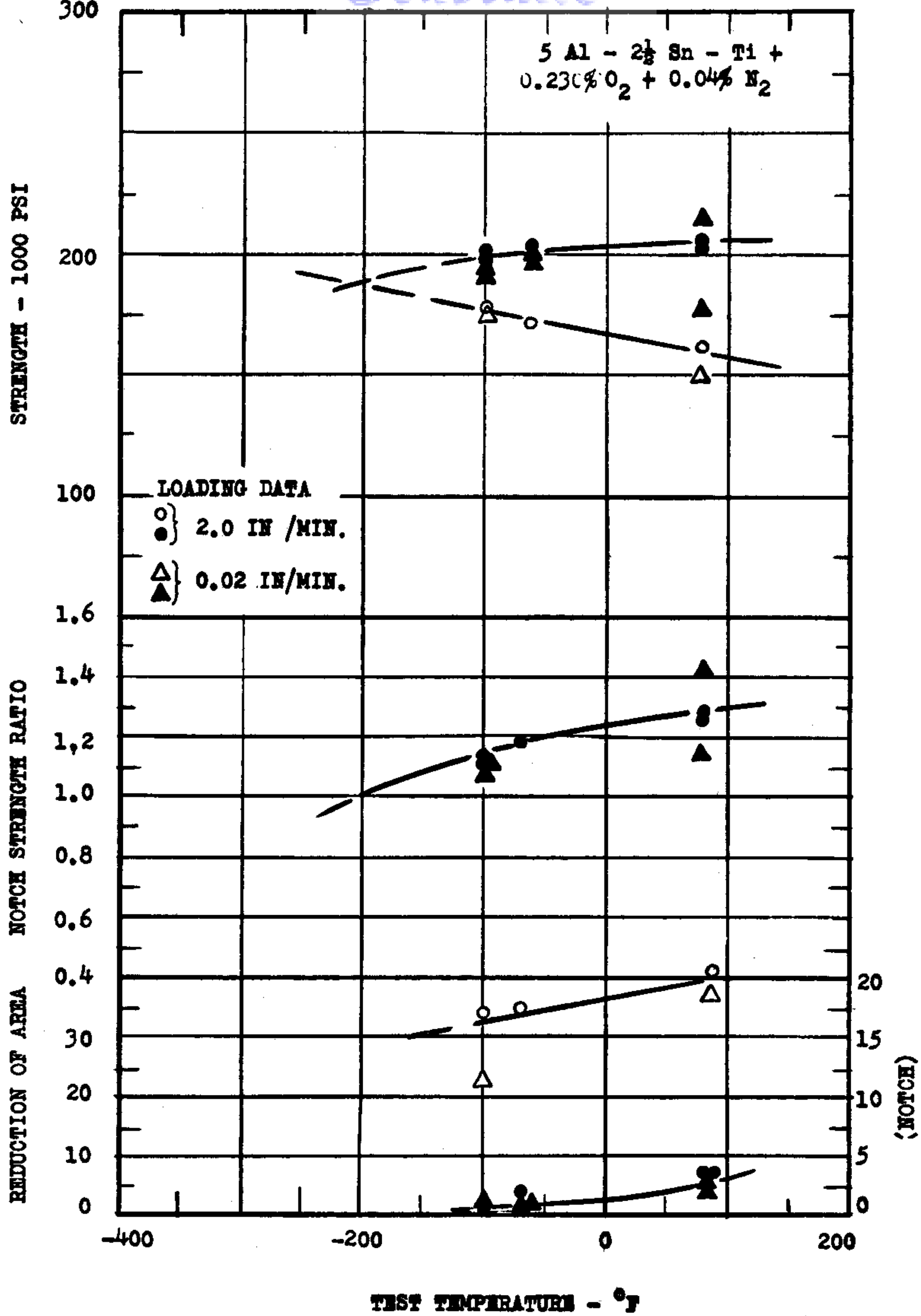


FIG. 21 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 5 Al - 2½ Sn - Ti +0.230% O_2 + 0.04% N_2. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

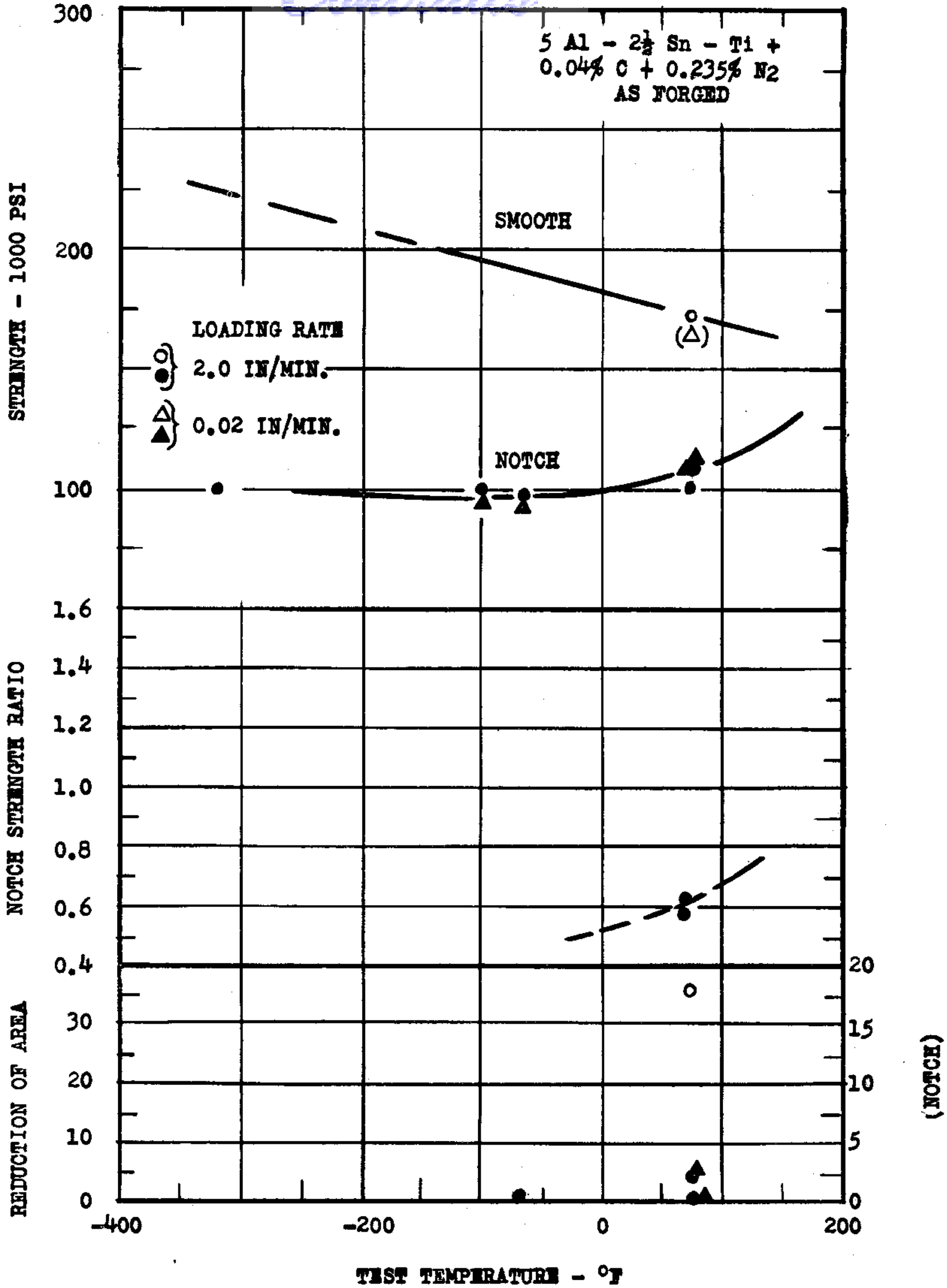


FIG. 22 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 5 Al - 2½ Sn - Ti + 0.04% C + 0.235% N_2 - AS FORGED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

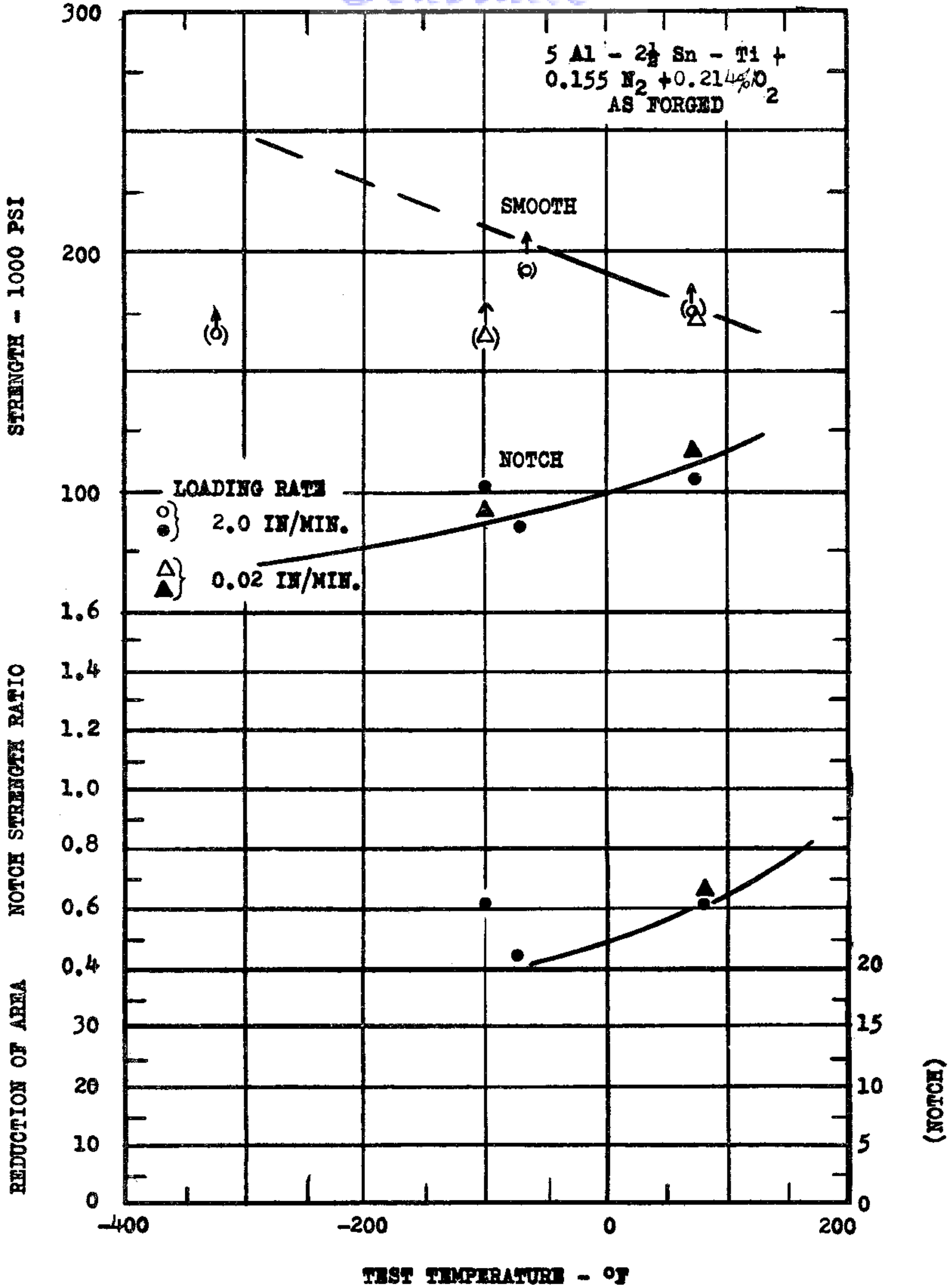


FIG. 23 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 5 Al - 2½ Sn - Ti + 0.155 N_2 +0.214% O_2 - AS FORGED.
SPECIMEN: 0.3 IN DIAM. 50% NOTCH. r≤ 0.002 IN.

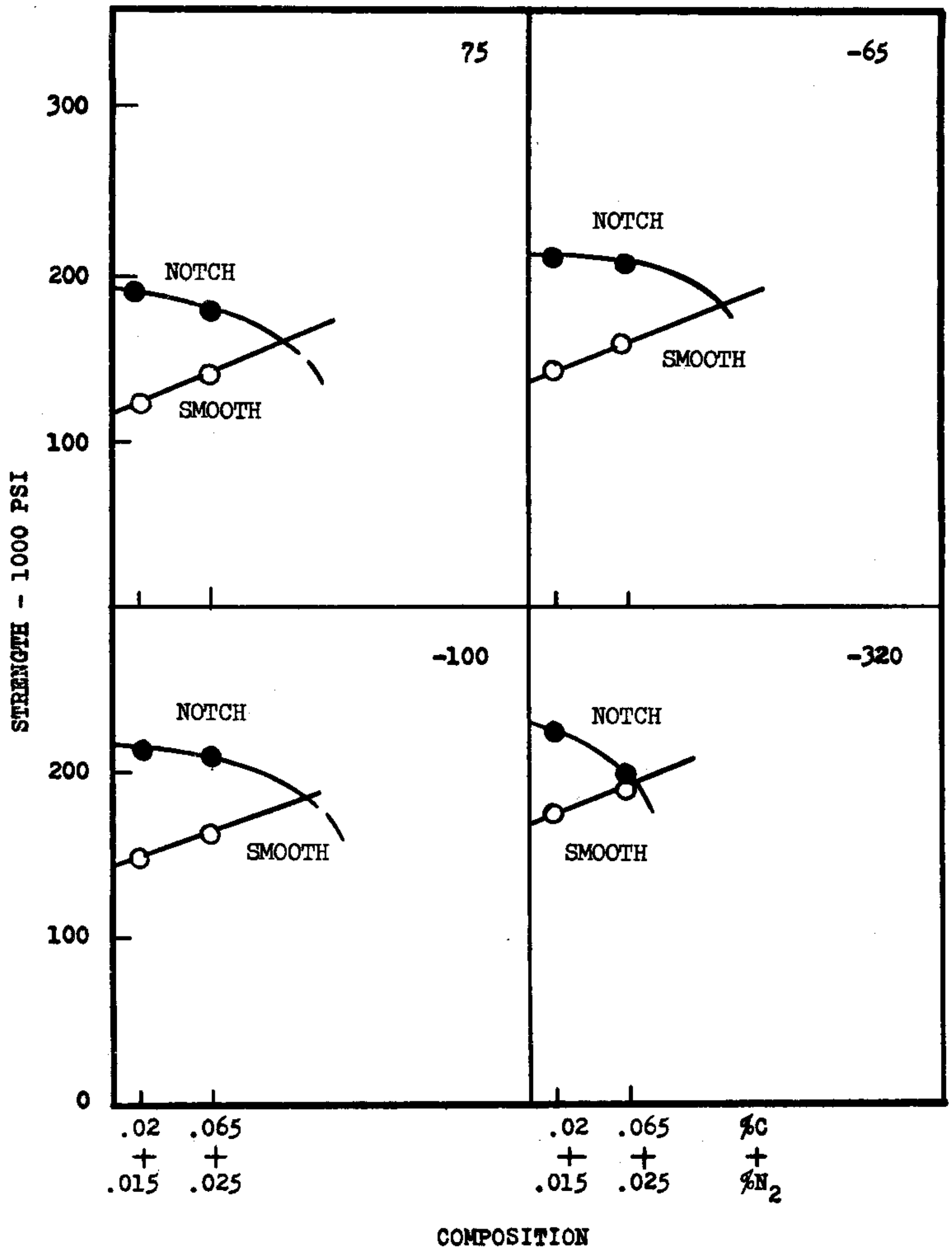


FIG. 24 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG THE TERNARY SECTION NO. 1. (CF. FIG. 3).

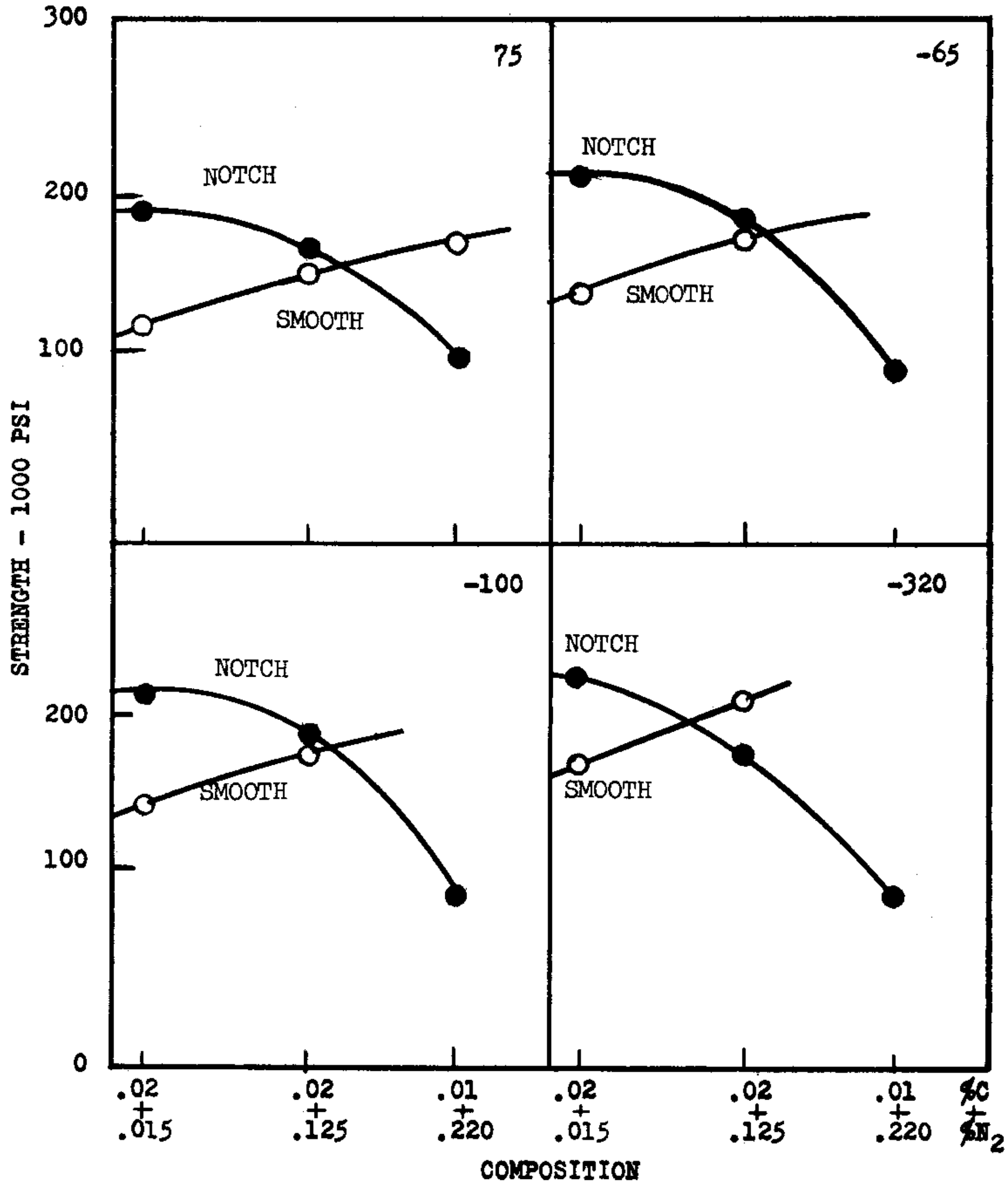


FIG. 25 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG THE TERNARY SECTION NO. 2. (CF. FIG 3).

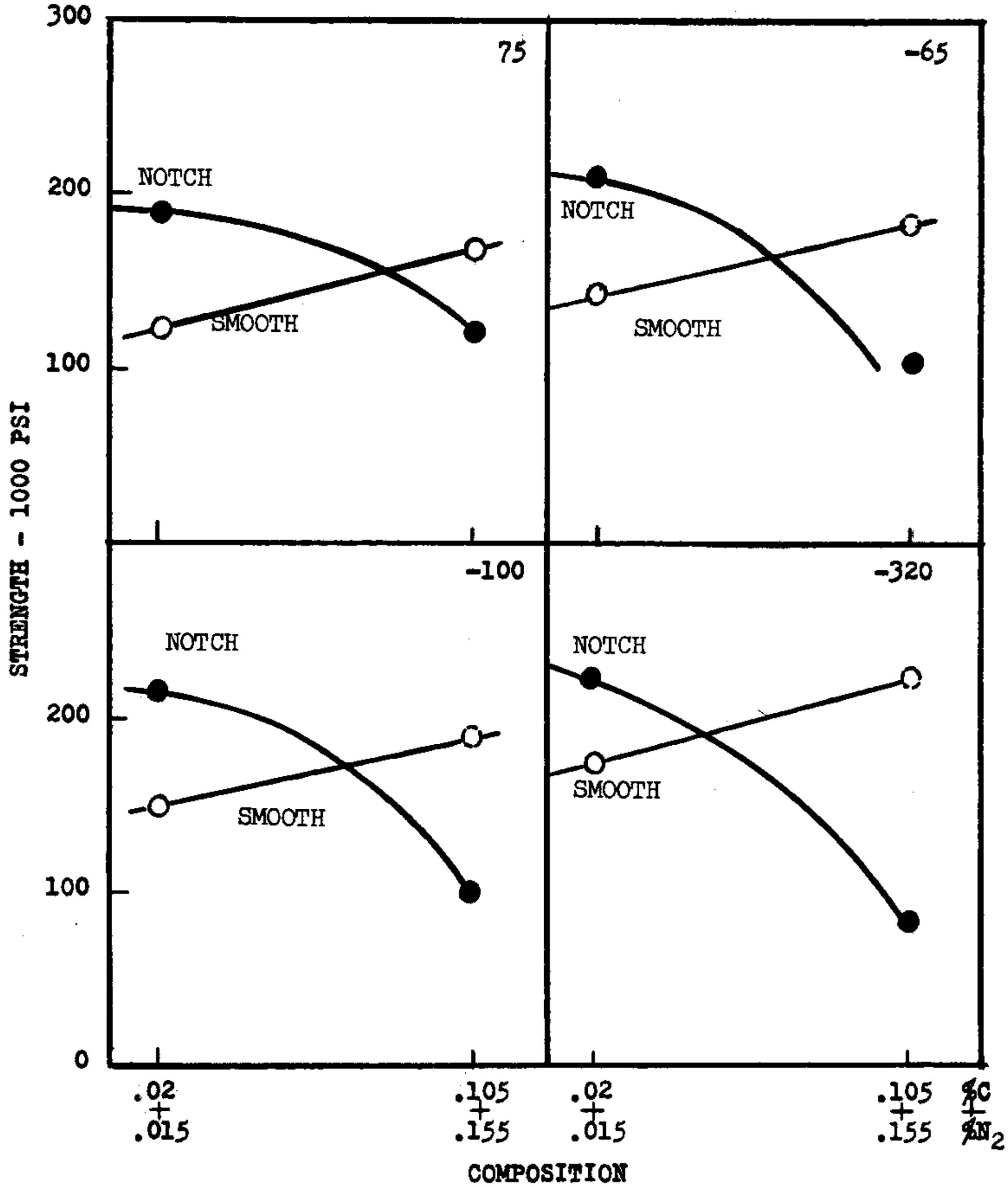


FIG. 26 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG THE TERNARY SECTION NO. 3. (CF. FIG. 3). THE TRENDS OF THE CURVES WERE ESTABLISHED BY REFERENCE TO THE CURVES IN FIGURE 25 .

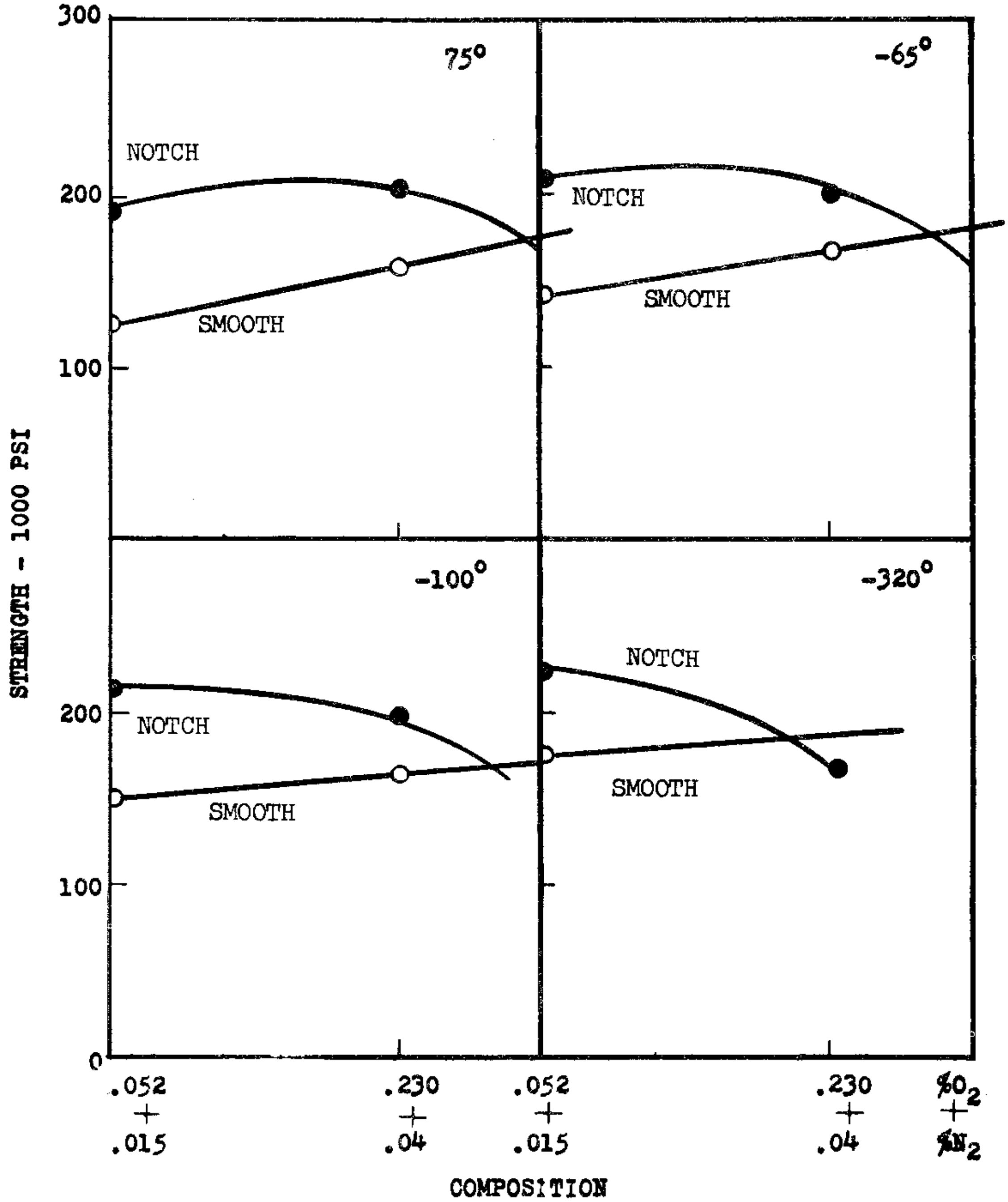


FIG. 27 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 4.

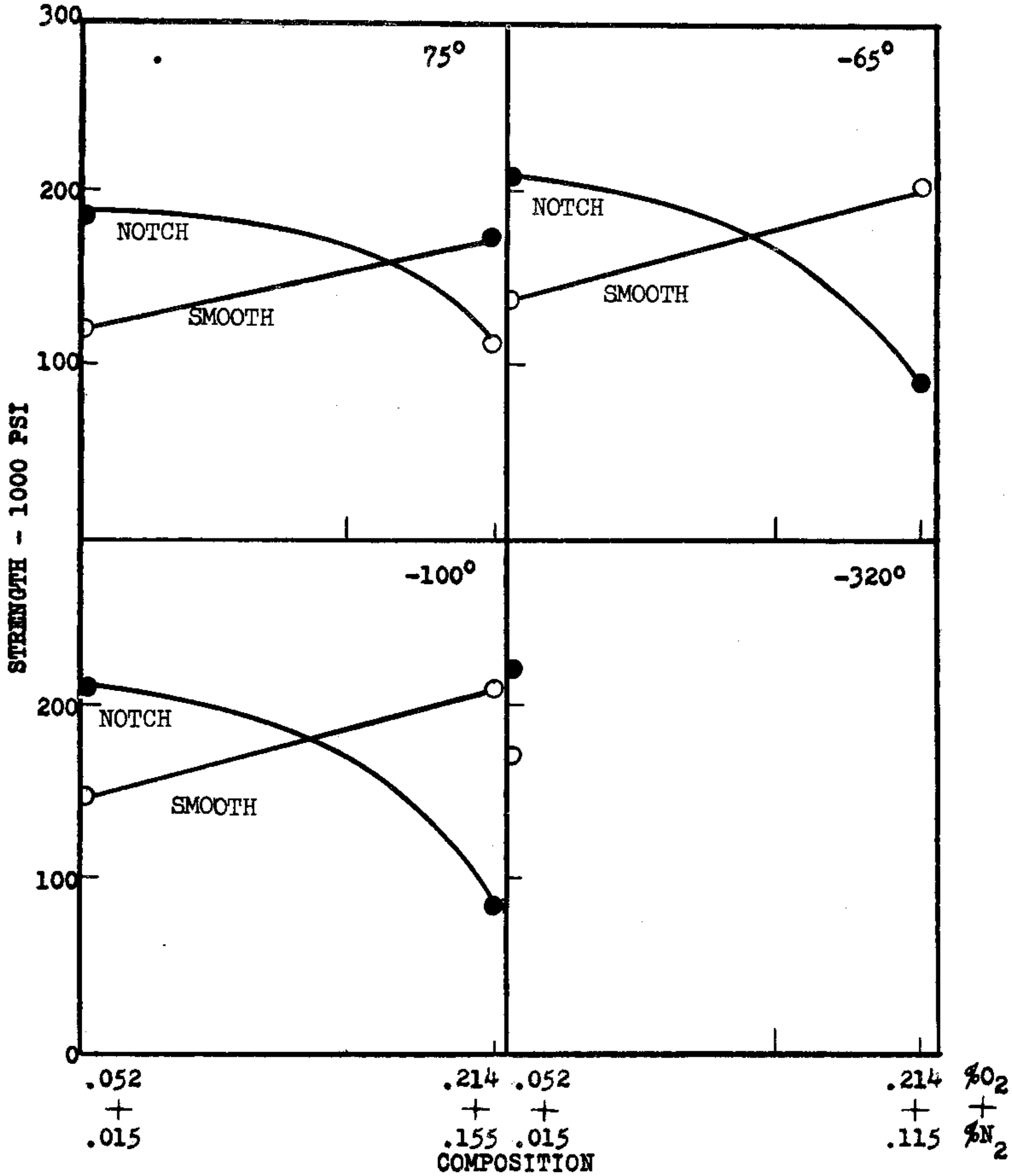


FIG. 28 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG THE TERNARY SECTION NO. 5. (CF. FIG. 3). THE TRENDS OF THE CURVES WERE ESTABLISHED BY REFERENCE TO THE CURVES IN FIGURE 25.

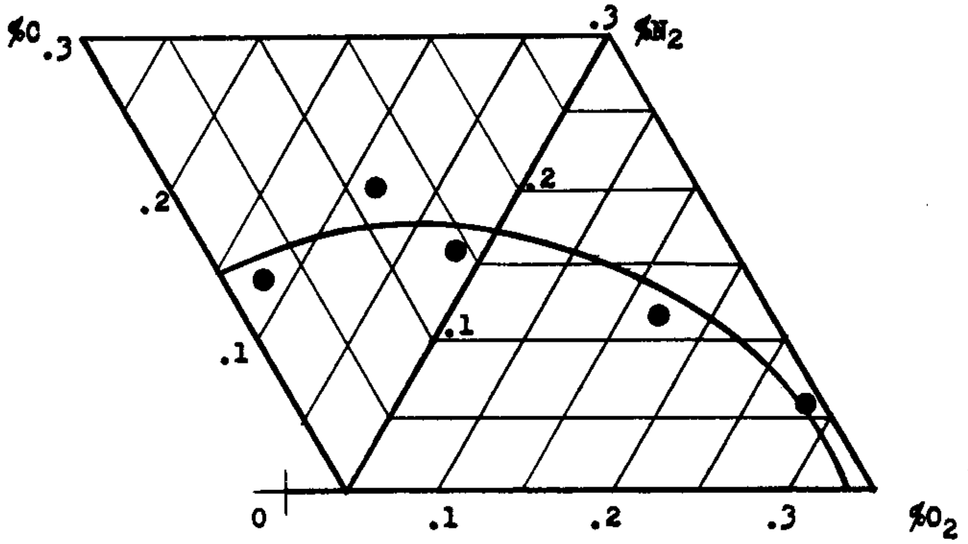


FIG. 29 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT 75°F. 5Al - 2½ Sn - Ti ALLOY.

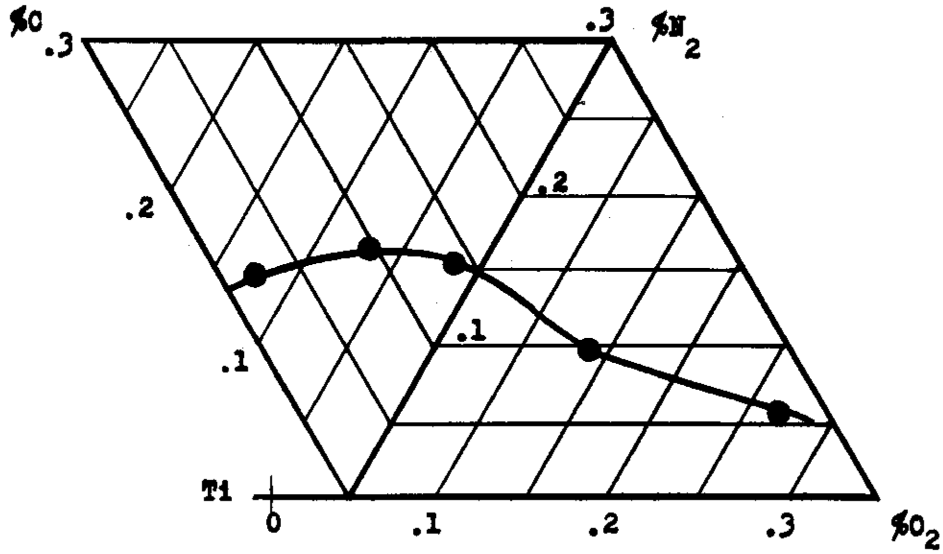


FIG. 30 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT -65°F. 5 Al - 2½ Sn - Ti ALLOY.

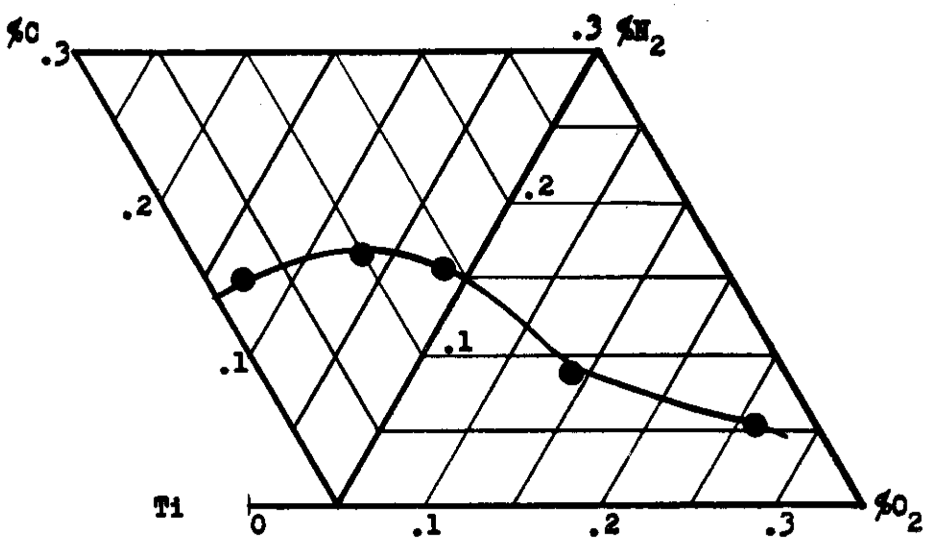


FIG. 31 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT -100°F. 5 Al - 2½ Sn - Ti ALLOY.

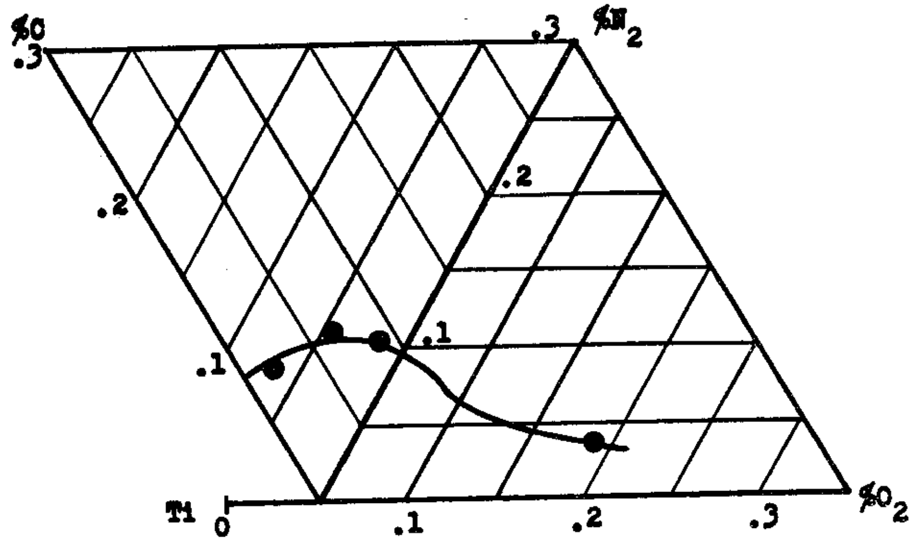


FIG. 32 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT -320°F. 5 Al - 2½ Sn - Ti ALLOY.

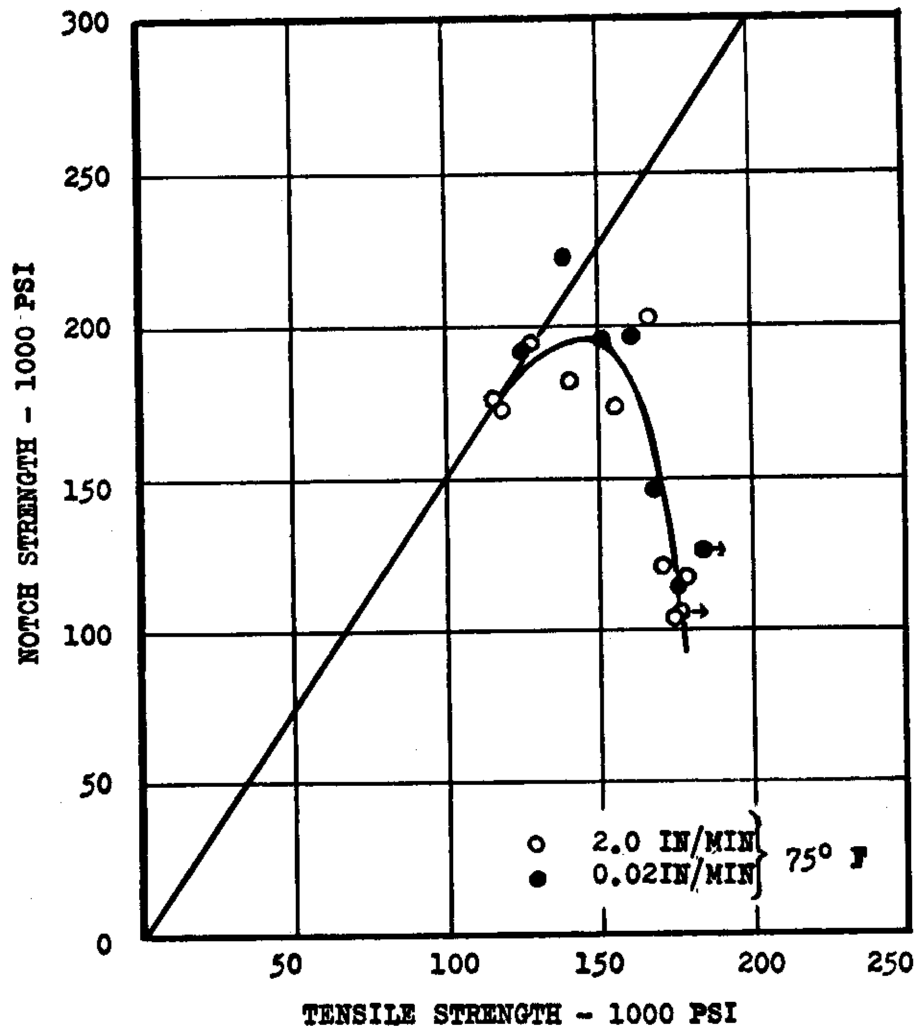
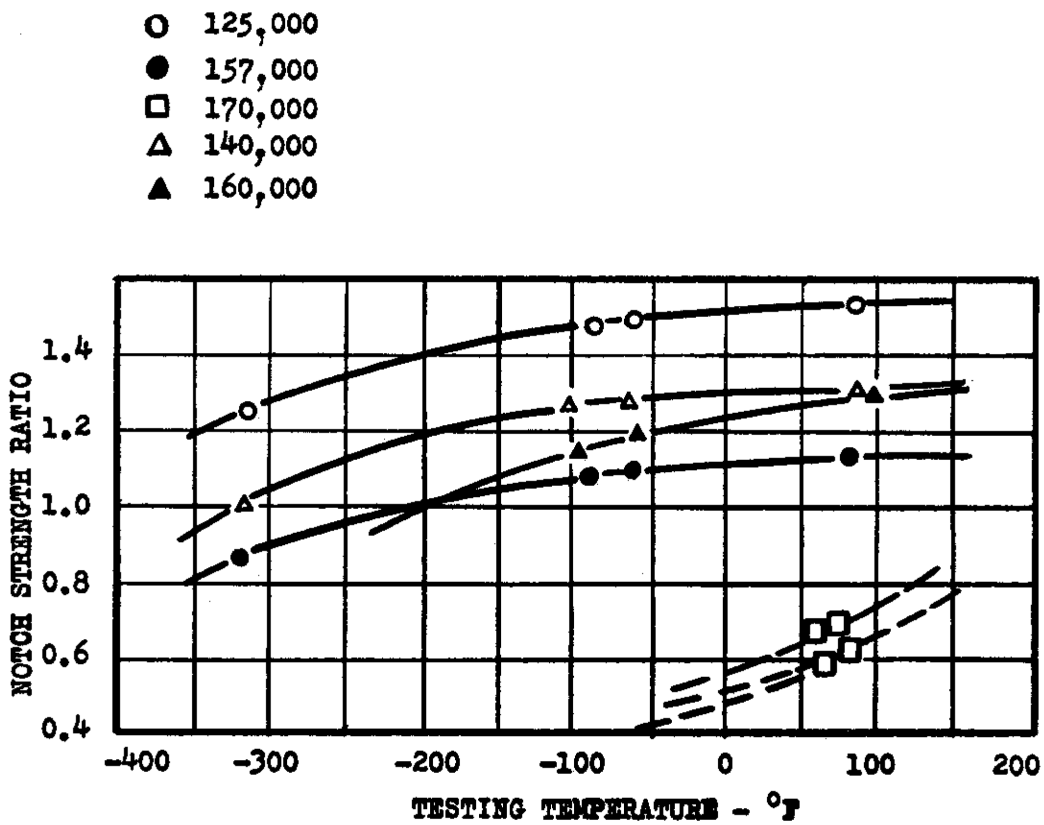


FIG. 33 THE NOTCH STRENGTH VS. THE TENSILE STRENGTH AT 75°F. ALLOYS 5 Al - 2½ Sn - Ti.



DUCTILE - BRITTLE TRANSITION IN THE NOTCH TENSILE TEST FOR THE INDICATED ALLOY.

FIG. 34 THE NOTCH STRENGTH RATIO VS. TEST TEMPERATURE VS. TENSILE STRENGTH AT 75° F. ALLOY: 5 Al - $2\frac{1}{2}$ Sn - Ti.

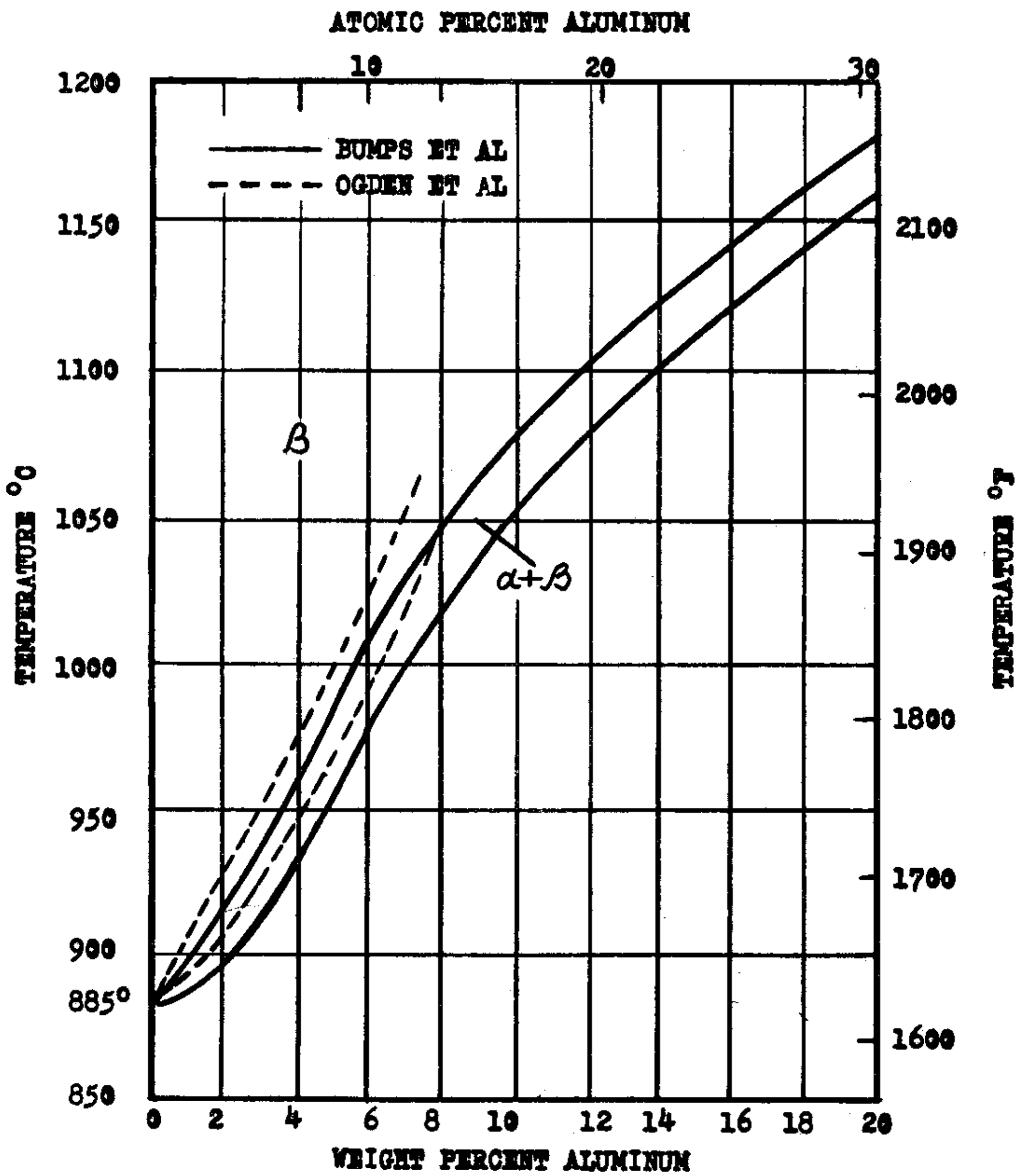


FIG. 35 **THE Ti - Al PHASE DIAGRAM.**

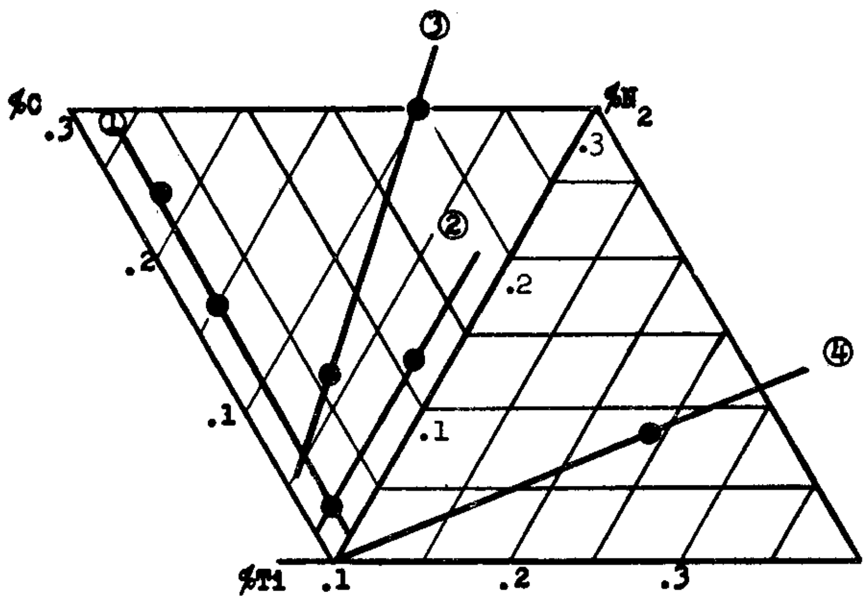
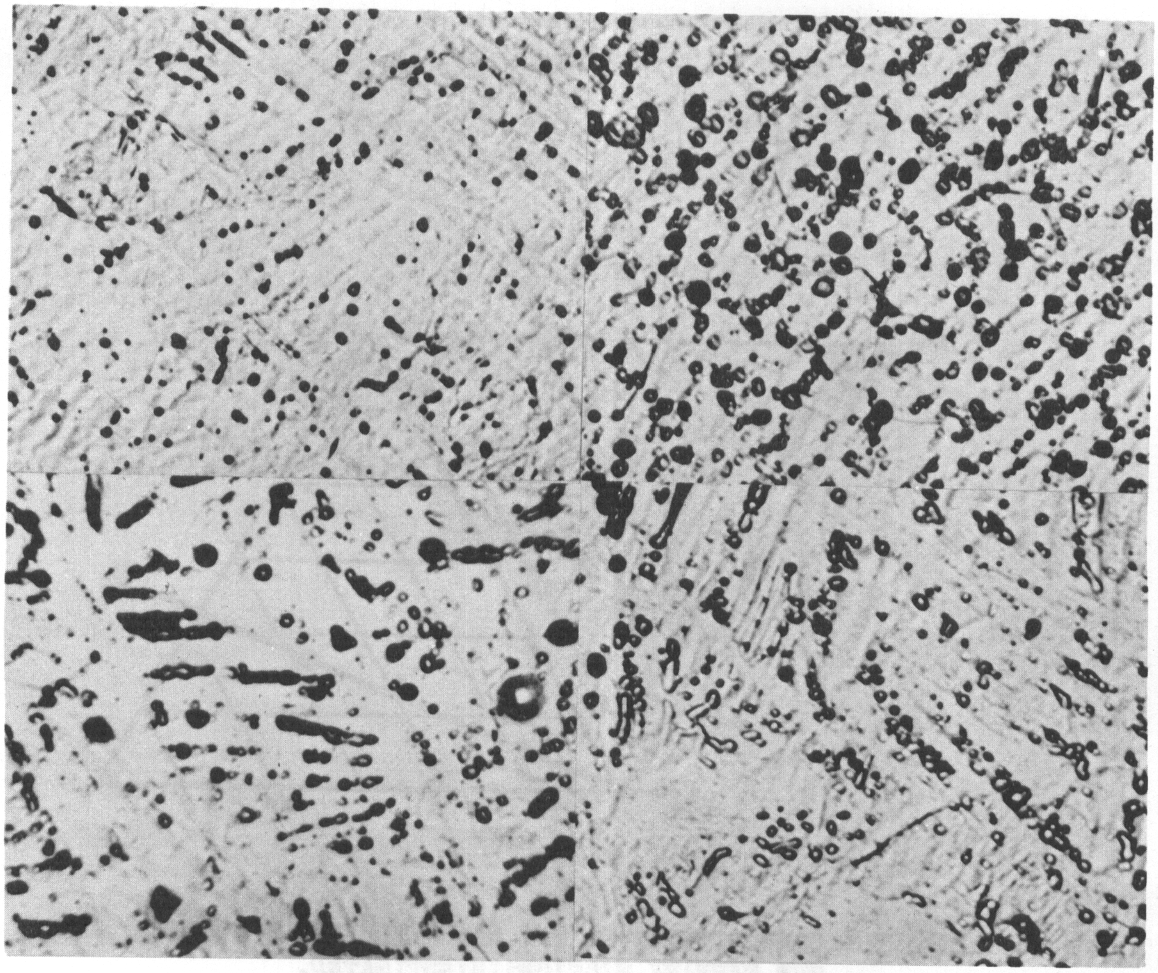


FIG. 36 COMPOSITIONS OF THE 6Al - Ti INGOTS STUDIED, AND THE TERNARY SECTIONS INVESTIGATED.

37 38



39 40

FIGS. 37 TO 40 MICROSTRUCTURES OF THE INDICATED 6Al - Ti ALLOYS ELECTROPOLISHED, KELLER'S ETCH x500.

FIG. 37 AS ANNEALED
FIG. 38 + 0.15 C
FIG. 39 + 0.22 C + 0.025 N_2
FIG. 40 + 0.02 C + 0.116 N_2

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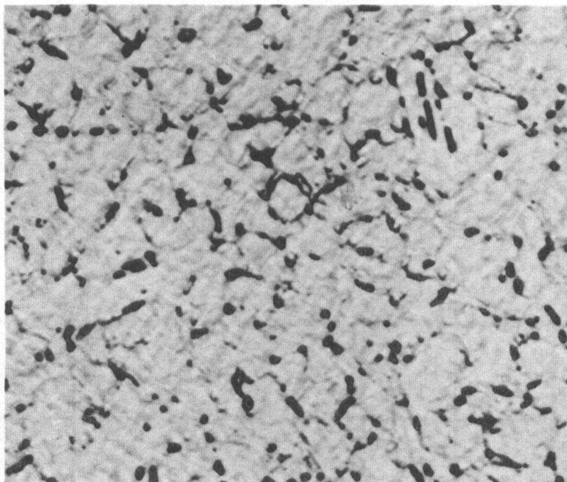
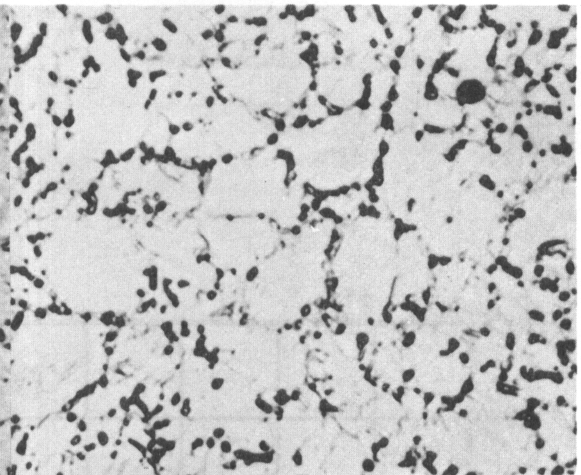


42


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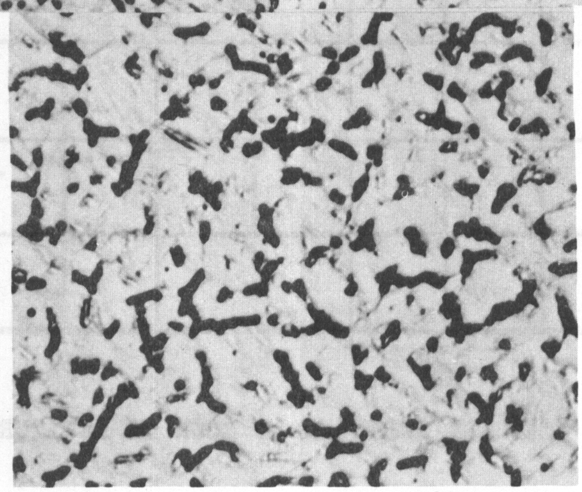


FIGS. 41 TO 43 MICROSTRUCTURES OF THE INDICATED 6Al - Ti ALLOYS. ELECTROPOLISHED, KELLER'S ETCH x500.

FIG. 41 + 0.065 C + 0.06 N_2
FIG. 42 + 0.10 C + 0.201 N_2
FIG. 43 + 0.24O_2 + 0.086 N_2

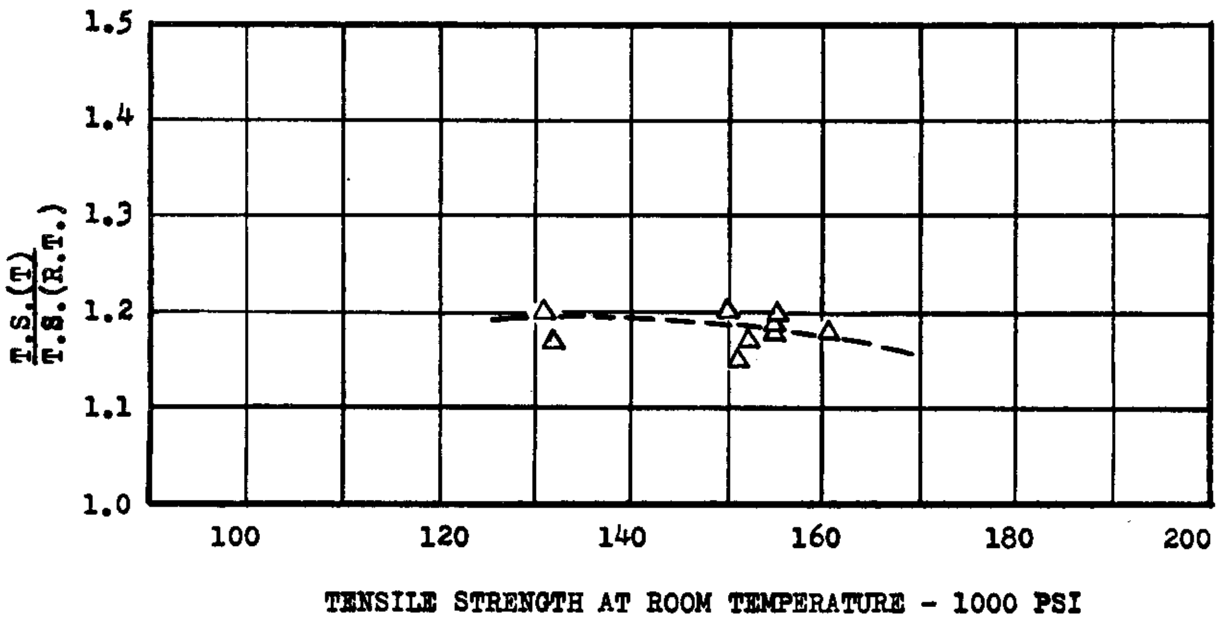


FIG. 44 THE TENSILE STRENGTH AT -100°F AS A FUNCTION OF THE TENSILE STRENGTH AT 75°F. 6Al - Ti ALLOYS.

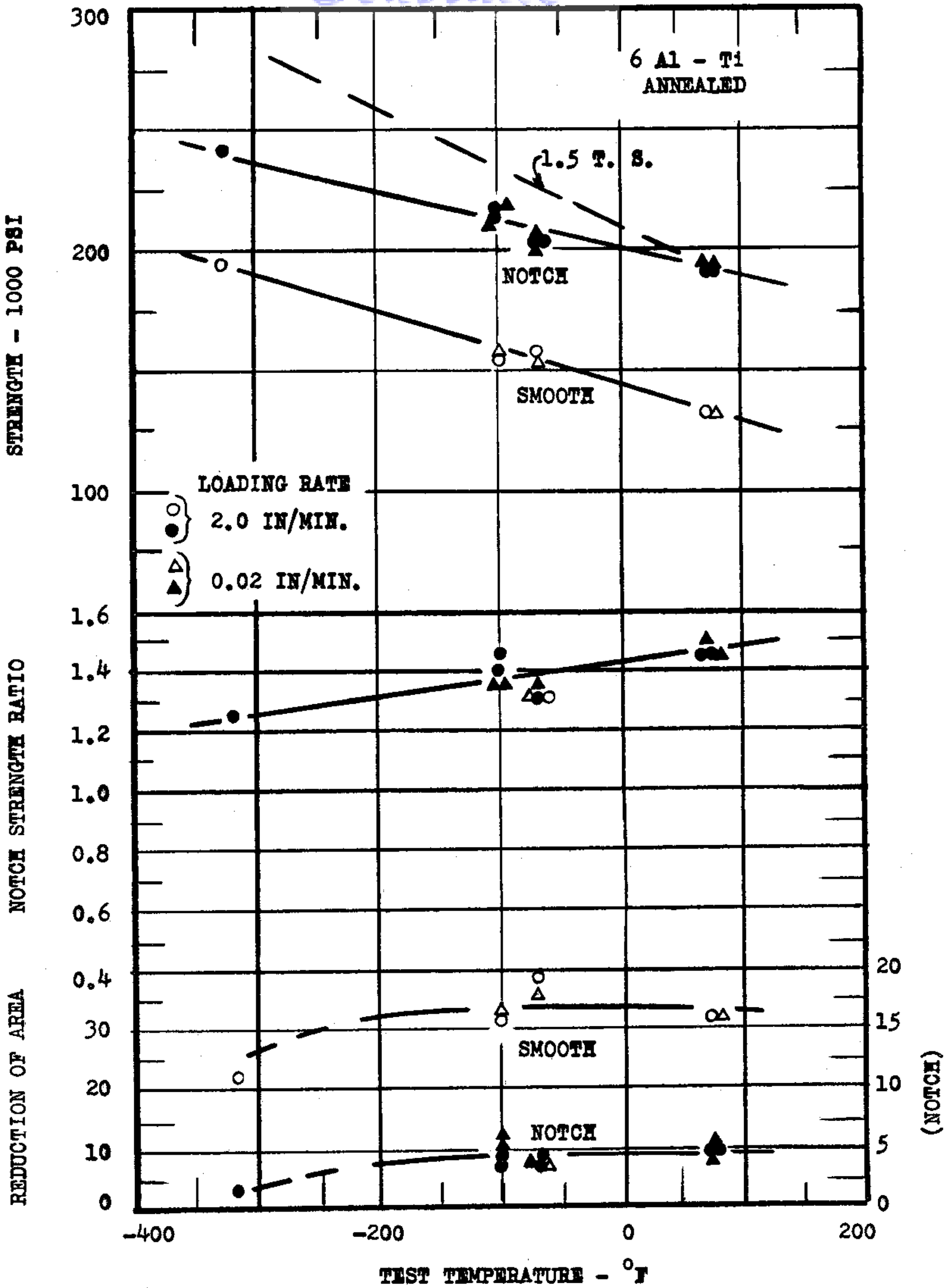


FIG. 45 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 6 Al - Ti - ANNEALED
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

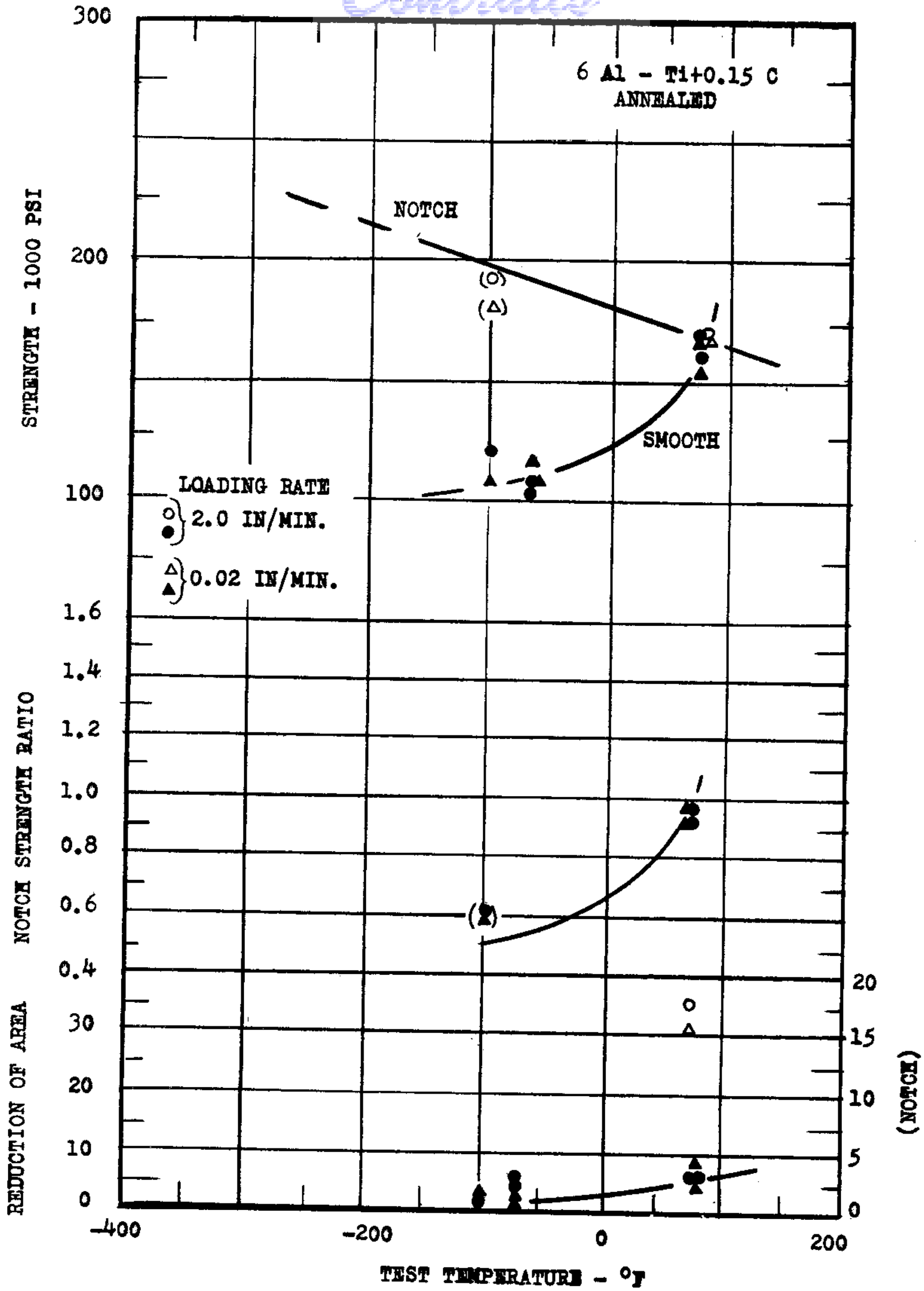


FIG. 46 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOYS AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 6 Al - Ti+0.15 C.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≦ 0.002 IN.

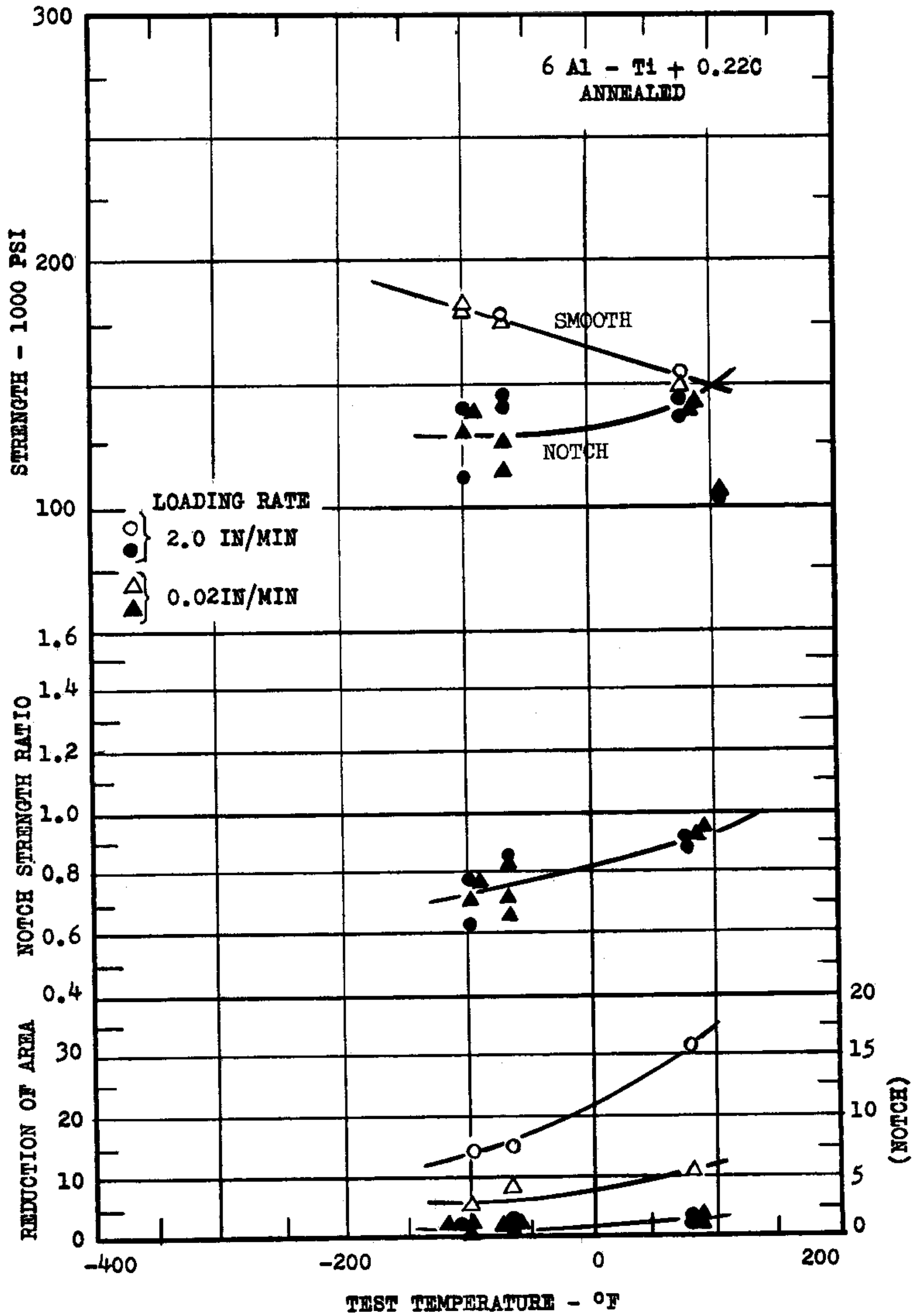


FIG. 47 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 6Al - Ti + 0.22C - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

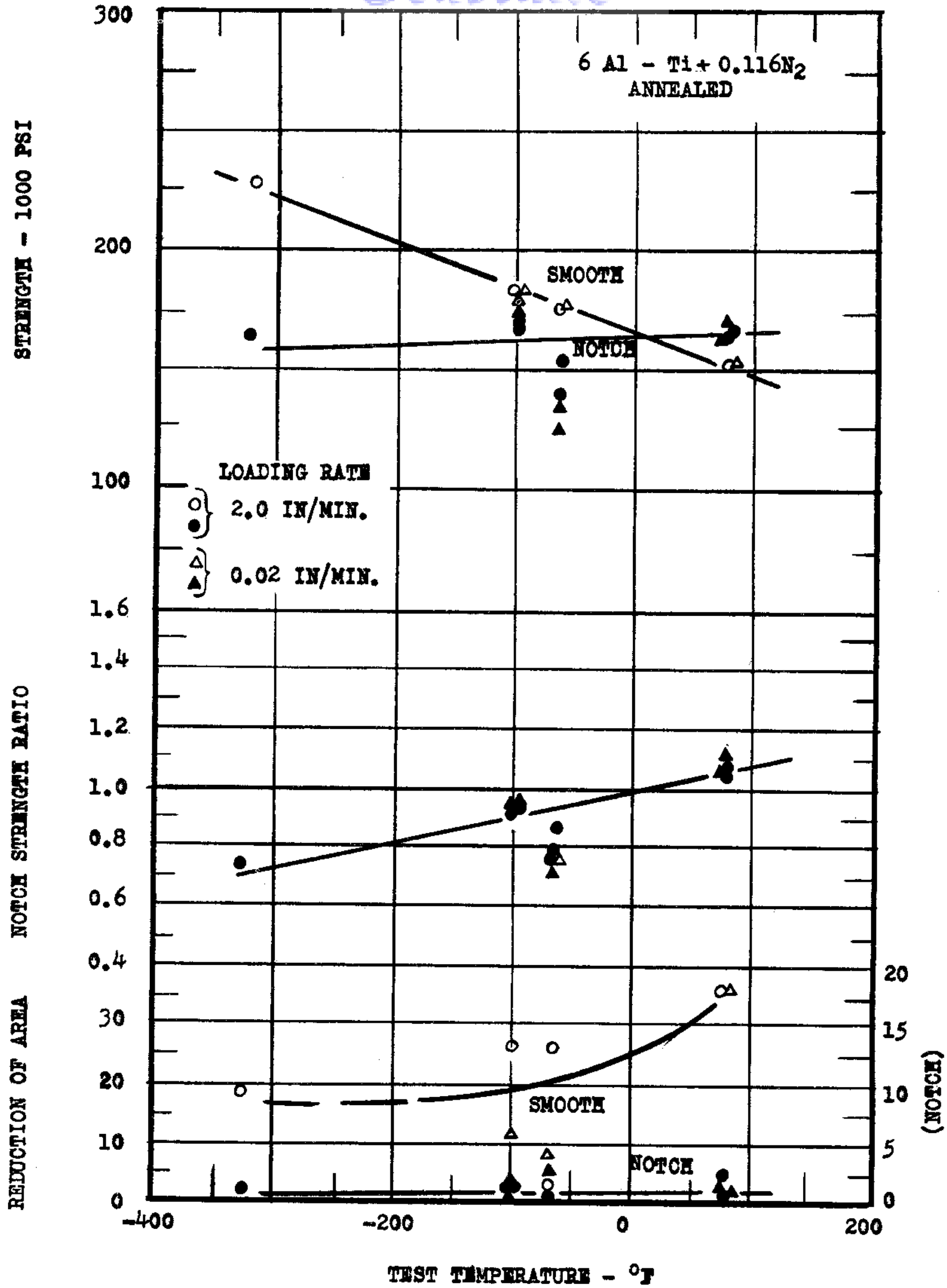


FIG. 48 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 6 Al - Ti + 0.116 N_2 - ANNEALED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r = 0.002 IN.

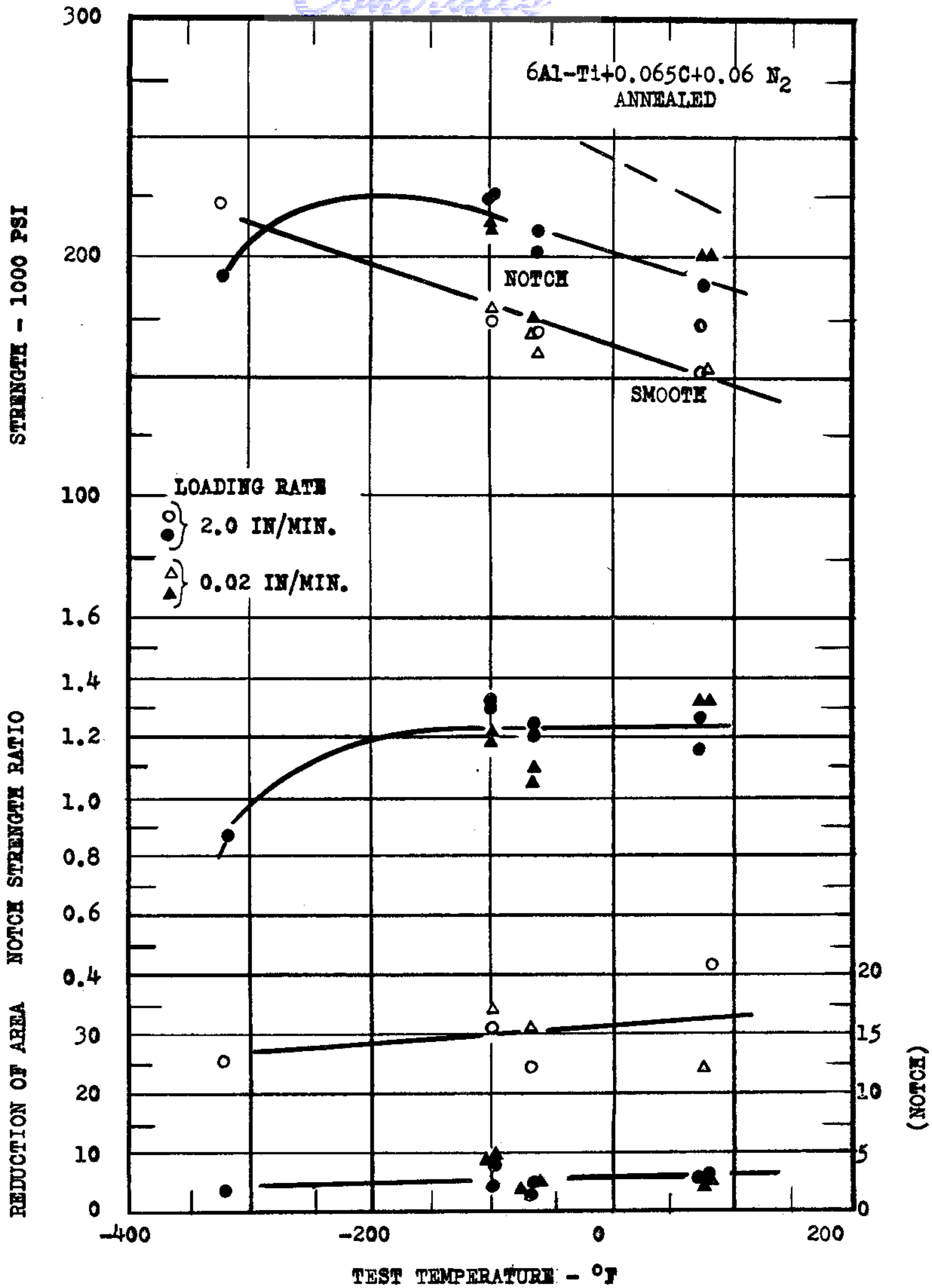


FIG. 49 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 6 Al - Ti + 0.0065 C + 0.06 N_2 - ANNEALED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r≤0.002 IN.

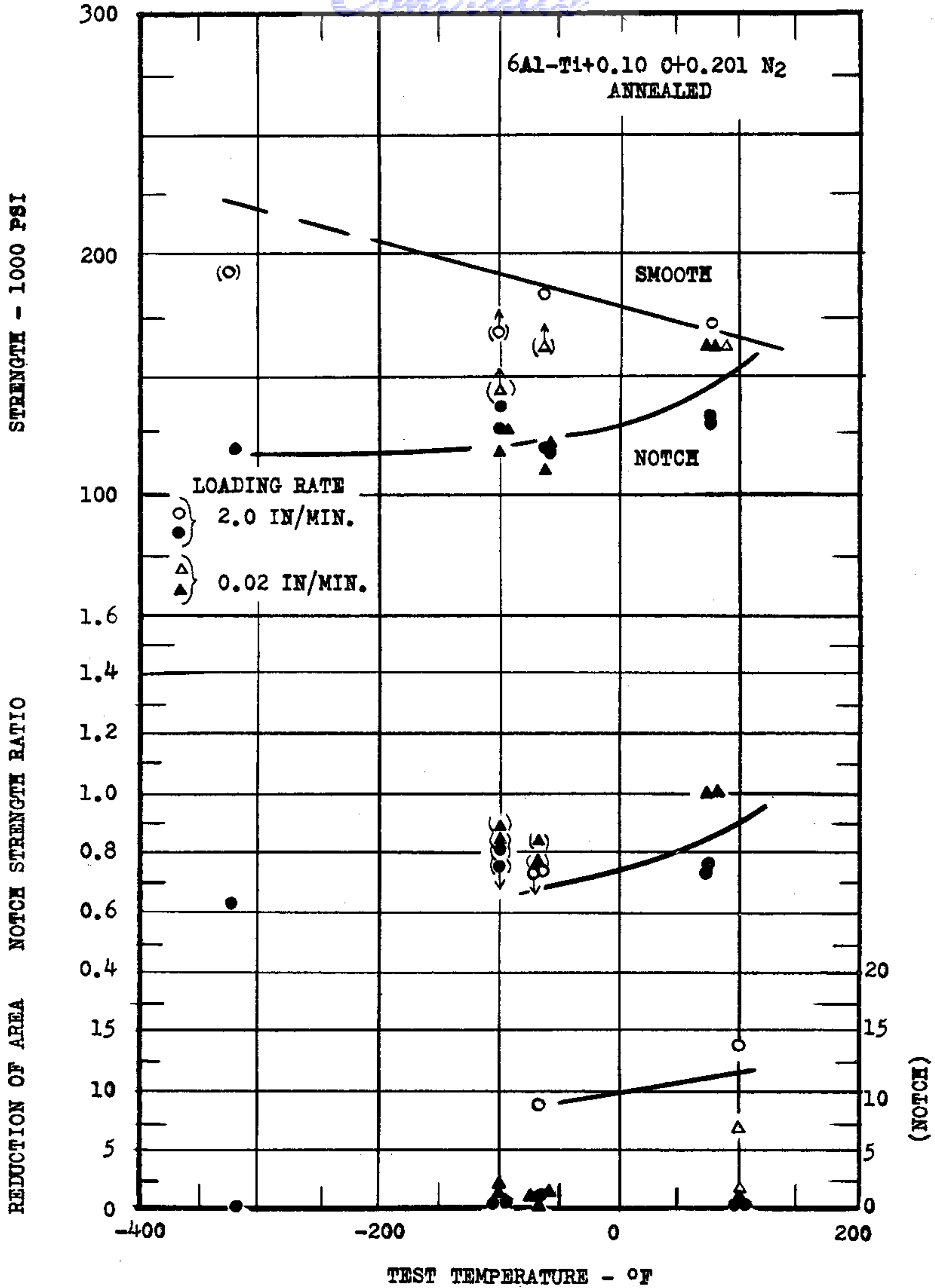


FIG. 50 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 6Al - Ti + 0.10 C+0.201 N_2 - ANNEALED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

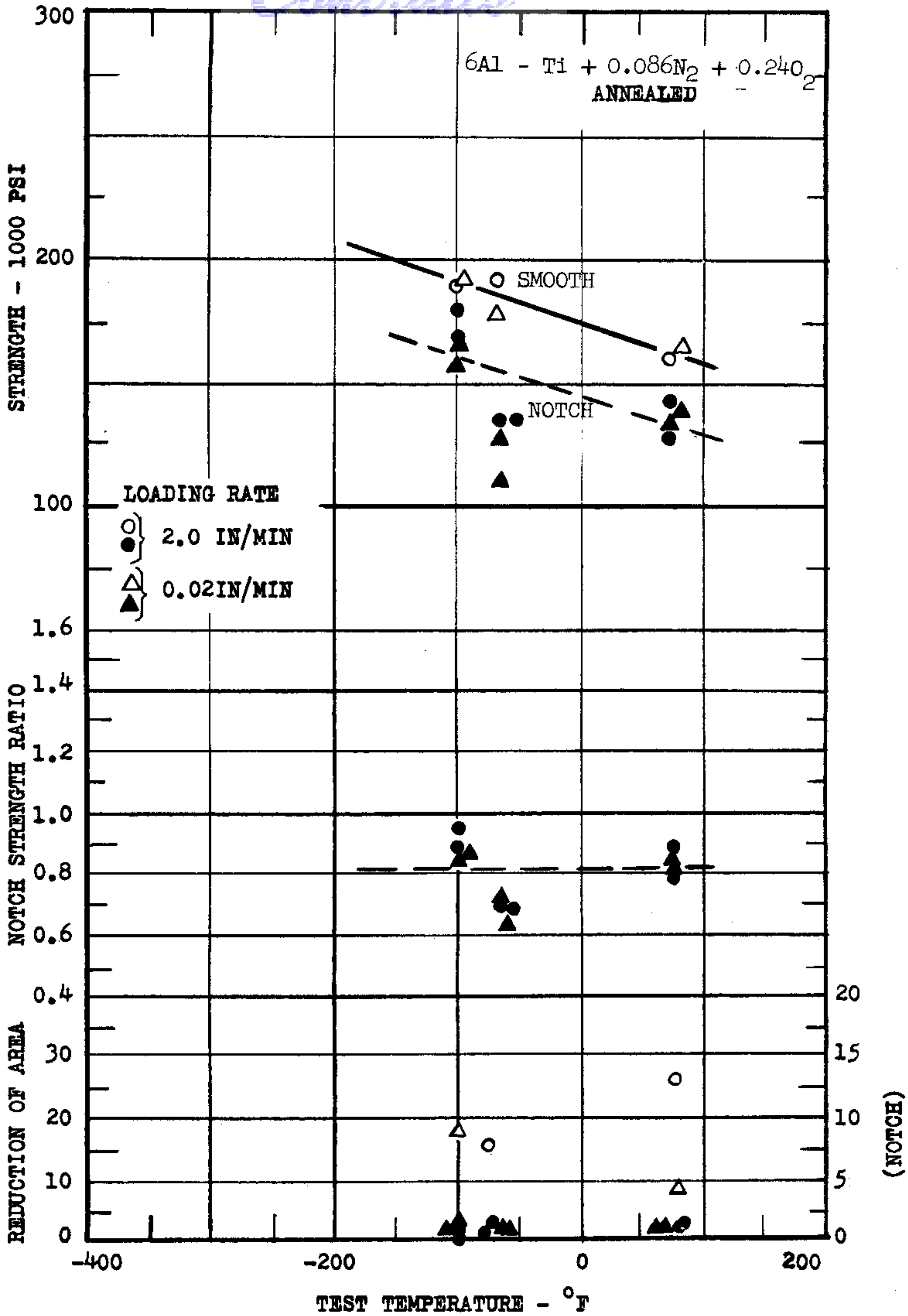


FIG. 51 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 6Al - Ti + 0.086N_2 + 0.24O_2 ANNEALED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r = 0.002 IN.

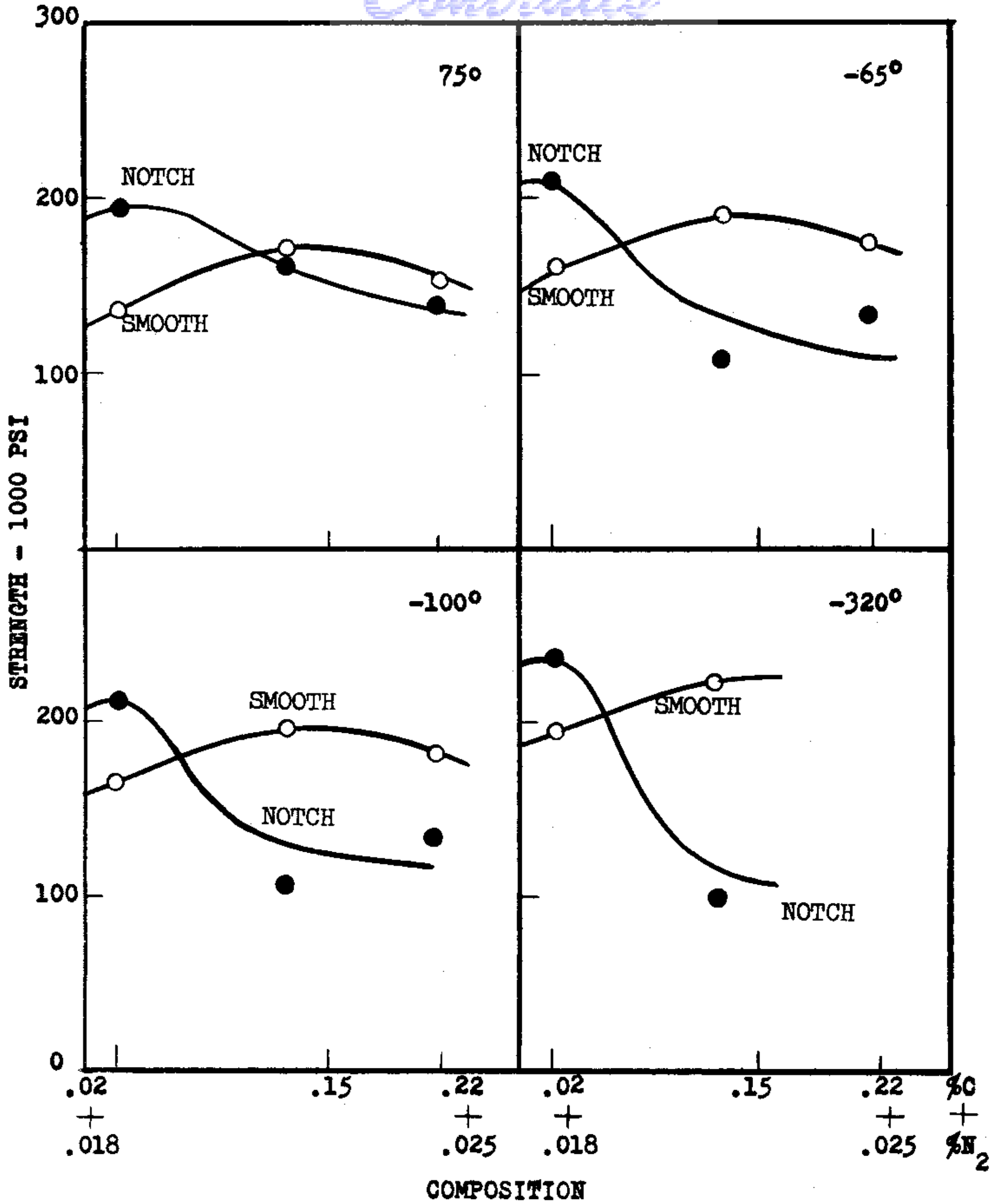


FIG. 52 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 1 (CF. FIG. 36)

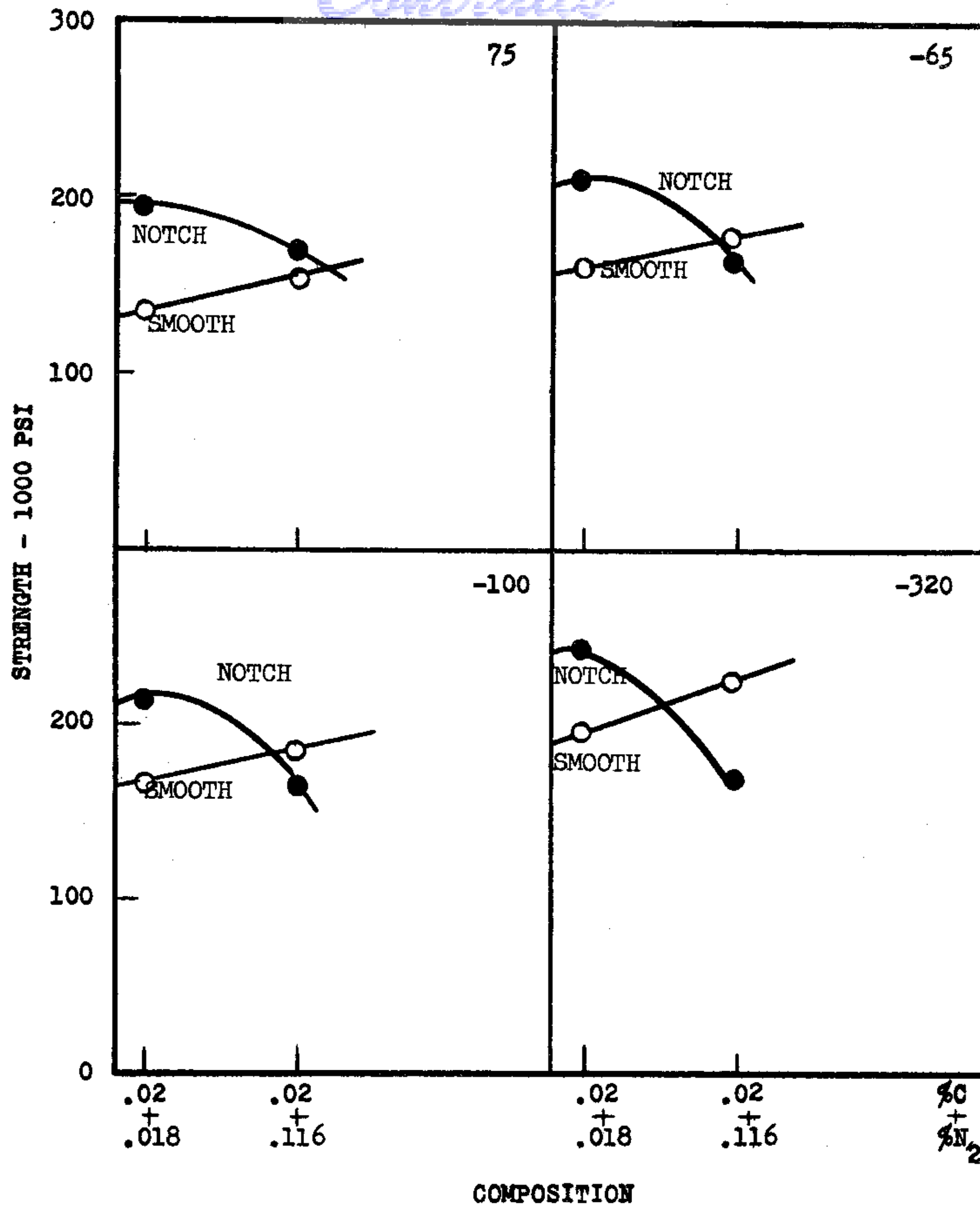


FIG. 53 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 2. (CF. FIG. 36)

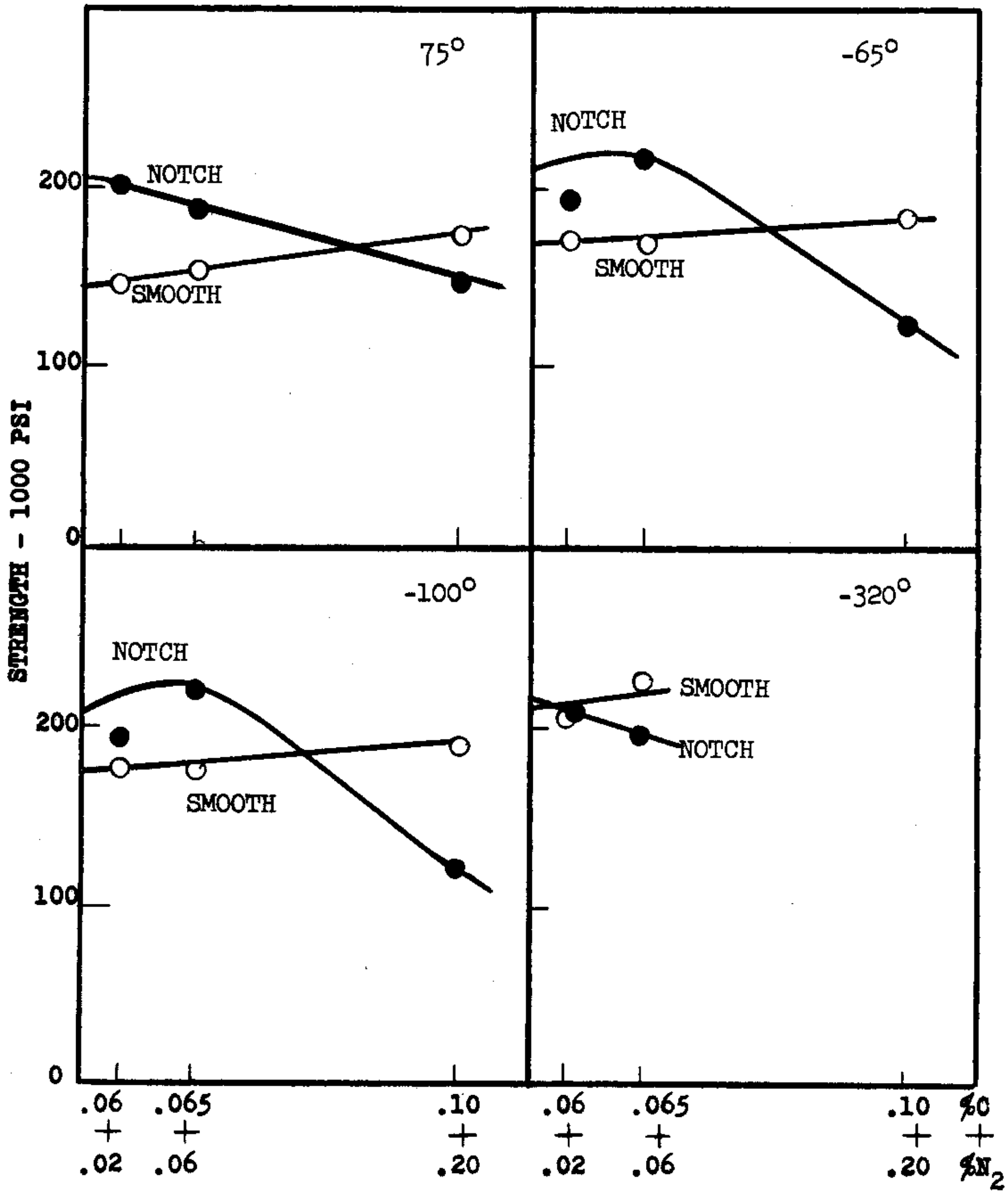


FIG. 54 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 3 (CF. FIG. 36)

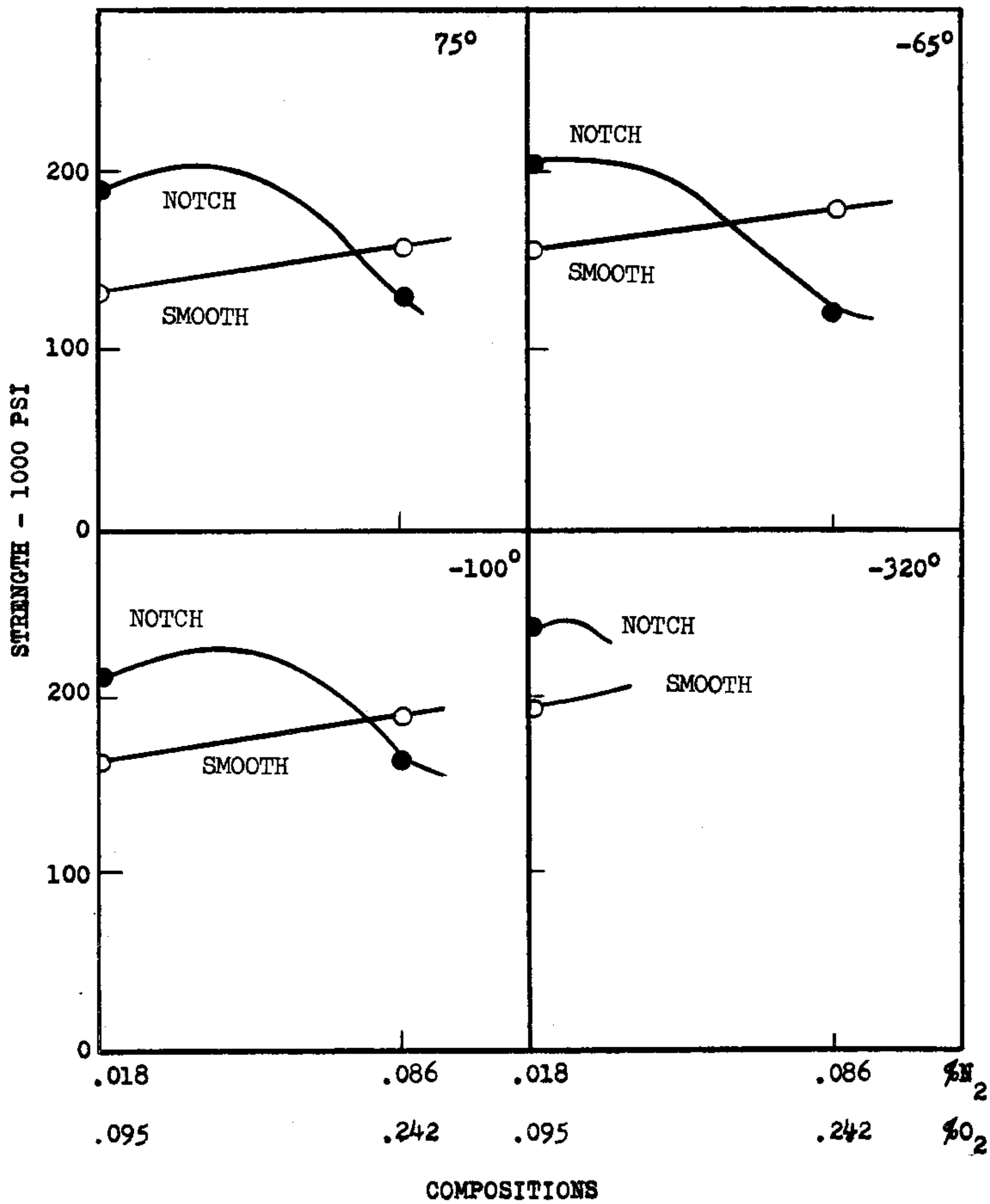


FIG. 55 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 4 (CF. FIG. 36)

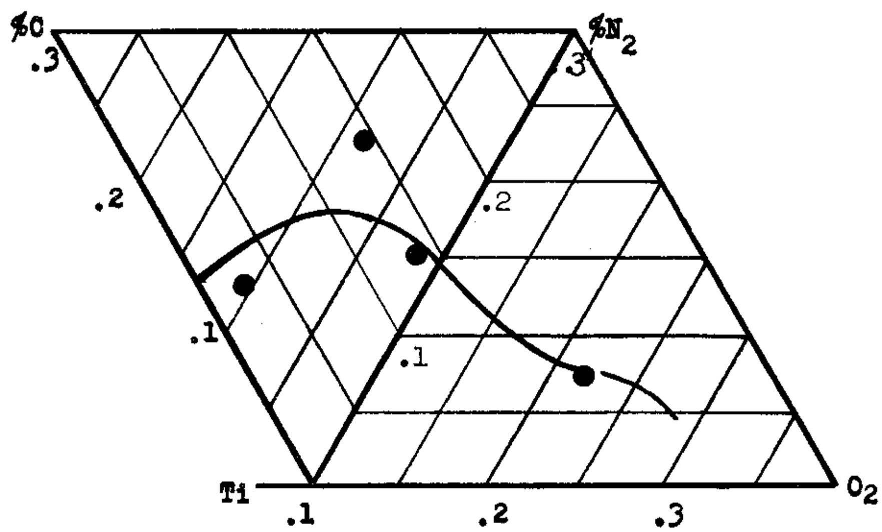


FIG. 56 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT 75°F. 6Al - Ti ALLOY.

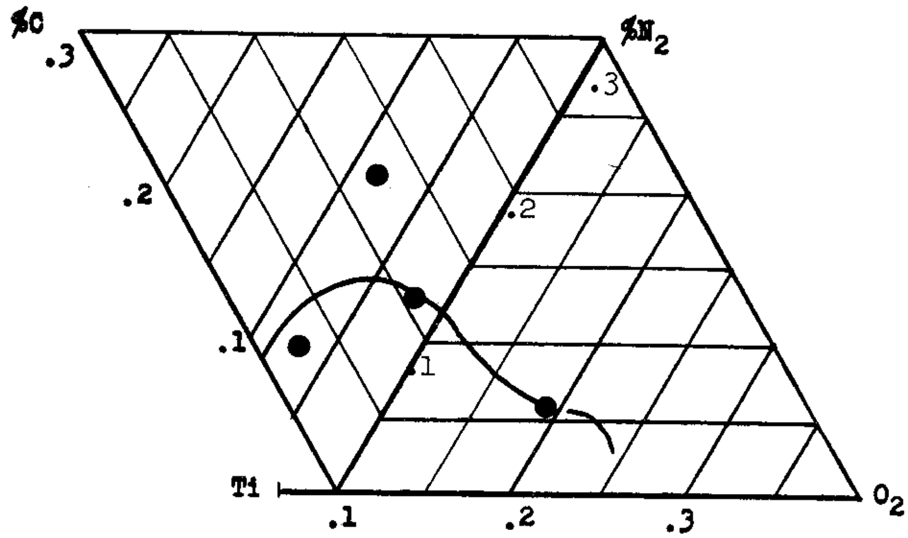


FIG. 57 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT -65°. 6Al - Ti ALLOY.

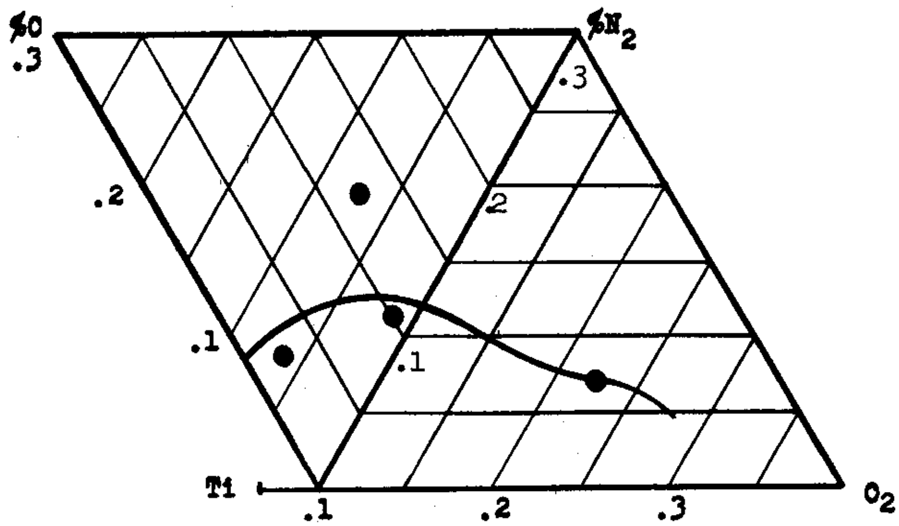


FIG. 58 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT -100°F. 6Al - Ti ALLOY.

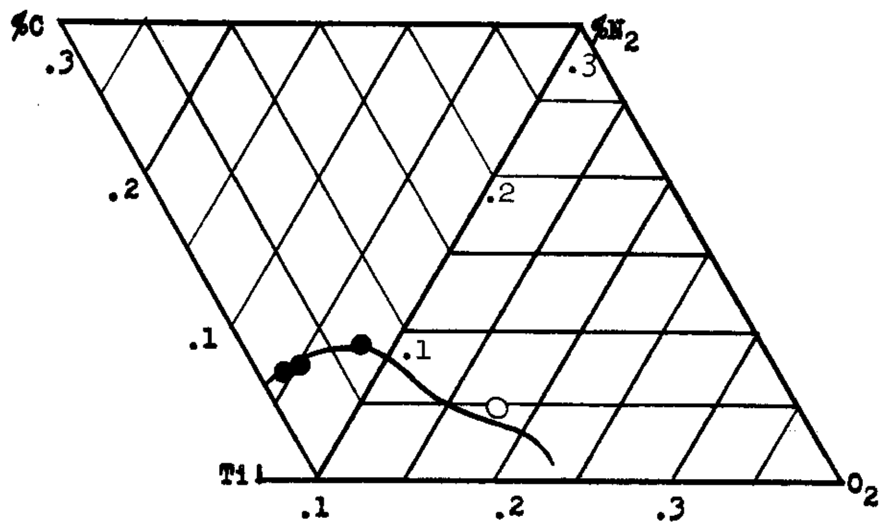


FIG. 59 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT -320°F. 6Al - Ti ALLOY.

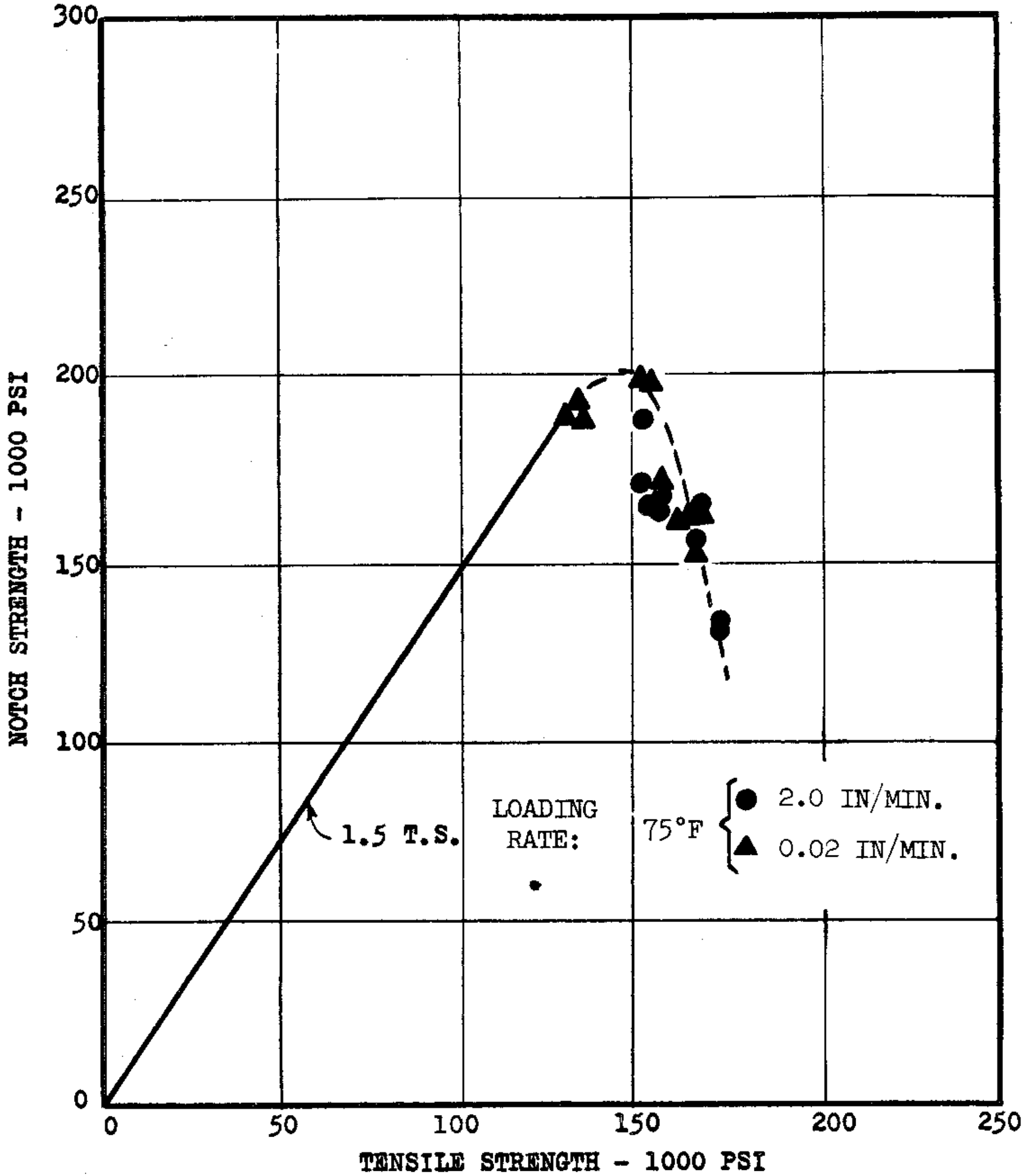


FIG. 60 THE NOTCH STRENGTH VS. THE TENSILE STRENGTH AT 75°F.
ALLOY: 6Al - Ti.

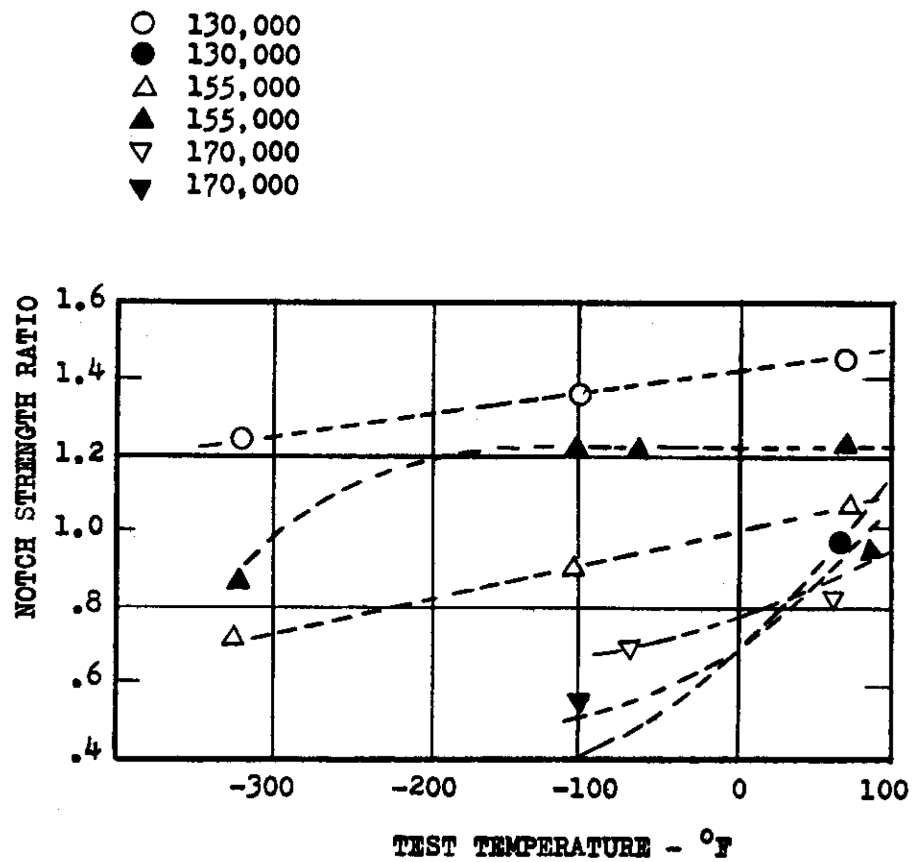


FIG. 61 **THE NOTCH STRENGTH RATIO VS. TEST TEMPERATURE VS. TENSILE STRENGTH AT 75°F. ALLOYS: 6Al-Ti.**

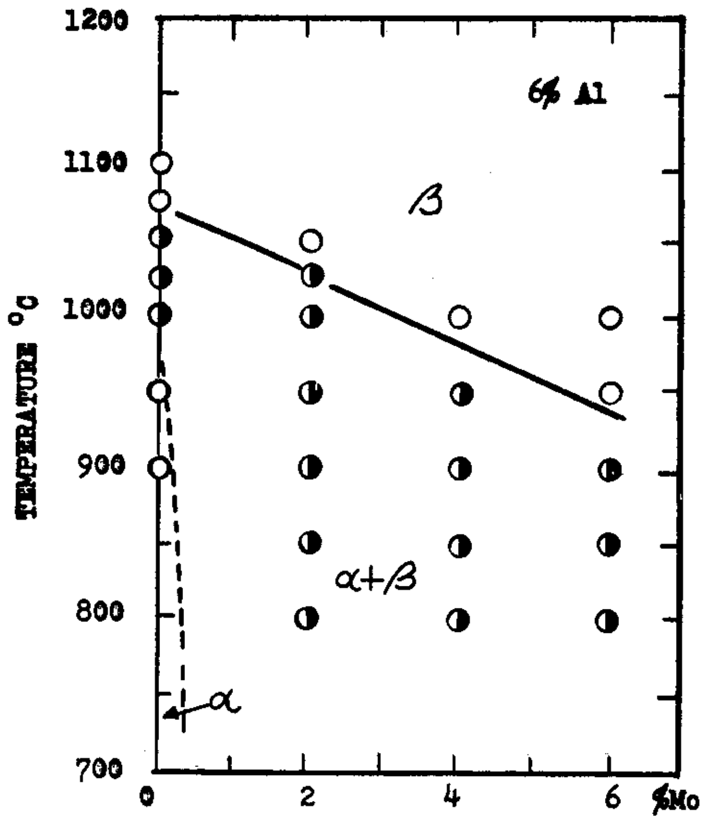


FIG. 62 VERTICAL SECTION IN THE Ti - Al - Mo SYSTEM AT 6% ALUMINUM. (5)

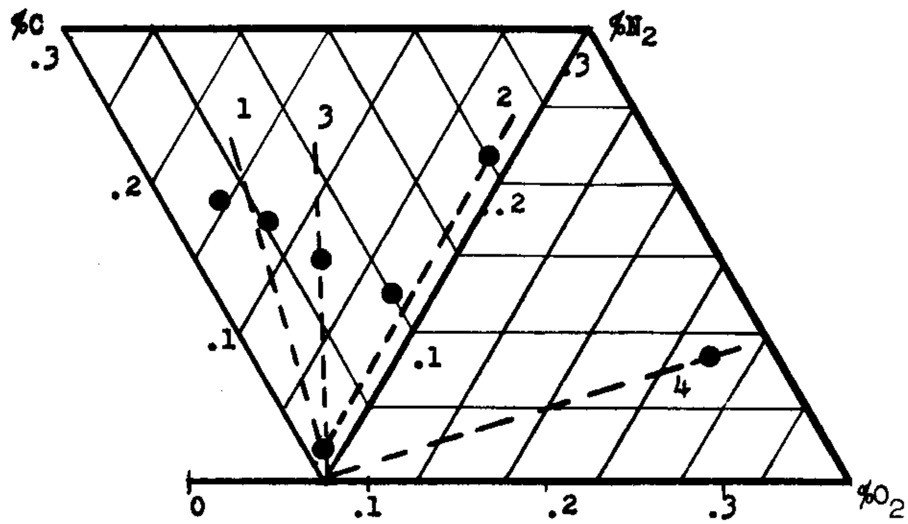
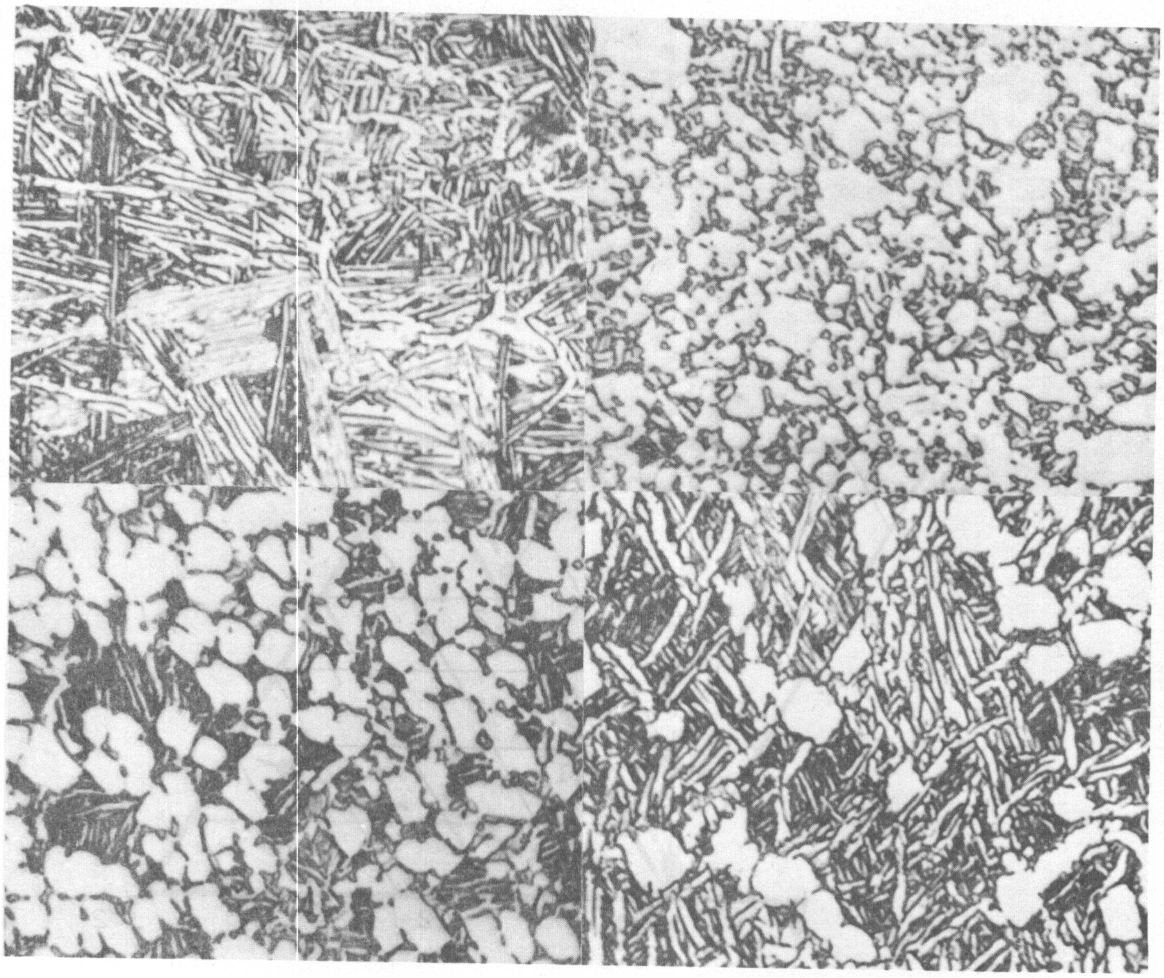


FIG. 63 COMPOSTITIONS OF THE 7Al - 3Mo - Ti INGOTS STUDIED AND SECTIONS INVESTIGATED.



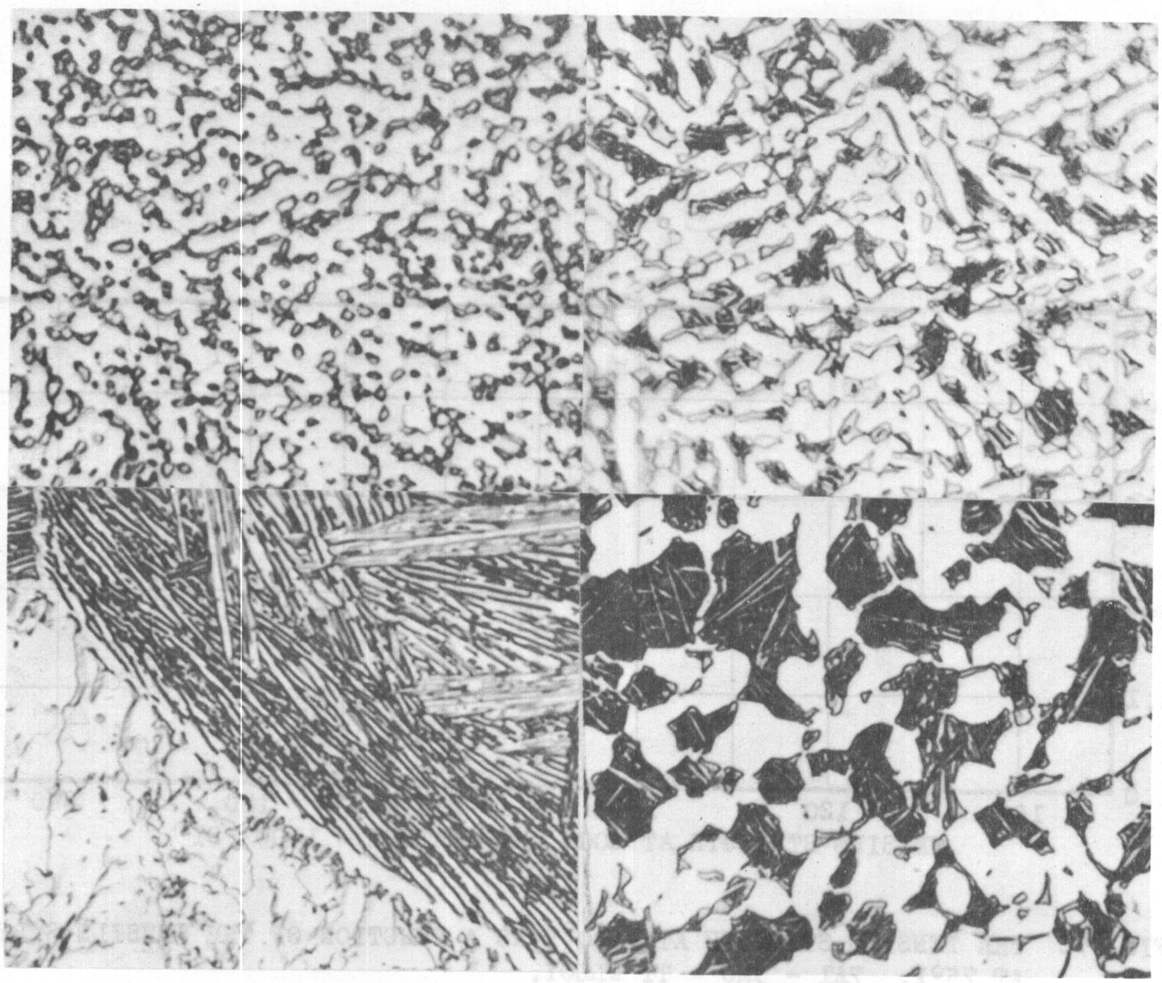
64 65 66 67

FIGS. 64 TO 67 MICROSTRUCTURES OF THE INDICATED 7Al - 3Mo - Ti ALLOYS. ELECTROPOLISHED. GLYCERINE ETCH x500.

FIG. 64 AS ANNEALED
FIG. 65 + 0.105 N_2 - ANNEALED
FIG. 66 + 0.205 N_2 - ANNEALED
FIG. 67 + 0.12 C + 0.056 N_2 - ANNEALED

68

69



70

71

FIGS. 68 TO 71 MICROSTRUCTURES OF THE INDICATED 7Al - 3Mo - Ti ALLOYS. ELECTROPOLISHED. GLYCERINE ETCH x500.

FIG. 68	+ 0.155 C + 0.0372 N_2 - ANNEALED
FIG. 69	+ 0.087 N + 0.26 O_2 - ANNEALED
FIG. 70	+ 0.08 C + 0.066 N_2 - ANNEALED
FIG. 71	+ 0.16 C

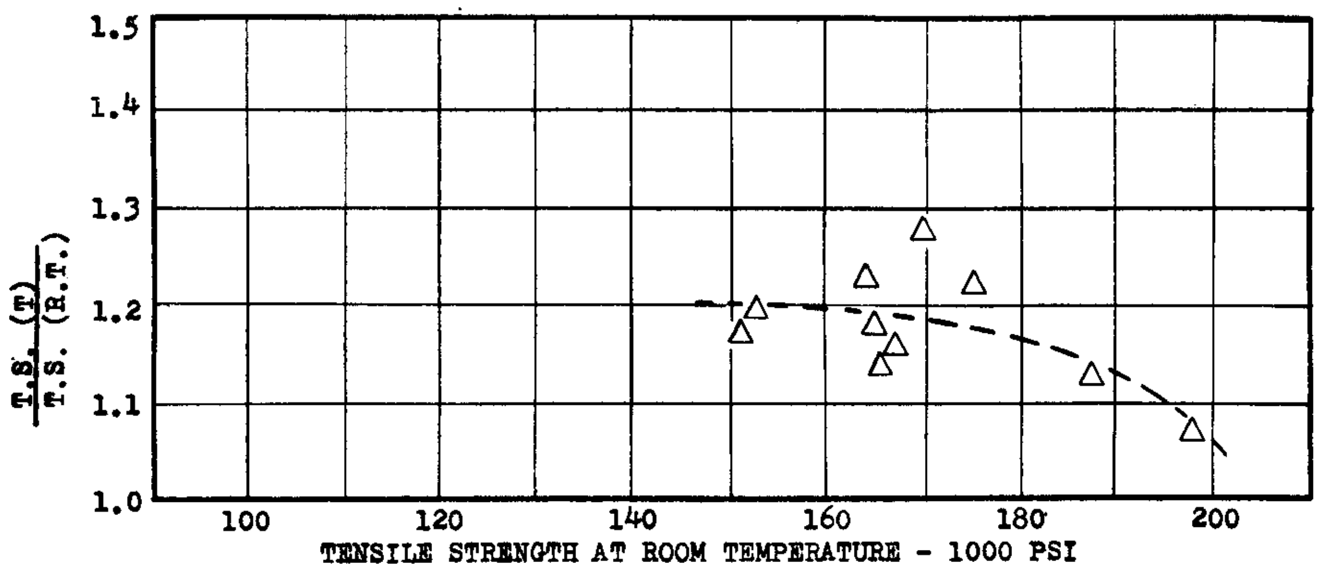


FIG. 72 THE TENSILE STRENGTH AT -100°F AS A FUNCTION OF THE TENSILE STRENGTH AT 75°F. 7Al - 3Mo - Ti ALLOY.

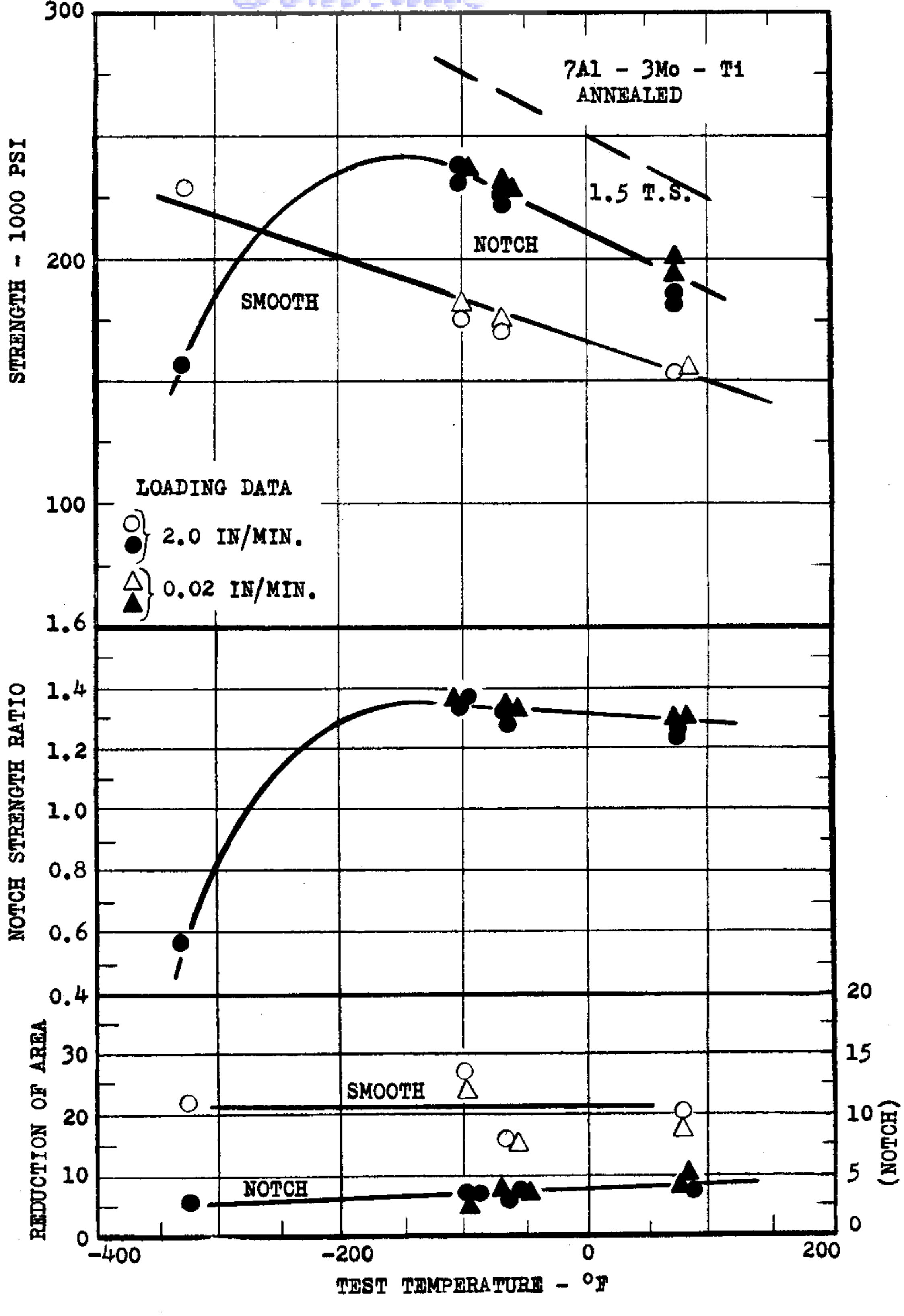


FIG. 73 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 7Al - 3Mo - Ti - AS ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≅ 0.002 IN.

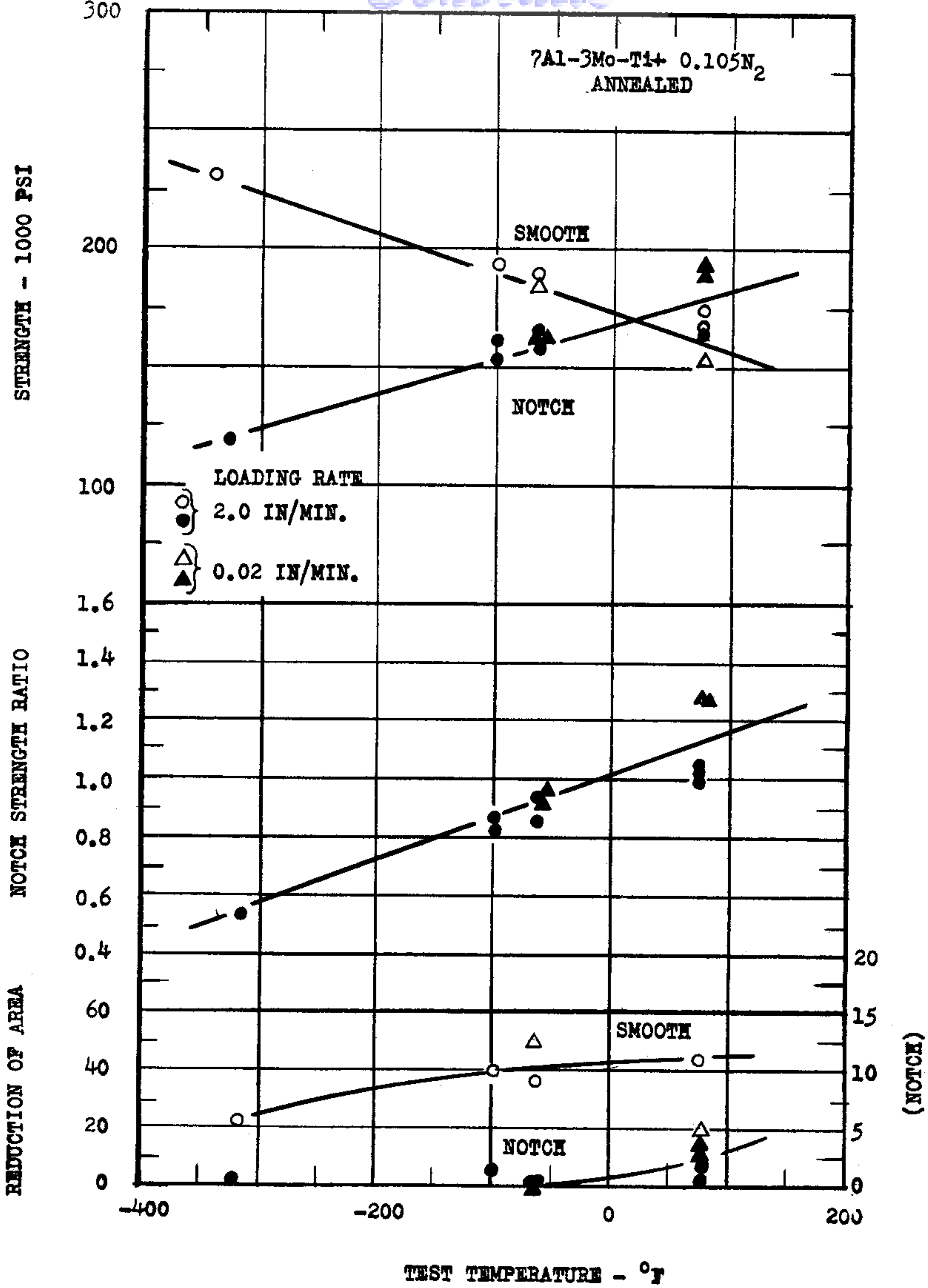


FIG. 74 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 7Al - 3Mo - Ti + $0.105N_2$ - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≈ 0.002 IN.

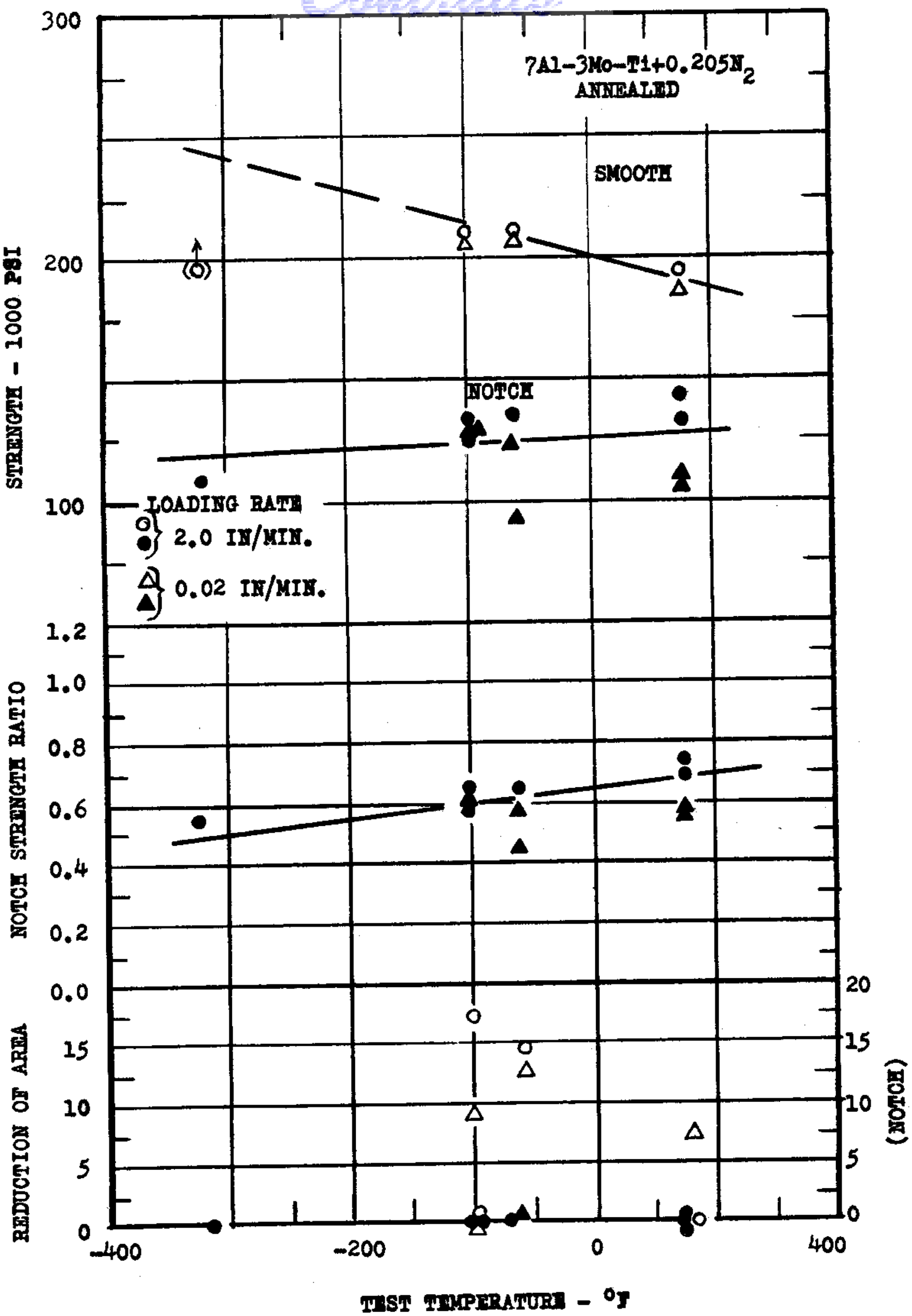


FIG. 75 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 7Al - 3Mo - Ti + 0.205N_2.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

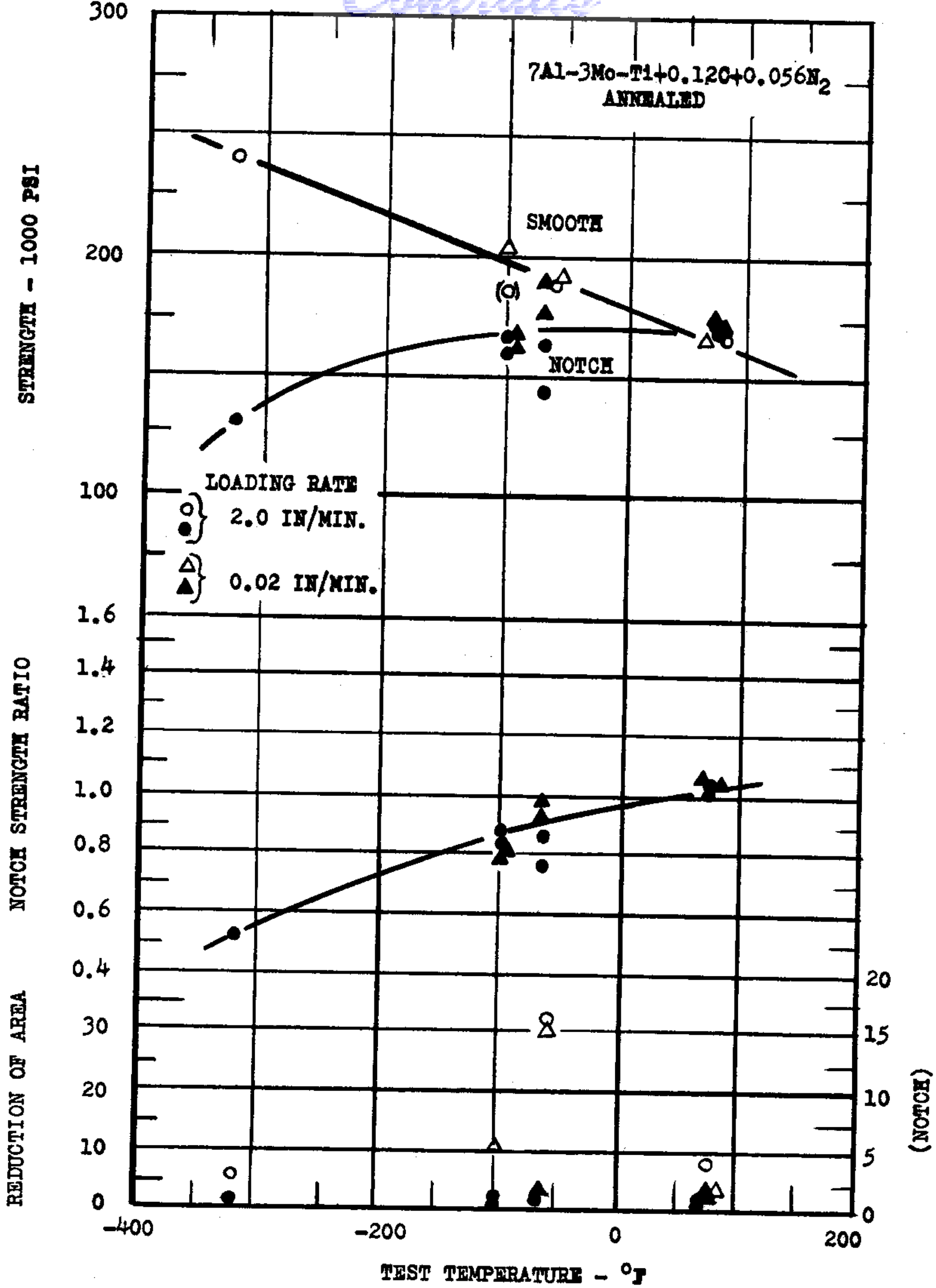


FIG. 76 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 7Al - 3Mo - Ti + 0.12C + $0.056N_2$ - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r = 0.002 IN.

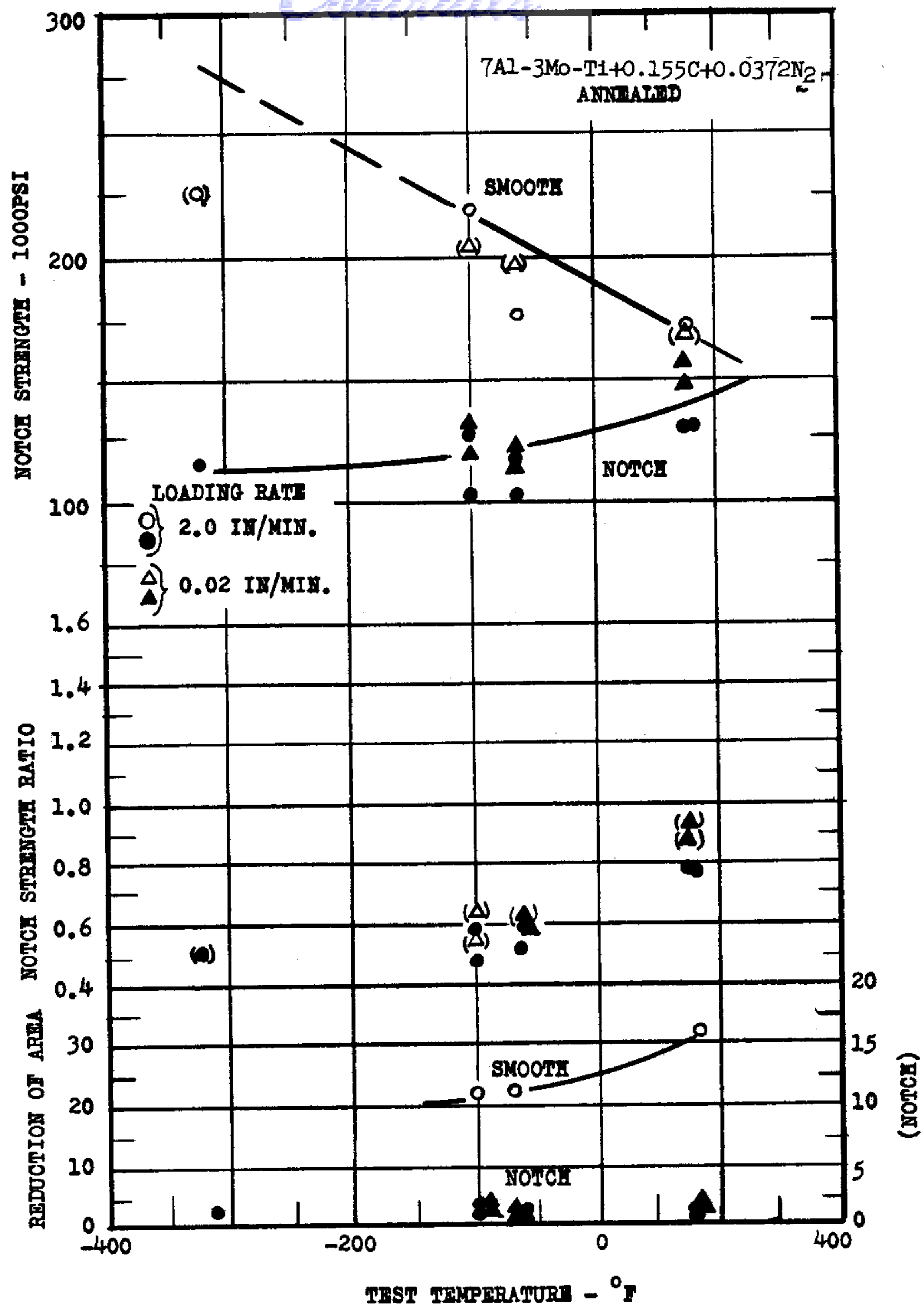


FIG. 77 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOYS AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 7Al - 3Mo - Ti + 0.155C + 0.0372 N_2 - ANNEALED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r = 0.002 IN.

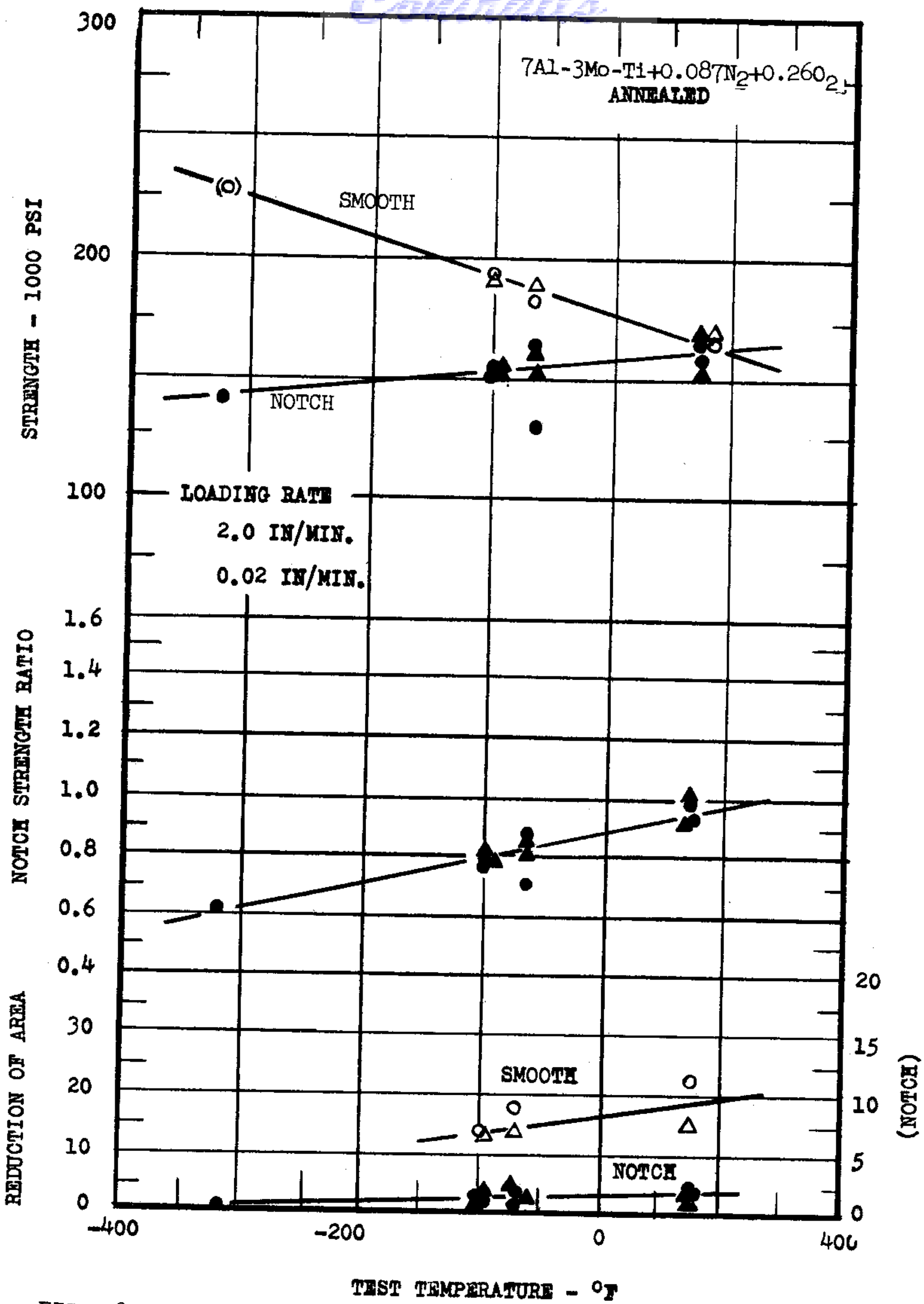


FIG. 78 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 7Al-3Mo-Ti+0.087N_2+0.26O_2 ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

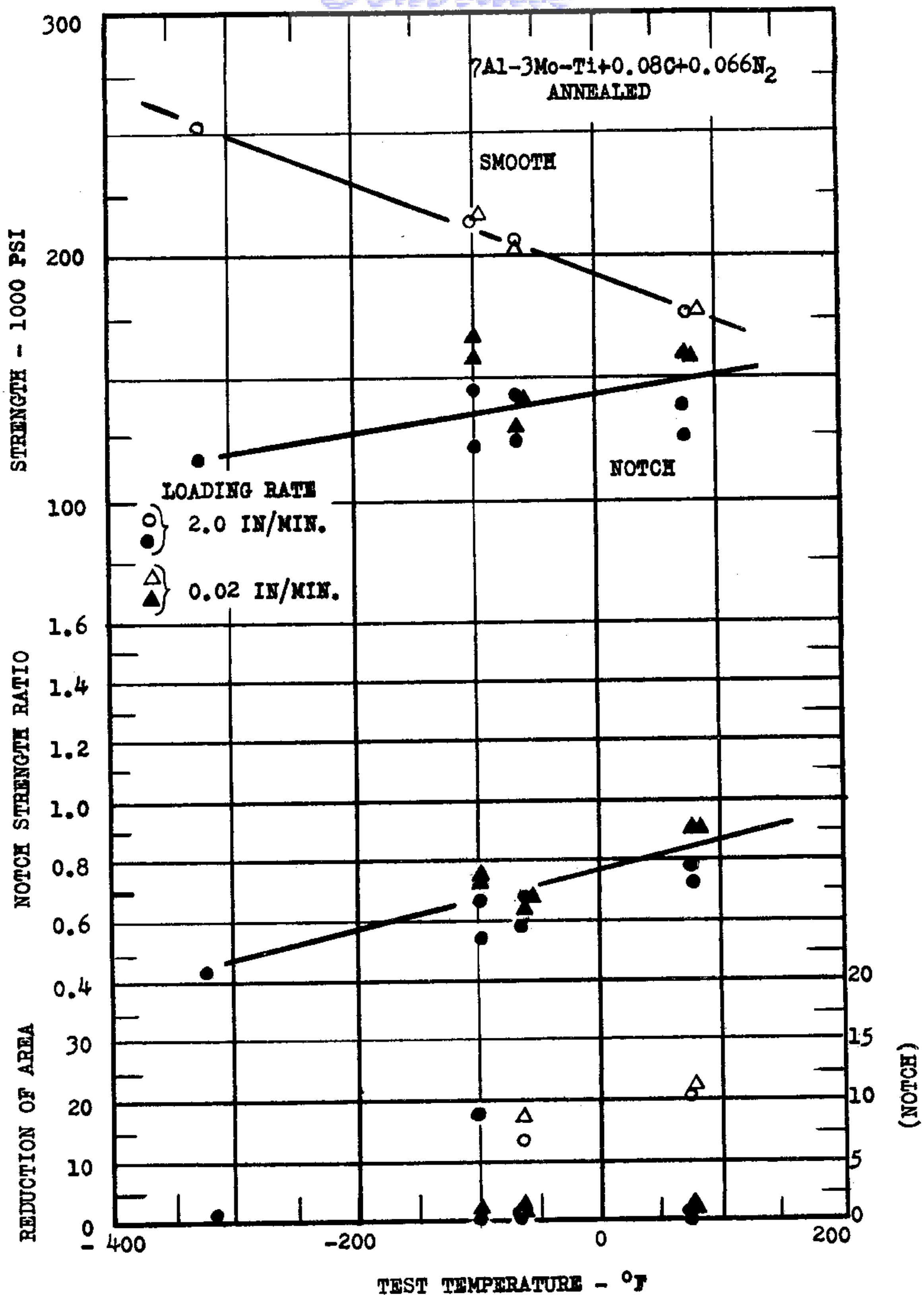


FIG. 79 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 7Al - 3Mo - Ti + 0.08C + $0.066N_2$ - ANNEALED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

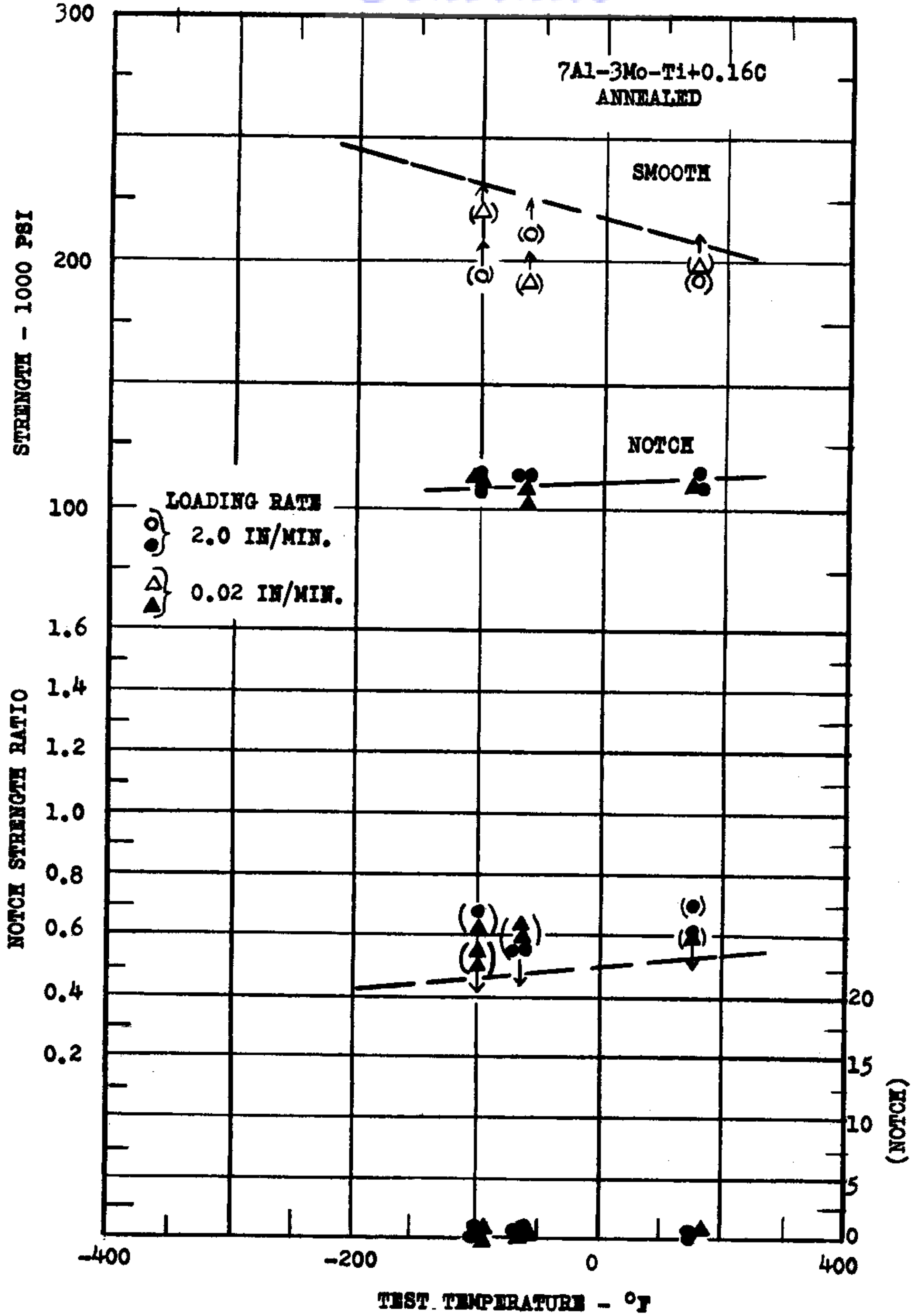


FIG. 80 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 7Al - 3Mo - Ti + 0.16C ANNEALED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

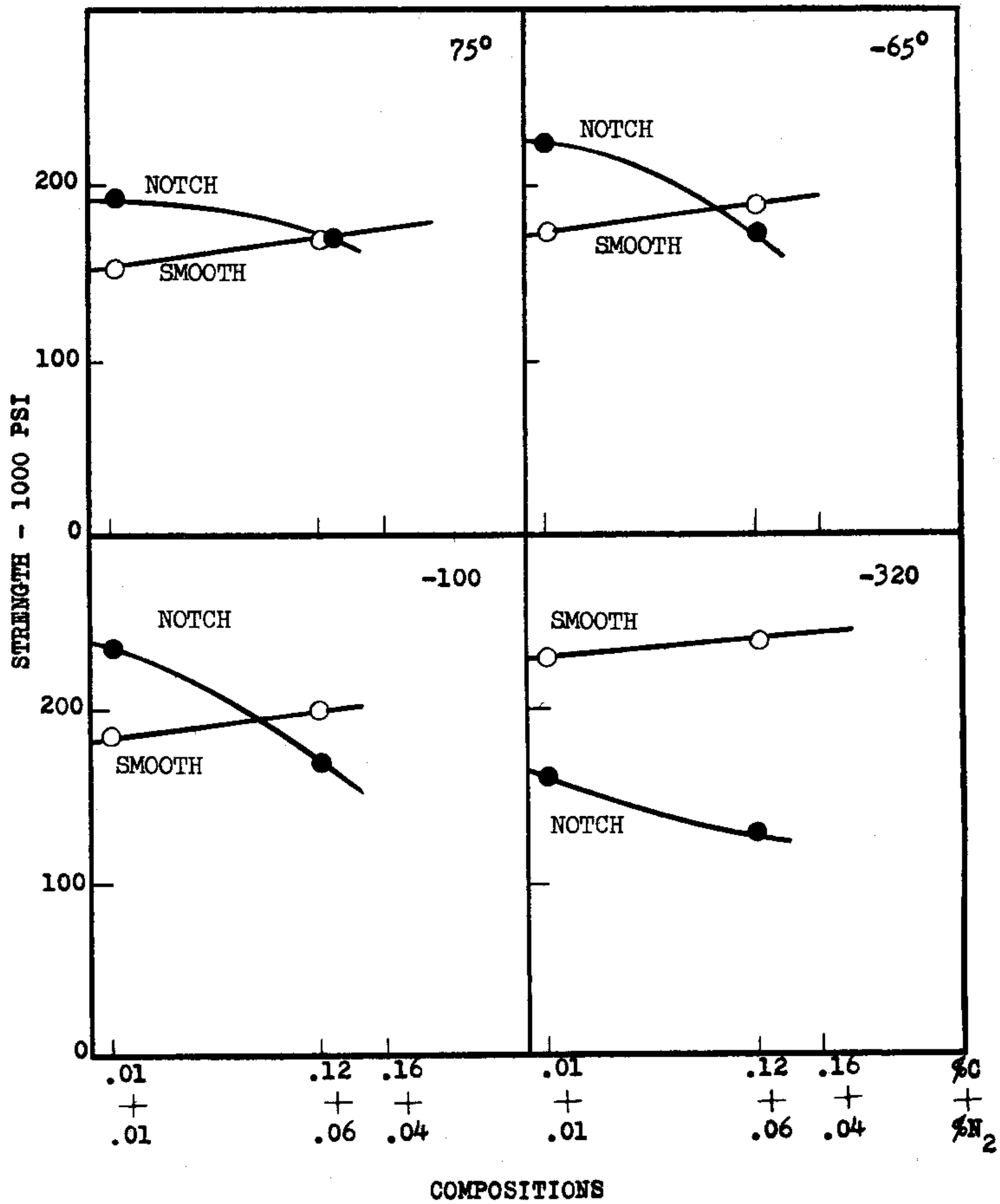


FIG. 81 THE VARIATION OF THE TENSILE AND NOTCH TENSILE STRENGTHS ALONG THE TERNARY SECTION NO. 1 (CF. FIG. 63)

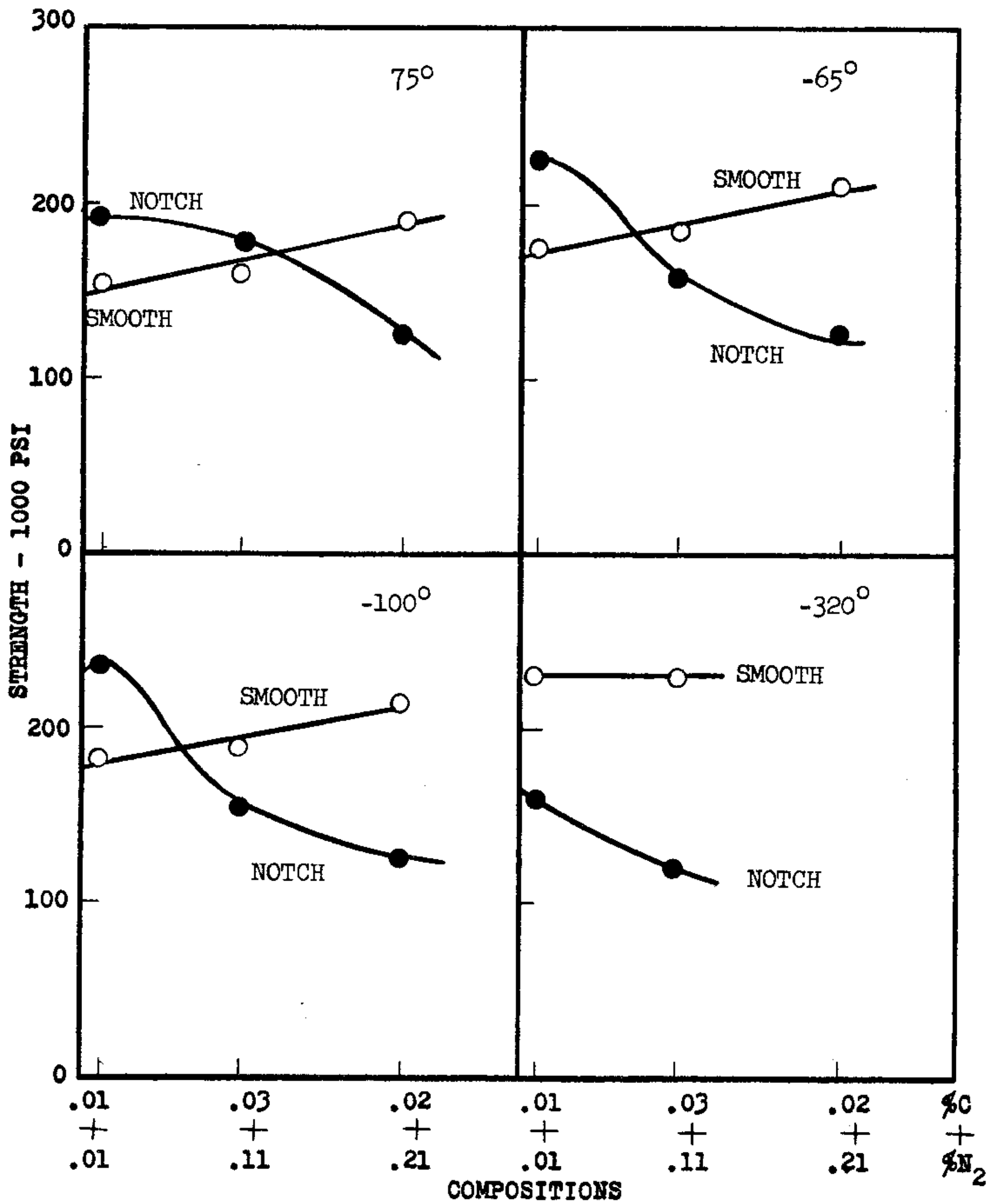


FIG. 82 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG THE TERNARY SECTION NO. 2 (CF. FIG. 63)

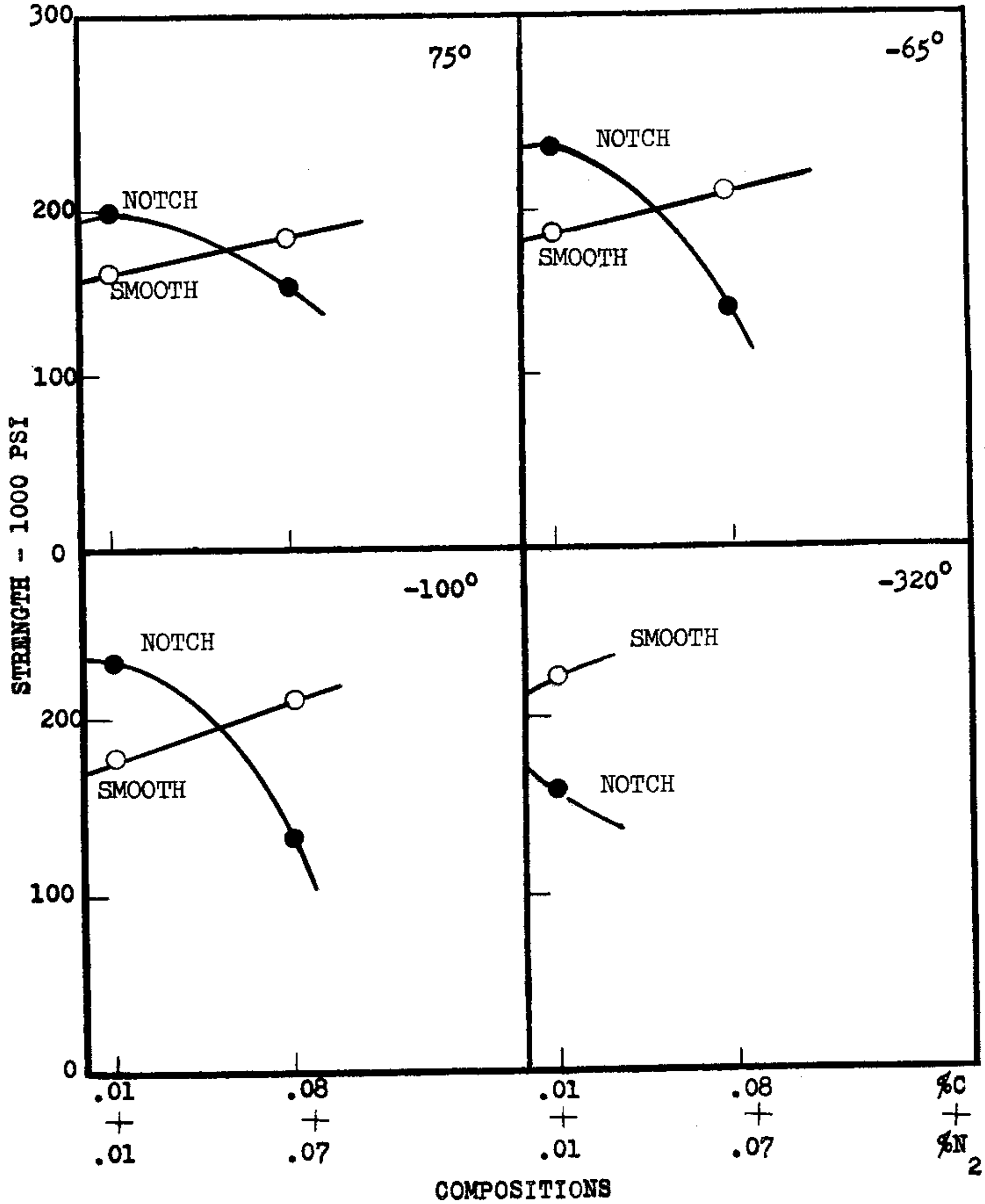


FIG. 83 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 3 (CF. FIG. 63)

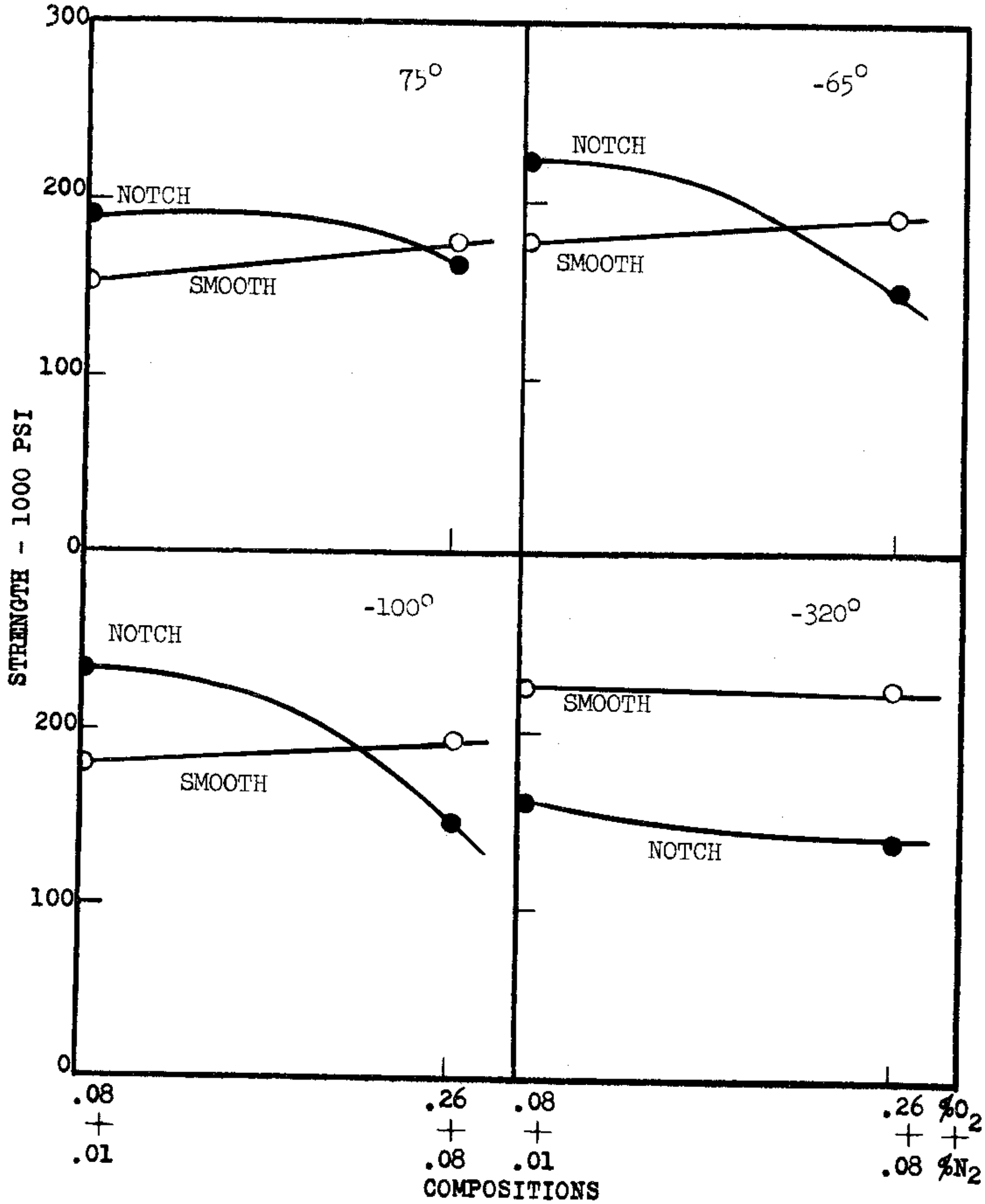


FIG. 84 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG THE TERNARY SECTION NO. 4 (CF. FIG. 63)

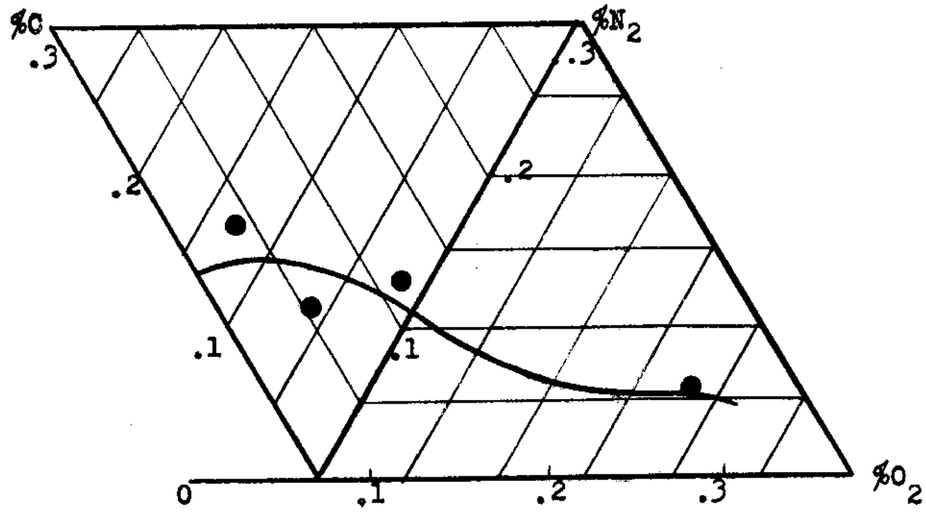


FIG. 85 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT 750F. 7Al - 3Mo - Ti ALLOY.

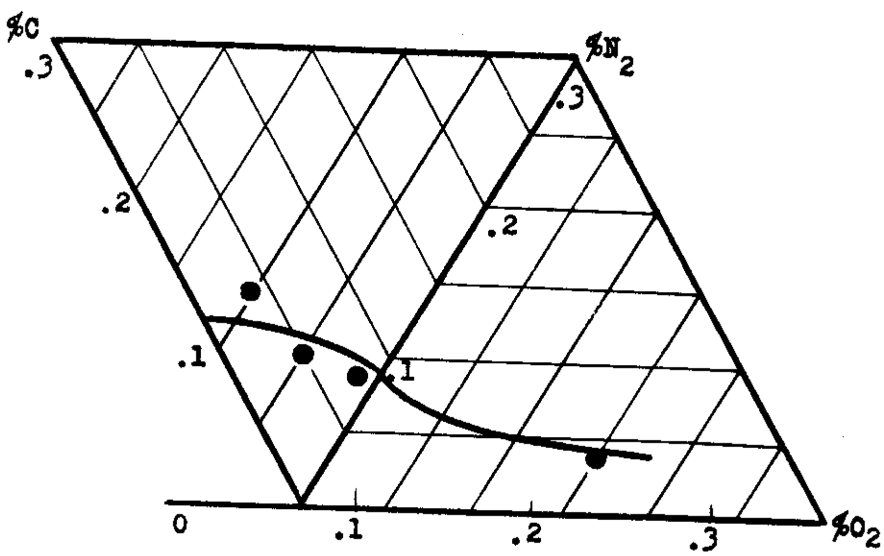


FIG. 86 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT -65°F. 7Al - 3Mo - Ti ALLOY.

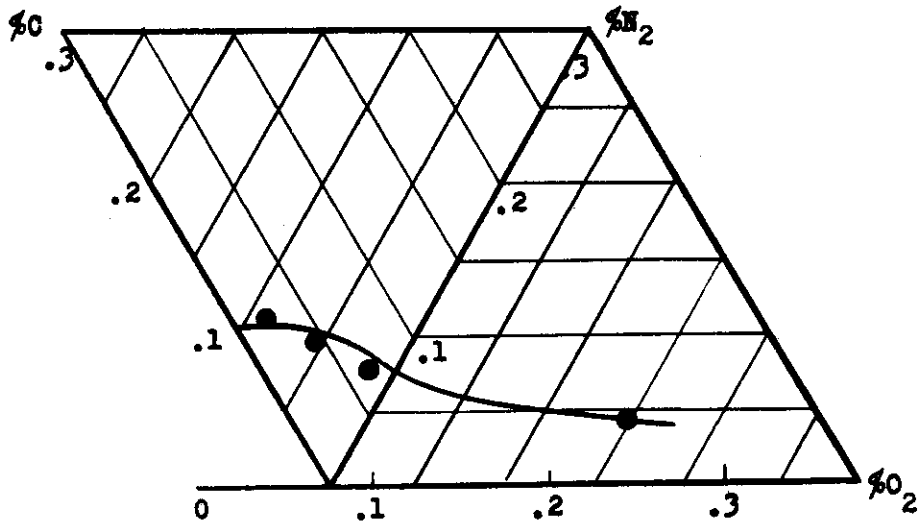


FIG. 87 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT -100°F. 7Al - 3Mo - Ti ALLOY.

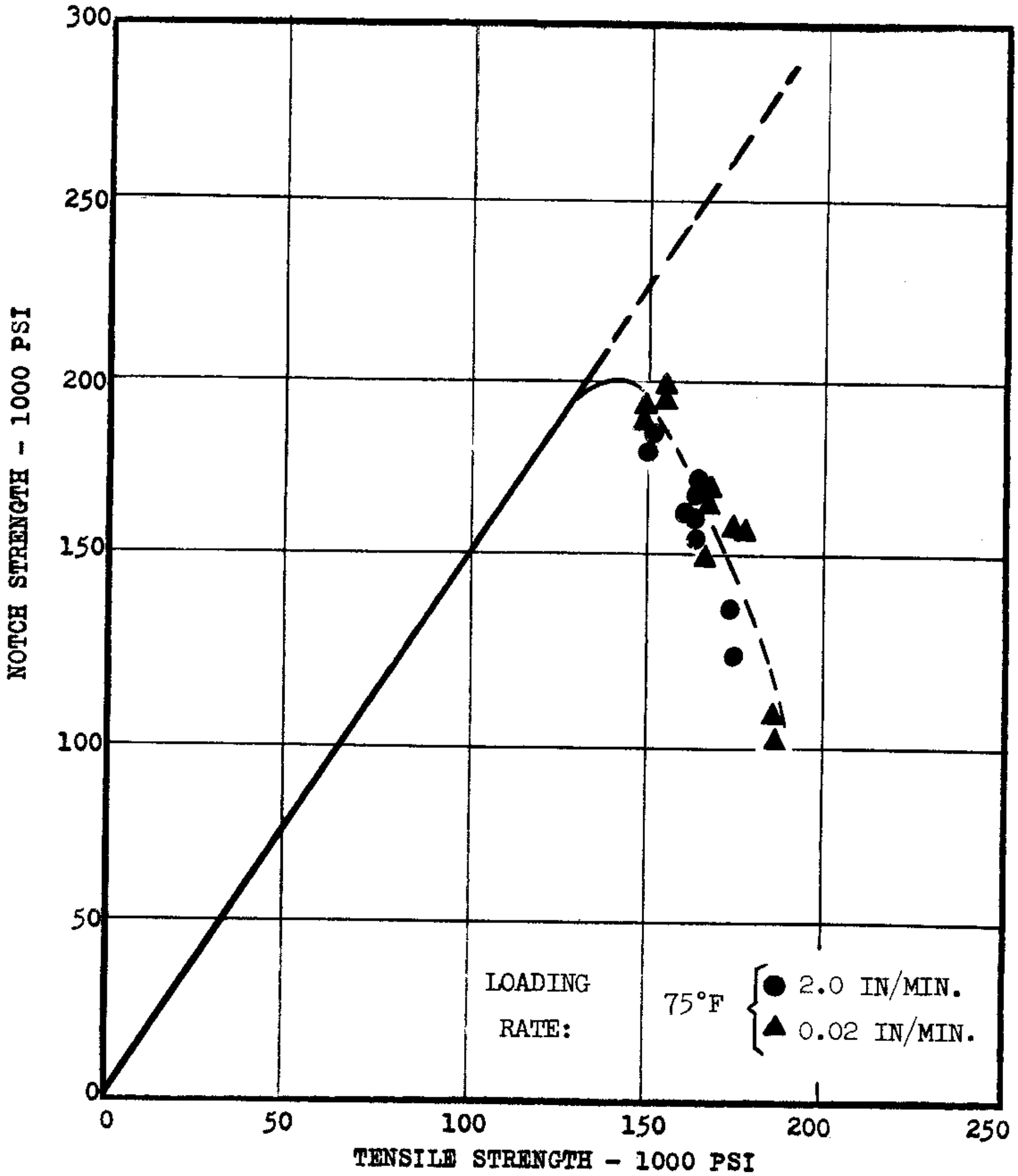


FIG. 88 THE NOTCH STRENGTH VS. THE TENSILE STRENGTH AT 75°F. ALLOY: 7Al - 3Mo -- Ti.

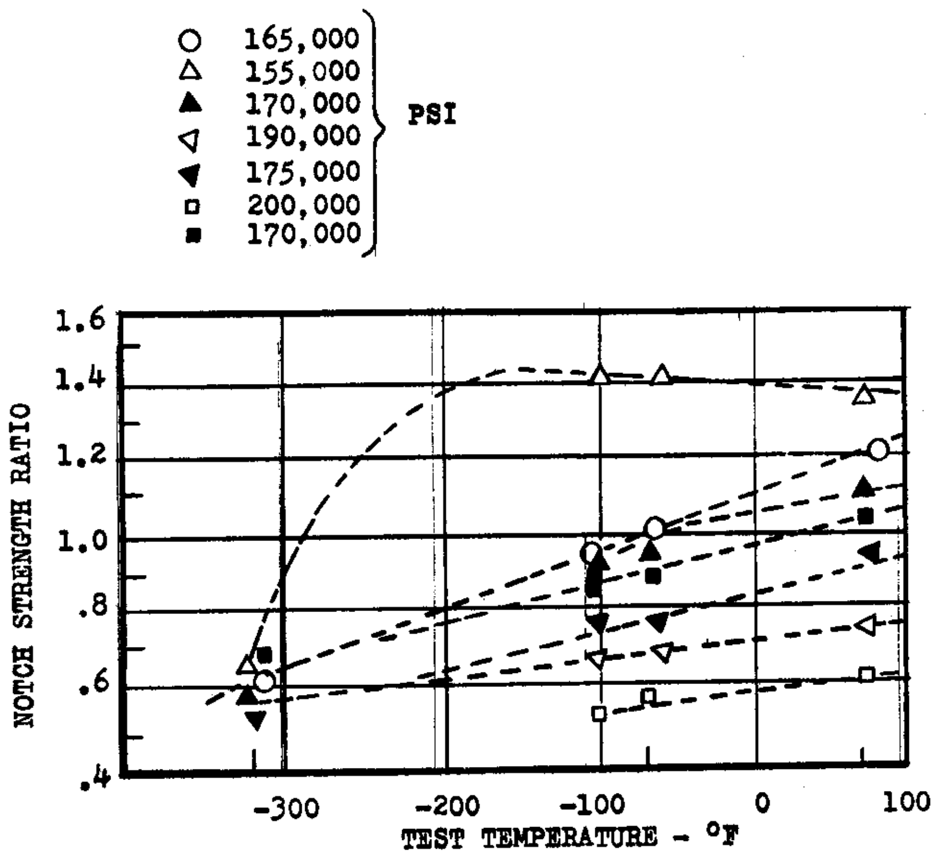


FIG. 89 THE NOTCH STRENGTH RATIO VS. TEST TEMPERATURE VS. TENSILE STRENGTH AT 75°F. ALLOY: 7Al - 3 Mo - Ti.

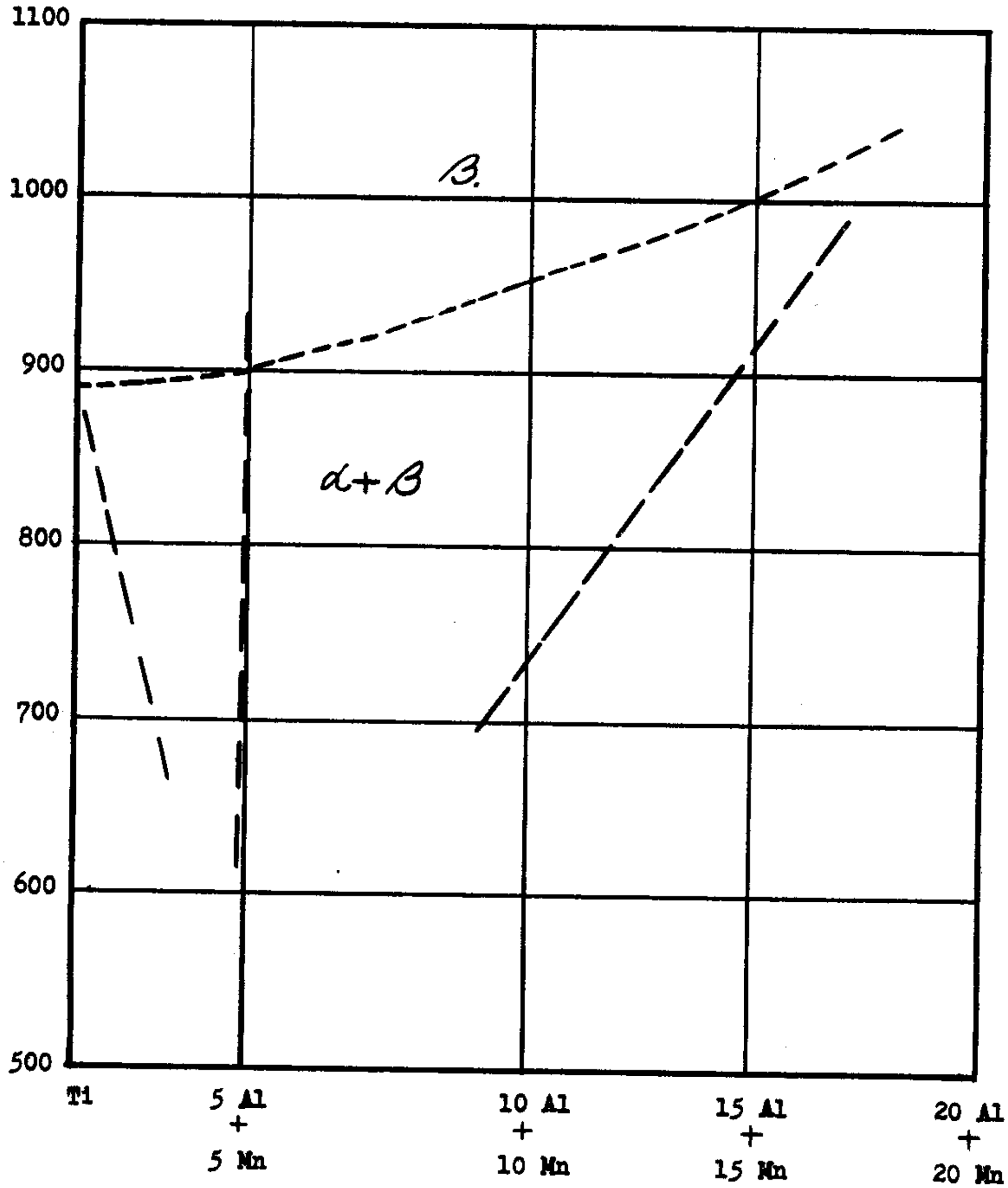


FIG. 90 **PHASE EQUILIBRIA IN THE SYSTEM Ti - Al - Mn.**(5)

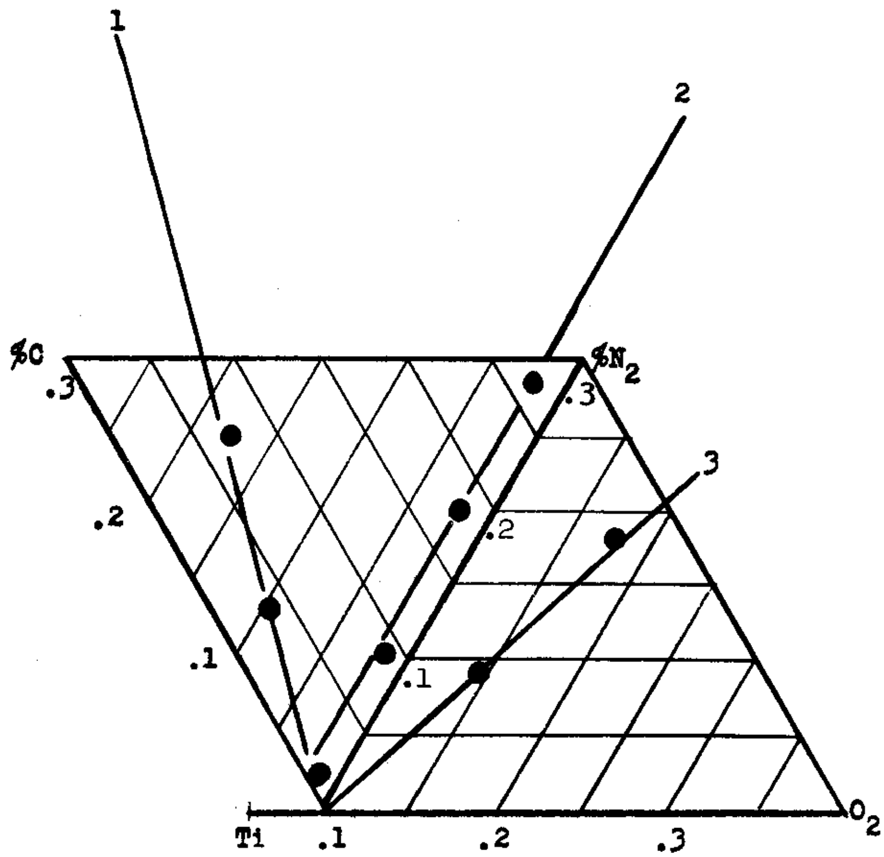
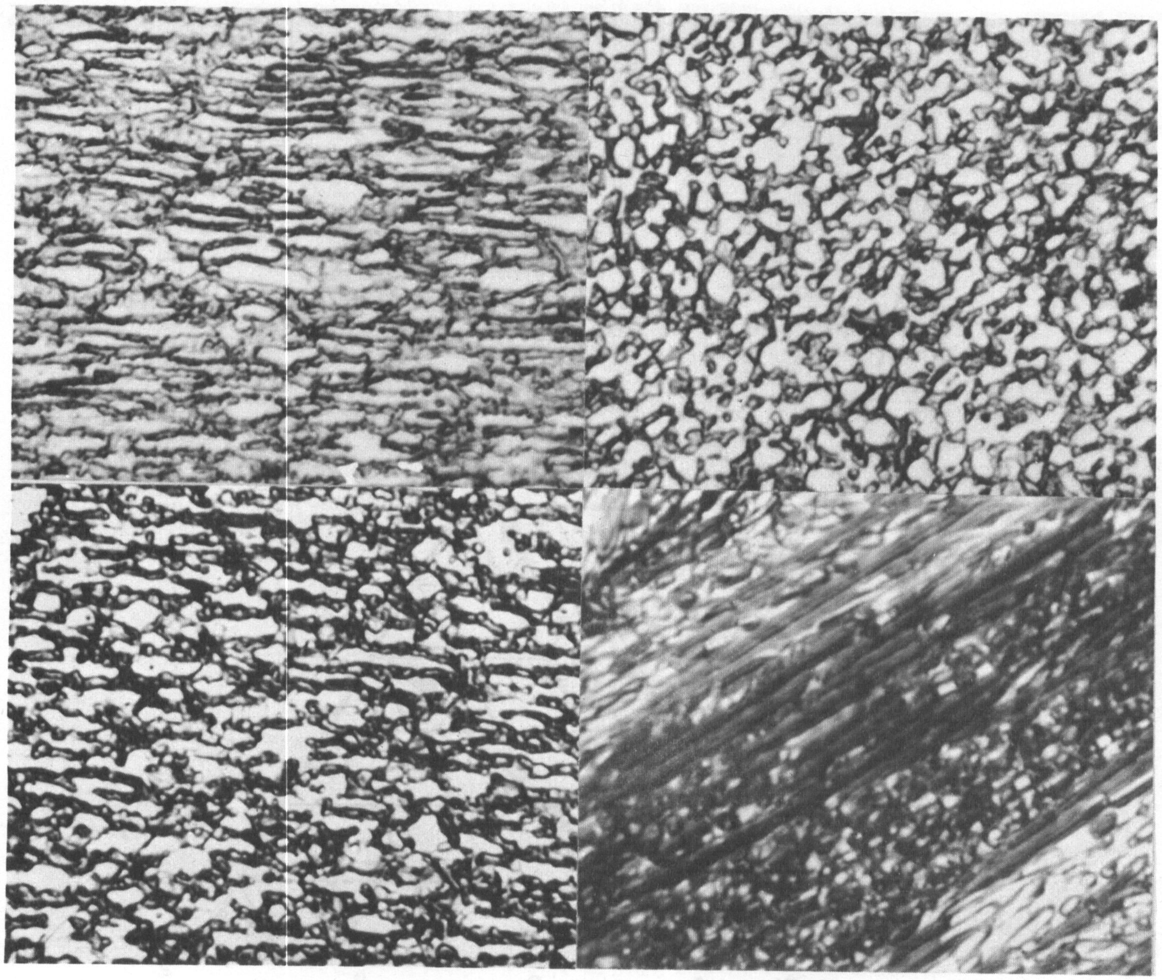


FIG. 91 COMPOSITIONS OF THE 4Al - 4Mn - Ti INGOTS STUDIED AND TERNARY SECTIONS INVESTIGATED.

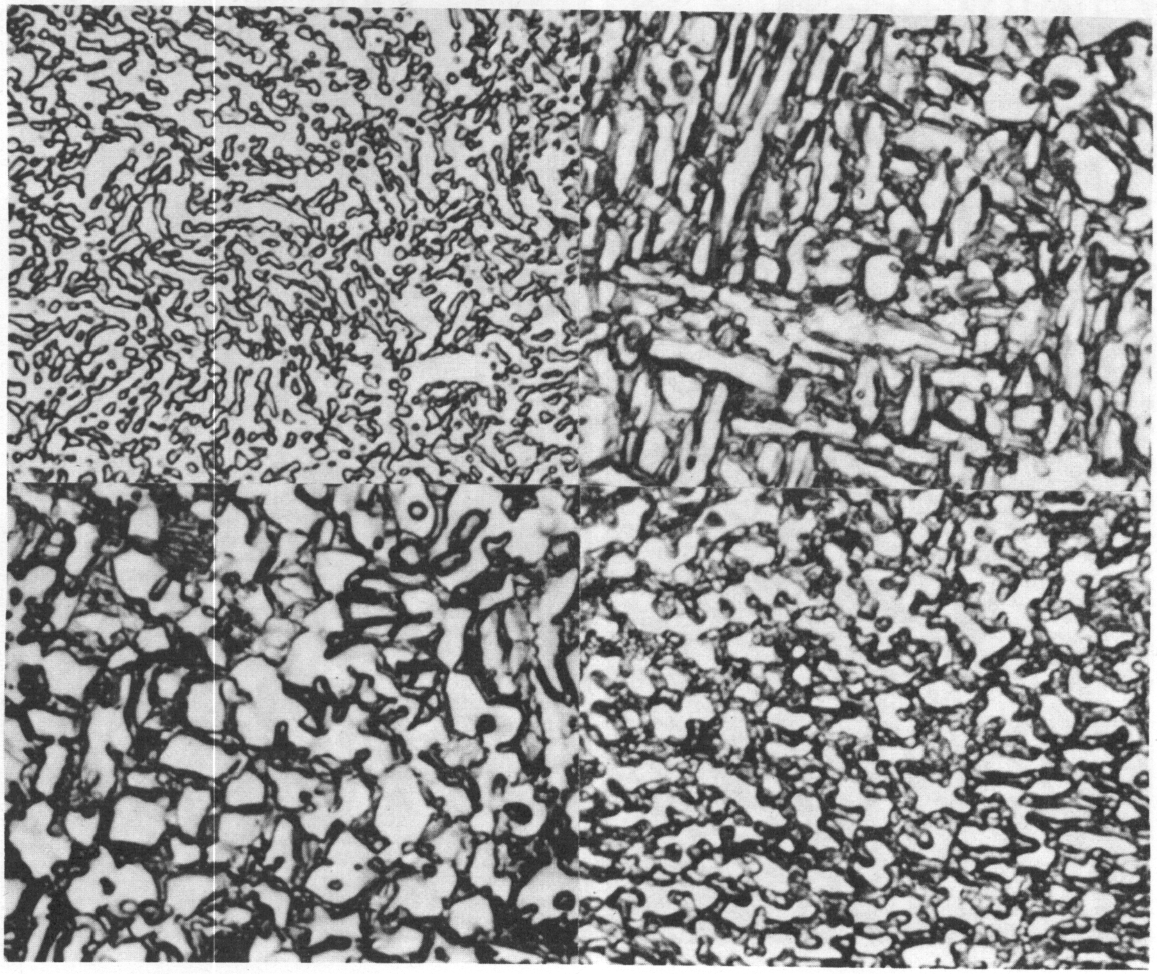
92  93

94 95

FIGS. 92 TO 95 MICROSTRUCTURES OF THE INDICATED 4Al - 4Mn - Ti ALLOYS ELECTROPOLISHED. KELLER'S ETCH.

FIG. 92 AS ROLLED. x 500
FIG. 93 AS ANNEALED. INGOT 1. x 500
FIG. 94 AS ANNEALED. INGOT 2. x 500
FIG. 95 AS ANNEALED. INGOT 2. FLAT BAR. x 1100

96 97

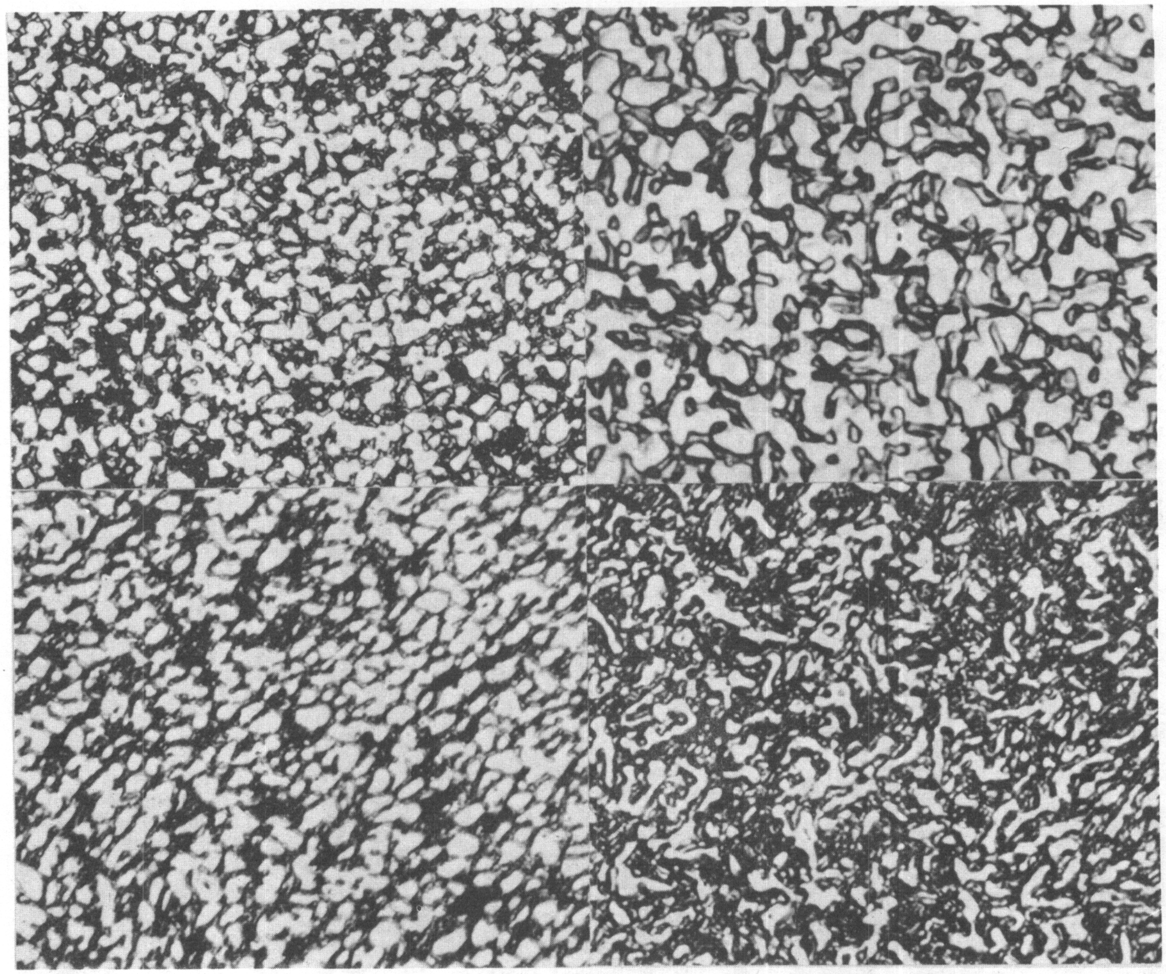


98 99

FIGS. 96 TO 99 MICROSTRUCTURES OF THE INDICATED 4Al - 4Mn - Ti ALLOYS ELECTROPOLISHED. KELLER'S ETCH.

FIG. 96 C - 130 AM - x 800
FIG. 97 + 0.09 % C - ANNEALED x 800
FIG. 98 + 0.17 % C + 0.07% N_2 - ANNEALED x 800
FIG. 99 + 0.09 % N_2 - ANNEALED x 800

100 101



102 103

FIGS. 100 TO 103 MICROSTRUCTURES OF THE INDICATED 4Al - 4 Mn - Ti ALLOYS. ELECTROPOLISHED. KELLER'S ETCH.

FIG. 100 + 0.26% N_2 - ANNEALED - x 500
FIG. 101 + 0.09% N_2 + 0.15% O_2 - ANNEALED - x 800
FIG. 102 + 0.18% N_2 - ANNEALED - x 500
FIG. 103 + 0.18% C - ANNEALED - x 500

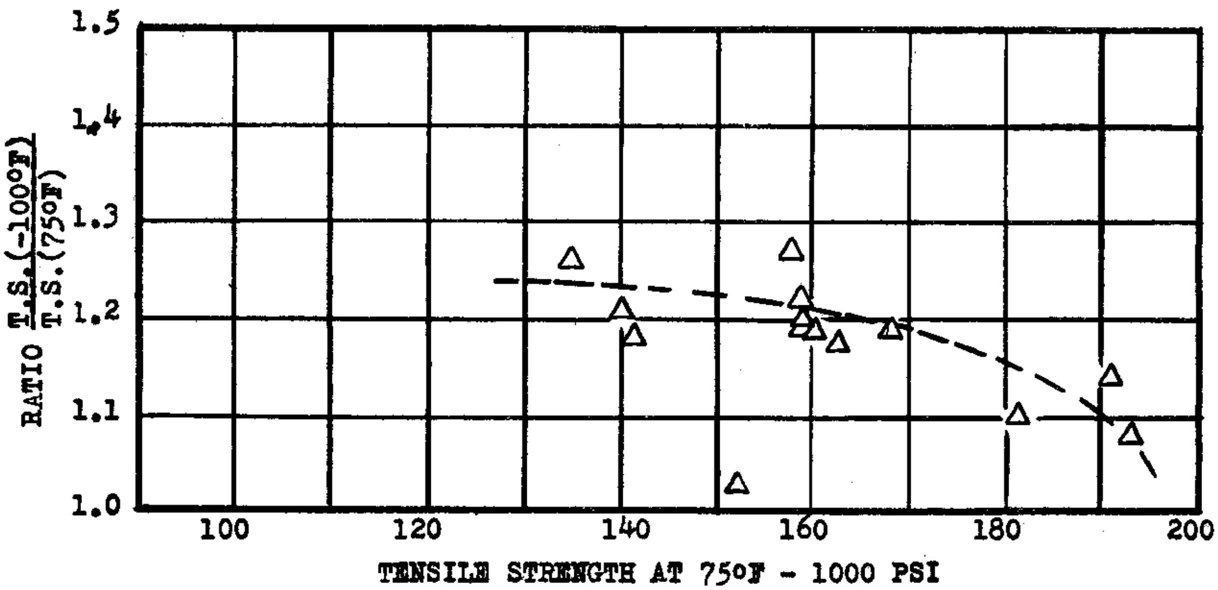


FIG. 104 THE TENSILE STRENGTH AT -100°F AS A FUNCTION OF THE TENSILE STRENGTH AT 75° F. 4% Al - 4% Mn - Ti ALLOY.

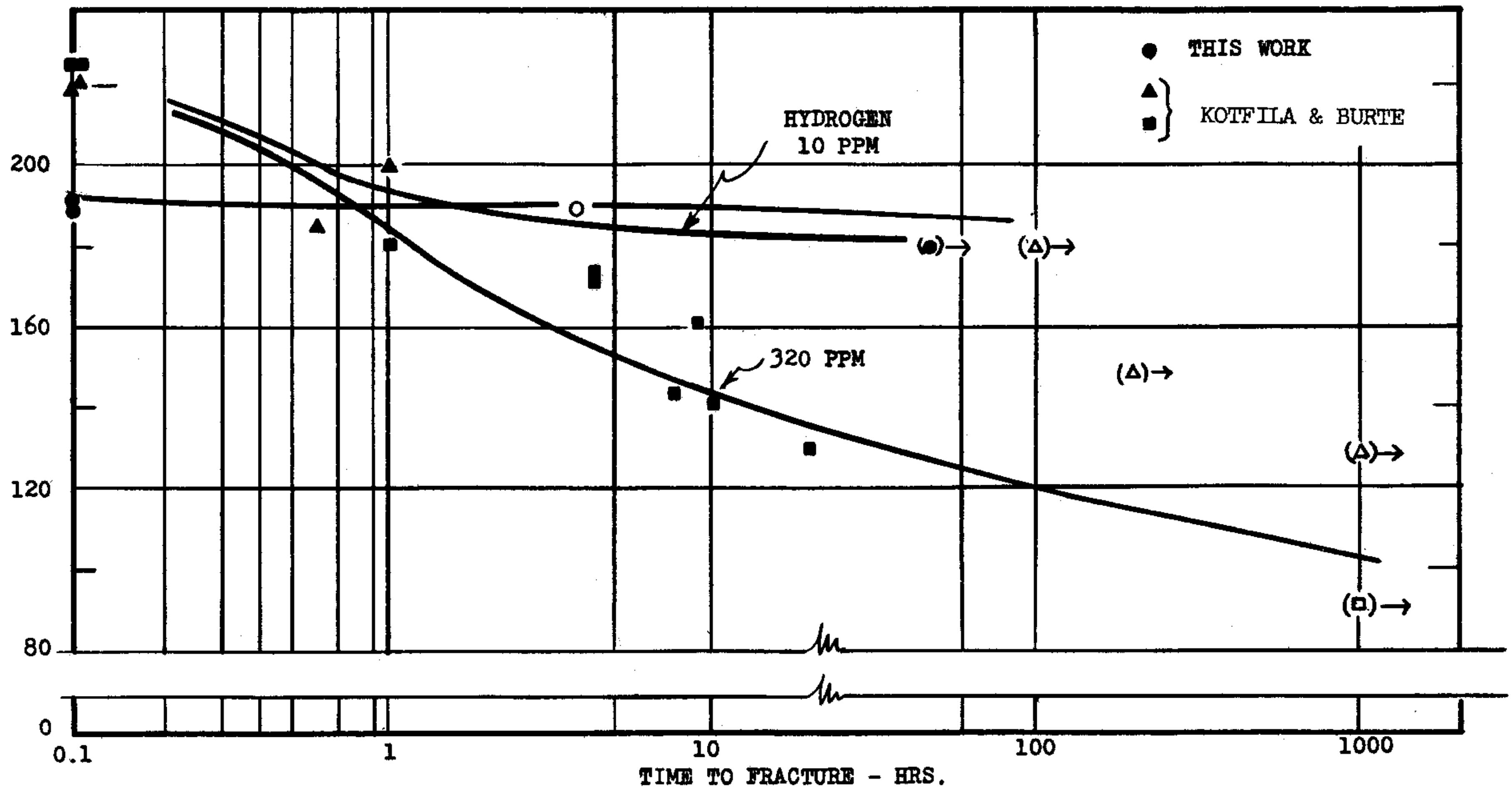


FIG. 105 THE NOTCH STRENGTH AS A FUNCTION OF THE TIME OF SUSTAINED LOAD TO FRACTURE AT 75°F. 4% Al - 4% Mn TITANIUM ALLOY.

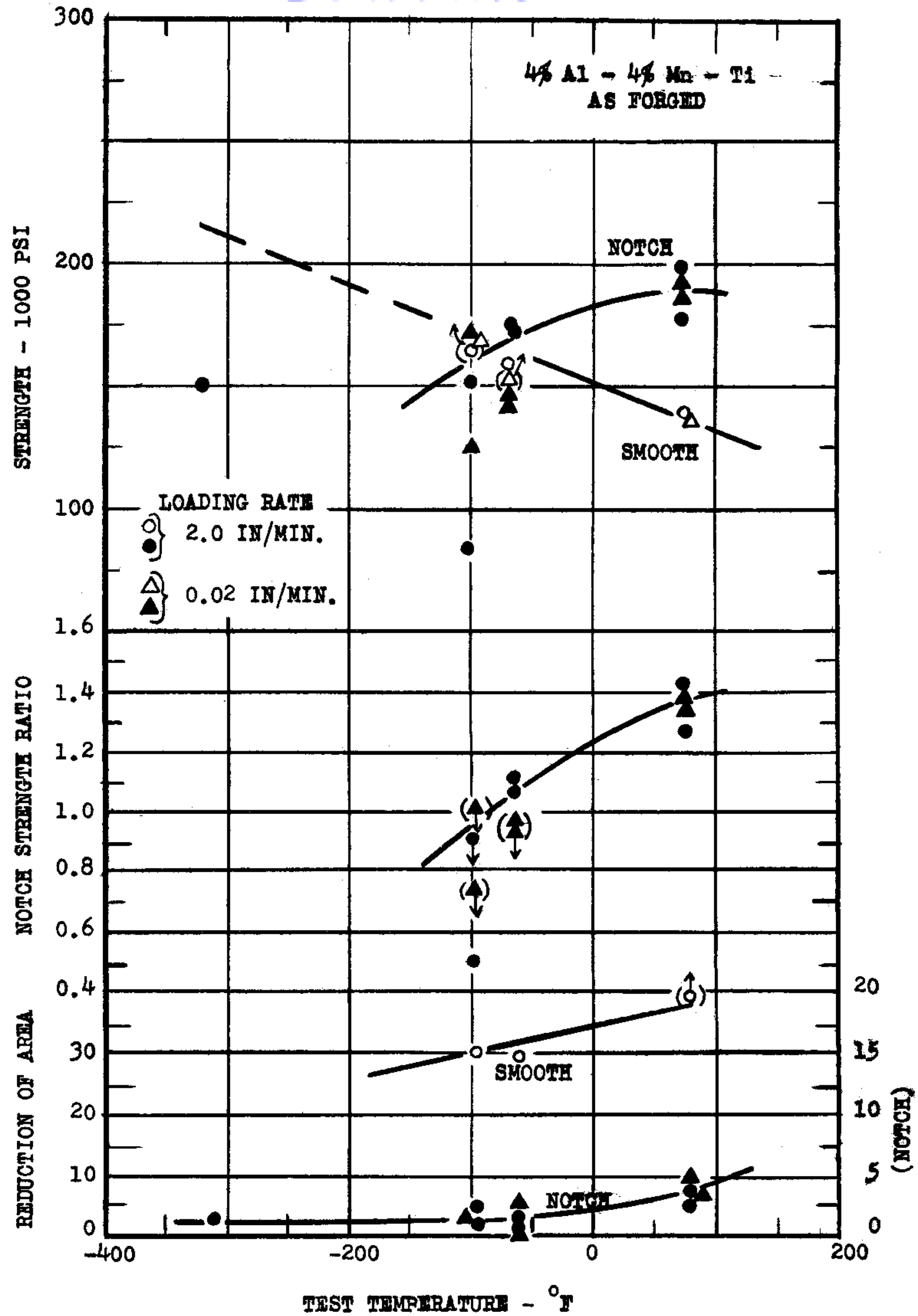


FIG. 106 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4% Al - 4% Mn - Ti - AS FORGED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≦ 0.002 IN.

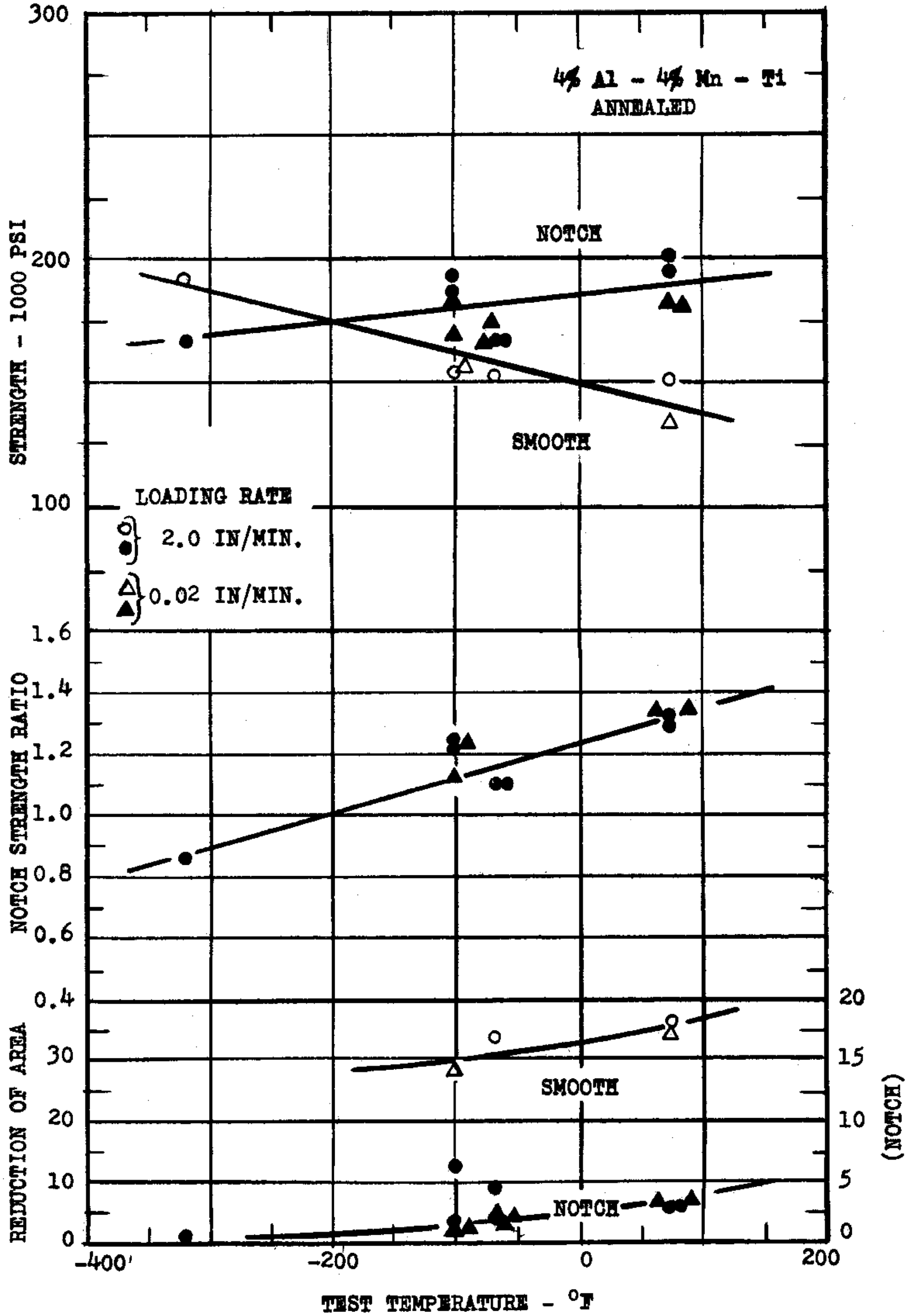


FIG. 107 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4% Al - 4% Mn - Ti:ANNEALED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≦ 0.002 IN.

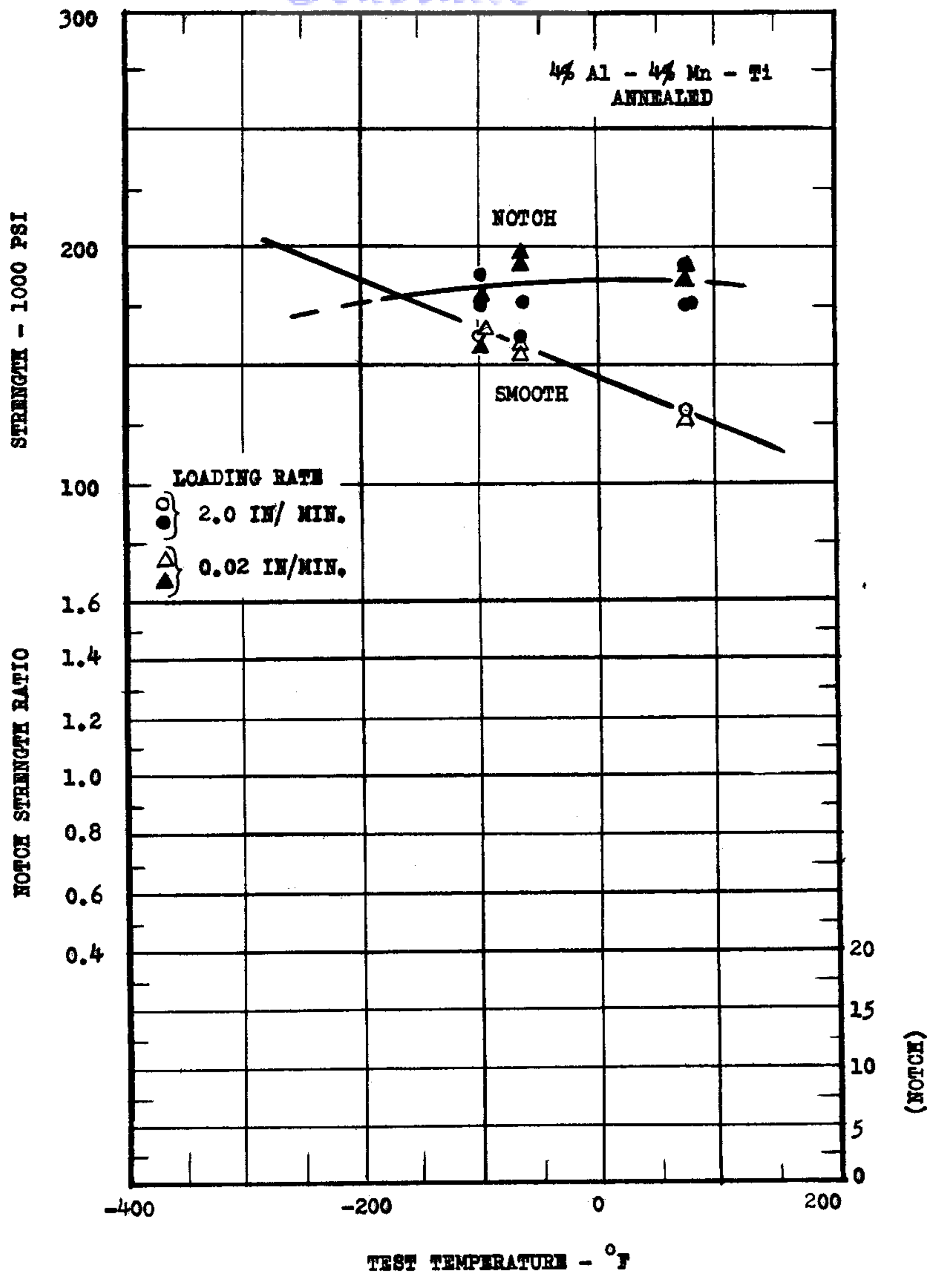


FIG. 108 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4% Al - 4% Mn - Ti - ANNEALED. SPECIMEN: 0.3 IN.DIAM. 50% NOTCH. r ≤ 0.002 IN.

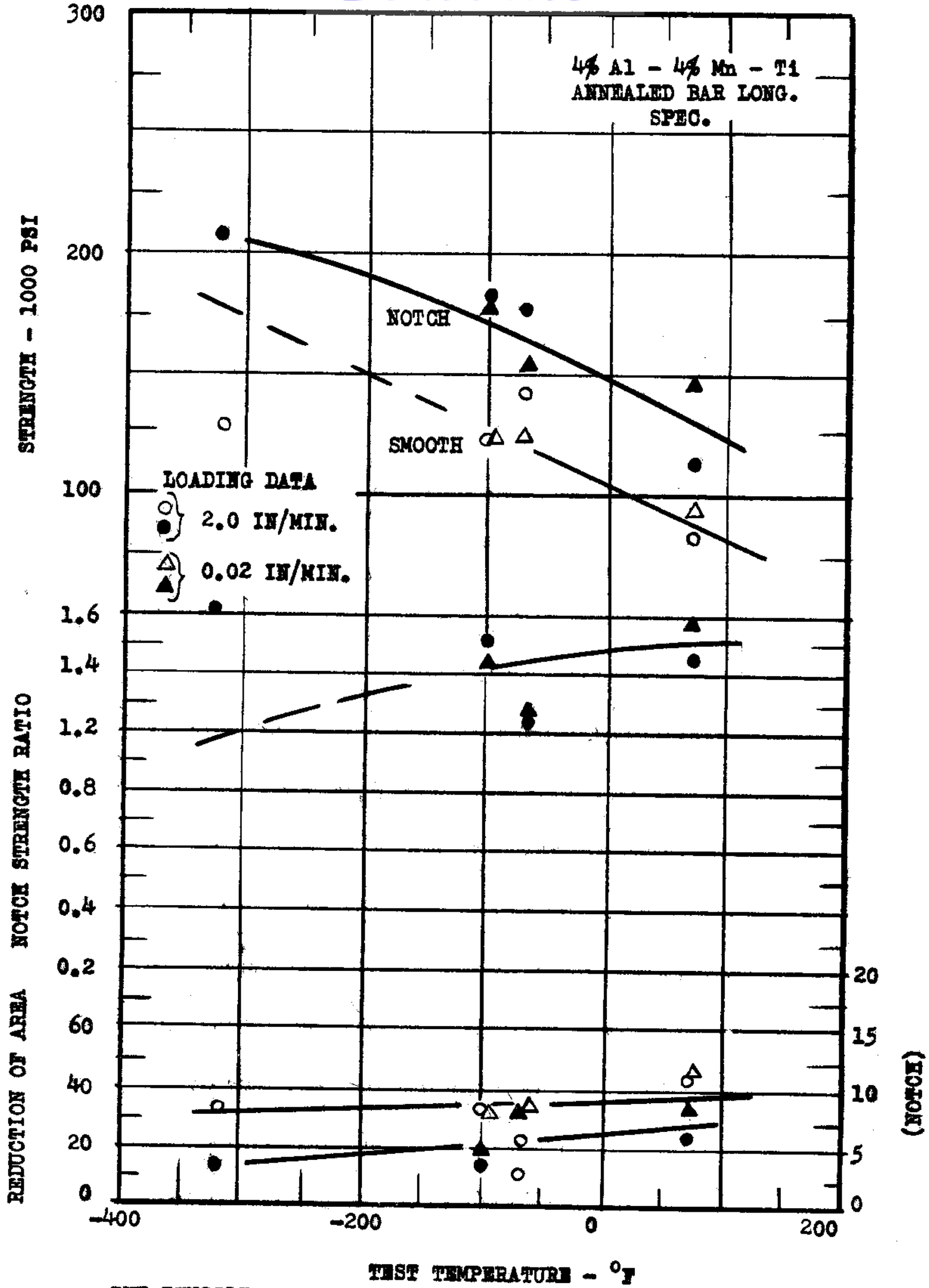


FIG. 109 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4% Al - 4% Mn - Ti -ANNEALED BAR LONG. SPEC. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r = 0.002 IN.

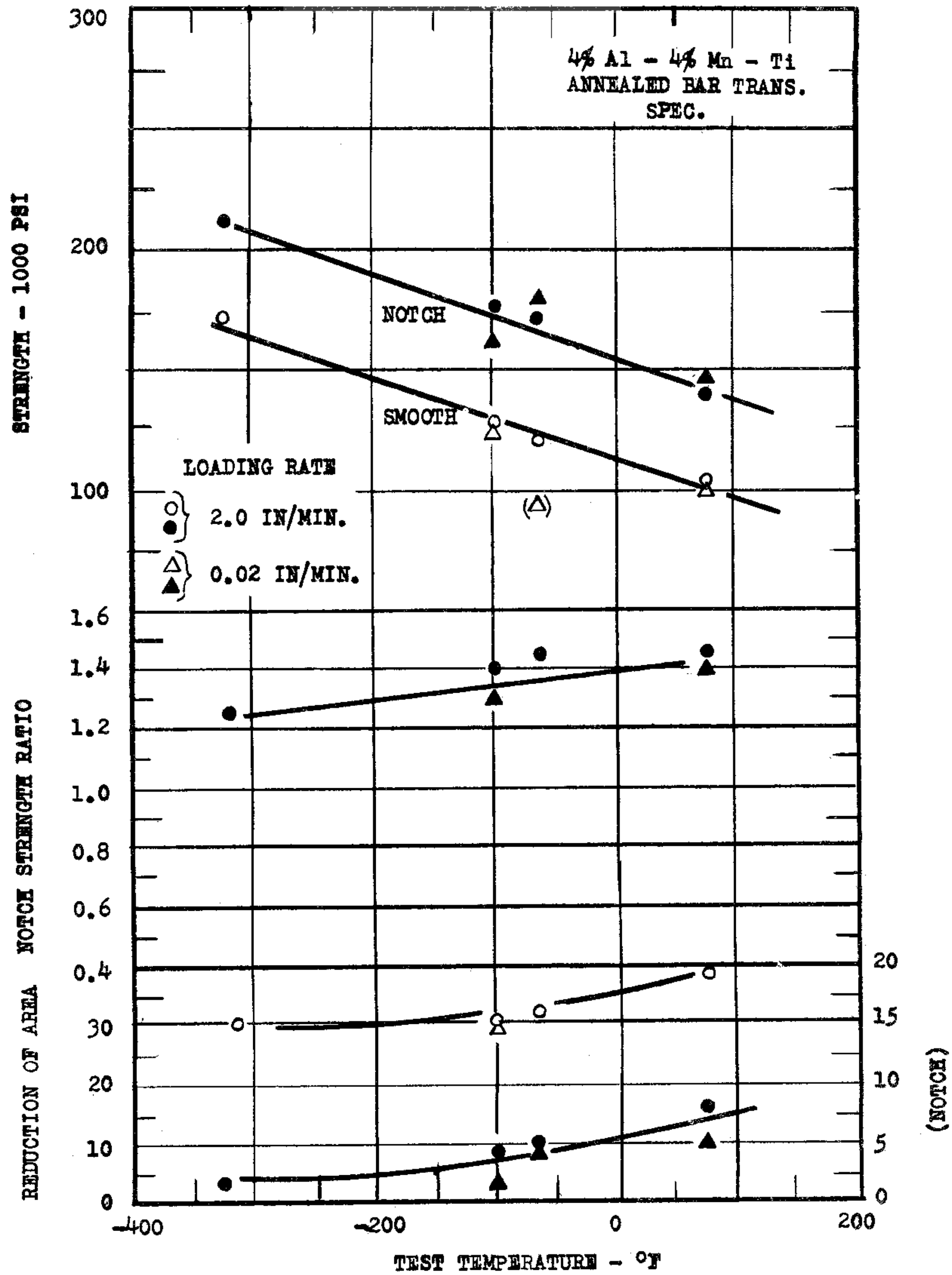


FIG. 110 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE, ALLOY: 4% Al - 4% Mn - Ti : ANNEALED BAR TRANS. SPEC. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. $r \leq 0.002$ IN.

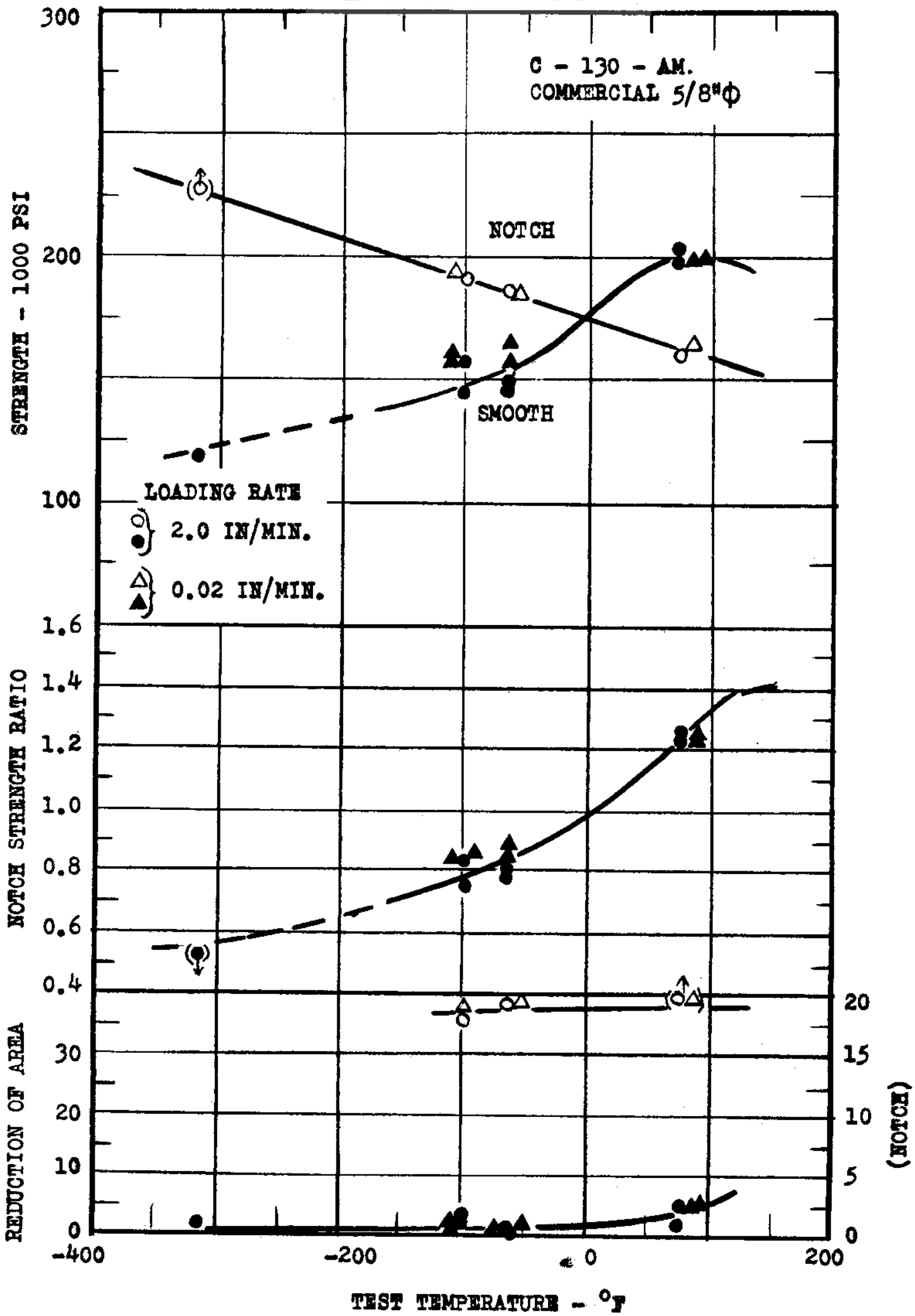


FIG. 111 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: C - 130 - AM. COMMERCIAL 5/8" Φ. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

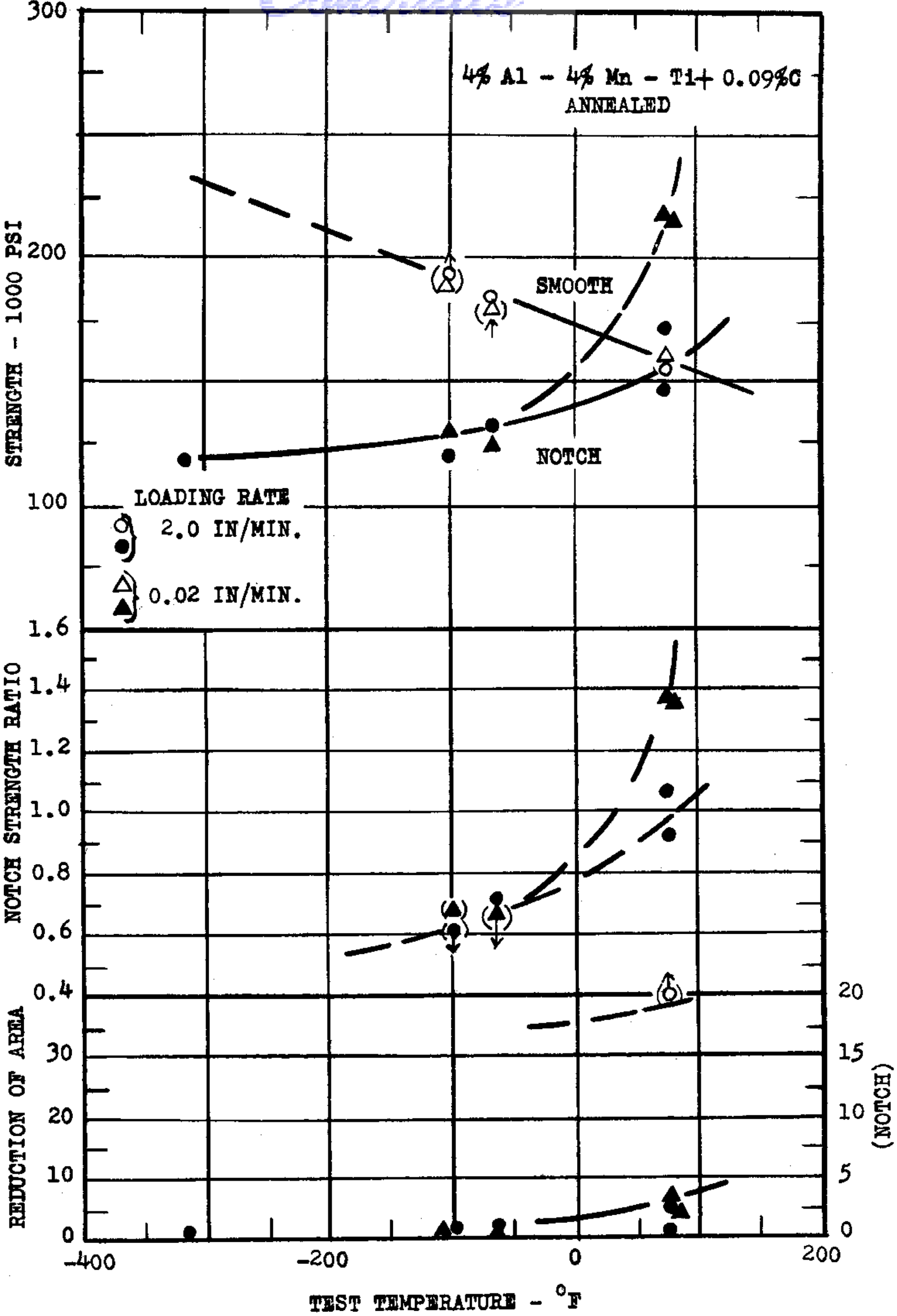


FIG. 112 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4% Al-4% Mn - Ti + 0.09% C. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

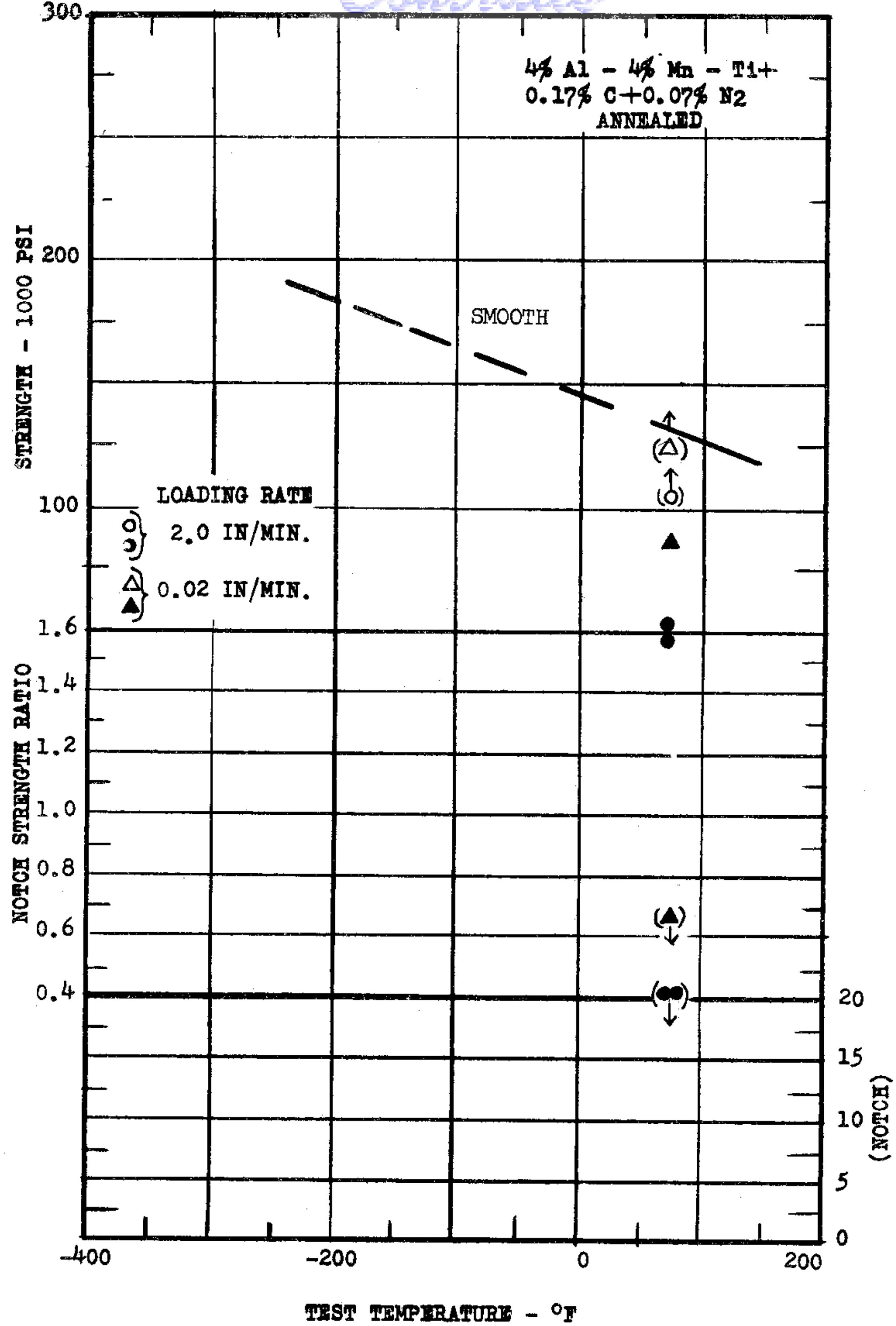


FIG. 113 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4% Al - 4% Mn - Ti + 0.17% C + 0.07% N_2. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

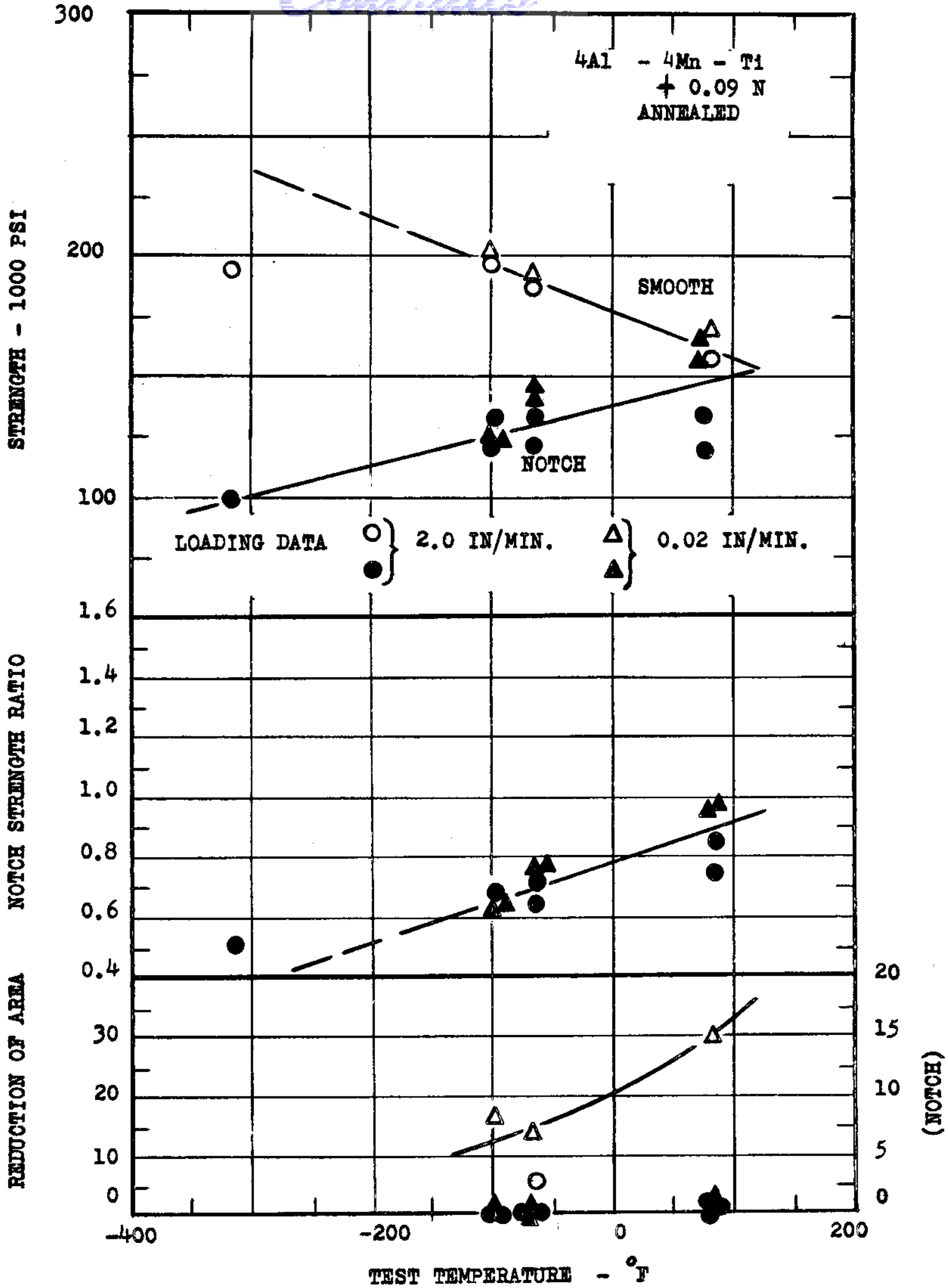


FIG. 114 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 4Al - 4Mn - Ti - 0.09 N_2 ANNEALED
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

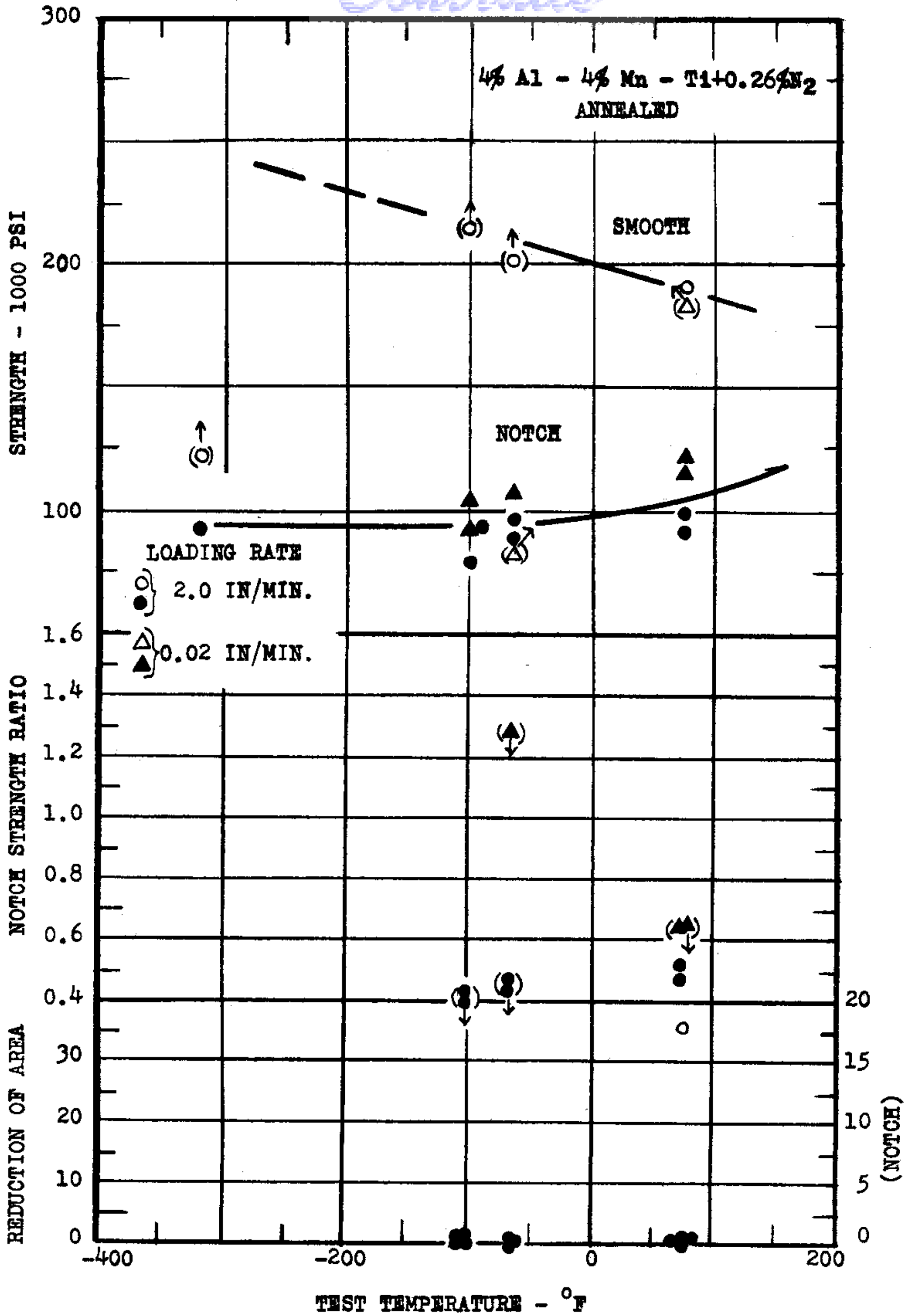


FIG. 115 THE TENSILE AND THE NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4% Al - 4% Mn - Ti + 0.26% N_2. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≅ 0.002 IN.

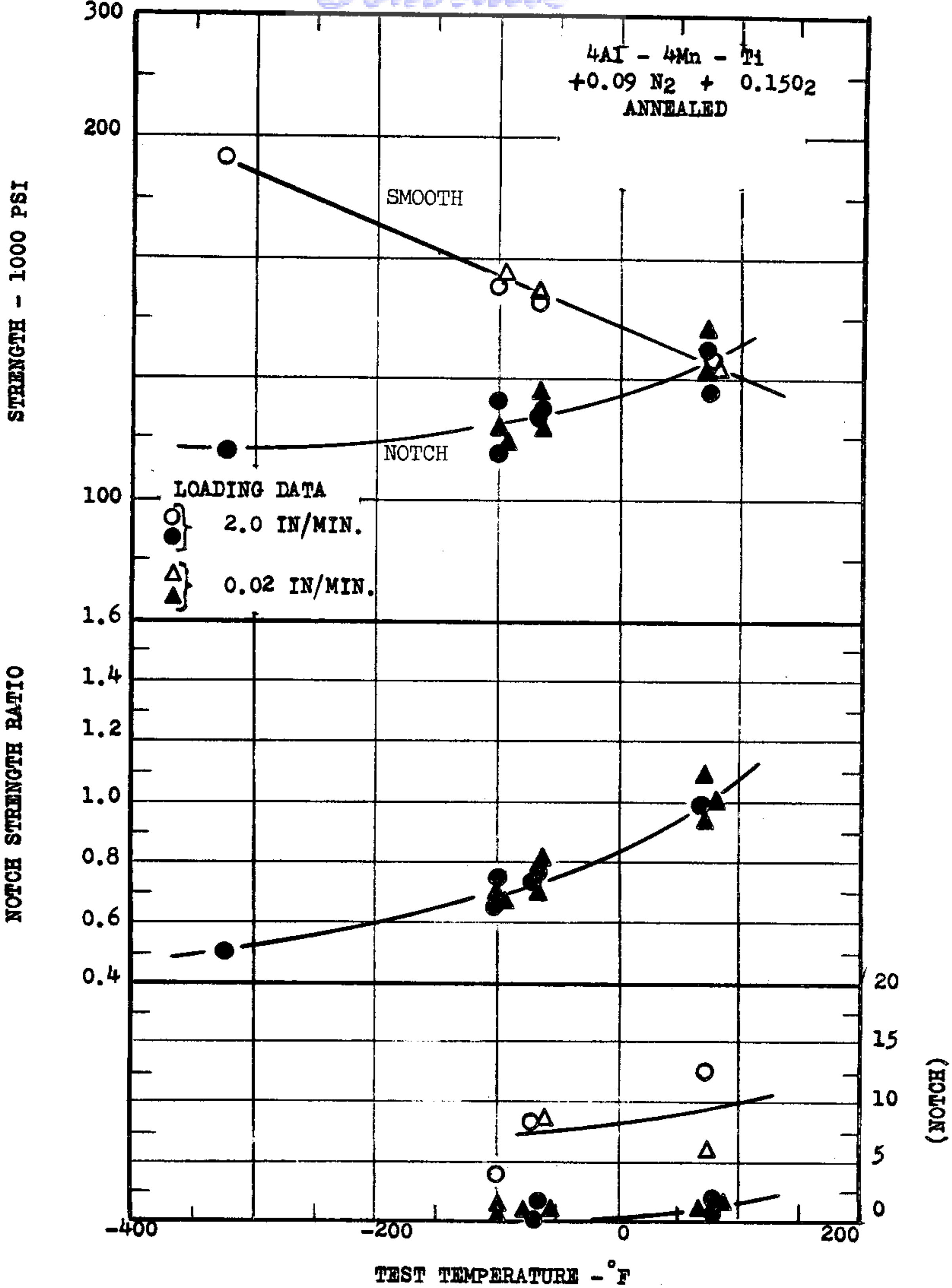


FIG. 116 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4Al - 4Mn - Ti + $0.09N_2$ + $0.15O_2$ ANNEALED SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

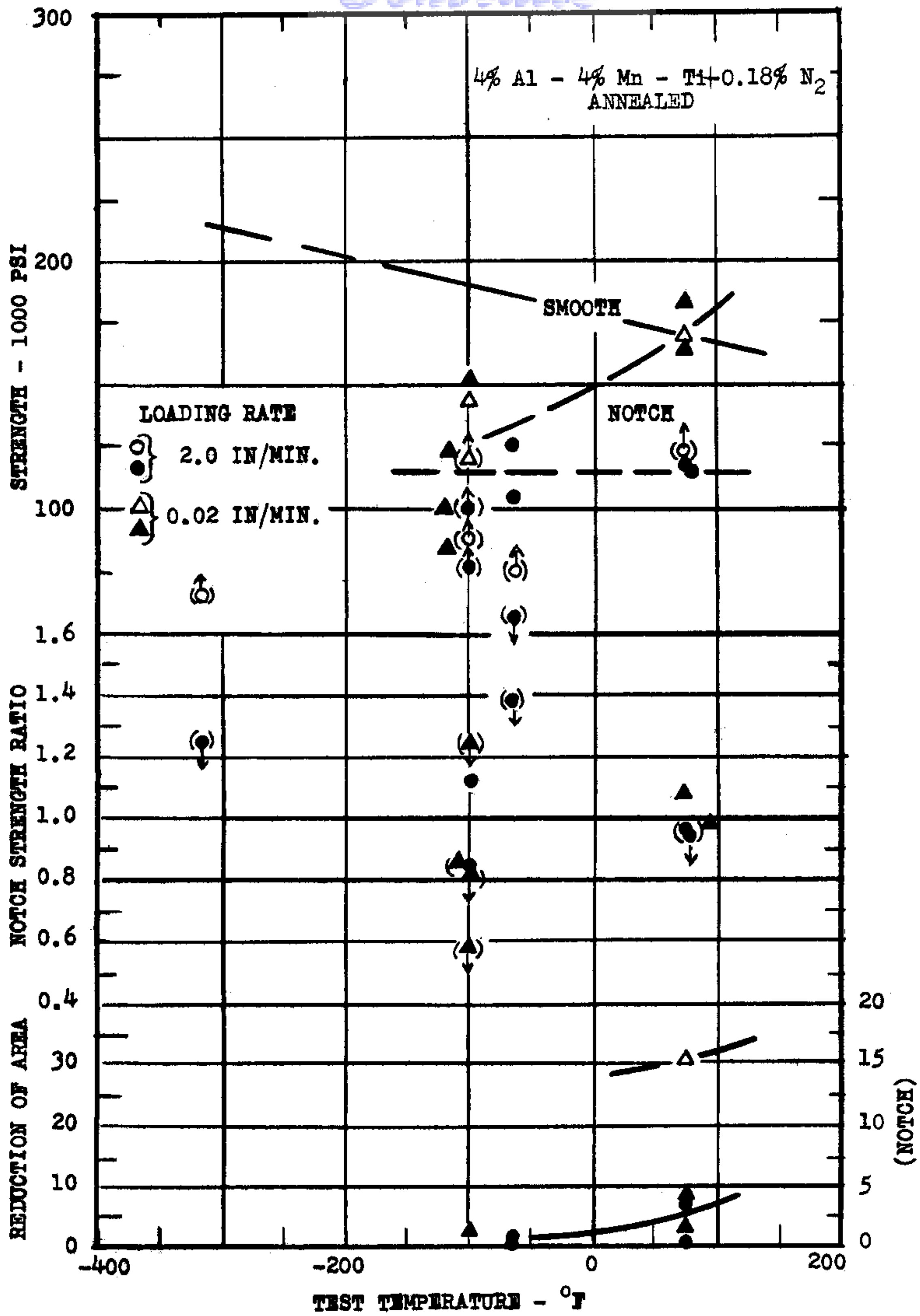


FIG. 117 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4% Al - 4% Mn - Ti+0.18% N_2. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r = 0.002 IN.

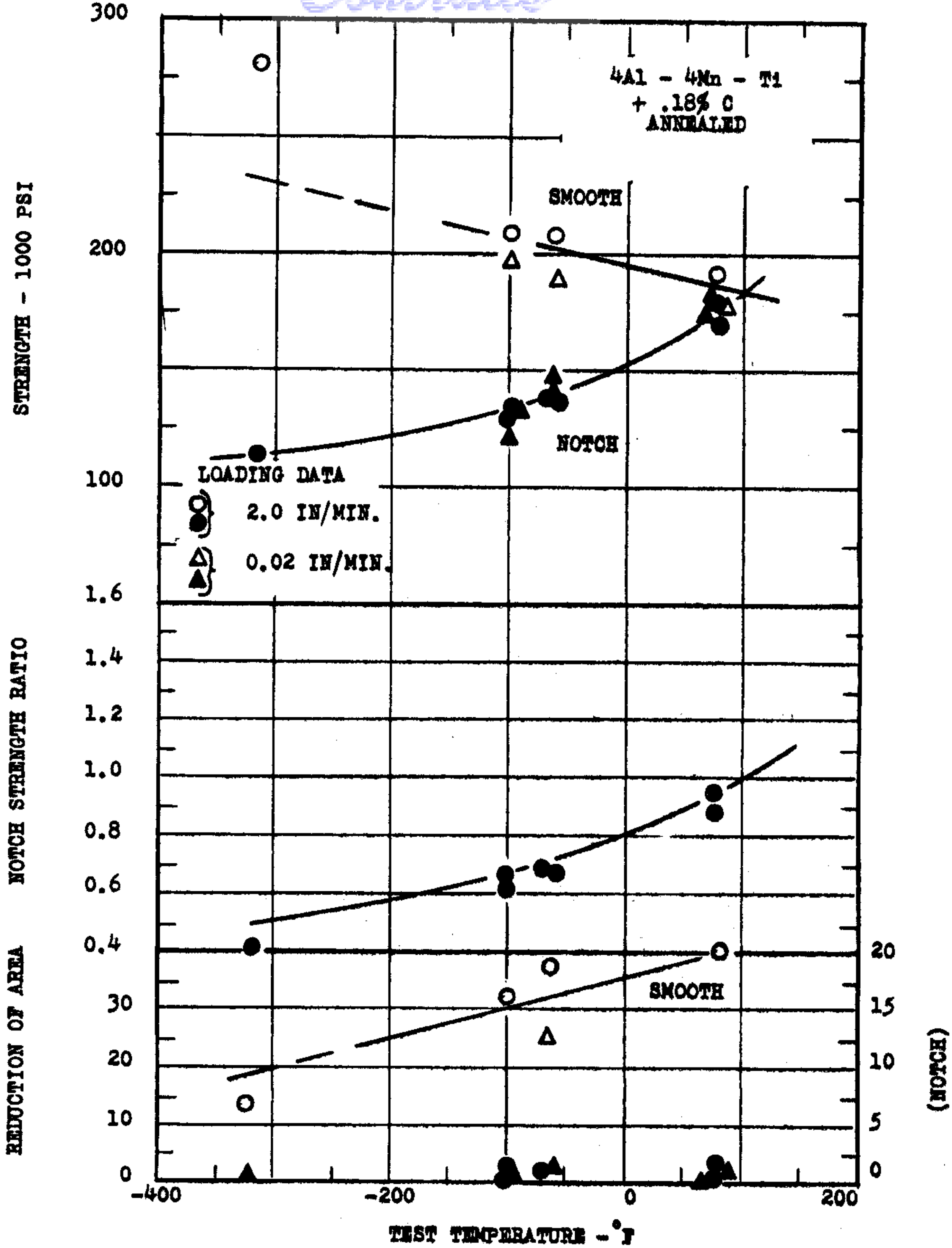


FIG. 118 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 4Al - 4Mn - Ti + 0.18 C ANNEALED SPECIMEN: 0.3 IN. DIAM. 50% NOTCH r ≤ 0.002 IN.

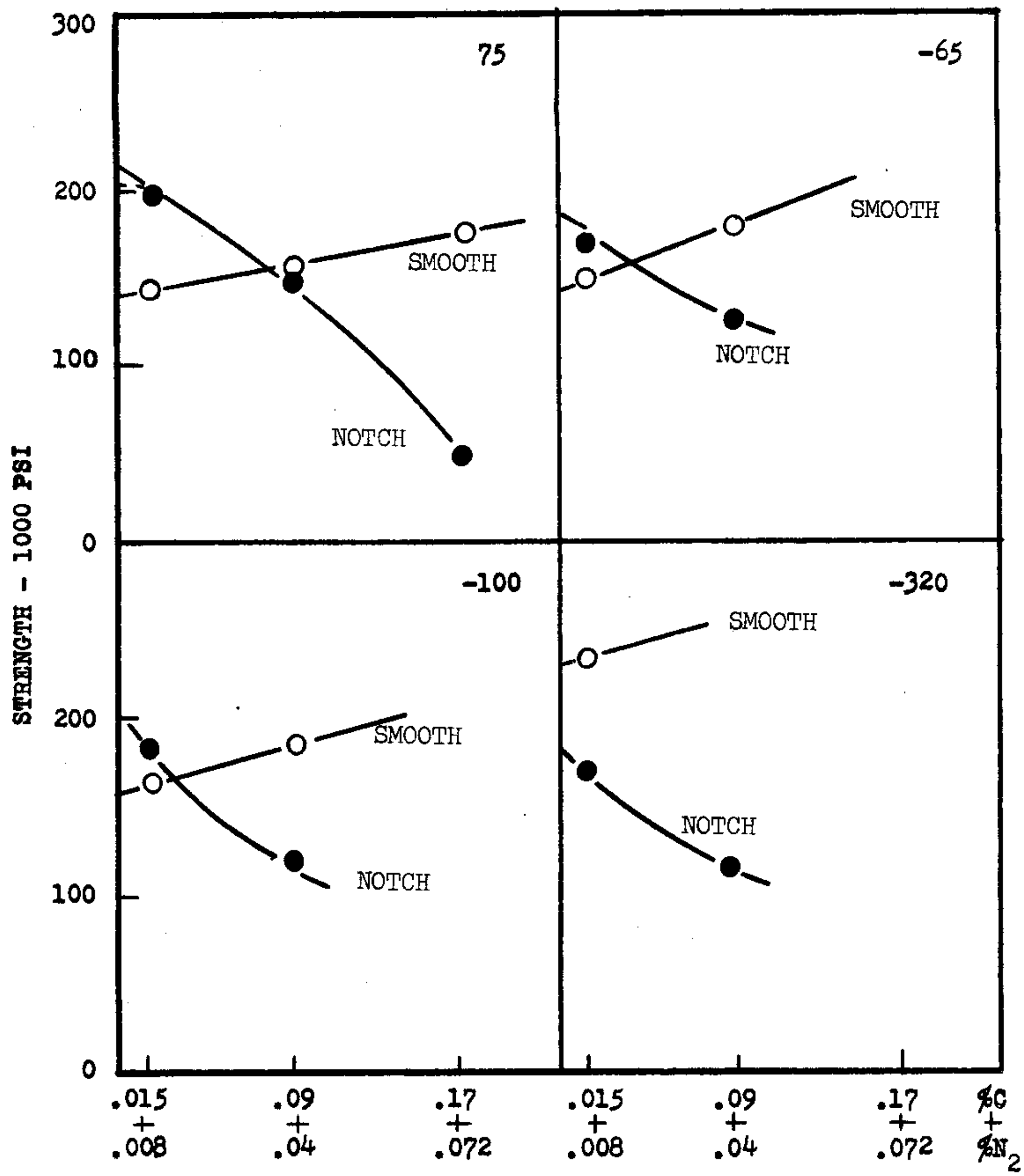


FIG. 119 **THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 1 (cf. FIGURE 91).**

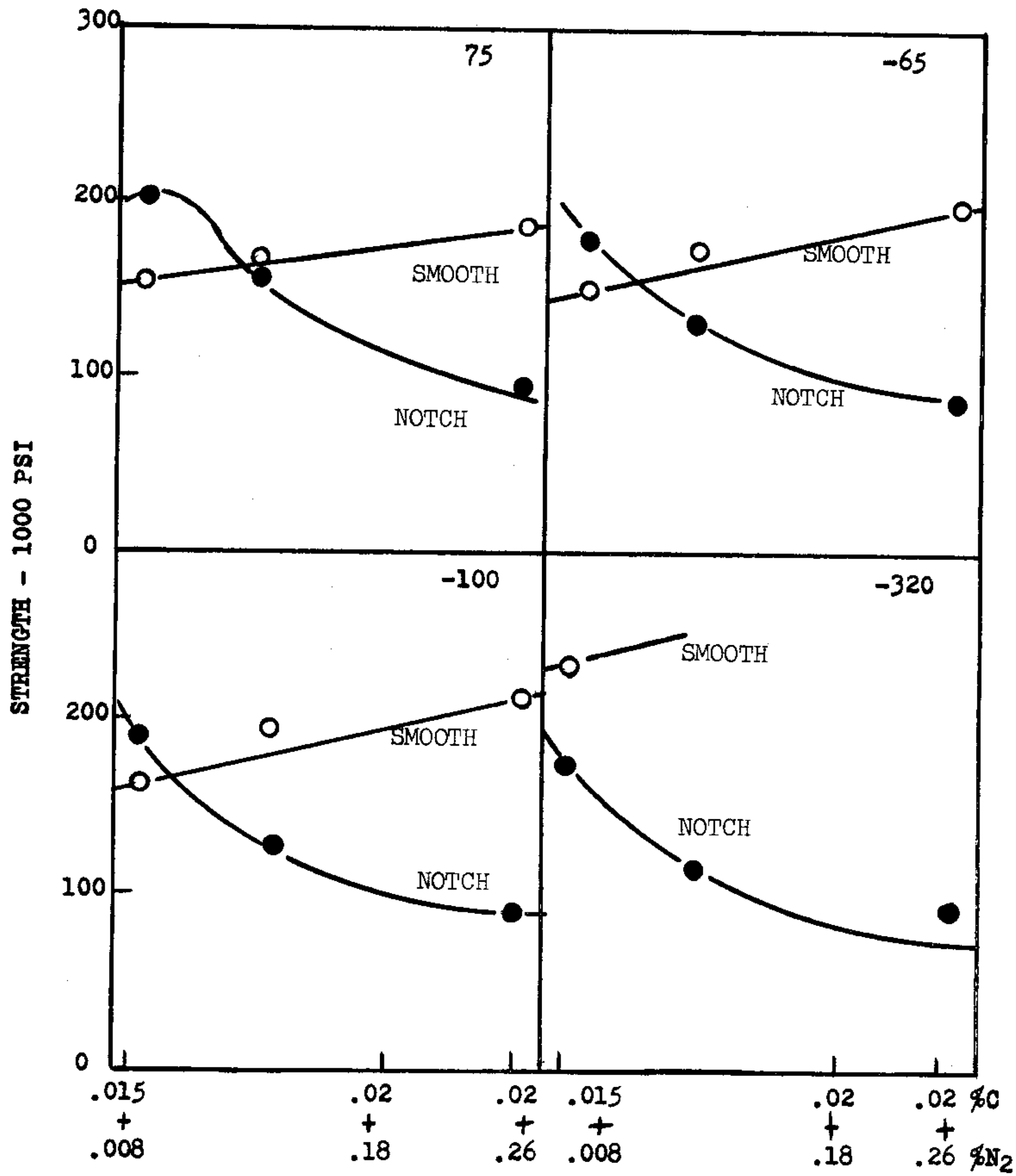


FIG. 120 THE VARIATION OF THE TENSILE AND NOTCH STRENGTH ALONG THE TERNARY SECTION NO. 2. (cf. FIGURE 91).

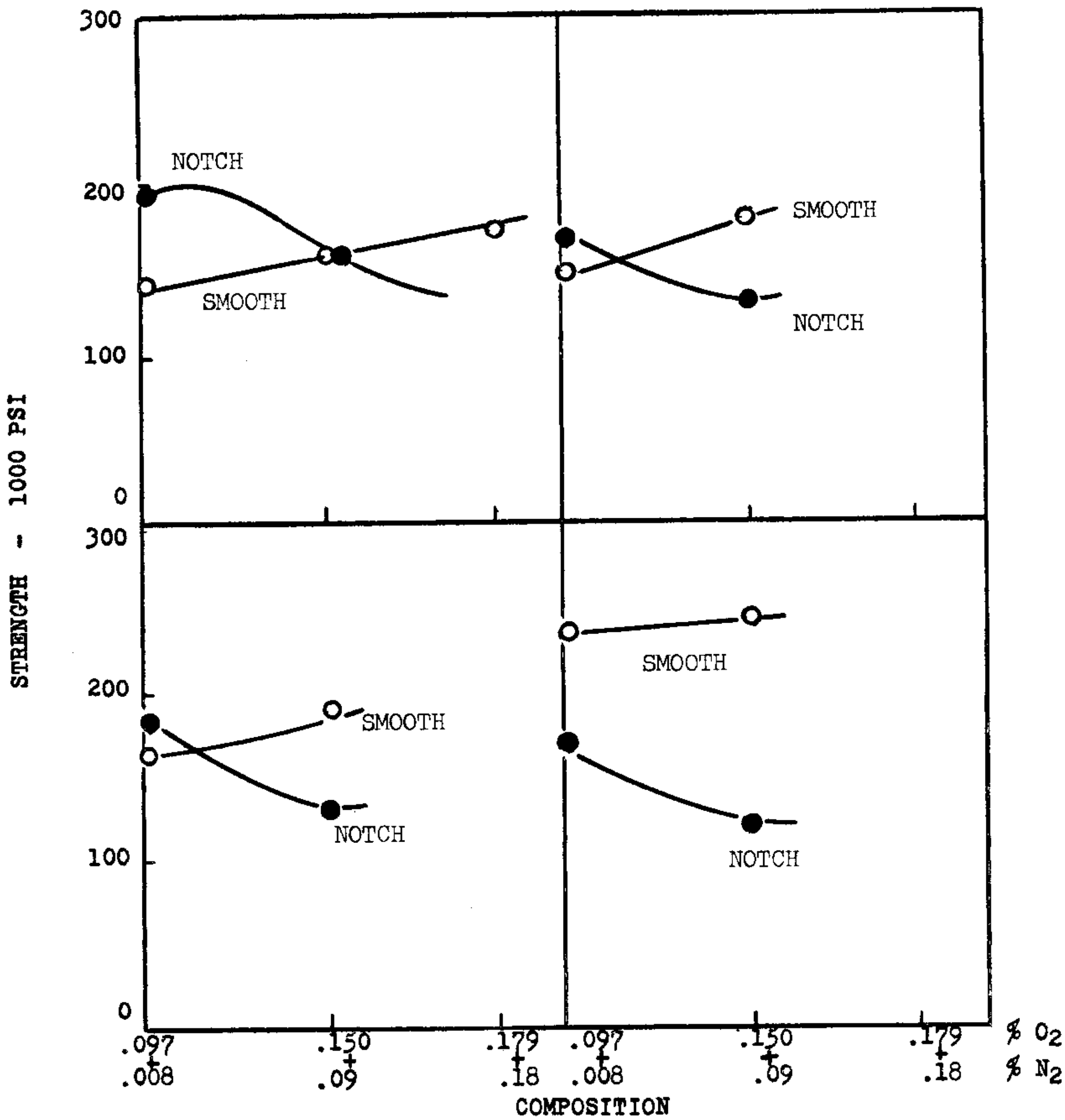


FIG. 121. THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 3 (cf. Figure 91).

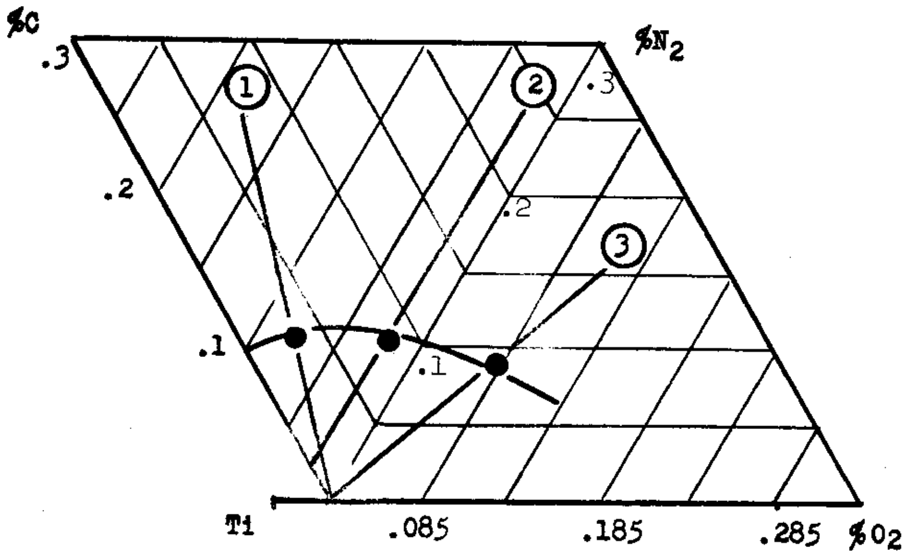


FIG. 122 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT 75°F. 4Al - 4Mn - Ti ALLOY.

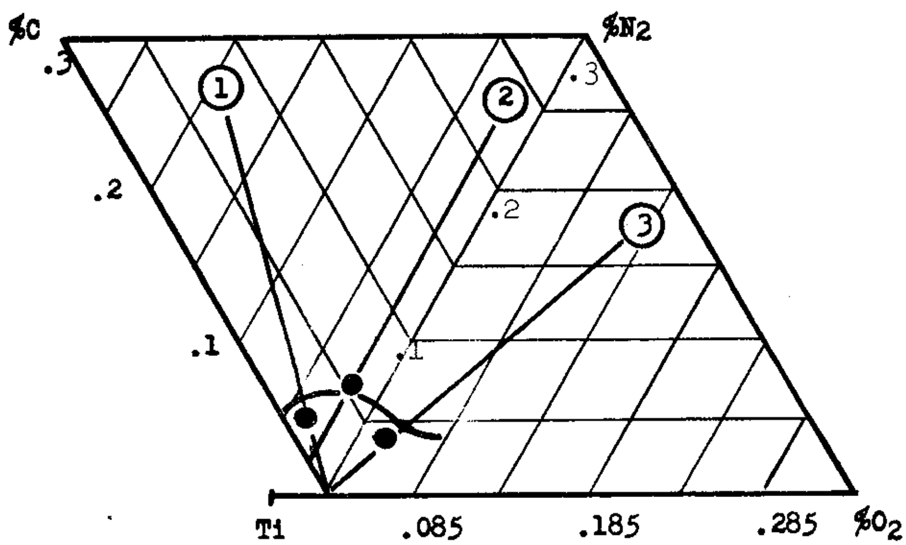


FIG. 123 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT -65° F. 4Al - 4Mn - Ti ALLOY.

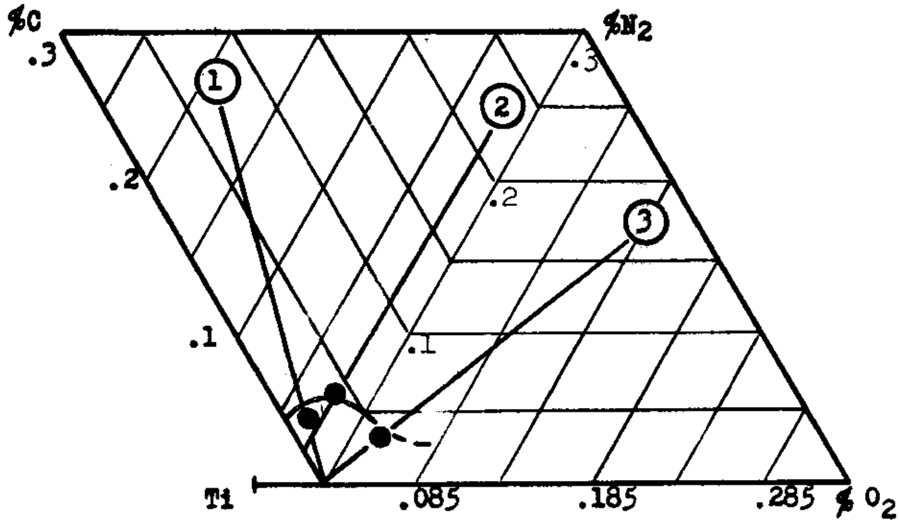


FIG. 124 THE CONTAMINATION LIMITS YIELDING A NOTCH STRENGTH RATIO OF 1 AT - 100°F. 4Al - 4Mn - Ti ALLOY.

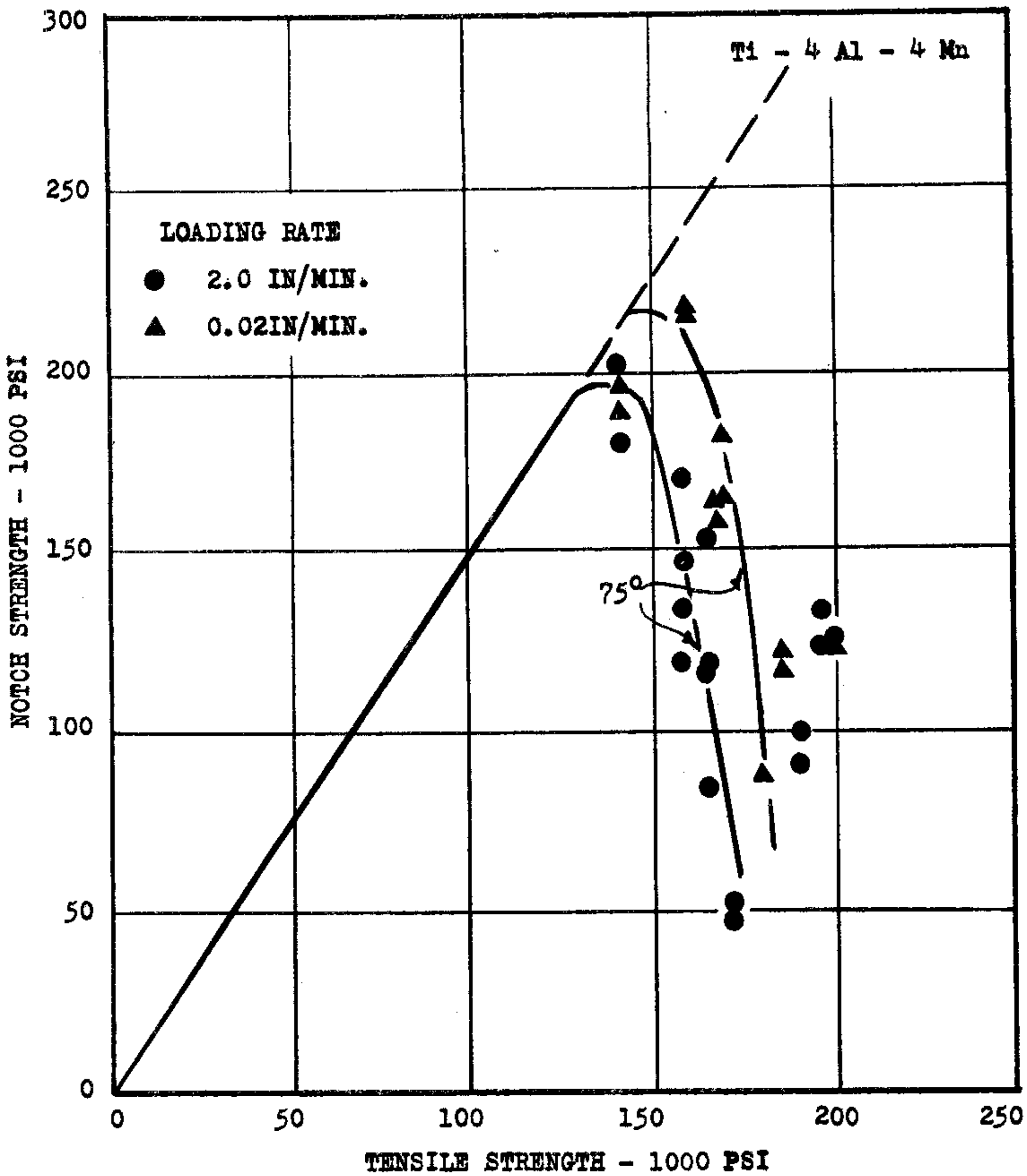


FIG. 125 THE NOTCH STRENGTH VS. THE TENSILE STRENGTH AT 75°F. ALLOY: 4Al - 4Mn - Ti.

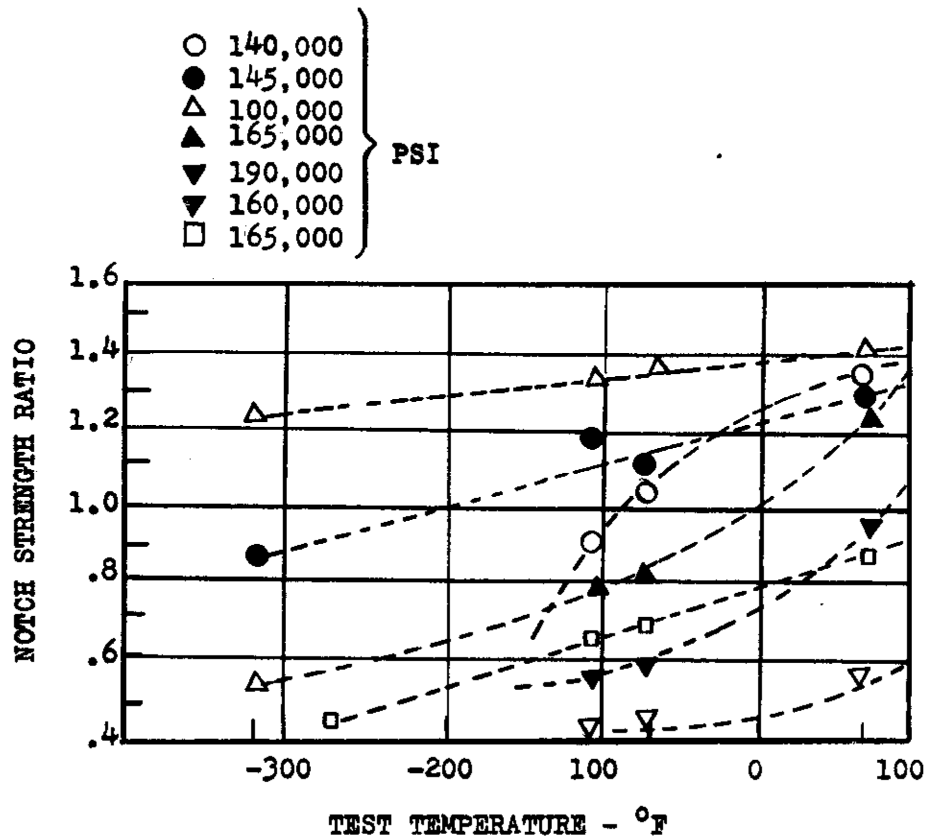


FIG. 126 THE NOTCH STRENGTH RATIO VS. TEST TEMPERATURE VS. TENSILE STRENGTH AT 75°F. ALLOY: 4Al - 4Mn - Ti.

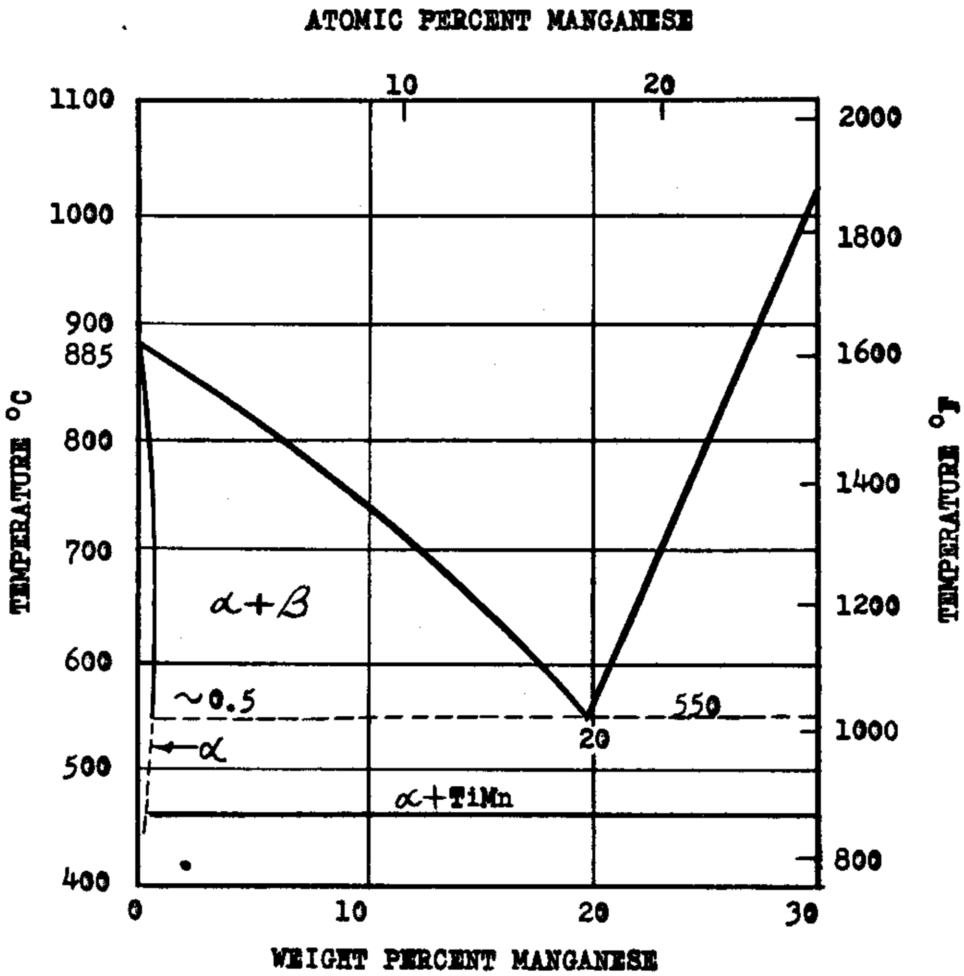


FIG. 127 THE Ti - Mn EQUILIBRIUM DIAGRAM(5)

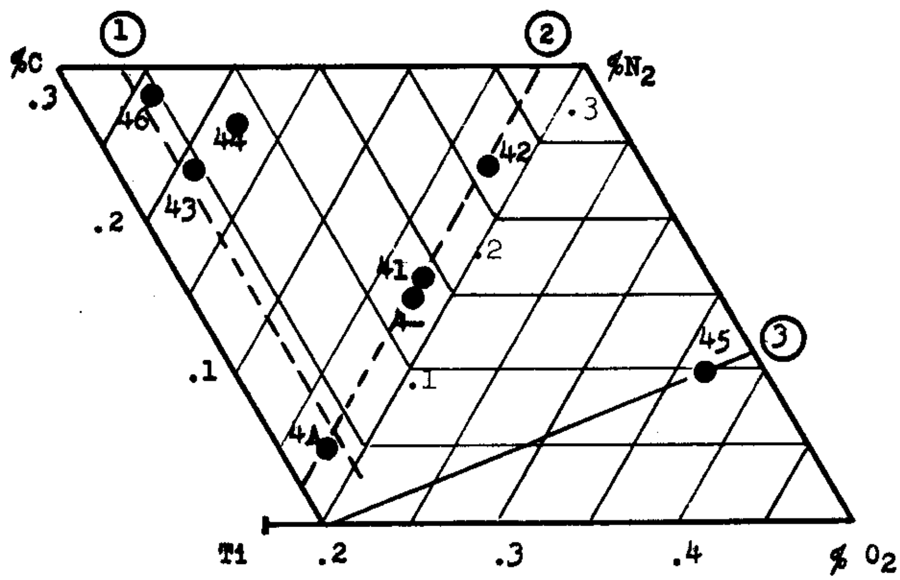
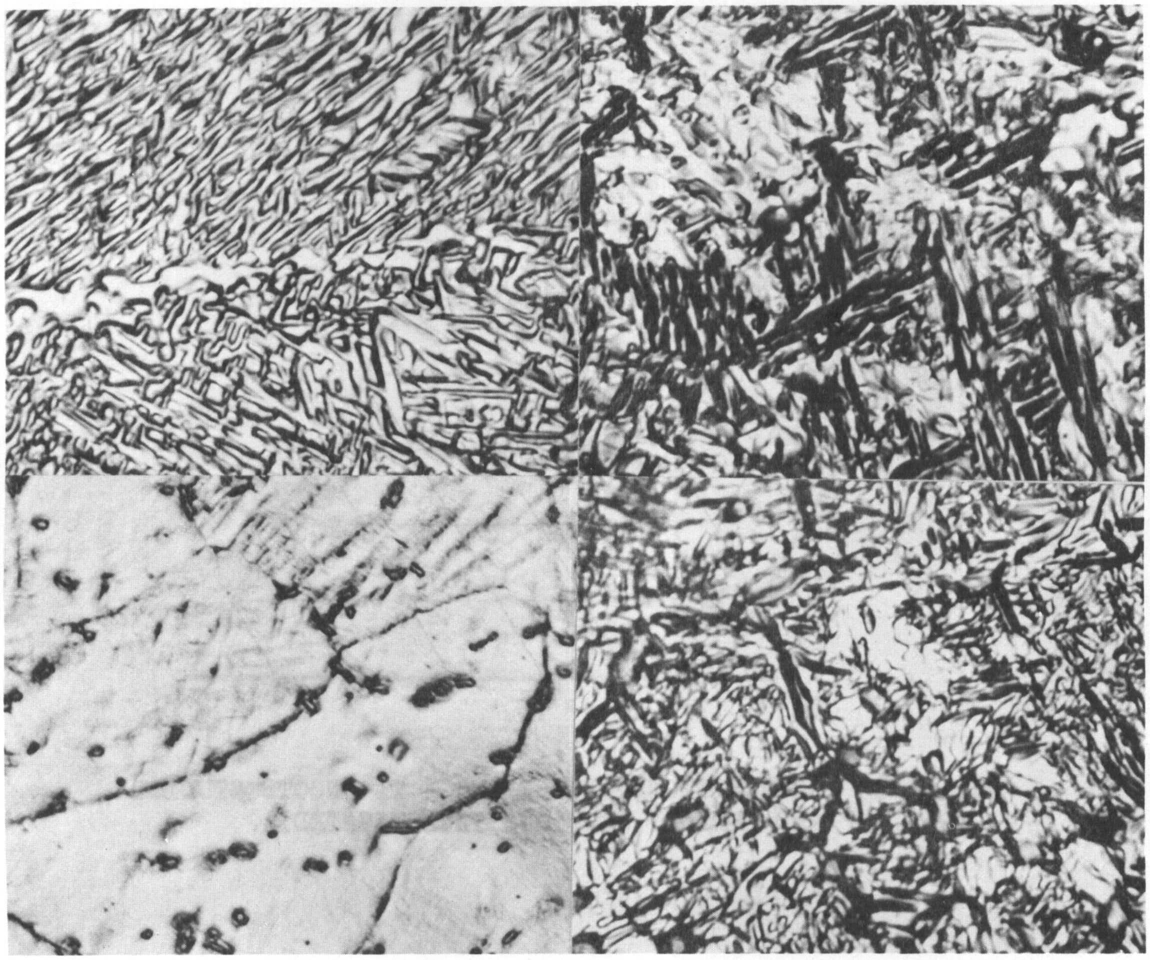


FIG. 128 COMPOSITIONS OF THE 8Mn - Ti INGOTS STUDIED AND TERNARY SECTIONS INVESTIGATED.

129 130



131 132

FIGS. 129 TO 132 MICROSTRUCTURES OF THE INDICATED 8Mn - Ti ALLOYS. ELECTROPOLISHED. KELLER'S ETCH x 500.

FIG. 129 AS ANNEALED.
FIG. 130 +0.19%C - ANNEALED.
FIG. 131 +0.18%C + 0.085%N_2 - ANNEALED.
FIG. 132 +0.24%C - ANNEALED.

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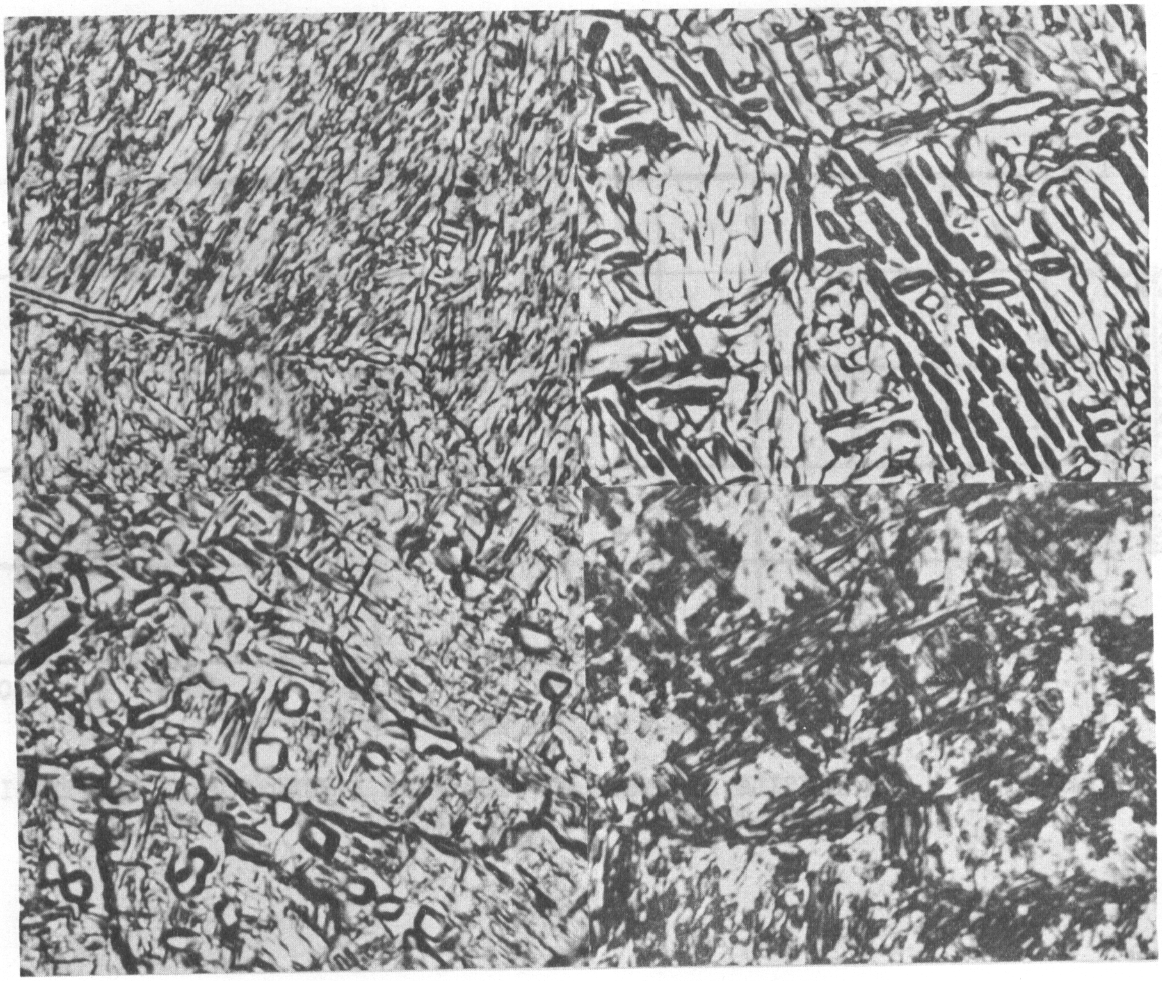

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FIGS. 133 TO 136 MICROSTRUCTURES OF THE INDICATED 8Mn - Ti ALLOYS. ELECTROPOLISHED. KELLER'S ETCH x 500.

FIG. 133 +0.125% N_2 - ANNEALED
FIG. 134 +0.133% N_2 - ANNEALED
FIG. 135 +0.210% N_2 - ANNEALED
FIG. 136 +0.361% O_2 + 0.108% N_2 - ANNEALED

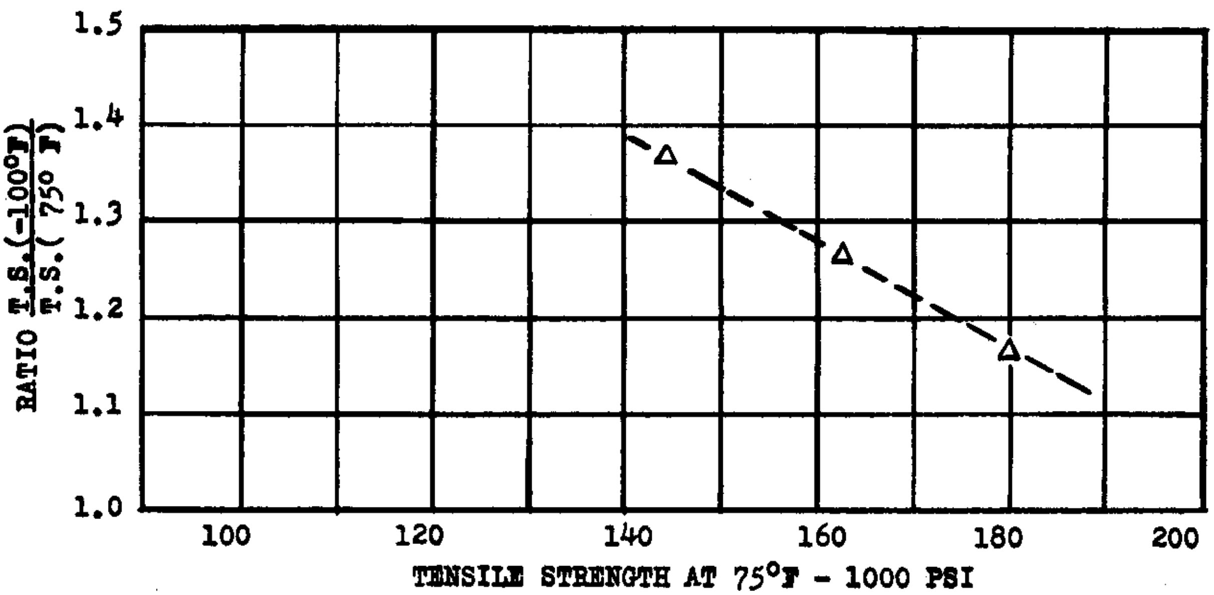


FIG. 137 THE TENSILE STRENGTH AT -100°F AS A FUNCTION OF THE TENSILE STRENGTH AT 75°F. 8Mn - Ti ALLOY.

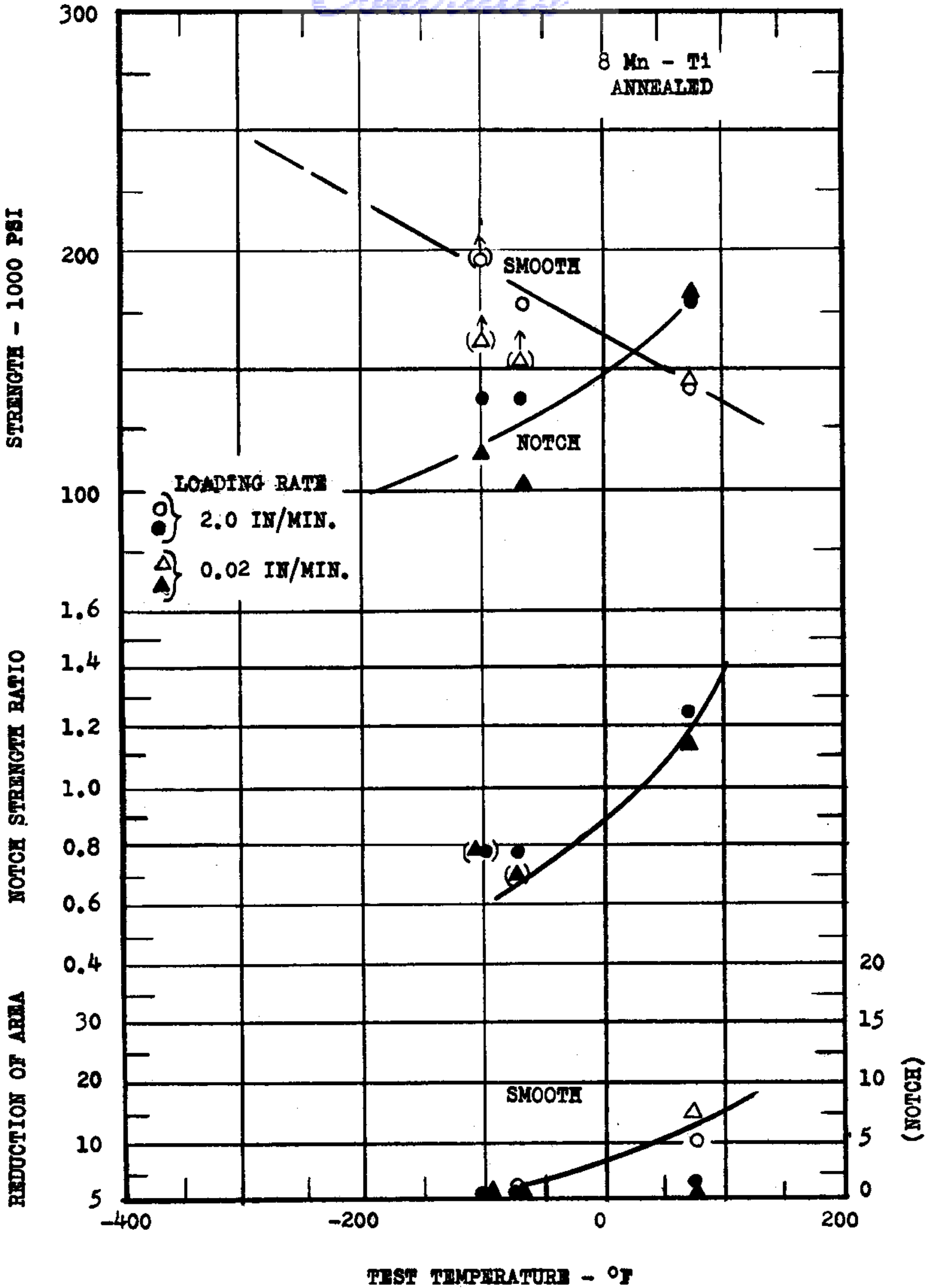


FIG. 138 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8 Mn - Ti - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r = 0.002 INCH.

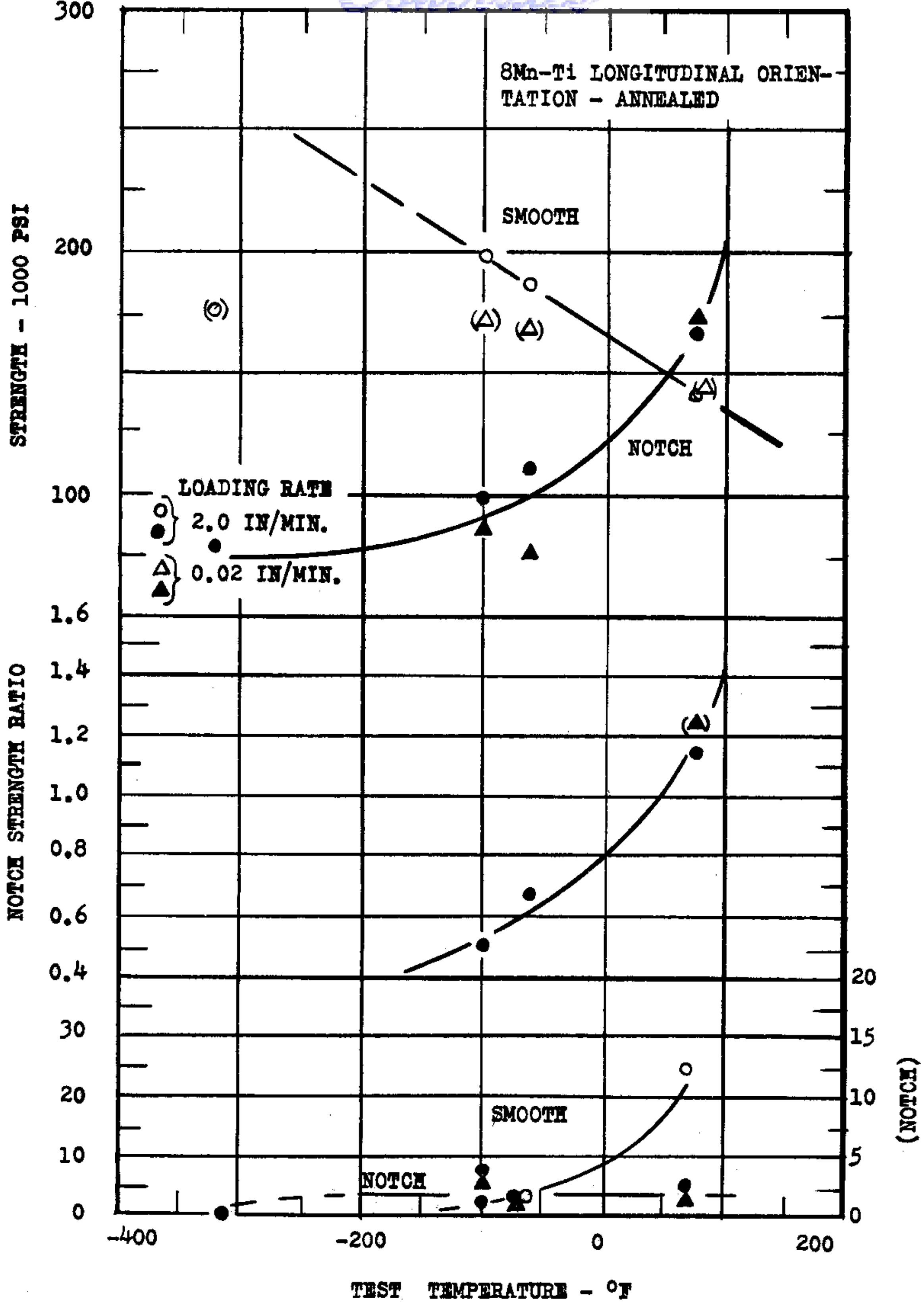


FIG. 139 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8Mn - Ti-LONGITUDINAL - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r = 0.002 IN.

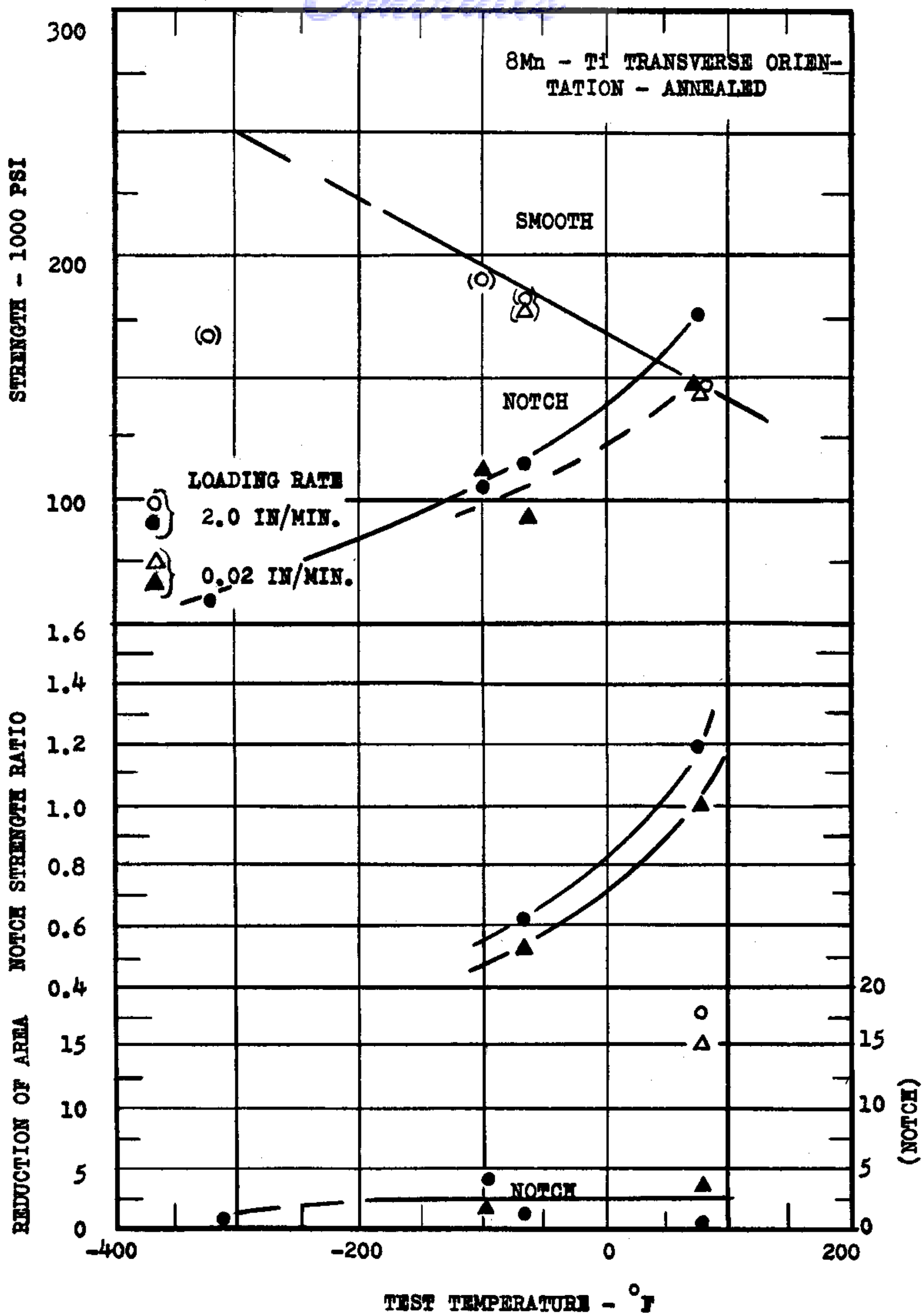


FIG. 140 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8Mn - Ti - TRANSVERSE ORIENTATION - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

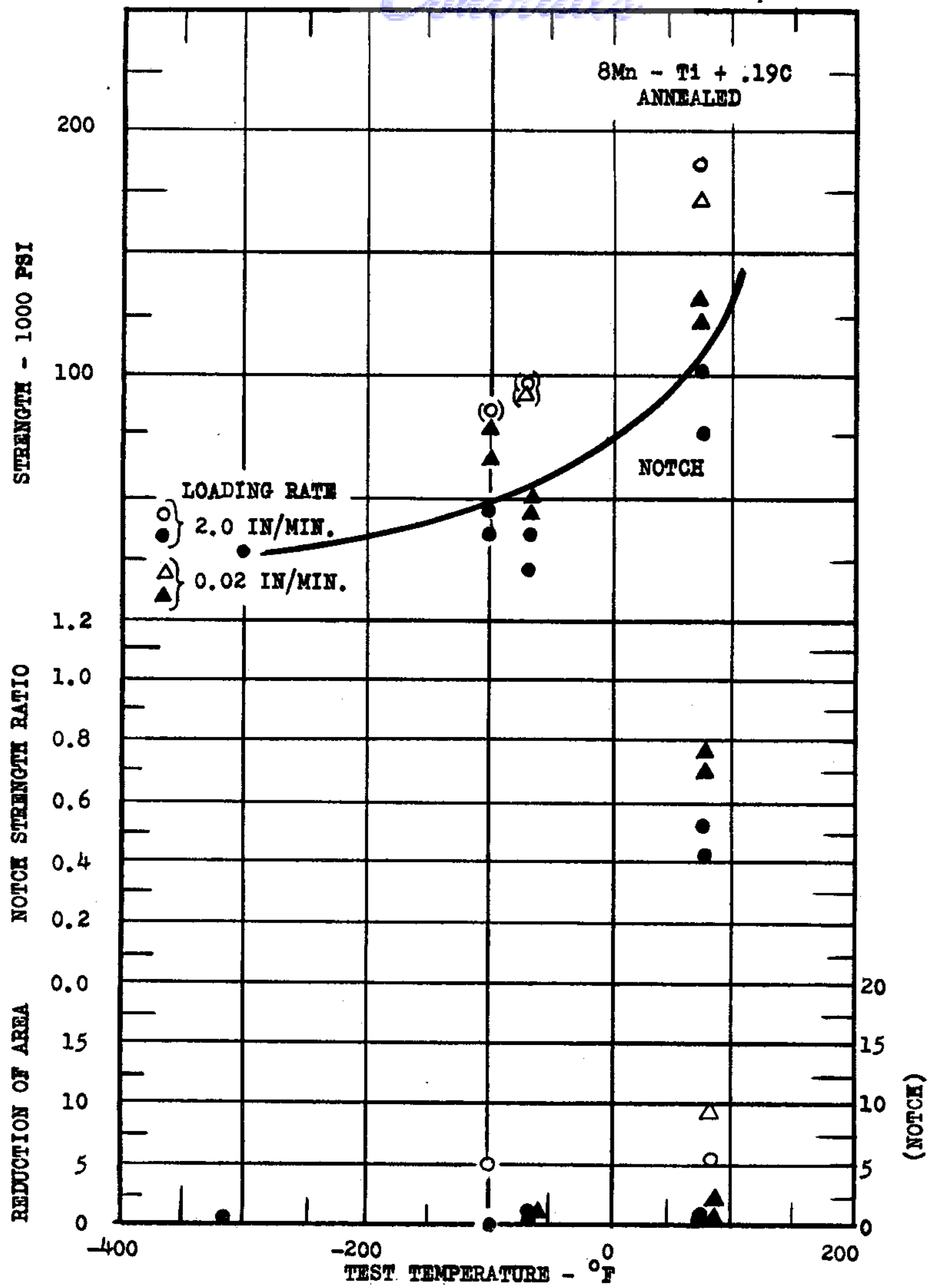


FIG. 141 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8Mn - Ti + .19%C - ANNEALED
SPECIMEN: 0.3 IN.DIAM. 50% NOTCH. r ≤ 0.002 IN.

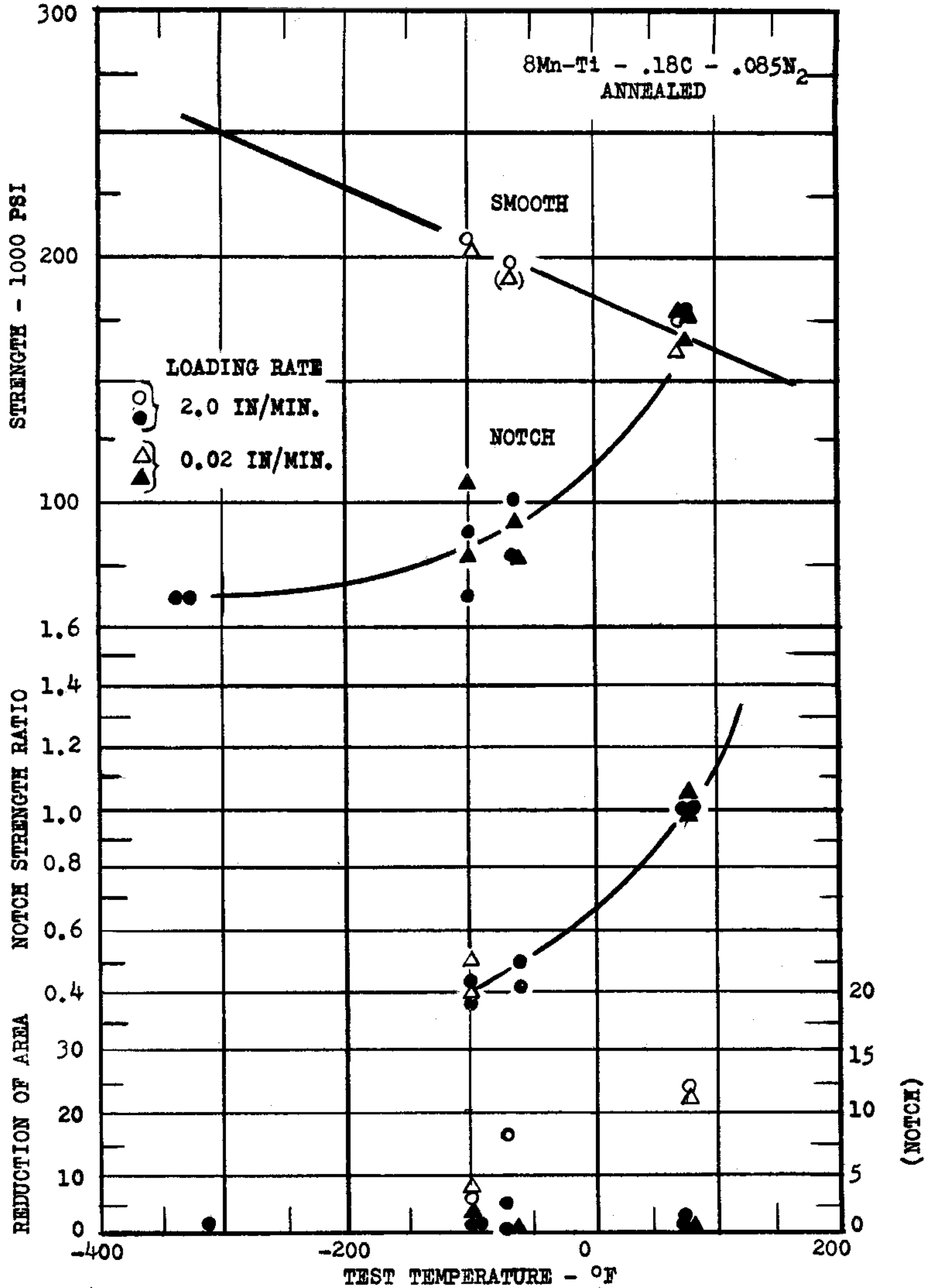


FIG. 142 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8Mn - Ti - .18%C - .085%N2 - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r = 0.002 IN.

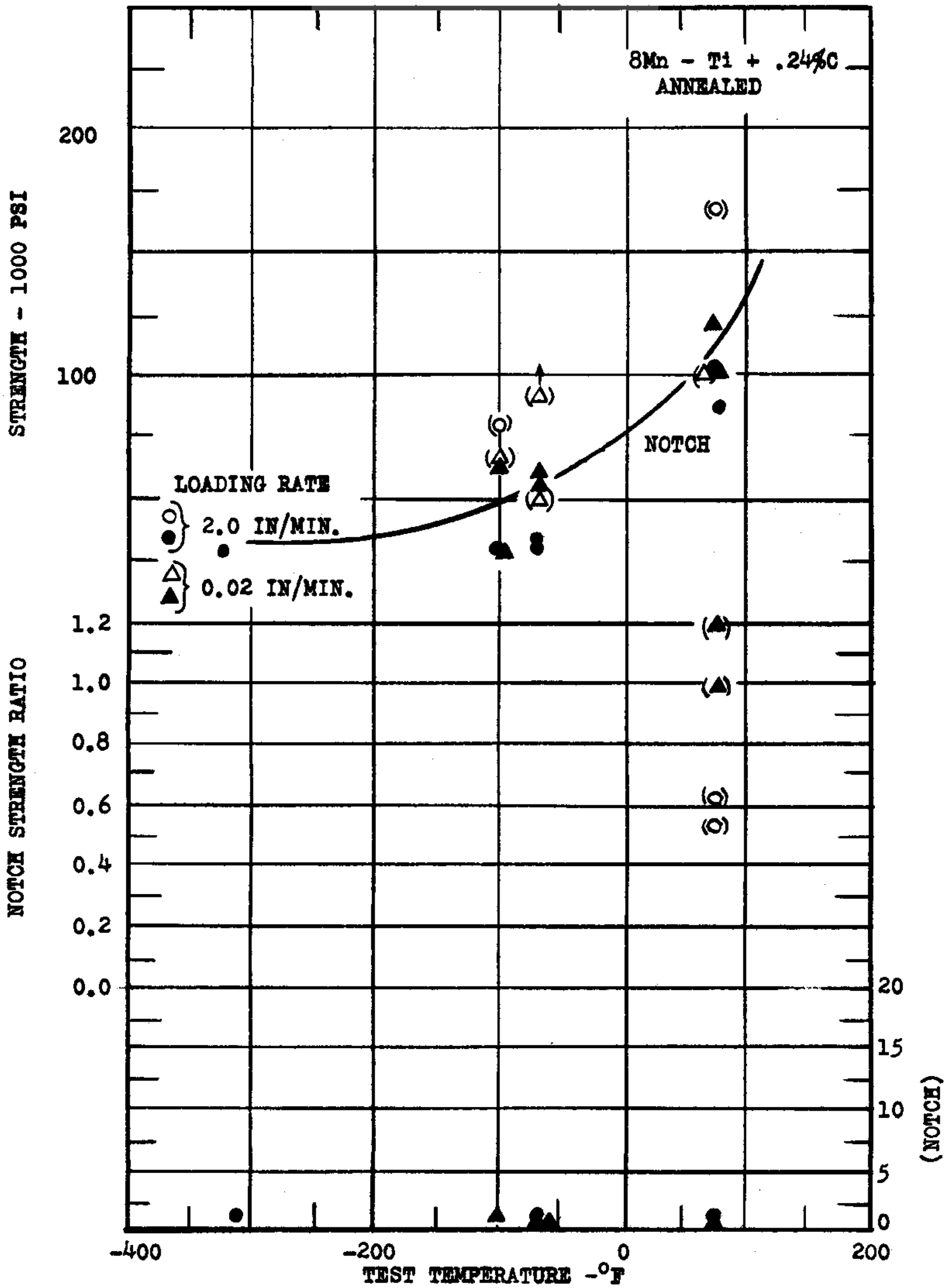


FIG. 143 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8Mn - Ti + .24%C - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

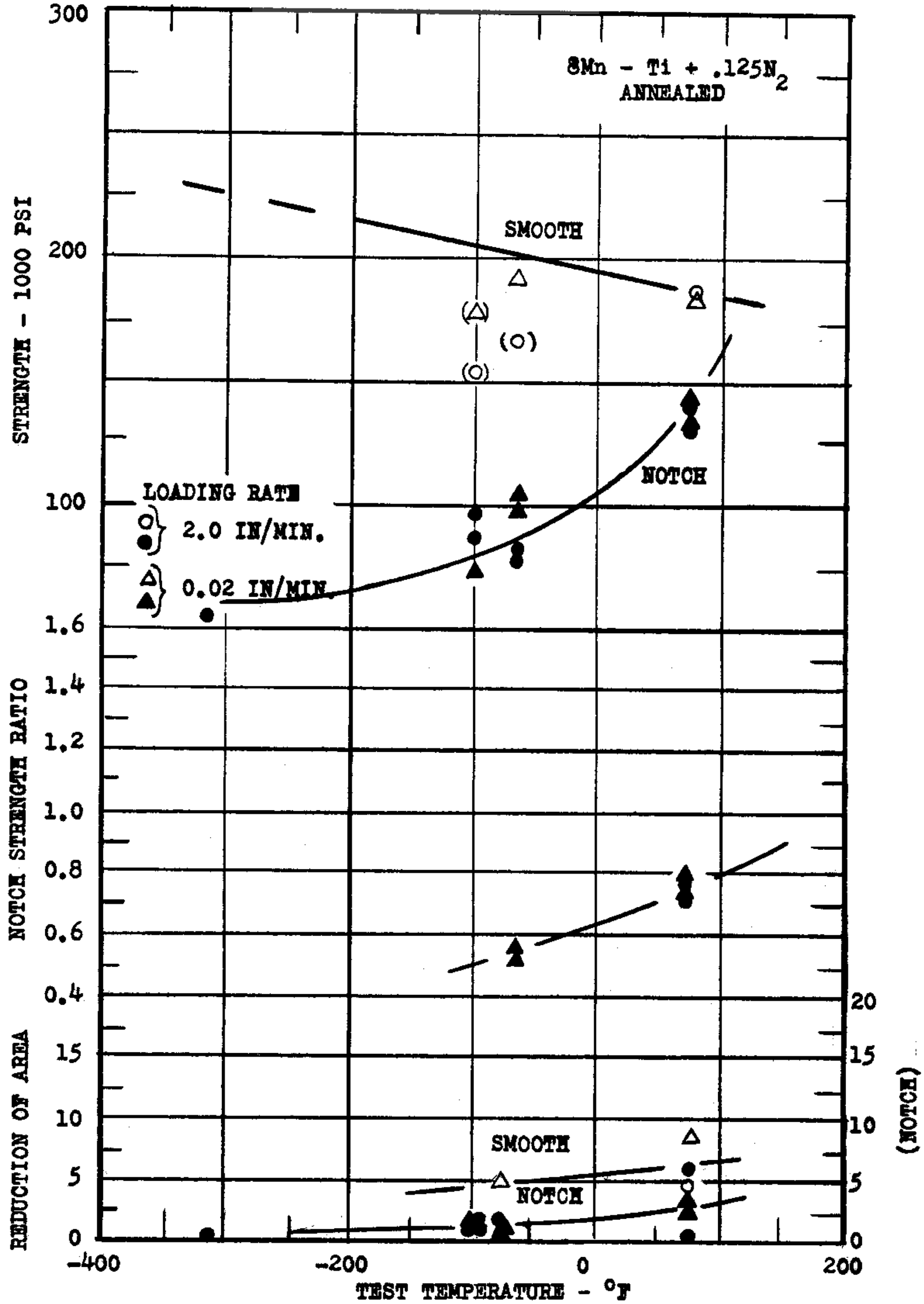


FIG. 144 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8Mn - Ti + .125N_2 - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

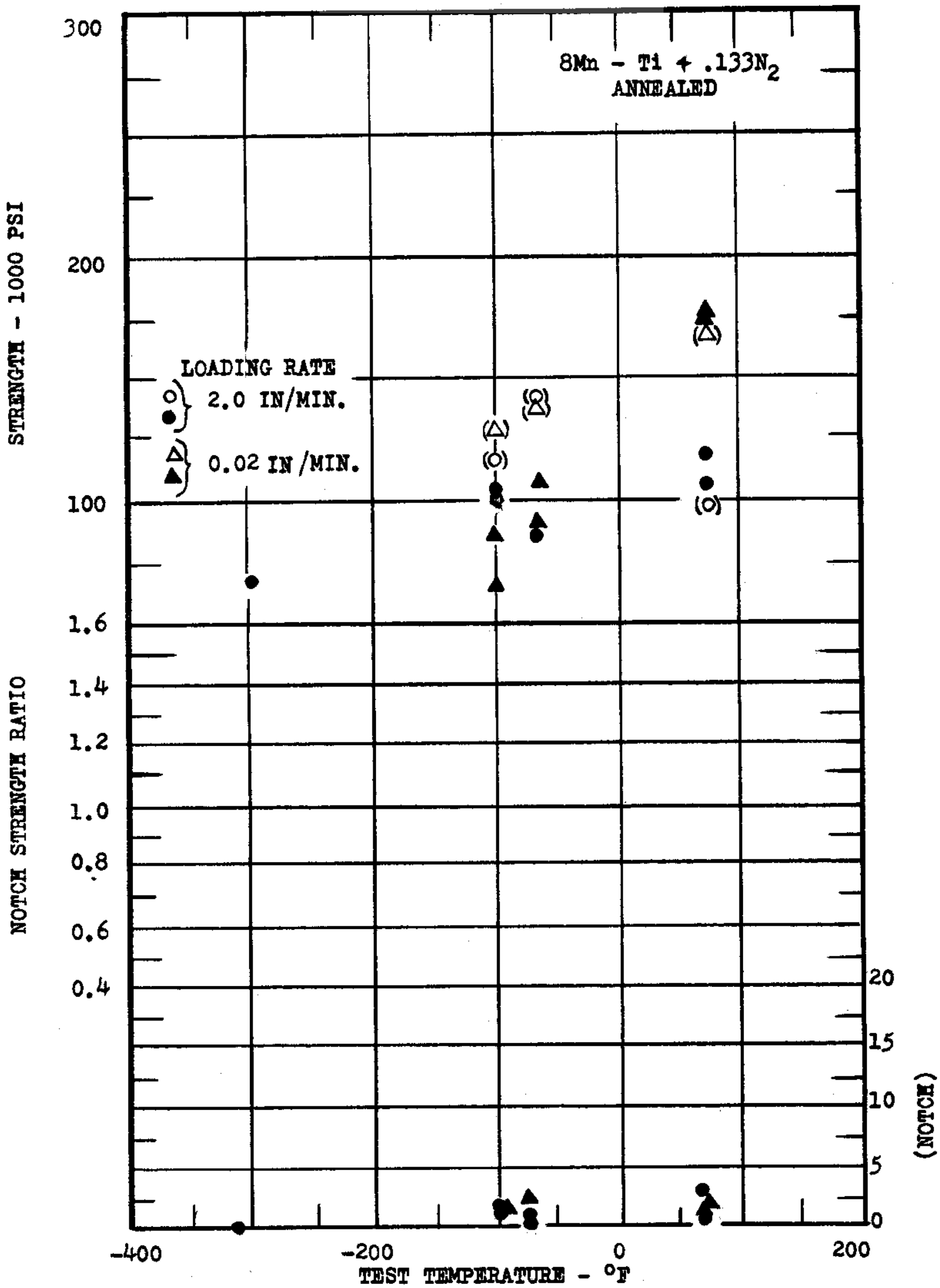


FIG. 145 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOYS AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8Mn - Ti + .133% N_2 - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

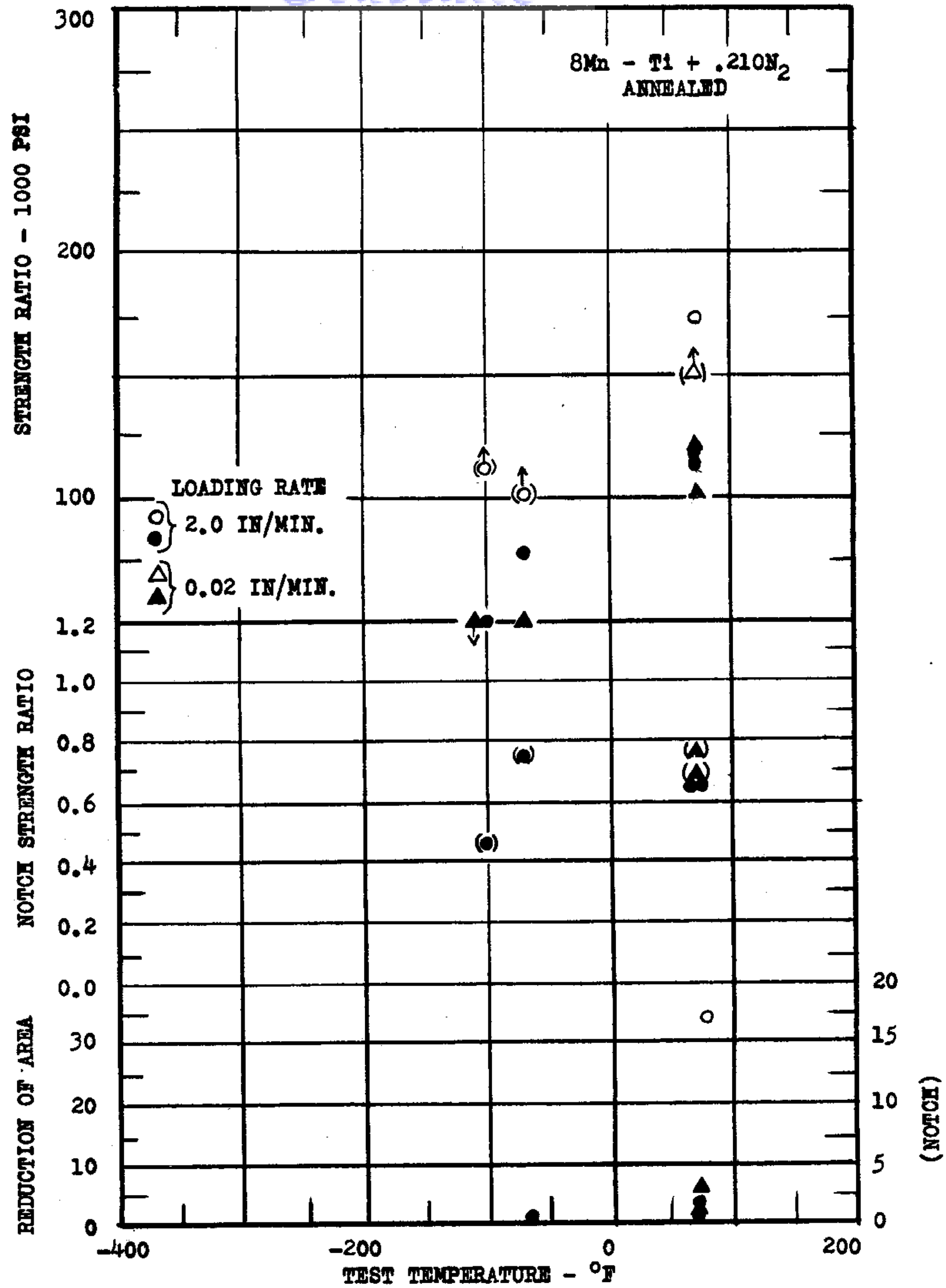


FIG. 146 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8Mn - Ti + .210N_2 - ANNEALED.
SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r ≤ 0.002 IN.

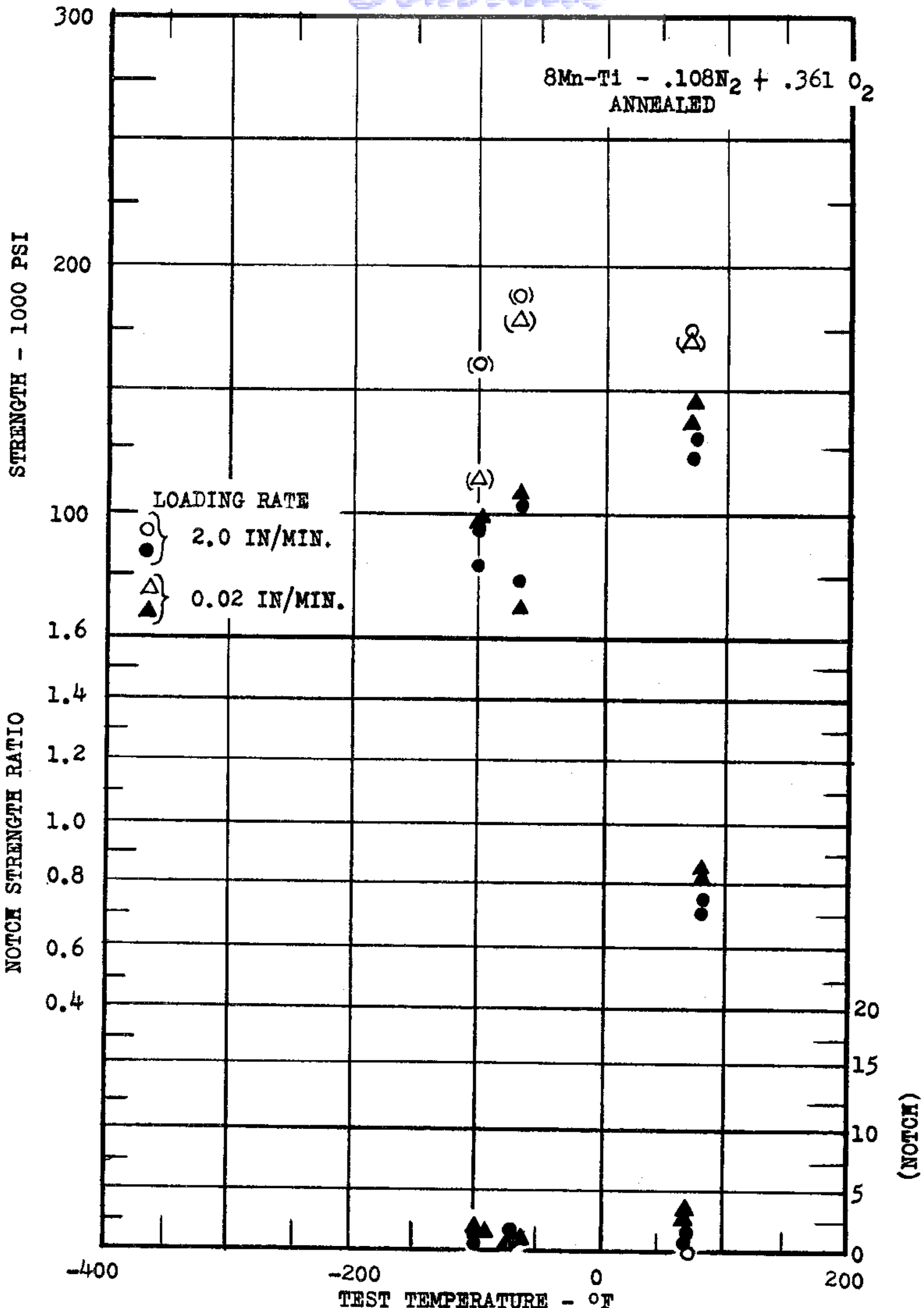


FIG. 147 THE TENSILE AND NOTCH PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE.
ALLOY: 8Mn - Ti - .108N_2
SPECIMEN: 0.3 IN.DIAM. 50% NOTCH. r = 0.002 IN.

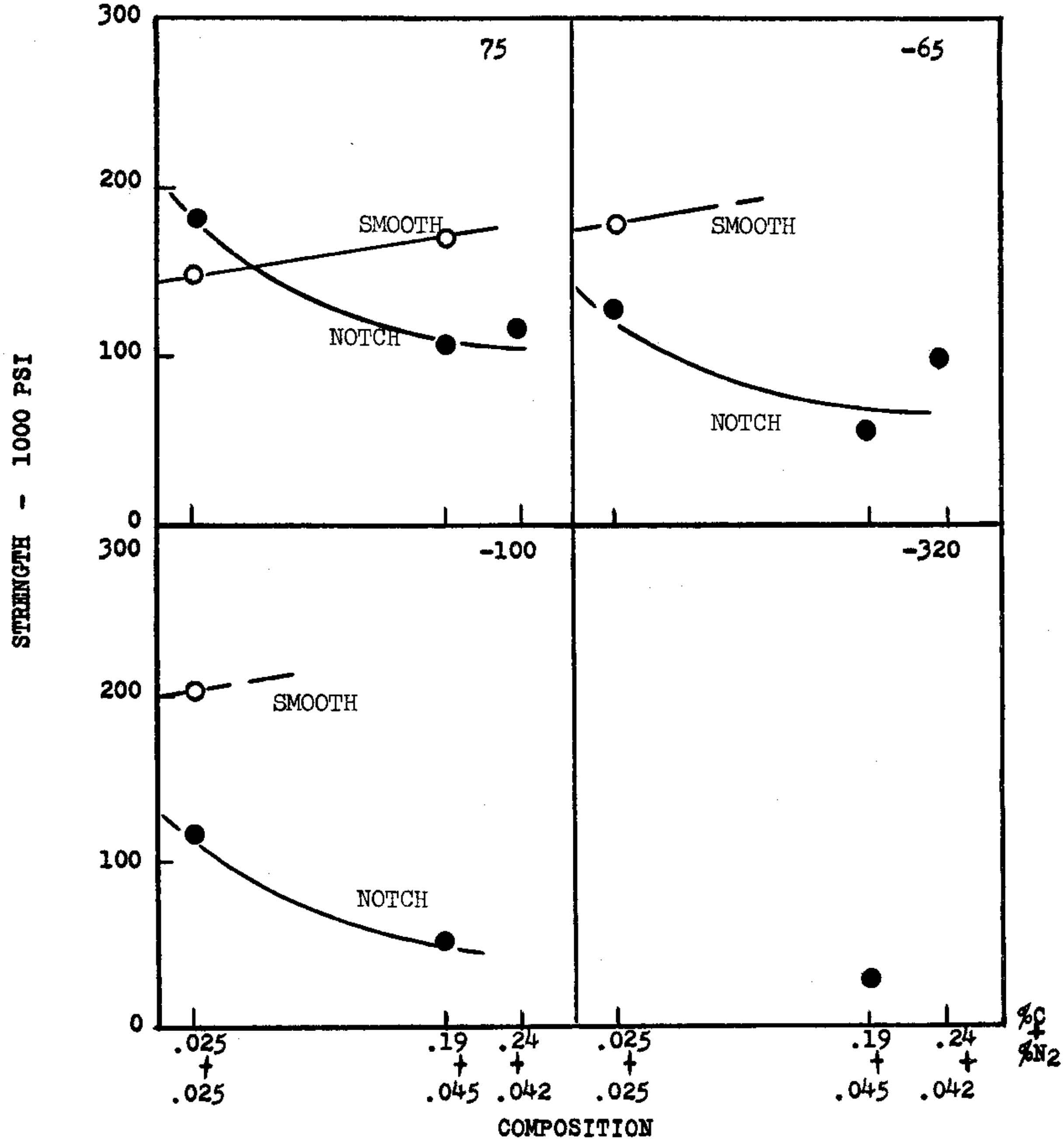


FIG. 148. THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 1. (cf. FIGURE 128)

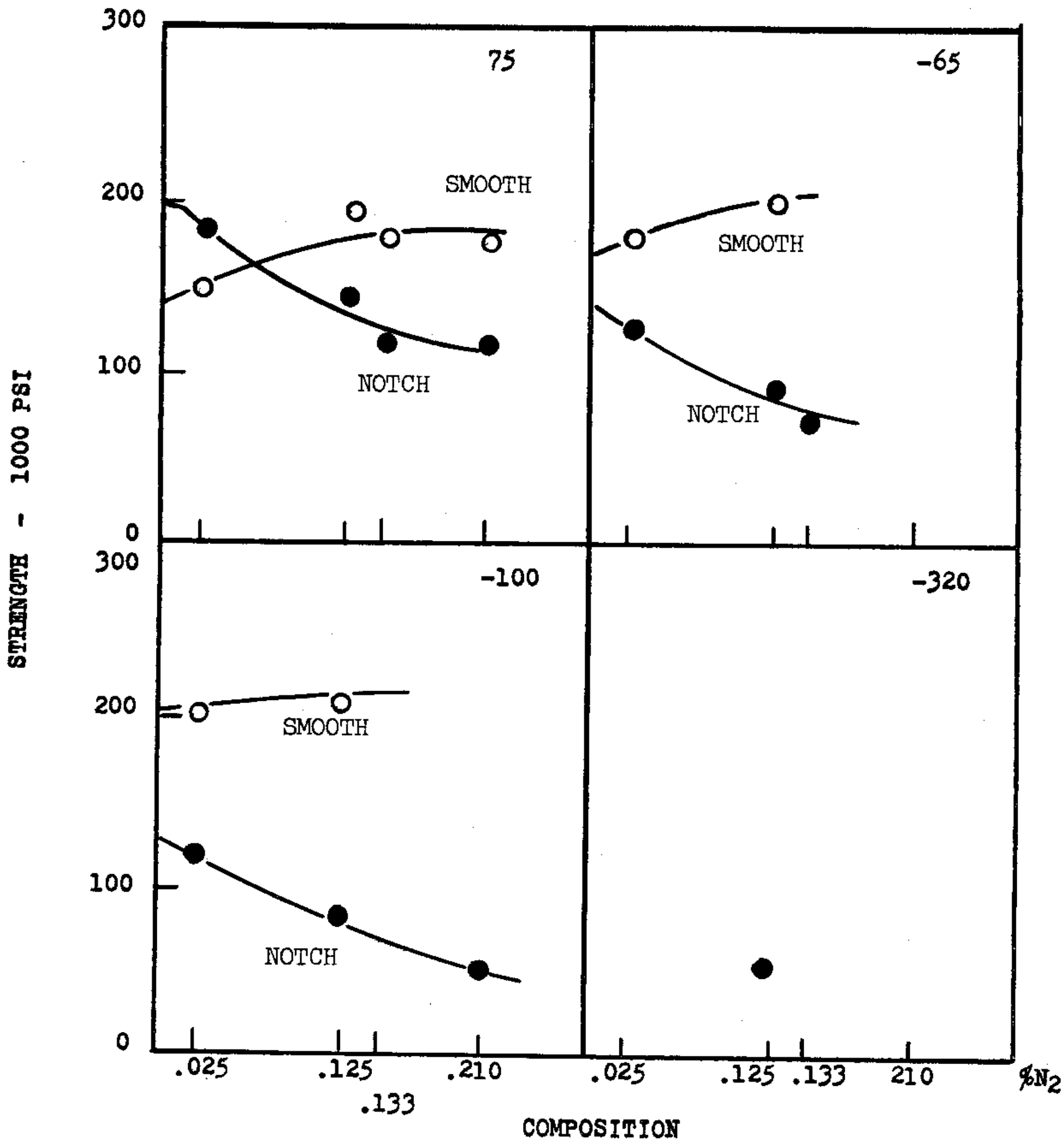


FIG. 149 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 2. (cf. FIGURE 128).

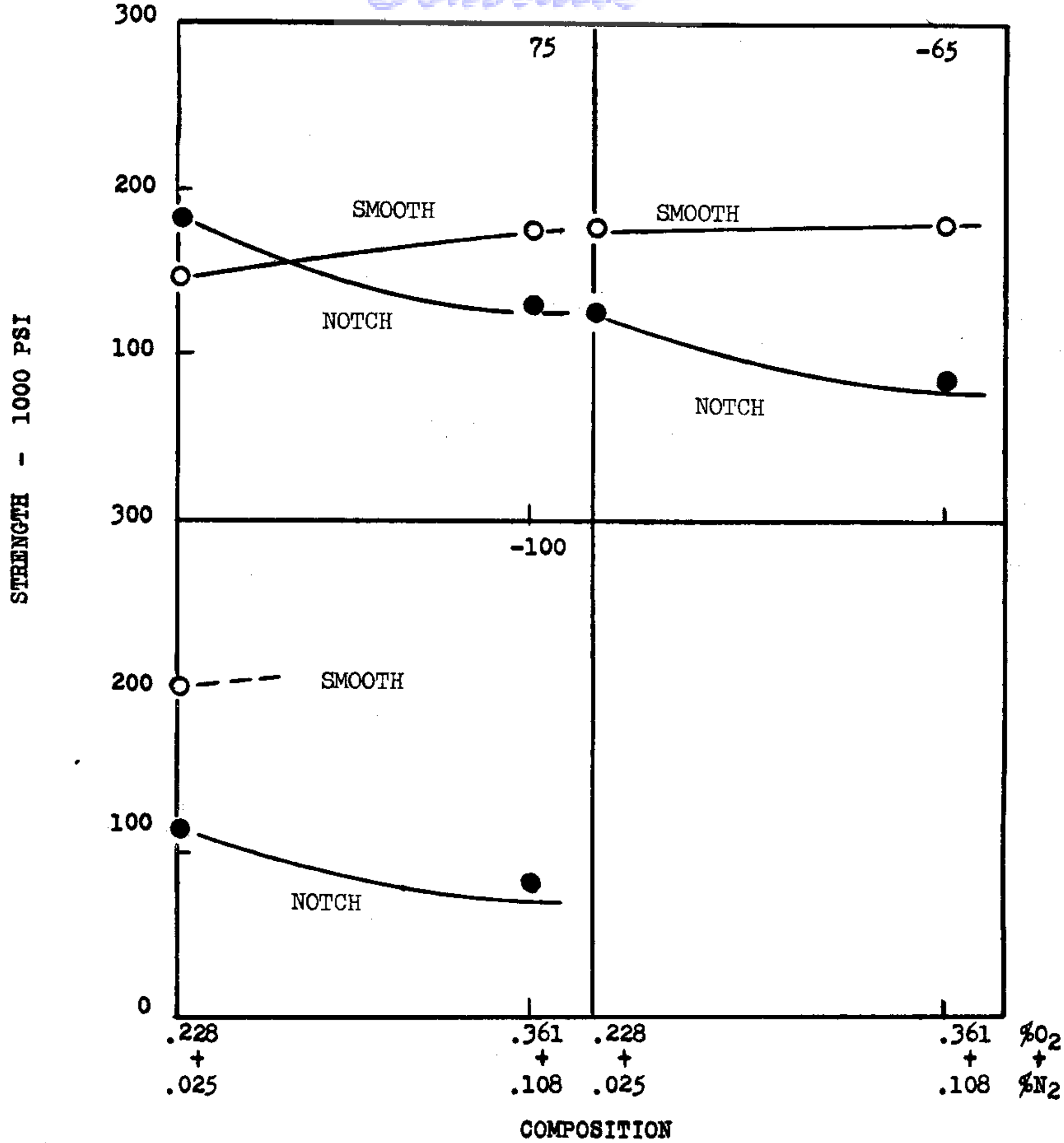


FIG. 150 THE VARIATION OF THE TENSILE AND NOTCH STRENGTHS ALONG TERNARY SECTION NO. 3 (cf. Figure 128)

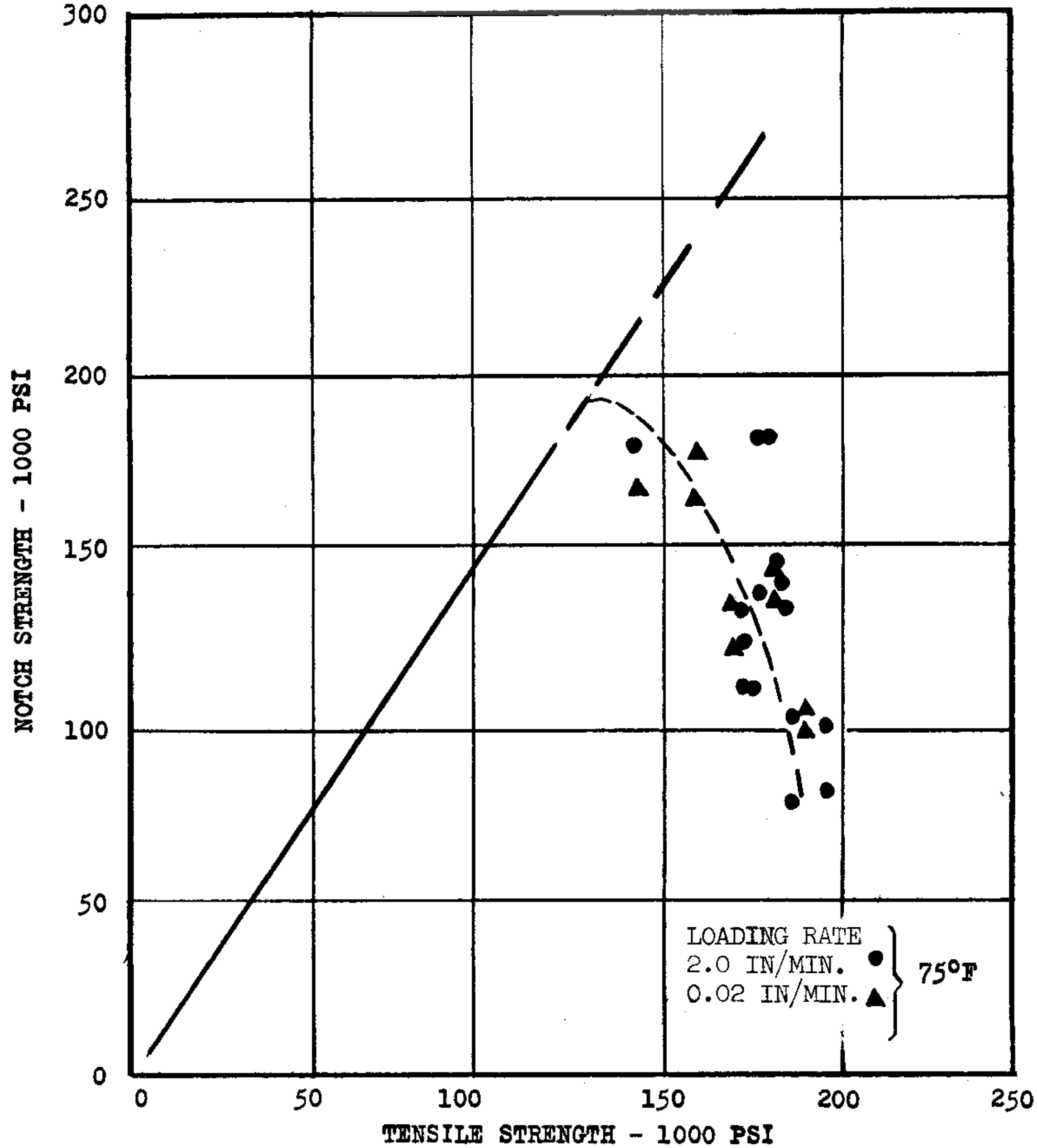


FIG. 151 .THE NOTCH STRENGTH VS. THE TENSILE STRENGTH AT 75°F.
ALLOYS: 8Mn - Ti.

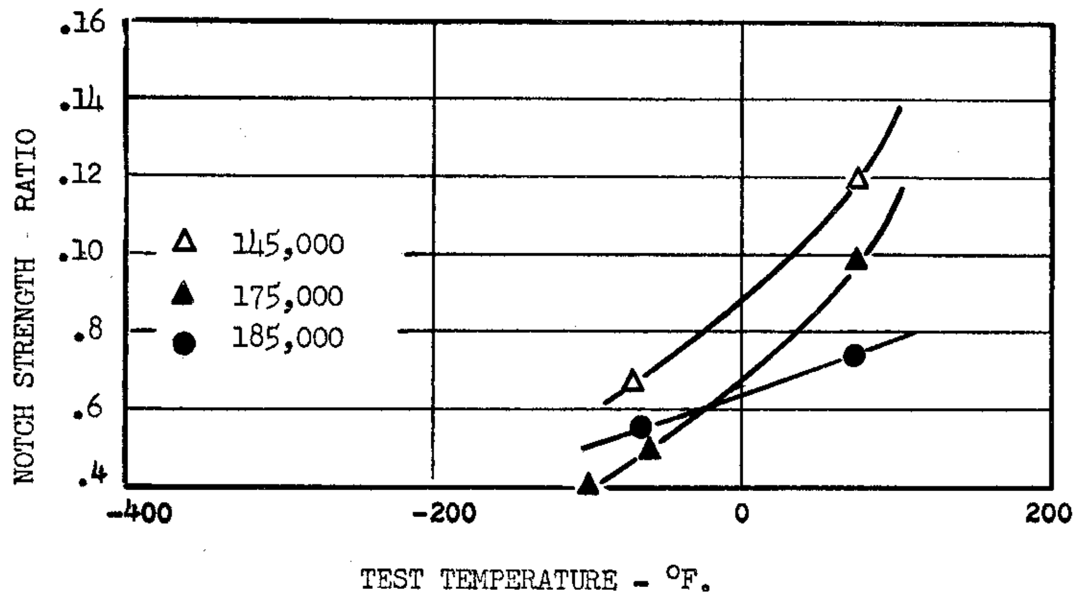


FIG. 152 NOTCH STRENGTH RATIO VS. TEST TEMPERATURE VS. TENSILE STRENGTH AT 75°F. ALLOY: 8 Mn - Ti.

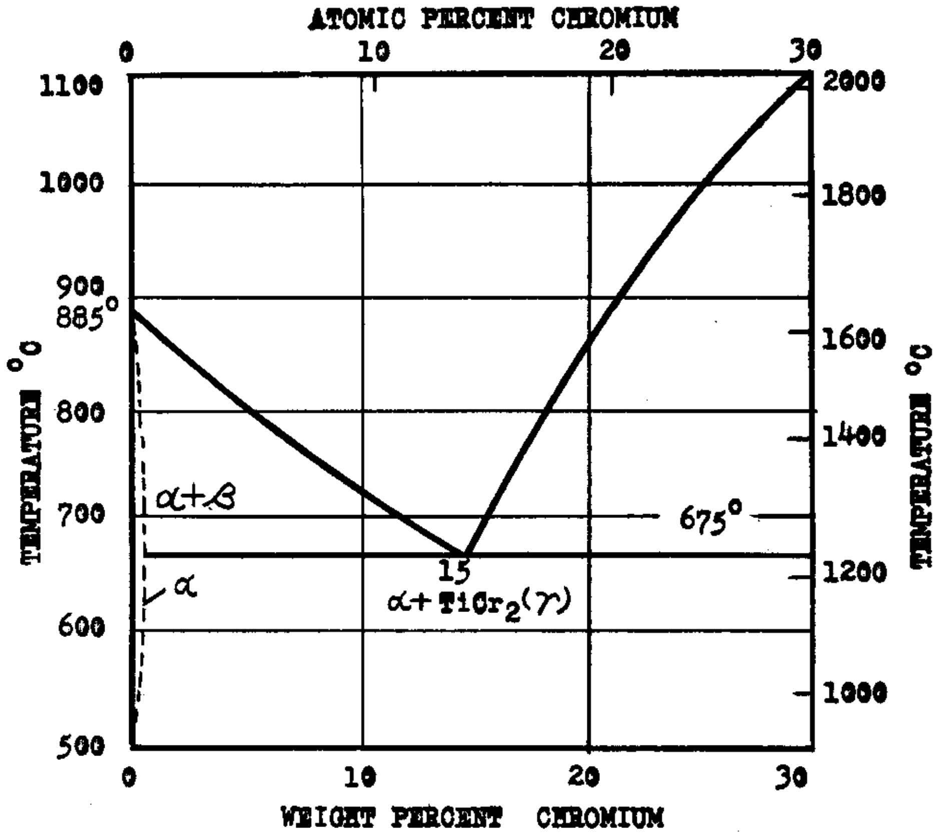
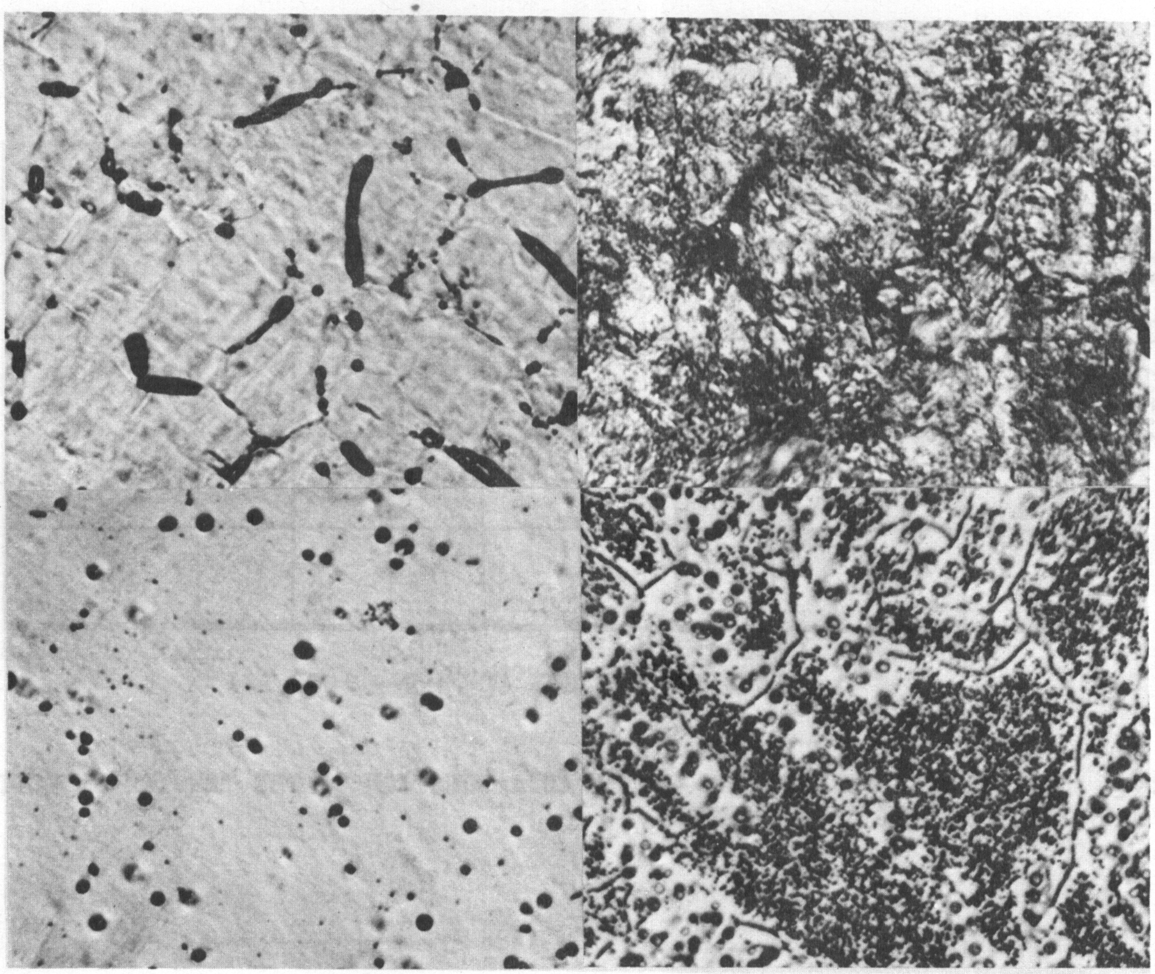


FIG. 153 PHASE EQUILIBRIA IN THE SYSTEM Ti - Cr.



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FIGS. 154 TO 157 MICROSTRUCTURES OF THE INDICATED 15% Cr - Ti ALLOYS. ELECTROPOLISHED. KELLER'S ETCH.

FIG. 154 AS FORGED x 500.
FIG. 155 ANNEALED x 1000.
FIG. 156 0.055%C x 500 - AS FORGED.
FIG. 157 0.27%N_2 x 500 - AS FORGED.

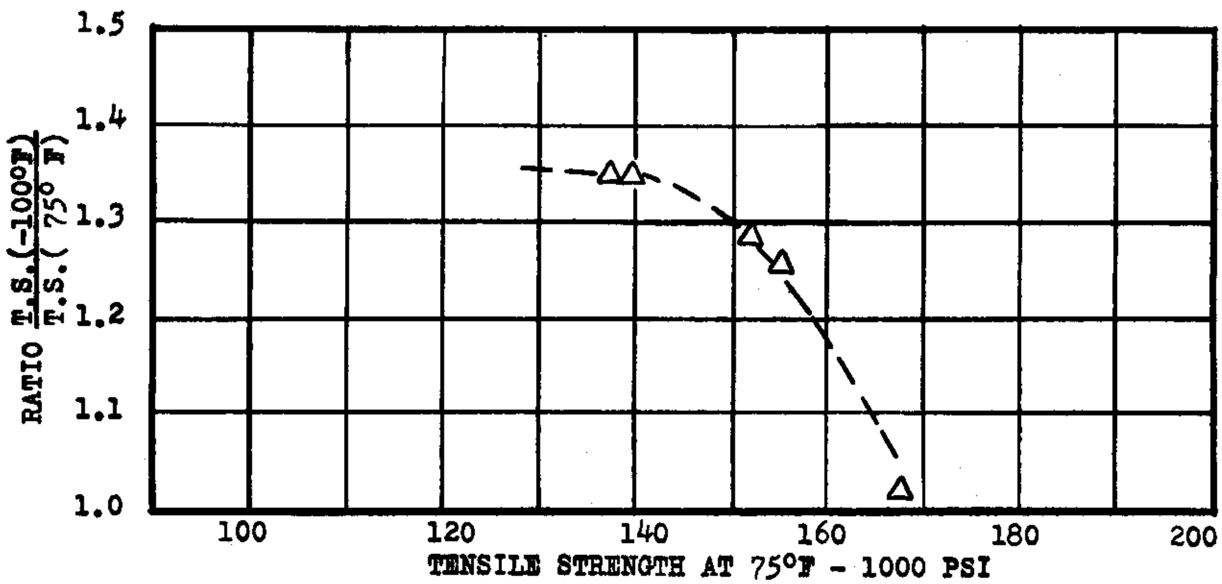

FIG. 158 THE TENSILE STRENGTH AT -100°F AS A FUNCTION OF THE TENSILE STRENGTH AT 75°F. 15% Cr - Ti ALLOY.

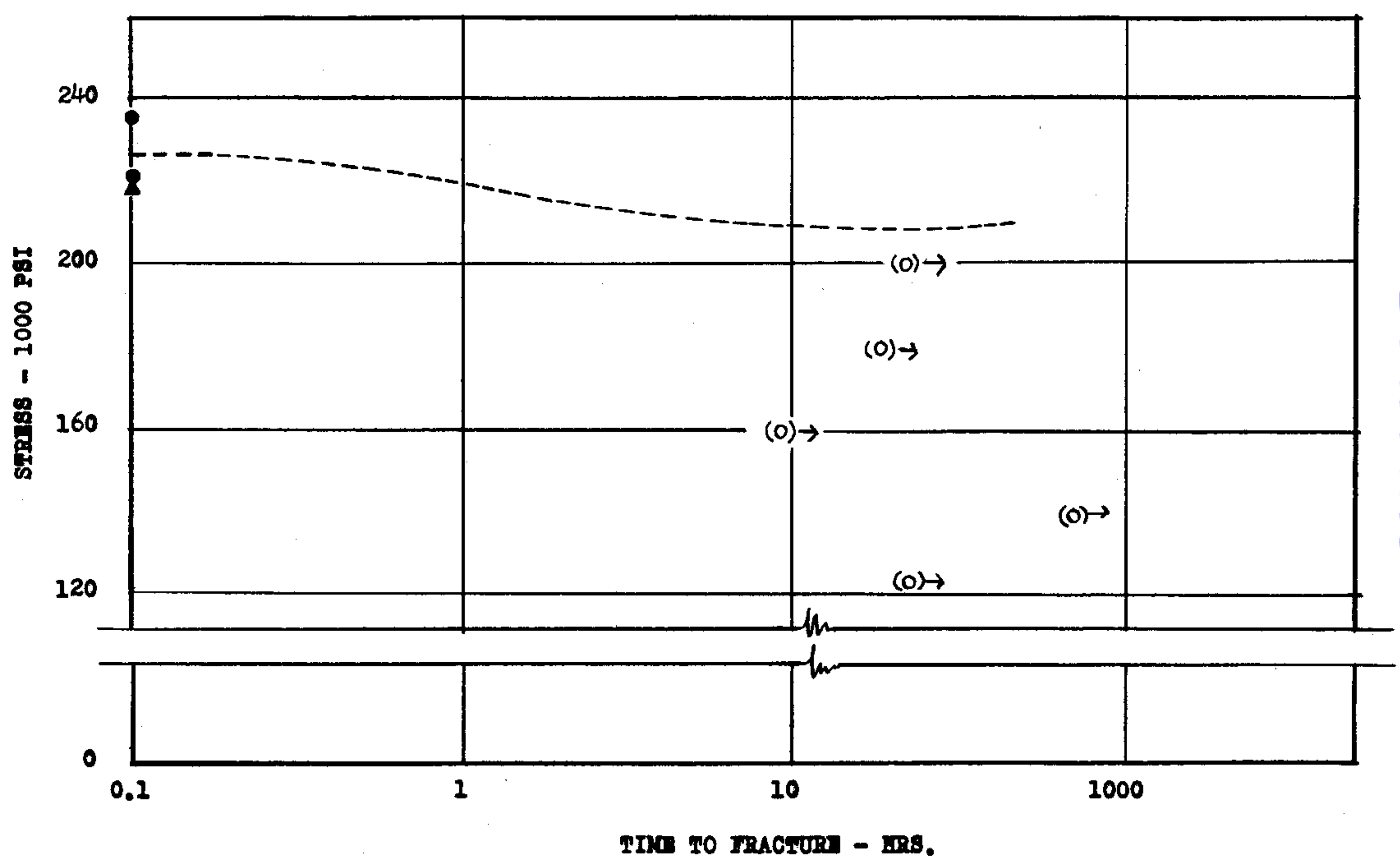

FIG. 159 THE NOTCH STRENGTH AS A FUNCTION OF THE TIME OF SUSTAINED LOAD TO FRACTURE AT 75° F. 15% Cr - Ti ALLOY.

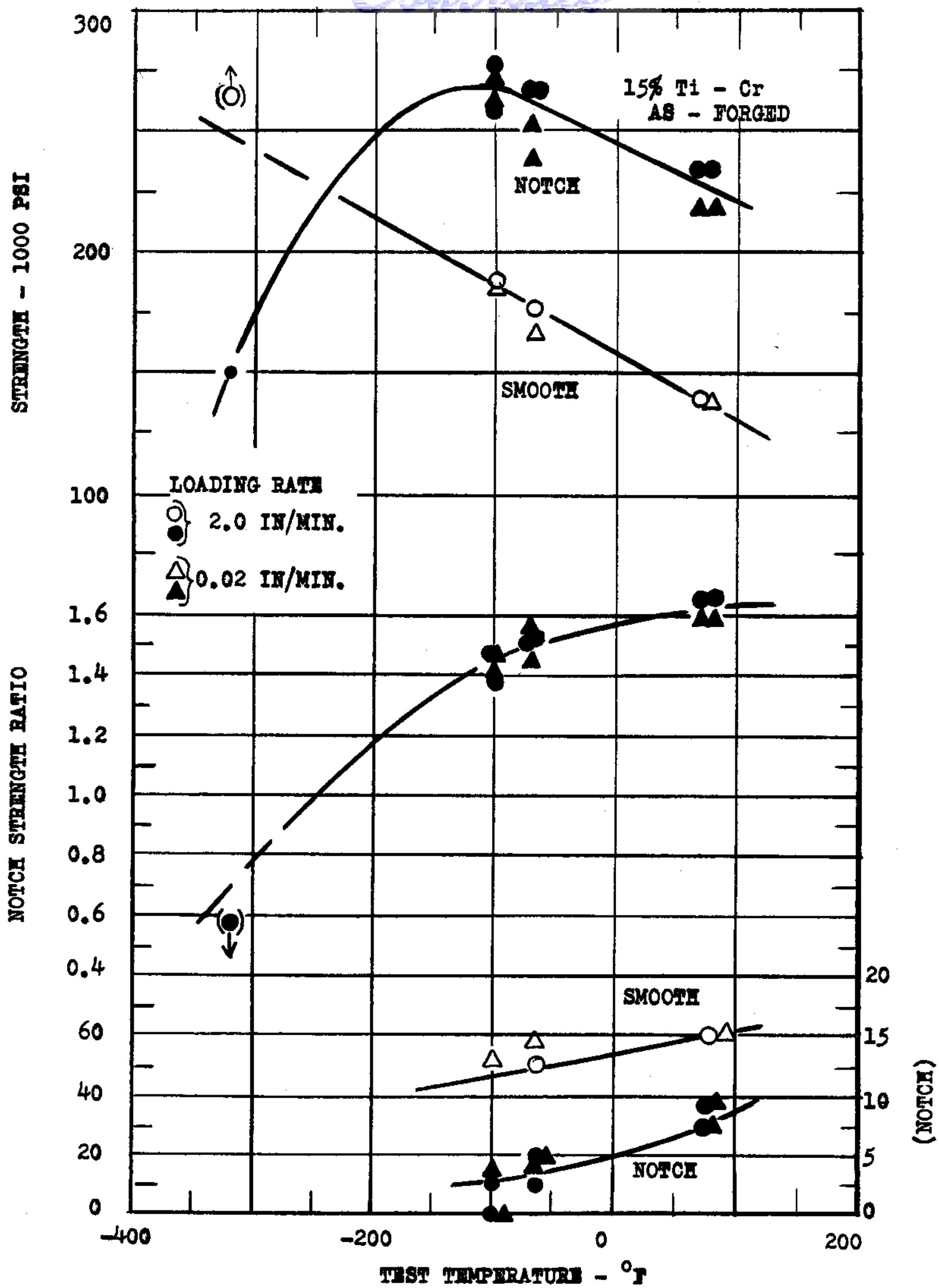

FIG. 160 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 15% Cr - Ti - AS FORGED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r≤0.002IN.

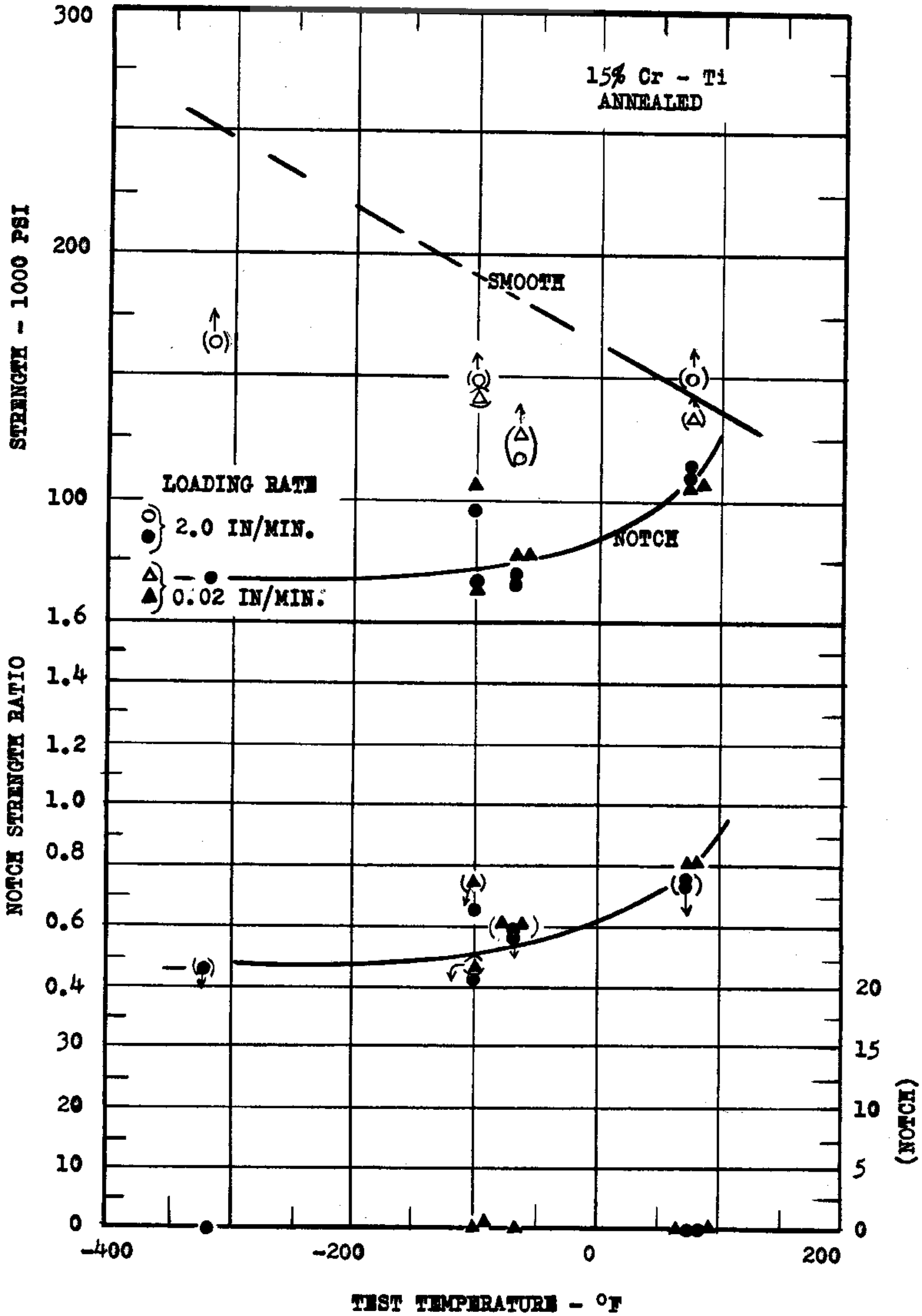

FIG. 161 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 15% Cr - Ti - ANNEALED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r≤0.002IN.

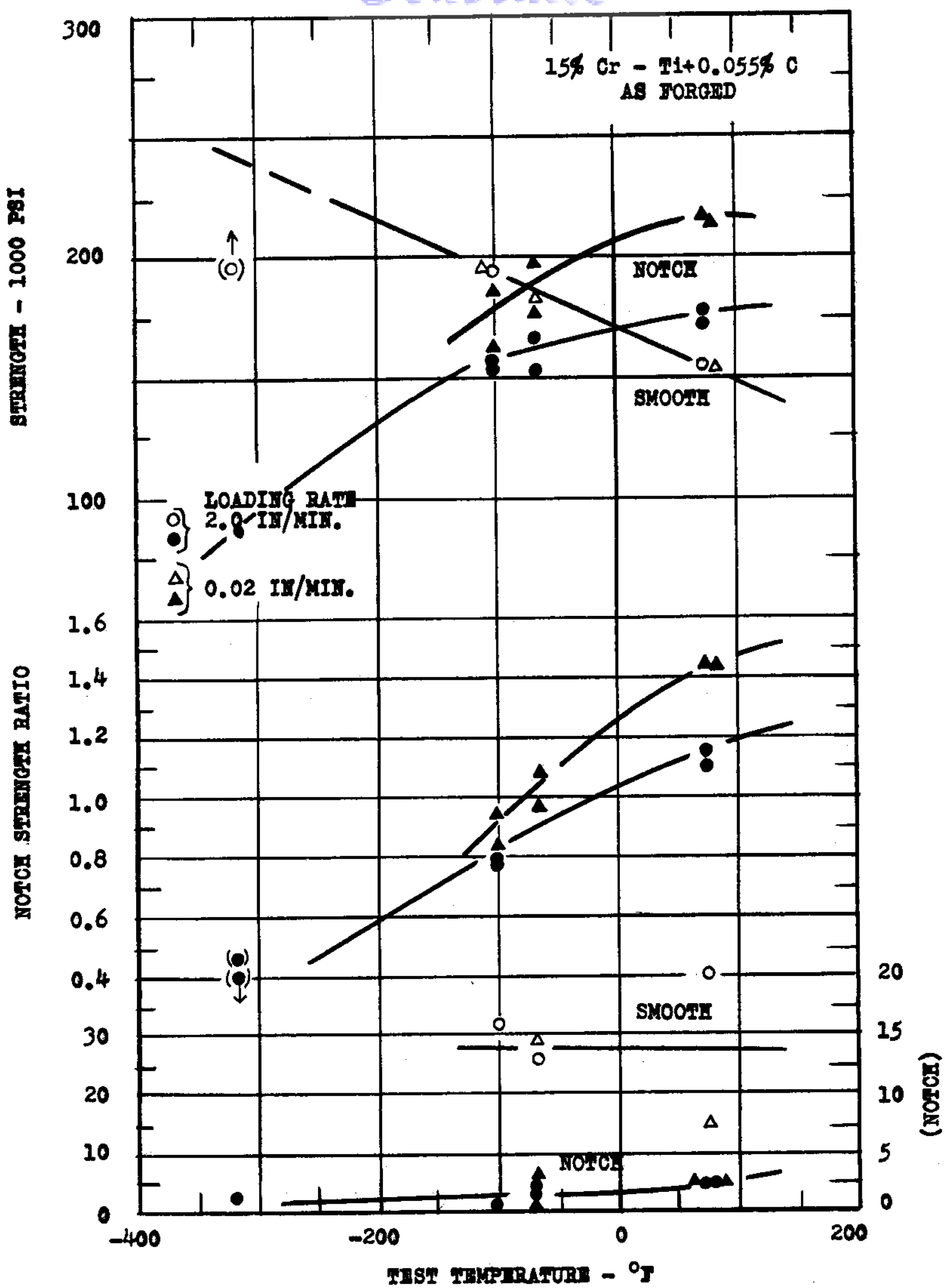

FIG. 162 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 15% Cr - Ti + 0.055% C - AS FORGED. SPECIMEN: 0.3 IN. DIAM. 15% NOTCH. r ≤ 0.002 IN.

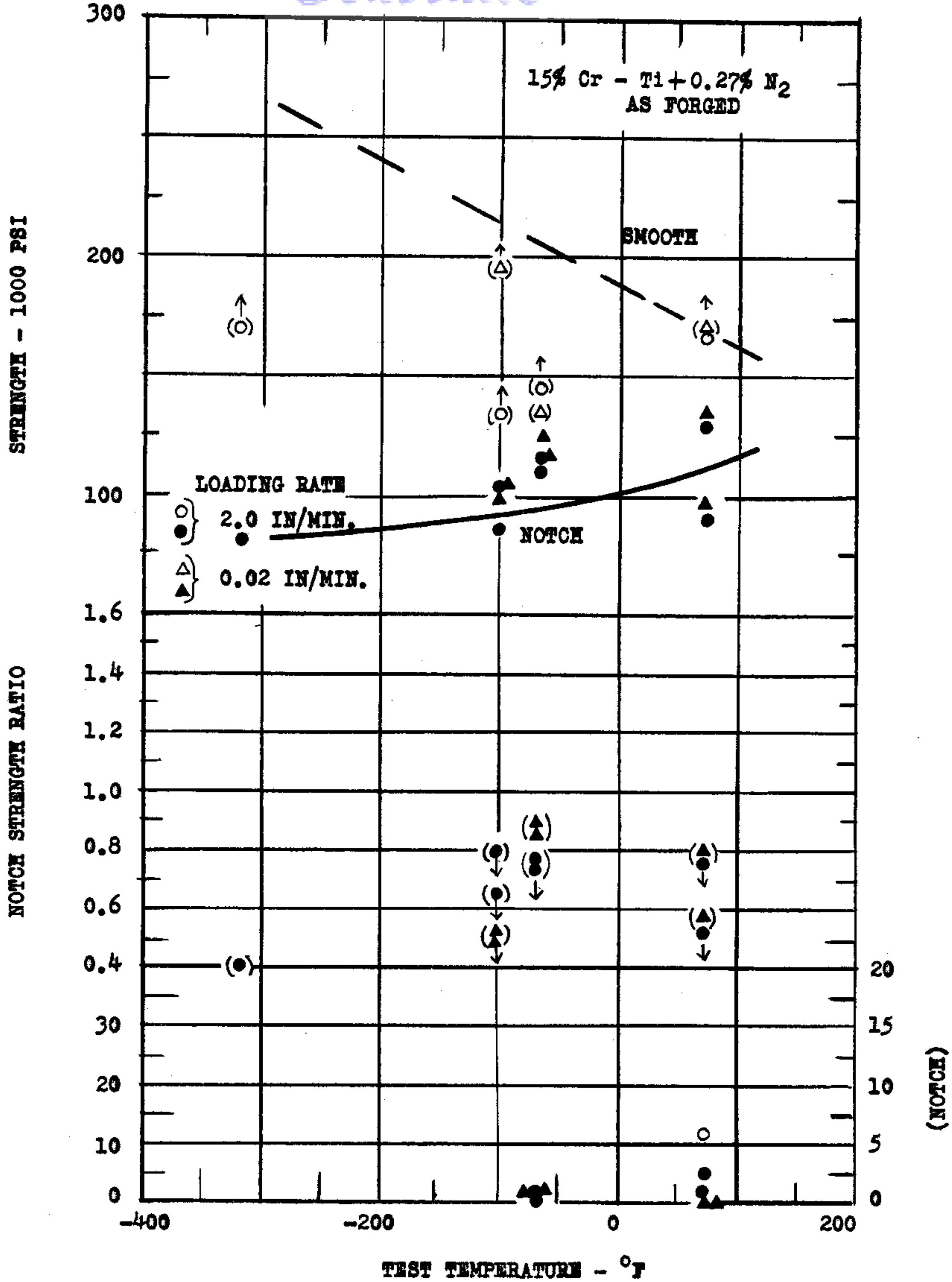

FIG. 163 THE TENSILE AND NOTCH TENSILE PROPERTIES OF THE INDICATED ALLOY AS A FUNCTION OF TEST TEMPERATURE. ALLOY: 15% Cr - Ti+0.27% N_2 - AS FORGED. SPECIMEN: 0.3 IN. DIAM. 50% NOTCH. r≤0.002 IN.

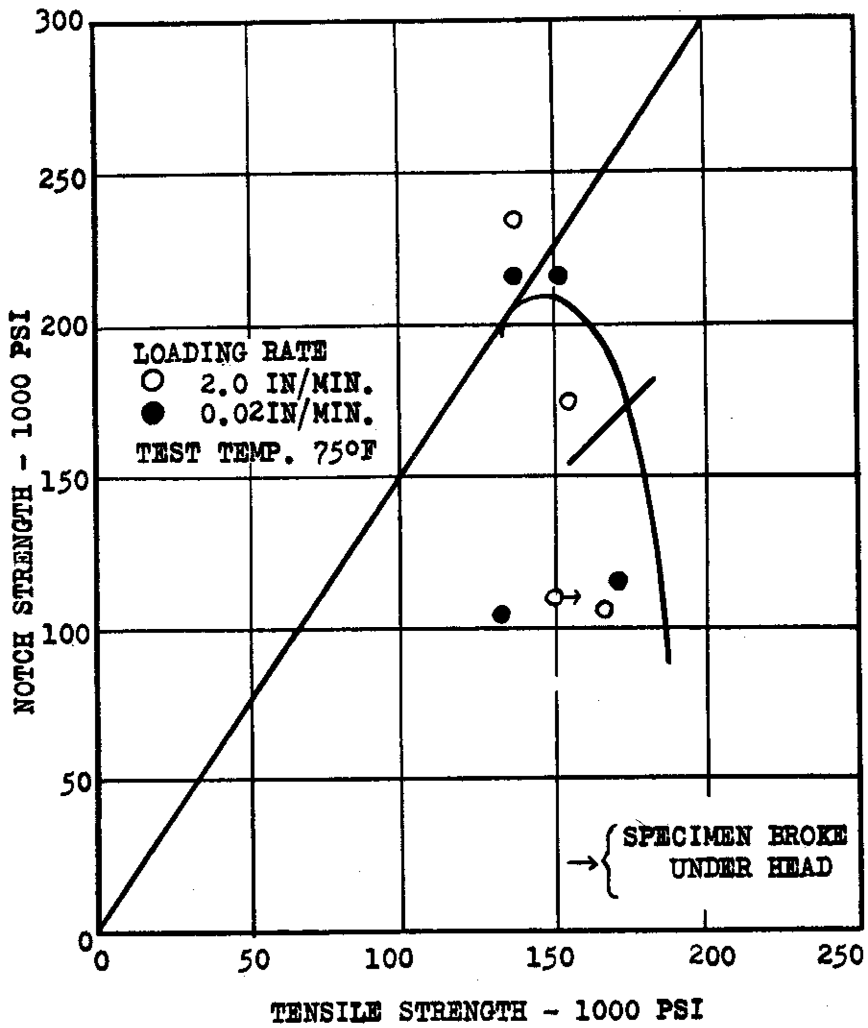

FIG. 164 THE NOTCH STRENGTH VS. THE TENSILE STRENGTH AT 75°F. ALLOY: 15% Cr - Ti.

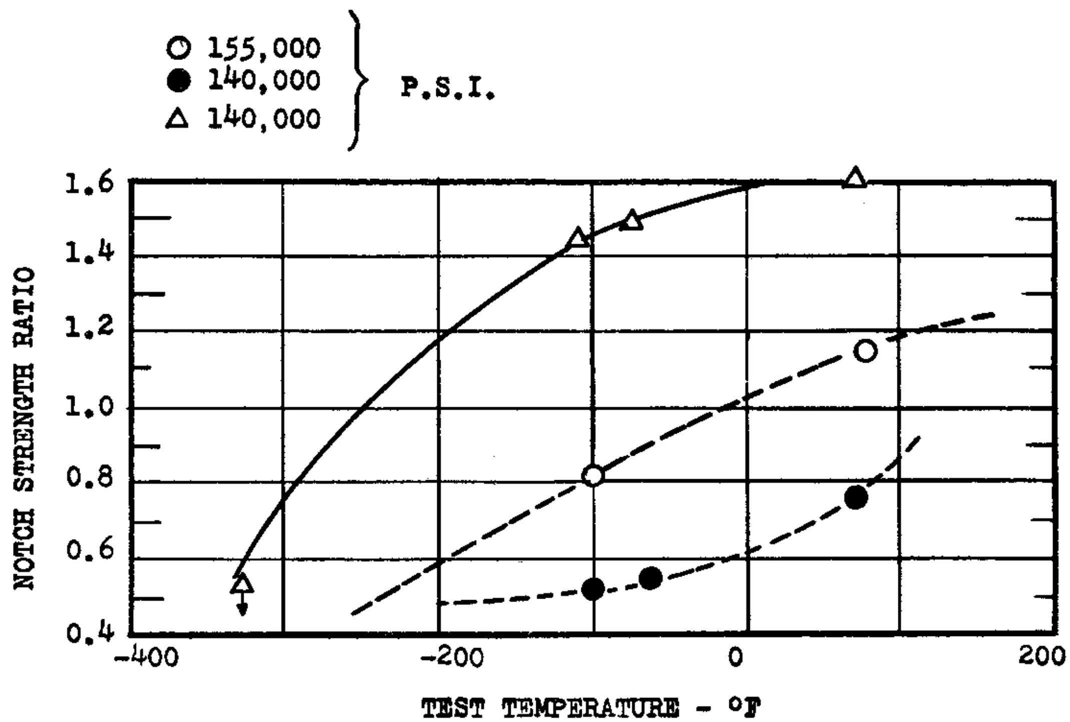

FIG. 165 THE NOTCH STRENGTH RATIO. VS. TEST TEMPERATURE V.S. TENSILE STRENGTH AT 75°F. ALLOY 15% Cr - Ti.

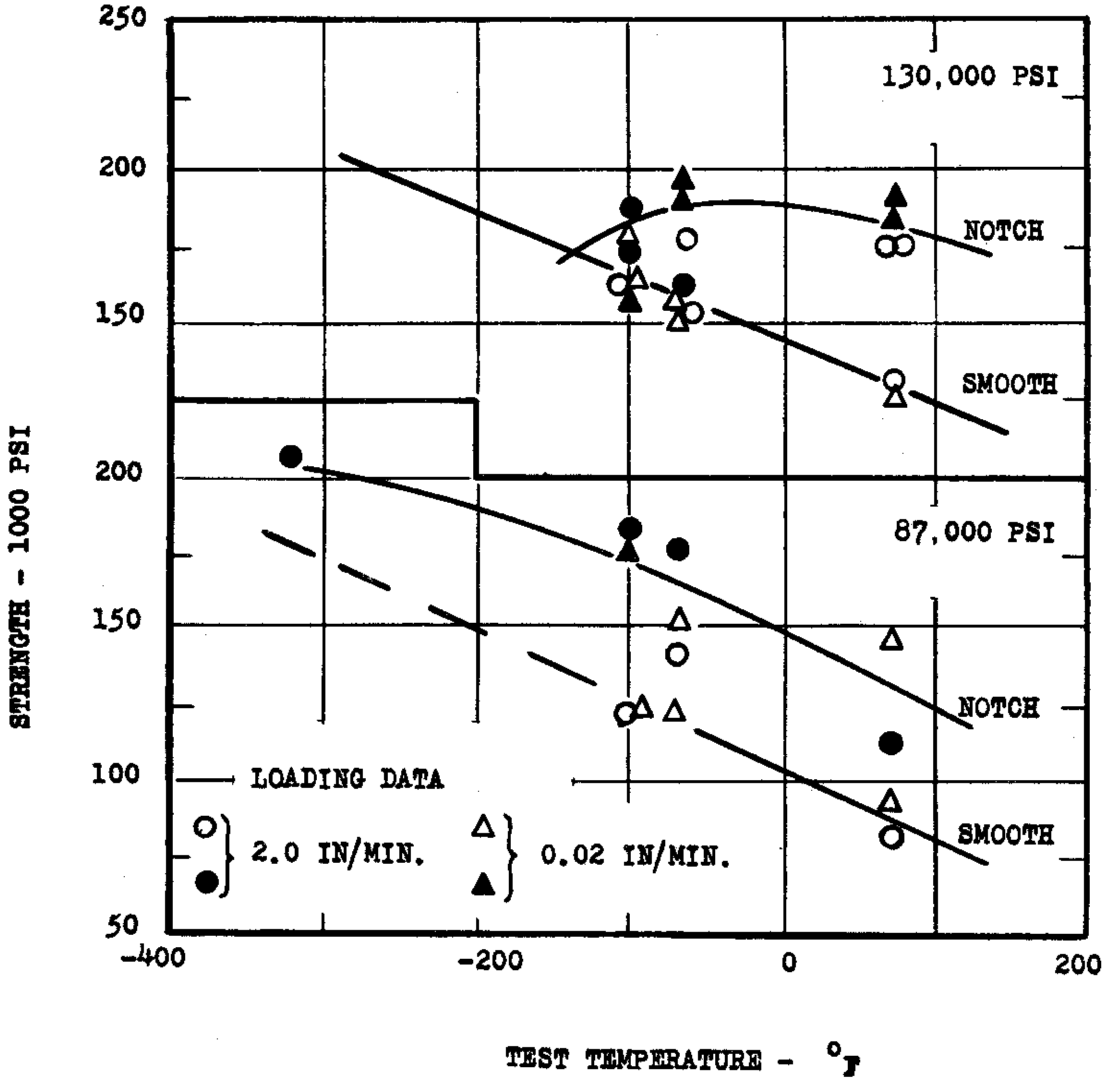

FIG. 166. NOTCH STRENGTH BEHAVIOR AS A FUNCTION OF TENSILE STRENGTH (75°F) FOR A 4 AL - 4 Mn ALLOY.

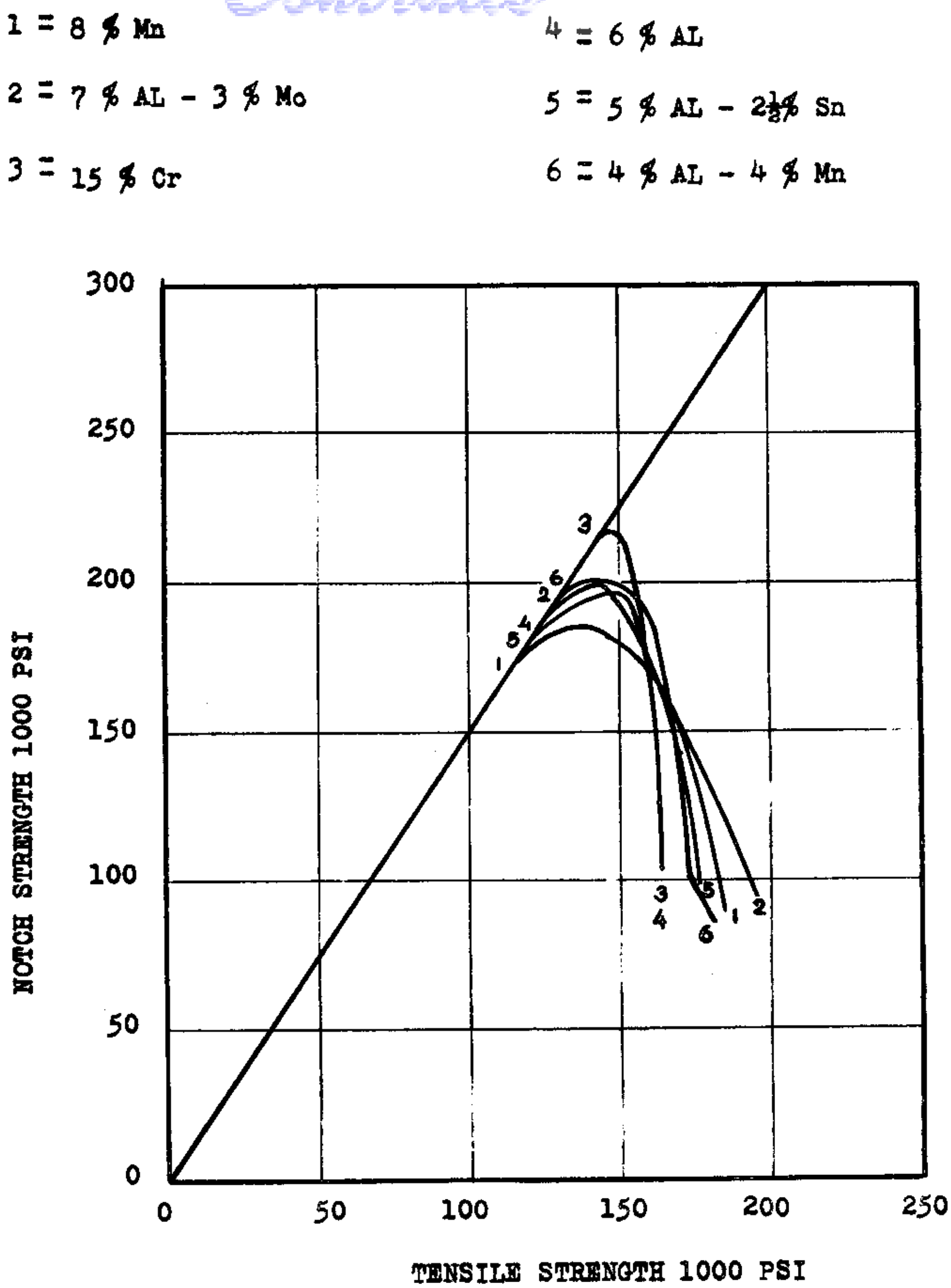

FIG. 167. NOTCH STRENGTH AS A FUNCTION OF TENSILE STRENGTH FOR THE INDICATED TITANIUM ALLOYS.

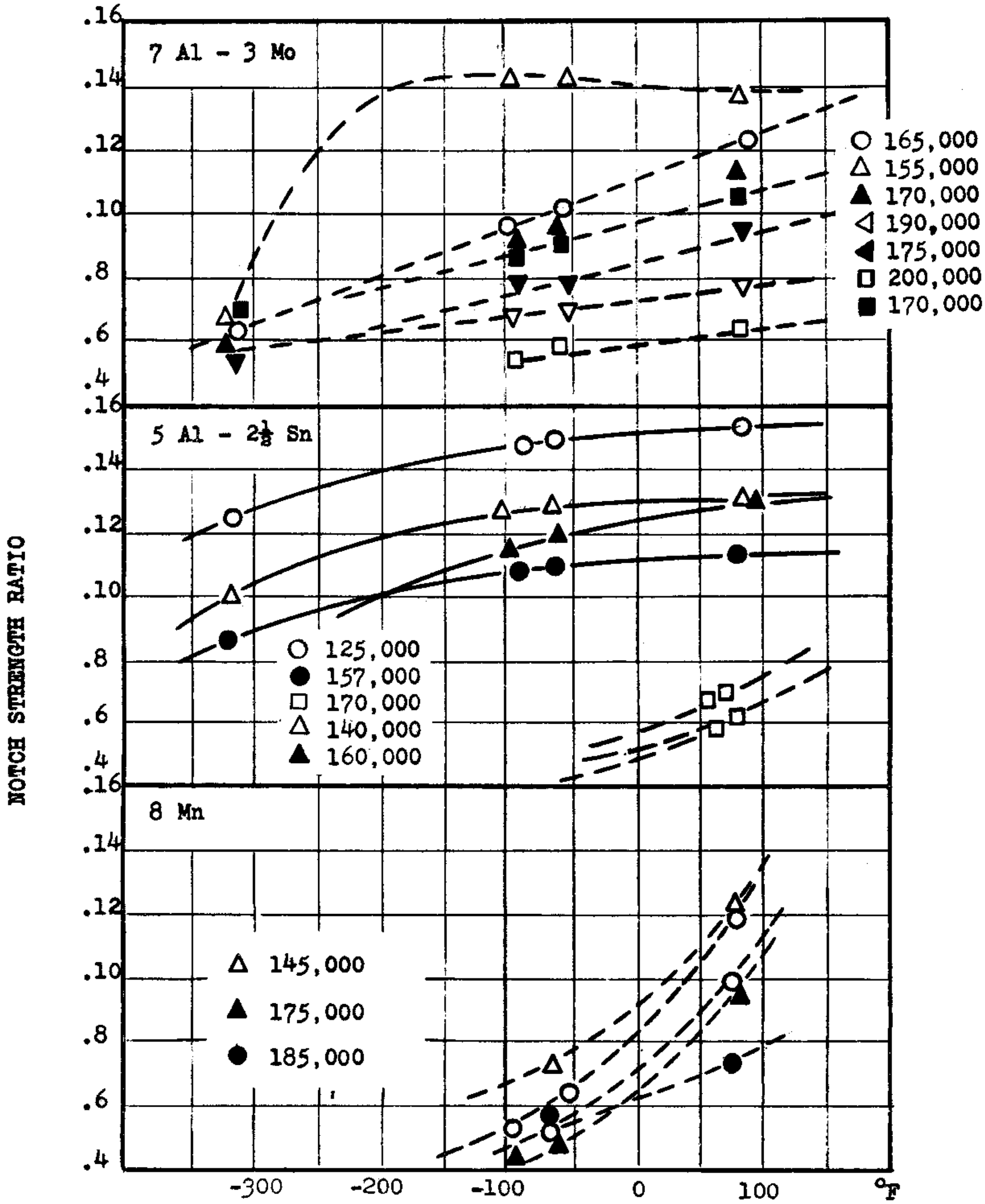

FIG. 168. DUCTILE - BRITTLE TRANSITION IN THE NOTCH TENSILE TEST FOR INDICATED ALLOYS.

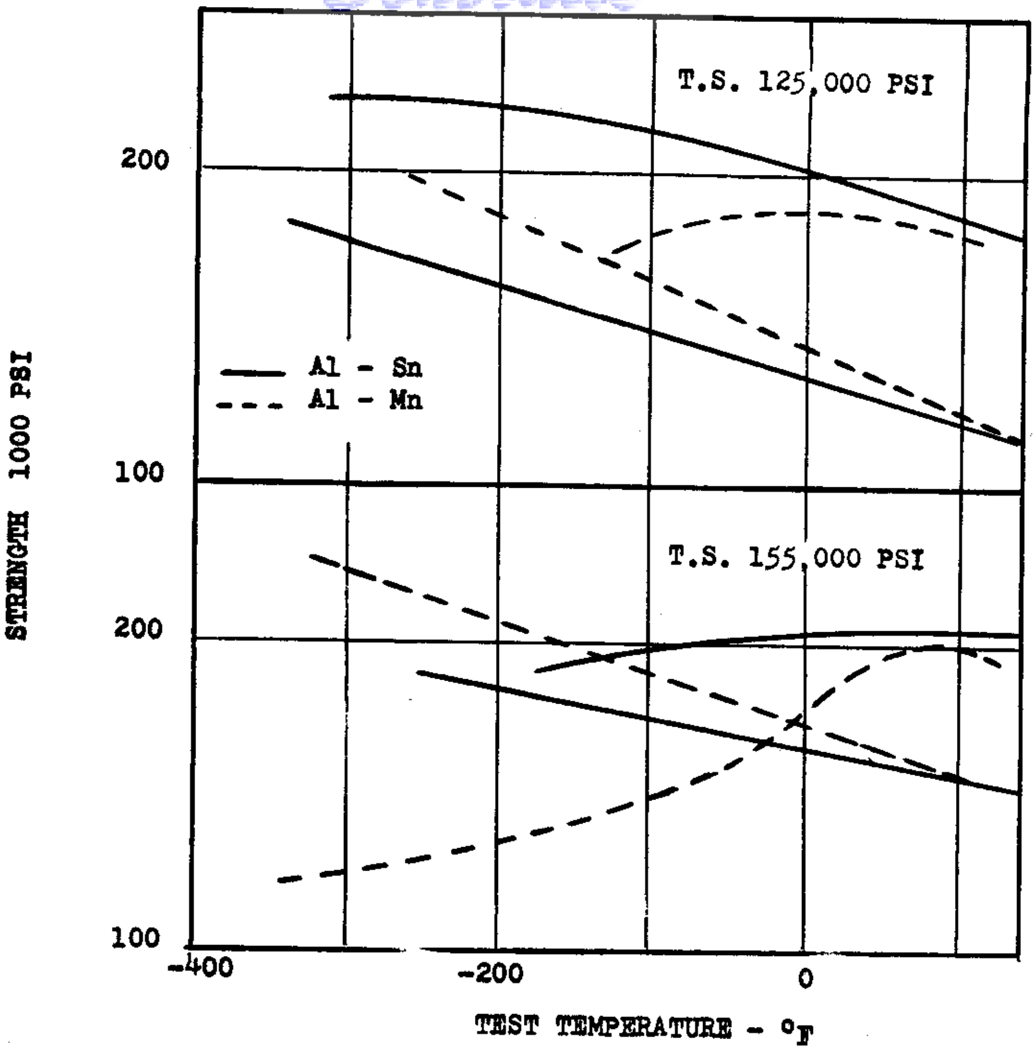

FIG. 169 THE TENSILE AND NOTCH TENSILE PROPERTIES OF TITANIUM ALLOYS AS MODIFIED BY ALLOY CONTENT. (THE ROOM TEMPERATURE TENSILE STRENGTH IS THE POINT OF REFERENCE).

TABLE I. Chemical Analyses of Contaminating and Alloying Additions and Inert Atmosphere

A. Acheson Graphite	Maximum Ash Maximum Iron	0.2% 0.05%
B. TiO_2	Water Soluble Salt Arsenic Iron Lead Zinc	0.05% 0.0002% 0.02% 0.03% 0.01%
C. TiN	Ca H_2 C Mg Fe Si	0.6% 0.2% 0.3% 0.5% 0.1% 0.7%
D. Helium		99.99% Pure
E. Argon		99.99% Pure
F. Tin		99.9 nom.
G. Chromium		99.3 nom.
H. Aluminum		99.2 Al nom.
I. Manganese		99.9 nom.
K. Molybdenum		99.9 nom.

TABLE II. The Forging and Annealing Schedules for the Several Titanium Materials

Alloy	Forging Temp. (°F)	Finishing Temp. (°F)	Annealing Temp. (°F)
5 Al - 2-1/2 Sn	1850	Min. Possible*	1450
6 Al	2000	Min. Possible*	1450
7 Al - 3 Mo	2000	Min. Possible*	**
4 Al - 4 Mn	1750	Min. Possible*	**
8 Mn	1850	Min. Possible*	**
15 Cr	1750	Min.Possible *	**

*Estimated as 1450°F.

**Heated to 1300°F - 30 min. furnace cool to 1000°F air cool.

TABLE III

Chemical Analyses of the 5 Al - 2-1/2 Sn - Ti Alloys

Ingot	Percent			
	C	N	O	H (ppm)
28	.02	.015	.052	33
28a	--	--	--	--
81	.065	.025	.097	57
85	.02	.125	.116	220
87	.01	.220	--	--
88	.02	.04	.230	74
83	.105	.155	--	--
86	.04	.235	.056	--
78	.03	.155	.214	97

TABLE IV. Numerical Data for the 5 Al - 2-1/2 Sn - Ti Alloys

Condition of Material	Cross-Head Movement (In./Min)	Test Temp. (°F)	Tensile Str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio: Referred to Test. Temp.		Notch Strength Ratio: Referred to Room Temp.		Reduction of Area (Per Cent): Notched		Reduction of Area (Per Cent): Unnotched	Elongation (%)	Hardness
Ingot No. 28	2.0	75	128.0	197.5	193.0	1.55	1.50	1.55	1.50	6.5	7.0	37.0		
		-65	145.5	211.0	213.0	1.45	1.45	1.65	1.65	3.0	4.5	37.0	11.5	
		-100	151.0	211.5	221.5	1.40	1.45	1.65	1.75	8.0	7.5	36.0	12.5	
As Forged		-320	181.5	225.0		1.25		1.75		5.5		30.5	12.5	
	0.02	75	124.5	194.5	191.5	1.55	1.55	1.55	1.55	5.0	6.5	40.0		
		-65	142.5	213.0	205.5	1.50	1.45	1.70	1.65	6.0	4.5	33.5	13.5	
		-100	144.0	2.5.5	211.0	1.50	1.45	1.75	1.70	7.0	6.0	33.5	15.0	
Ingot No. 282	2.0	75	117.5	173.5	173.5	1.50	1.50	1.50	1.50	7.5	8.0	36.0		
		-65	138.5	199.0	203.5	1.45	1.45	1.70	1.75	5.5	5.0	34.5		
		-100	140.0	224.0	213.0	1.60	1.50	1.90	1.80	4.5	4.5	32.0	20.5	
Annealed	0.02	75	115.0	177.0	172.5	1.55	1.50	1.55	1.50	6.5	5.0	37.0		
		-65	133.0	186.5	191.5	1.40	1.45	1.60	1.65	6.5	1.0	34.5	18.5	
		-100	137.0	198.0	182.5	1.45	1.35	1.70	1.60	3.5	4.5	33.0	33.0	
Ingot No. 81		75	140.0	180.5	181.5	1.30	1.30	1.30	1.30	3.5	3.5	38.5	16.5	
		-65	157.0	211.0	203.0	1.35	1.30	1.50	1.45	3.0	3.5	32.0	15.5	
		-100	163.0	205.5	201.5	1.25	1.25	1.45	1.45	2.5	2.5	28.0	13.5	
.065%C		-320	155.0*	201.5		1.30		1.45		2.5				
	0.02	75	139.0	221.0	221.5	1.60	1.60	1.60	1.60	5.5	4.0	30.5	19.0	
		-65	161.5	194.5	212.5	1.20	1.35	1.40	1.55	1.8	3.0	37.0	19.5	
		-100	166.0	217.0	216.5	1.30	1.30	1.55	1.55	2.5	1.0	12.5	7.0	
Ingot No. 83	2.0	75	170.5	122.5	117.5	.70	.70	.70	.70	1.5	0.5	22.5	12.5	
		-65	154.0*	108.0	108.0	.70	.70	.65	.65	1.0	1.0			
		-100	169.0*	96.5	104.0	.55	.60	.55	.60	1.0	1.0			
.105% C		-320	166.0*	88.5		.55		.50						
+ .155% N_2	0.02	75	169.0	149.5	145.5	.90	.85	.90	.85	1.0	1.0	30.5	11.6	
		-65	184.5*	104.5	98.5	.55	.55	.60	.60	0.5	0.5			
		-100	170.0*	111.0	109.5	.65	.65	.65	.65		1.0			
Ingot No. 85	2.0	75	155.0	174.5	173.5	1.10	1.10	1.10	1.10	3.5	3.0	35.5	16.5	
		-65	174.5	180.5	189.5	1.05	1.10	1.15	1.20	1.0	2.0	19.0	11.0	
		-100	177.0	188.5	191.5	1.05	1.10	1.20	1.25	2.5	1.5	28.5	13.0	
.125% N_2		-320	214.0	184.0		.85		1.20		1.5		20.0	7.0	
	0.02	75	160.0	202.5	194.5	1.25	1.20	1.25	1.20	2.5	2.5	35.0	18.0	
		-65	174.5	174.5	170.0	1.00	1.00	1.10	1.05	2.0	2.0	23.5		
		-100	178.5	179.5	190.0	1.00	1.05	1.10	1.20	1.5	2.0	29.5	13.5	

*Specimen broke under the Head

TABLE IV. Numerical Data for the 5 Al - 2-1/2 Sn - Ti Alloys (cont'd)

Condition of Material	Cross-Head Movement (In./Min)	Test Temp. (°F)	Tensile Str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio: Referred to Test Temp.		Notch Strength Ratio: Referred to Room Temp.		Reduction of Area (Per Cent): Notched		Reduction of Area (Per Cent): Unnotched	Elongation (%)	Hardness
Ingot No. 87	2.0	75	172.0	101.0	109.5	.60	.65	.60	.65	2.0	0.5	36.0		
		-65		99.5				.60		0.5				
		-100		102.5				.60						
		-320		101.0				.60						
.2 N_2	0.02	75	165.0*											
		-65		95.0				.60						
		-100		97.0				.60						
Ingot No. 88	2.0	75	162.5	202.5	208.5	1.25	1.30	1.25	1.30					
		-65	173.0	205.0		1.20		1.25						
		-100	177.5	203.5	198.0	1.15	1.10	1.25	1.20					
		-320												
.23% O_2	0.02	75	151.5	177.0	215.0	1.15	1.40	1.15	1.40					
		-65	201.5	199.0			1.35	1.30						
		-100	175.5	193.5	190.5	1.10	1.10	1.30	1.25					
Ingot No. 86	2.0	75	177.5	118.5		.65		.65		2.0		33.0	1.0	
		-65		92.5				.50		0.5				
		-100	101.5*	92.0		.90		.50						
.2 N_2		-320		94.0				.55						
+	0.02	75	183.0*	127.5		.70		.70		0.5				
.06 O_2		-65		83.5				.45		1.5				
		-100		101.5				.55						
Ingot No. 78	2.0	75	175.5*	106.5		.60		.60						
		-65	190.0*	86.5		.45		.50						
.155 N_2		-100	165.0*	103.5		.65		.60						
		-320												
+	0.02	75	174.5	115.5		.65		.65				44.5		
.214 O_2		-65												
		-100		91.5				.50						

* Specimen broke under the head.

TABLE V

Chemical Analyses of the 6 Al - Ti Alloys

Ingot	Percent			
	C	N	O	H(ppm)
6A	.02	.018	.095	110
62	.065	.06	.104	150
69	.22	.025	.12	180
61	.02	.116	.12	145
63	.10	.201	.125	115
68	.02	.086	.242	171
64	.15	--	.111	120

TABLE VI. Numerical Data for the 6 Al - Ti Alloys

Condition of Material	Cross-Head Movement (In./Min)	Test Temp. (°F)	Tensile Str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio: Referred to Test Temp.		Notch Strength Ratio: Referred to Room Temp.		Reduction of Area (per cent): Notched		Reduction of Area (per cent): Unnotched	Elongation (%)	Hardness
Ingot No. 6A	2.0	75	132.0	192.0	191.5	1.45	1.45	1.45	1.45	4.8	5.1	30.7		
		-65	125.0	202.0	203.0	1.30	1.30	1.55	1.55	4.2	4.5	39.0		
		-100	154.0	214.0	219.0	1.40	1.45	1.60	1.65	3.4	4.2	30.0		
		-320	195.0	241.0		1.25		1.85		2.0		21.7		
Annealed	0.02	75	131.0	194.5	193.0	1.50	1.45	1.50	1.45	5.1	4.8	31.8		
		-65	153.0	201.5	204.0	1.30	1.35	1.55	1.55	3.7	4.0	34.5		
		-100	157.5	213.0	216.0	1.35	1.35	1.65	1.65	5.6	6.5	31.4		
Ingot No. 61	2.0	75	155.0	164.0	168.0	1.05	1.1	1.05	1.1	2.5	0.8	36.7		
		-65	177.0	140.0	154.0	.80	.85	.90	1.0	0.6	1.5	26.5		
		-100	186.0	169.0	170.0	.90	.90	1.1	1.1	1.0	1.0	26.8		
		-320	321.0		168.0	.75		1.1		0.6		17.9		
.116 N_2	0.02	75	155.5	166.0	173.0	1.05	1.1	1.05	1.1	1.5	0.8	37.2		
		-65	176.5	125.5	135.5	.70	.75	.80	.85	2.8	1.0	8.0		
		-100	185.0	174.0	178.5	.95	.95	1.1	1.15	1.0	2.0	11.8		
Ingot No. 62	2.0	75	151.0	190.0	173.5	1.24	1.15	1.25	1.15	3.0	3.0	43.0		
		-65	170.5	204.0	213.0	1.2	1.25	1.35	1.40	2.5	3.0	25.0		
		-100	175.0	229.0	230.0	1.30	1.30	1.50	1.50	2.2	4.5	34.7		
.065 C		-320	221.5	194.0		.90		1.30		1.5		26.6		
+ .06 N_2	0.02	75	152.0	201.0	201.0	1.3	1.3	1.3	1.3	2.5	2.5	24.2		
		-65	160.0	176.0	167.0	1.1	1.05	1.15	1.1	3.0	3.0	32.5		
		-100	177.5	2.410	212.0	1.2	1.2	1.40	1.40	5.0	5.0	31.2		
Ingot No. 63	2.0	75	171.5	131.0	133.5	.75	.80	.75	.80	0.5	0.5	13.4		
		-65	186.5	120.5	119.5	.65	.65	.70	.70	0.5	1.5	8.4		
		-100	169.0*	137.0	129.0	.80	.75	.80	.75	0	0.3			
.10C		-320	195.0*	119.0		.62		.70		0				
+ .201 N_2	0.02	75	160.5	162.0	1.0	1.0	1.0	1.0	1.7	1.2	6.8			
		-65	161.0*	120.0	109.0	.75	.70	.75	.70	1.0	1.0			
		-100	143.5*	118.0	129.0	.80	.90	.75	.80	1.0	2.0			

*Specimen broke under the head

TABLE VI. Numerical Data for the 6 Al - Ti Alloys (cont'd)

Condition of Material	Cross-Head Movement (In./Min)	Test Temp. (°F)	Tensile Str. (1000 psi	Notch Strength (1000 psi)		Notch Strength Ratio: Referred to Test Temp.		Notch Strength Ratio: Referred to Room Temp.		Reduction of Area (Per Cent): Notched		Reduction of Area (Per Cent): Unnotched	Elongation (%)	Hardness
Ingot No. 64	2.0	75	167.0	166.0	157.5	1.0	.90	1.0	.90	3.0	3.0	36.2		
		-65		108.0	102.0			.65	.60	2.0	2.5			
.15 C		-100	196.5*	119.5		.60		.70		0.5				
		-320												
	0.02	75	165.0	154.5	164.0	.95	1.0	.95	1.0	2.5	4.5	32.5		
		-65		116.0	168.0			.70	.65	0	1.5			
		-100	181.5*	109.0		.60		.65		1.5				
Ingot No. 68	2.0	75	160.5	127.5	141.5	.80	.90	.80	.90	1.0	1.5	27.8		
		-65	192.0	135.0	135.0	.70	.70	.80	.85	1.7	1.0	16.3		
.086 N_2		-100	189.0	181.0	168.0	.95	.90	1.15	1.05	0.5	0	18.2		
+		-320												
.242 O_2	0.02	75	162.0	132.0	136.0	.80	.85	.80	.80	1.0	1.0	9.6		
		-65	179.0*	127.5	111.0	.70	.60	.80	.70	1.5	1.0			
		-100	192.5*	162.0	167.5	.86	.85	1.0	1.05	1.5	1.0			
Ingot No. 69	2.0	75	155.0	136.5	143.0	.90	.90	.90	.90	1.0	1.5	31.7		
		-65	176.5	141.5	146.0	.80	.85	.90	.95	1.2	0.3	15.3		
.22 C		-100	181.5	141.0	114.0	.80	.65	.90	.75	1.0	1.0	14.6		
+		-320												
.025 N_2	0.02	75	150.0	138.0	139.5	.90	.95	.90	.95	1.0	1.5	11.0		
		-65	175.5	118.0	126.0	.70	.70	.80	.85	1.0	1.0	8.6		
		-100	179.5	140.0	129.0	.80	.70	.95	.85	0	1.0	5.4		

* Specimen broke under the head.

TABLE VII

Chemical Analyses of the 7Al - 3Mo - Ti Alloys

Ingot	Percent				
	C	N	O	H(ppm)	Remarks
5AA	.01	.008	.081	169	
53	.08	.066	--	--	
56	.155	.0372	--	--	
51	.12	.056	.117	130	
5-	.025	.105	--	--	
52	.105	.205	.124	120	
59		.039	--	--	Nominal 0.2% C too brittle to machine
54	.16	.056			
55	.02	.087	.26	38	

TABLE VIII. Numerical Data for the 7 Al - 3 Mo - Ti Alloys

Condition of Material	Cross-Head Movement (In./Min.)	Test Temp. (°F)	Tensile Str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio				Reduction of Area (Per Cent)			Elongation (%)	Hardness
						Referred to Test Temp.		Referred to Room Temp.		Notched		Unnotched		
Ingot No. 5AA	2.0	75	151.0	183.5	187.0	1.20	1.25	1.2	1.25	4.2	4.0	20.4		
		-65	171.5	221.5	226.0	1.30	1.30	1.45	1.50	3.1	3.5	15.0		
		-100	176.5	235.5	240.0	1.35	1.35	1.55	1.60	3.5	4.0	27.2		
		-320	229.0	156.0		.68		1.05		2.8		21.4		
Annealed	0.02	75	152.5	195.0	200.0	1.30	1.30	1.30	1.30	4.3	4.9	17.2		
		-65	174.0	228.5	232.0	1.30	1.35	1.50	1.52	3.4	4.5	14.0		
		-100	181.0	242.0		1.35		1.60		3.0		24.2		
Ingot No. 5-	2.0	75	165.5	163.0	173.5	1.00	1.05	1.00	1.05	0.8	1.5	43.8		
		-65	183.5	168.5	156.5	0.90	0.85	1.02	.95	0.5	0.4	37.2		
		-100	188.5	154.5	160.5	0.80	0.85	.93	.97	1.0	1.3	29.4		
		-320	259.0	137.0		0.55		.83		0.6		22.3		
.1 N_2	0.02	75	150.5	190.5	192.0	1.25	1.30	1.25	1.30	3.5	2.5	2.0		
		-65	176.5	166.5	163.5	0.95	0.95	1.1	1.1	0	0	53.2		
		-100												
Ingot No. 52	2.0	75	197.5	143.5	135.0	0.70	0.70	0.70	0.70	0	0	0		
		-65	216.0	138.0		0.65		0.70		0.4		14.7		
		-100	211.0	136.0	122.0	1.65	0.60	0.69	0.62	0.8	0	17.5		
		-320	197.0*	106.0		0.55		0.54		0				
.2 N_2	0.02	75	187.5	103.5	109.5	0.55	0.60	0.55	0.60	0.5	1.4	4.3		
		-65	206.0	122.0	87.5	0.60	0.45	0.65	0.47	0	0.6	12.7		
		-100	211.0	125.0	133.0	0.60	0.65	0.67	0.71	0	0.7	8.8		
Ingot No. 54	2.0	75	189.5*	129.0	117.0	0.70	0.60	0.70	0.60					
		-65	222.0*	121.0	121.0	0.55	0.55	0.64	0.64					
		-100	185.0*	116.0	124.5	0.65	0.70	0.61	0.66					
.16 C		-320												
	0.02	75	197.5*	118.5		0.60		0.60						
		-65	181.5*	111.0	116.0	0.60	0.65	0.56	0.59					
		-100	227.5	114.5	124.0	0.50	0.55	0.58	0.63					

*Specimen broke under the head.

TABLE VIII. Numerical Data for the 7 Al - 3 Mo - Ti Alloys (cont'd)

Condition of Material	Cross-Head Movement (In./Min.)	Test Temp. (°F)	Tensile str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio: Referred to Test Temp.		Notch Strength Ratio: Referred to Room Temp.		Reduction of Area (PerCent): Notched		Reduction of Area (PerCent): Unnotched	Elongation (%)	Hardness
Ingot No. 51	2.0	75	164.5	168.5	170.0	1.0	1.05	1.0	1.05	2.8	1.1	8.2		
		-65	187.5	143.0	162.0	.76	.86	.87	.99	1.4	1.1	33.2		
		-100	186.5*	164.0	157.0	.88	.85	1.0	.95	1.1	0.8			
.12 C		-320	240.5	127.0		.53		.77		1.1		6.0		
+	0.02	75	164.0	172.5	149.0	1.05	1.05	1.05	1.05	1.4	2.8	2.8		
.056 N_2		-65	188.5	175.5	188.0	.93	1.0	1.05	1.15	2.0	1.7	30.2		
		-100	202.0	158.0	165.0	.78	.82	.96	1.0	1.1	0.8	11.5		
Ingot No. 53	2.0	75	175.0	125.0	138.5	0.72	0.79	0.72	0.79	0.3	1.4	21.7		
		-65	205.0	121.0	142.0	.59	.69	.69	.81	1.7	0.6	15.0		
		-100	213.5	120.0	147.0	.56	.69	.69	.84	0.5	0.9			
.08 C		-320	253.0*	114.0		.45		.65		1.7				
+	0.02	75	175.0	159.0	158.0	.91	.91	.91	.91	1.4	2.0	22.1		
.066 N_2		-65	201.0	140.0	131.5	.70	.65	.80	.75	1.1	2.2	18.7		
		-100	214.0*	163.5	158.0	.76	.84	.93	.90	0	1.1			
Ingot No. 55	2.0	75	165.5	163.5	156.0	.99	.95	.99	.95	2.8	2.5	22.9		
		-65	186.5	163.5	132.0	.87	.71	.99	.80	2.3	1.4	18.4		
		-100	195.5	151.2	155.1	.77	.79	.91	.94	1.7	1.4	13.7		
.087 N_2		-320	230.0*	140.0		.61		.85						
+	0.02	75	167.0	167.5	151.5	1.0	.91	1.0	.91	1.7	2.3	14.5		
.26 O_2		-65	190.5	153.5	160.0	.81	.84	.92	.96	1.7	3.1	14.2		
		-100	193.0	156.0	151.0	.81	.78	.93	.90	2.0	0.6	13.5		
Ingot No. 56	2.0	75	170.0	132.2	132.5	.78	.78	.78	.78	0.7	0.3	33.4		
		-65	198.5	104.0	118.0	.53	.60	.61	.70	1.15	0.6	22.2		
		-100	217.5	106.0	127.5	.49	.59	.62	.75	0.6	2.0	21.8		
.155 C		-320	225.0*	113.0		.50		.67		1.4				
+	0.02	75	167.0*	160.0	149.5	.94	.90	.94	.90	1.7	2.0			
.04 N_2		-65	198.0*	118.0	123.0	.60	.62	.71	.74	1.15	0.9			
		-100	207.5*	129.5	118.6	.63	.57	.78	.71	0.6	1.1			

*Specimen broke under the head

TABLE IX

Chemical Analyses of the 4 Al - 4 Mn - Ti Alloys

Ingot	Percent			
	C	N	O	H(ppm)
32	0.15	.008	.097	16
32a	--	--	--	--
25	.09	.04	--	--
24	.17	.072	--	--
23	.02	.18	.179	73
26	.02	.26	--	--
327	.015	.09	.129	24
328	.18	--	.130	82
329	.03	.09	.150	69
C-130-AM	--	.025	--	--
29	.015	--	.117	100
3 L	.015	--	--	--

TABLE X. Numerical Data for the 4 Al - 4 Mn - Ti Alloys

Condition of Material	Cross-Head Movement (In./Min.)	Test Temp. (°F)	Tensile Str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio: Referred to Test Temp.		Notch Strength Ratio: Refered to Room Temp.		Reduction of Area (Per Cent): Notched		Reduction of Area (Per Cent): Unnotched	Elongation (%)	Hardness
Ingot No. 32 As Received	2.0	75	141.0	179.5	201.5	1.25	1.45	1.25	1.45	2.5	3.0	42.0	20.5	
		-65	160.5	179.0	176.0	1.10	1.10	1.25	1.25	1.5	1.0	30.0		
		-100	167.0	85.0	153.0	.50	.90	.60	1.10	1.0	2.0	30.5		
		-320	231.0	151.0		.65		1.05		1.5		20.5		
	0.02	75	140.0	195.0	187.5	1.40	1.35	1.40	1.35	3.0	4.5			
		-65	154.0	144.0	147.5	.95	.95	1.05	1.05	2.5	0.0			
		-100	170.0	128.5	174.0	.75	1.05	.90	1.25	1.5	1.5			
Ingot No. 32 Annealed (1300°F - 1 Hr, FC-1000°F AC)	2.0	75	203.0	197.5	1.35	1.30	1.35	1.30	3.0	3.0	36.0	22.8		
		-65	152.5	169.0	169.5	1.10	1.00	1.00	0.15	2.0	4.0	33.5		
		-100	155.5	194.5	190.0	1.25	1.25	1.30	0.25	1.5	6.0			
		-320	193.0	169.0		.90		1.10		1.0		24.5	9.3	
	0.02	75	135.0	183.0	182.5	1.35	1.35	1.35	1.35	3.0	3.0	35.0	36.2	
		-65	176.5	180.5	168.5	1.05	.95	1.35	1.25	2.5	2.0	2.5		
		-100	170.0	185.5	170.0	1.25	1.15	1.35	1.25	1.0	1.0	28.5		
C-130-AM	2.0	75	160.0	202.0	198.0	1.25	1.25	1.25	1.25	1.0	2.5	42.5		
		-65	185.5	149.0	146.5	.80	.80	.95	.90	1.0	0.5	38.0		
		-100	190.0	157.5	144.5	.85	.75	1.00	.90	1.0	1.0	36.0		
		-320	227.5	119.0		.50		.75		1.0				
	0.02	75	162.5	199.0	199.5	1.25	1.25	1.25	1.25	2.5	3.0	42.0		
		-65	184.5	164.5	158.5	.90	.85	1.0	.95	0.5	1.0	38.5		
		-100	191.0	160.5	157.5	.85	.85	1.00	.95	0	1.5	37.5		
Ingot No. 25 .09 C + .04 N_2	2.0	75	158.5	171.5	147.5	1.08	.93	1.08	.93	2.5	1.0	46.0	15.5	
		185.0	131.0		.71		.83		1.0					
		-100	194.0	120.5		.62		.76		1.0				
		-320		119.5				.75		1.0				
	0.02	75	159.5	219.0	217.0	1.37	1.36	1.37	1.36	3.0	2.5			
		-65	180.5	124.5		.69		.78		0.5				
		-100	189.5	130.5		.69		.82		1.0				
Ingot No. 24 .17 C + .072 N_2	2.0	75 -65 -100	171.5	47.0	51.0	.25	.30	.25	.30	0	0	8.5		
	0.02	75	180.0	88.0		.50		.50		0		8.5		

TABLE X. Numerical Data for the 4 Al - 4 Mn - Ti Alloys (cont'd)

Condition of Material	Cross-Head Movement (In./Min)	Test Temp. (°F)	Tensile Str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio: Referred to Test Temp.		Notch Strength Ratio: Referred to Room Temp.		Reduction of Area (Per Cent): Notched		Reduction of Area (Per Cent): Unnotched	Elongation (%)	Hardness
Ingot No. 23	2.0	75	164.0	119.5	118.5	.95	.95	.95	.95	0.5	3.5			
		-65	75.5	105.0	126.5	1.40	1.65	.85	1.00	1.0	0.5			
		-100	89.5	75.5	100.5	.85	1.00	.60	.80					
		-320	66.5	83.5		1.25		.65						
.18 N_2	0.02	75	170.0	183.5	165.5	1.10	.95	1.00	.95	1.5	4.0	30.5		
+		-65	120.0		100.5		.85		.60		1.5			
.18 O_2		-100	143.5	85.0	123.0	.80	.85	.50	.70					
Ingot No. 26	2.0	75	190.5	100.5	93.0	.55	.50	.55	.50	1.0	1.0	36.5		
		-65	202.0	98.5	90.0	.50	.45	.50	.45	0.5	0.5			
		-100	216.5	92.0	80.0	.45	.35	.50	.40	1.0	0.0			
		-320	131.5*	94.5		.70		.50						
.26 N_2	0.02	75	187.0	118.0	122.0	.65	.65	.65	.65	0.5	0.0			
		-65	84.0	87.5	107.5	1.30	1.30	.45	.60					
		-100		105.0	92.5			.55	.50	0.5				
Ingot No. 327	2.0	75	157.5	120.0	135.0	.75	.85	.75	.85	0.5	0.5			
		-65	187.0	123.0	134.5	.65	.70	.80	.85	0.5	0			
		-100	197.0	123.0	134.0	.65	.70	.80	.85	0.5	0.5			
.09 N_2		-320	195.5	100.0		.50		.65						
+	0.02	75	168.0	164.5	159.0	1.00	.95	1.00	.95	0.5	1.5			
.129 O_2		-65	191.5	142.5	145.0	.75	.75	.85	.85	0.5	0			
		-100	200.0	126.0	125.5	.65	.65	.75	.75	1.5	0			
Ingot No. 329	2.0	75	159.0	161.0	148.5	1.00	.95	1.00	.95	1.0	2.0	50.5		
		-65	182.5	138.5	134.0	.75	.75	.85	.85	.5	1.5	35.0		
		-100	191.5	141.5	119.5	.75	.60	.90	.75	.5	1.0	17.5		
.09 N_2		-320	244.5*	121.0		.50		.50						
+	0.02	75	155.0	155.5	171.0	1.00	1.10	1.00	1.10	1.5	1.0	24.2		
.150 O_2		-65	184.0	147.0	129.6	.80	.70	.95	.85	1.0	1.0	37.0		
		-100	192.5*	121.5	129.5	.65	.65	.80	.85	1.9	.5			
Ingot No. 328	2.0	75	193.0	170.0	181.5	.90	.95	.90	.95	1.5	1.0	39.0		
		-65	208.0	138.0	138.0	.65	.65	.70	.70	1.0		37.2		
		-100	209.0	133.0	130.0	.65	.60	.70	.65	1.0	.5	34.0		
.18 C		-320	282.5		117.5		.40		.60		2.0	14.5		
	0.02	75	181.0	184.0	182.0	1.00	1.00	1.00	1.00	1.5	9.0			
		-65	188.0	149.5	141.0	.80	.75	.85	.80		1.0	25.5		
		-100	198.5	122.5	127.5	.60	.65	.70	.70		.5			

*Specimen broke under the head.

TABLE XI

Chemical Analyses of the 8 Mn - Ti Alloys

Ingot	Percent			
	C	N	O	H(ppm)
4A	.025	.025	.228	280
4	.025	.125	.209	110
42	.02	.210	--	--
43	.19	.045	--	--
46	.24	.042	--	--
41	.02	.133	--	--
44	.18	.085	--	--
45	.02	.108	.361	260

TABLE XII. Numerical Data for the 8 Mn - Ti Alloys

Condition of Material	Cross-Head Movement (In./Min)	Test Temp. (°F)	Tensile Str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio: Referred to Test Temp.		Notch Strength Ratio: Referred to Room Temp.		Reduction of Area (Per Cent): Notched		Reduction of Area (Per Cent): Unnotched	Elongation (%)	Hardness
Ingot No. 4A	2.0	75	144.5	181.0		1.25		1.25		2.0		10.0		
		-65	178.5	138.5		0.80		0.95		0		1.0		
		-100	193.0*	138.5		0.70		0.95		0				
Annealed	0.02	75	145.5	167.0		1.15		1.15		1.0		14.5		
		-65	153.0*	107.0		0.70		0.75		0				
		-100	162.0*	115.0		0.70		0.80		0				
Annealed Bar Long.	2.0	75	144.0	167.0		1.15		1.15						
		-65	187.5	109.0		0.60		0.75						
		-100	197.0	98.5		0.50		0.70						
	0.02	75	144.5	175.0		1.20		1.20						
		-65	167.0*	76.0		0.45		0.50						
		-100	170.5*	86.5		0.50		0.60						
Annealed Bar Trans.	2.0	75	148.0	175.5		1.20		1.20						
		-65	183.0*	114.0		0.60		0.75						
		-100	191.0*	104.0		0.55		0.70						
	0.02	75	145.5	147.5		1.0		1.0						
		-65	177.0*	93.0		0.50		0.70						
		-100		112.0				0.75						
Ingot No. 4	2.0	75	187.5	141.5	134.0	0.75	0.70	0.75	0.70	1.0	0	4.5		
		-65	168.5*	87.0	82.0	0.50	0.50	0.45	0.45	0	0			
		-100	154.5*	98.5	87.5	0.65	0.55	.55	.45	0.5	1.0			
		-320		57.5				.30		0				
.125 N_2	0.02	75	185.5	137.5	146.0	0.50	0.50	0.50	0.50	0	0	8.0		
		-65	193.5	104.0	98.5	0.55	0.50	0.55	0.55	0	1.0	5.5		
		-100	178.0	70.5		0.40		0.40		1.5				
Ingot No. 42	2.0	75	190.0	102.0	79.0	.55	.40	0.55	0.40	1.15	0	5.35		
		-65	96.0*	22.0	38.5	.25	.40			.55	.85			
		-100	89.0*	47.0	37.0	.55	.40			.08	.65	5.35		
		-320		.29						0				
.210 N_2	0.02	75	172.0	133.0	122.5	0.75	0.70	0.75	0.70	.65	.25	9.30		
		-65	93.0*	51.0	47.0	0.55	0.50			.28	.84			
		-100		66.0	76.0					.28	5.65			

*Specimen broke under the head

TABLE XII. Numerical Data for the 8 Mn - Ti Alloys (cont'd)

Condition of Material	Cross-Head Movement (In./Min)	Test Temp. (°F)	Tensile Str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio: Referred to Test Temp.		Notch Strength Ratio: Referred to Room Temp.		Reduction of Area (Per Cent): Notched	Reduction of Area (Per Cent): Unnotched		Elongation (%)	Hardness
Ingot No. 41	2.0	75	173.5	111.0	112.5	0.65	0.65	0.65	0.65	0	0	35.0		
		-65	101.5*	77.0		.75				0				
		-100	111.0*	49.0		.45				0				
.133 N_2	0.02	75	151.0*	101.0	114.0	.65	.75	.65	.75	0	3.40			
		-65		48.0						0				
		-100		32.0						0				
Ingot No. 44	2.0	75	180.0	181.5	183.0	1.0	1.0	1.0	1.0	0.15	0.15	0.25		
		-65	199.0	101.0	81.5	.50	.40			0.35	0.55	0.20		
		-100	210.0	60.0	88.5	.30	.40			6.55	6.50	5.95		
.18 C		-320			60.0					6.55				
+ .085 N_2	0.02	75	162.5	178.0	164.0	1.05	1.0	1.05	1.0	0.55	0	0.25		
		-65	194.5*	78.0	94.5					0.30	0			
		-100	206.5	106.0	80.5	.50	.40			2.40	4.80	7.80		
Ingot No. 43	2.0	75	167.0*	88.5	104.5	0.55	0.65	0.55	0.65					
		-65	54.0*	33.5	35.5	.62	.66	.20	.21					
		-100	80.0*	35.0		.44			.21					
.19 C + .045 N_2	0.02	75	101.0*	120.5	105.5	1.2	1.05	1.2	1.05					
		-65	90.0*	60.5	57.5	.65	.65	.60	.60					
		-100	68.5*	33.5	62.0	.50	.90	.35	.60					
Ingot No. 45	2.0	75	175.0	132.5	123.5	.76	.71	.76	.71	1.1	2.0	33.5		
		-65	190.0*	71.5	104.0	.37	.55	.41	.59	1.1	2.0			
		-100	161.0*	95.0	82.0	.59	.51	.54	.47	1.1	1.5			
.108 N_2 + .361 O_2	0.02	75	171.5*	139.0	147.0	.81	.86	.81	.86	3.1	2.8			
		-65	182.0*	61.5	106.5	.34	.59	.36	.62	0.3	1.4			
		-100	117.0*	96.0	98.0	.82	.84	.56	.57	2.5	2.3			
Ingot No. 46	2.0	75	100.0*	107.0	119.5	1.05	1.20	1.05	1.20					
		-65	144.0*	80.0		.56		.80						
		-100	118.5*	100.0	102.0	.84	.86	1.0	1.02					
.24 C		-320		65.5										
+ .042 N_2	0.02	75	170.0*	175.5	176.0	1.05	1.05	1.05	1.05					
		-65	141.5*	91.5	107.5	.65	.76	.54	.63					
		-100	130.0*	64.0	85.0	.49	.65	.38	.50					

*Specimen broke under the head.

TABLE XIII

Chemical Analyses of the 15 Cr - Ti Alloys

Ingot	Percent			
	C	N	O	H(ppm)
31	.02	.017	.041	183
31A	--	--	--	--
11	.055	.055	--	--
12	.01	.27	.0342	--

TABLE XIV. Numerical Data for the 15 Cr - Ti Alloys

Condition of Material	Cross-Head Movement (In./Min)	Test Temp. (°F)	Tensile Str. (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio				Reduction of Area (Per Cent)			Elongation (%)	Hardness
						Referred to Test Temp.		Referred to Room Temp.		Notched		Unnotched		
Ingot No. 31 As Forged	2.0	75	139.5	234.5	235.0	1.70	1.70	1.70	1.70	7.5	9.0	60.0		
		-65	176.5	266.5	268.5	1.50	1.55	1.90	1.90	4.5	3.0	49.5		
		-100	188.5	258.0	278.5	1.35	1.45	1.85	2.00	2.5	0.0			
		-320	265.5*	150.5		0.55		1.10						
	0.02	75	137.5	218.0	218.5	1.60	1.60	1.60	1.60	7.5	9.5	60.5		
		-65	164.0	252.0	239.0			1.85	1.75	5.0	3.5	57.5		
		-100	185.5	262.5	271.5	1.40	1.45	1.90	2.00	3.0		51.5		
Annealed	2.0	75	149.5*	160.0	113.0	.75	.75	.75	.75	0	0			
		-65	118.0*	70.0	67.5	.60	.60	.45	.45	0.5	0.5			
		-100	149.5	97.0	67.0	.65	.45	.65	.45					
		-320	162.5	74.0		.45		.50						
	0.02	75	132.5	107.0	108.0	.80	.80	.80	.80	0	0			
		-65	128.5*	78.0	78.0	.60	.60	.60	.60	0	0			
		-100	141.0*	106.0	64.0	.45	.75	.80	.50	0	0.5			
Ingot No. 11 .1% C	2.0	75	155.0	171.0	178.0	1.0	1.15	1.10	1.15	2.5	2.5	40.0		
		-65		154.5	167.5			1.00	1.10	1.5	2.0			
		-100	195.5	154.5	157.5	.80	.80	1.00	1.00	1.0	1.0	29.0	11.0	
		-320		80.0	88.5			.50	.55		1.0			
	0.02	75	152.0	217.0	215.5	1.45	1.40	1.45	1.40	2.5	2.5	15.0		
		-65	183.0	199.0	179.0	1.10	1.00	1.30	1.20	0.5	2.5	25.5	12.0	
		-100	195.5	186.5	161.5	.95	.85	1.25	1.05	1.5	0.5	33.5	17.0	
Ingot No. 12 .2% N_2	2.0	75	167.5	130.0	89.0	.80	.55	.80	.55	1.0	2.5	11.5	7.5	
		-65	145.0*	110.0	114.5	.75	.80	.65	.70	0	1.0			
		-100	133.0*	106.0	88.0	.80	.65	.65	.50	1.0	1.0			
		-320	170.5	80.0		.45								
	0.02	75	171.0*	136.0	98.5	.80	.60	.80	.60	0	0			
		-65	136.5	118.0	123.0	.85	.90	.70	.70	0.5	1.0			
		-100	198.5	104.0	100.0	.50	.50	.60	.60	1.0	1.0			

*Specimen broke under the head.