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MATERIALS-PROPERTY-DESIGN CRITERIA FOR METALS

PART 7. THE CONVENTIONAL SHORT-TIME, ELEVATED-TEMPERATURE PROPERTIES OF SELECTED LOW- AND MEDIUM-ALLOY STEELS

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FOREWORD

This report was prepared by Battelle Memorial Institute, Columbus, Ohio, under Contract No. AF 33(616)-2303. The investigation was initiated under Project No. 7360, "Materials Analysis and Evaluation Techniques", Task No. 73605, "Design Data for Metals". The work was administered under the direction of the Materials Laboratory, Directorate of Laboratories, Wright Air Development Center with Mr. D. A. Shinn acting as project engineer.

This research has been carried out under the supervision of H. J. Grover, Chief of the Applied Mechanics Division with considerable valuable consultation from S. A. Gordon. Other Battelle staff members who participated to a considerable extent in the program include A. H. Hunter, N. J. Weller, W. L. Belton, and I. E. Hanna.

This report covers work conducted from January 1 to December 15, 1956.

ABSTRACT

Presented in this report is a compilation of data on the conventional short-time, elevated-temperature properties of selected low- and medium-alloy steels applicable to airframe and missile fabrication. The resulting recommended design data obtained in this study have been presented in such form as to be directly applicable to the ANC-5 Bulletin (issued by the Air Force-Navy-Civil Panel) on "Strength of Metal Aircraft Elements".

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER: Richard R. Kennedy

RICHARD R. KENNEDY
Chief, Metals Branch
Materials Laboratory

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS
(Continued)

LIST OF ILLUSTRATIONS
(Continued)

LIST OF ILLUSTRATIONS
(Continued)

LIST OF ILLUSTRATIONS
(Continued)

MATERIALS-PROPERTY-DESIGN CRITERIA FOR METALS

PART 7. THE CONVENTIONAL SHORT-TIME, ELEVATED-TEMPERATURE PROPERTIES OF SELECTED LOW- AND MEDIUM-ALLOY STEELS

INTRODUCTION

In Parts 5 and 6 of WADC TR 55-150, a compilation of data on the short-time, elevated-temperature properties of selected stainless steels, heat-resistant alloys, and light alloys was presented. In Part 7 a similar compilation is made on medium-alloy steels.

It should be emphasized that the recommended design curves included herein are not necessarily identical to any which will ultimately appear in ANC-5. Use of any data appearing herein is therefore subject to approval by the cognizant procuring or certificating agency.

The steels included for investigation in this report are AISI 4340, AISI 4130, AISI 4140, AISI 8630, AISI 4037, and 17-22A. No pertinent short-time, elevated-temperature data that applied specifically to AISI 4140 and AISI 4037 were available. Chemical compositions of these two alloys are presented with AISI 4130. Some modulus and stress-strain data were found that were presented as representative of several medium alloy steels, such as 4340, 4130, and 4140 for similar heat treatments and strength levels; however, only data that applied to one specific alloy are considered in this report. The one exception to this procedure is that, in determining the modulus of elasticity versus temperature, it is metallurgically feasible to combine all of the data on this property for all steel alloys in order to come up with a bigger population from which to statistically determine an optimized modulus versus temperature curve.

All stress-strain curves for the steel alloys have been corrected to the statistically determined modulus.

Since these alloy steels all have one mode of basic treatment (excluding isothermal quenching) to obtain strength and hardness, that being to austenitize, quench, and temper, it is common practice in the airframe industry to describe the heat treatment of these alloys by some appropriate strength level at room temperature, such as heat treated to 180,000 psi ultimate tensile strength at room temperature.

A short description of each alloy is presented in its respective section of this report. Material comparison curves for these alloys are presented in the Appendix.

Manuscript released by authors 1 March 1957 for publication as a WADC Technical Report.

Reference numbers appearing on graphs in this report refer to the complete bibliography in WADC TR 55-150, Part 5.

The standard structural symbols used throughout this report are:

F_{tu}	Ultimate tensile stress
F_{ty}	Tensile yield stress
F_{cy}	Compressive yield stress
F_{su}	Ultimate shear stress
F_{bru}	Ultimate bearing stress
F_{bry}	Bearing yield stress
G	Modulus of rigidity
μ	Poisson's ratio
ksi	Kips (1000 pounds) per square inch
psi	Pounds per square inch
E	Modulus of elasticity in tension; average ratio of stress to strain below proportional limit
E_c	Modulus of elasticity in compression; average ratio of stress to strain below proportional limit

Treatment of Strength Properties

In presenting data showing the strength property as a function of temperature two graphs were prepared. The first shows actual stress versus temperature and the second shows the strength property plotted as a percentage of room temperature strength versus temperature. This second curve is labeled as a "design curve" and is in such format as to be readily insertable into the ANC-5 Bulletin on "Strength of Metal Aircraft Elements" (subject to approval by the ANC-5 Panel). A more detailed discussion on the treatment of data is found in Part 5 of WADC TR 55-150.

Wherever data in this report and those in the current ANC-5 Bulletin do not agree, it is suggested that the ANC-5 Bulletin be regarded as the authority. Precautions have been taken to reduce to a minimum any disagreement of these data and those published in ANC-5.

Optimization Process

In compiling data on the modulus of elasticity versus temperature, it became necessary to have a standard method of determining a mean curve. The method of polynomial regression which was readily adaptable to IBM computation was used. This method worked well in those cases where consistent data were available and proved to be an invaluable tool in analyzing data with a large amount of scatter. All stress-strain curves were corrected to the "optimized" modulus value for the temperature of the test. In those cases where meager data were available, this method was not used. A detailed description of the optimization process is reported in "Materials-Property-Design Criteria", WADC TR 55-150, Part 5, December, 1956.

AISI 4340 is a nickel-chromium-molybdenum steel with high hardenability and is capable of being heat treated to the so-called "ultra-high" strength level of 260,000 to 300,000 psi. Its general use at this time, however, lies in the 150,000- to 220,000-psi strength level. The nominal chemical composition of AISI 4340 is given in Table 1.

TABLE 1. NOMINAL CHEMICAL COMPOSITION OF AISI 4340 STEEL (AMS-6359A)

Element	Weight Per Cent
Carbon	0.40
Manganese	0.70
Nickel	1.80
Chromium	0.80
Molybdenum	0.25
Iron	Balance

The short-time, elevated-temperature properties of AISI 4340 are shown in the following curves:

(1) Tensile properties, Figures 1 through 14

(2) Compressive properties, Figures 15 and 16

(3) Modulus of elasticity, Figures 17 and 22

(4) Stress-strain curves, Figures 18 through 21 and 23

Bearing and shear properties are lacking on 4340.

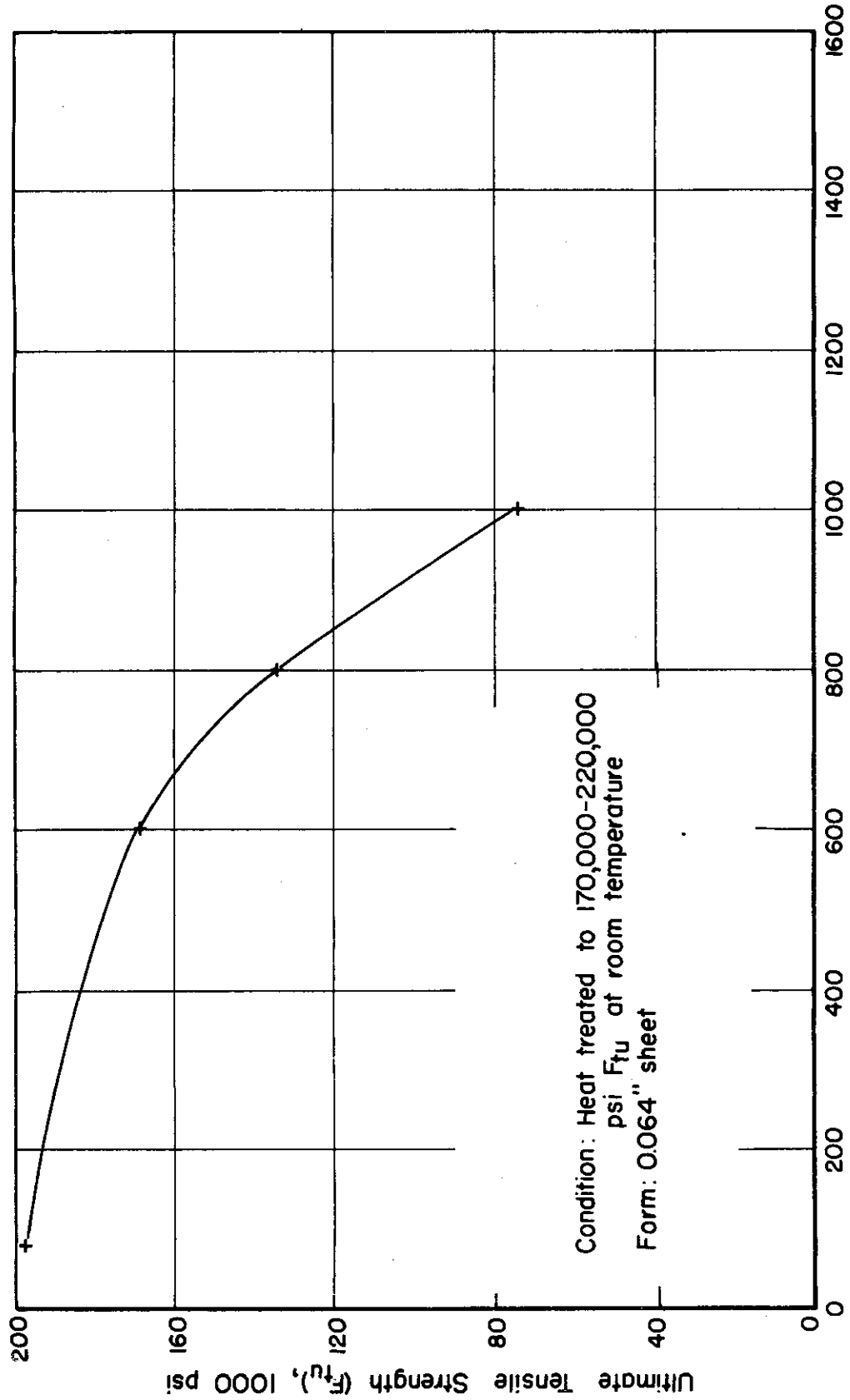

FIGURE 1. TENSILE STRENGTH (F_{tu}) OF AISI 4340 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 361.

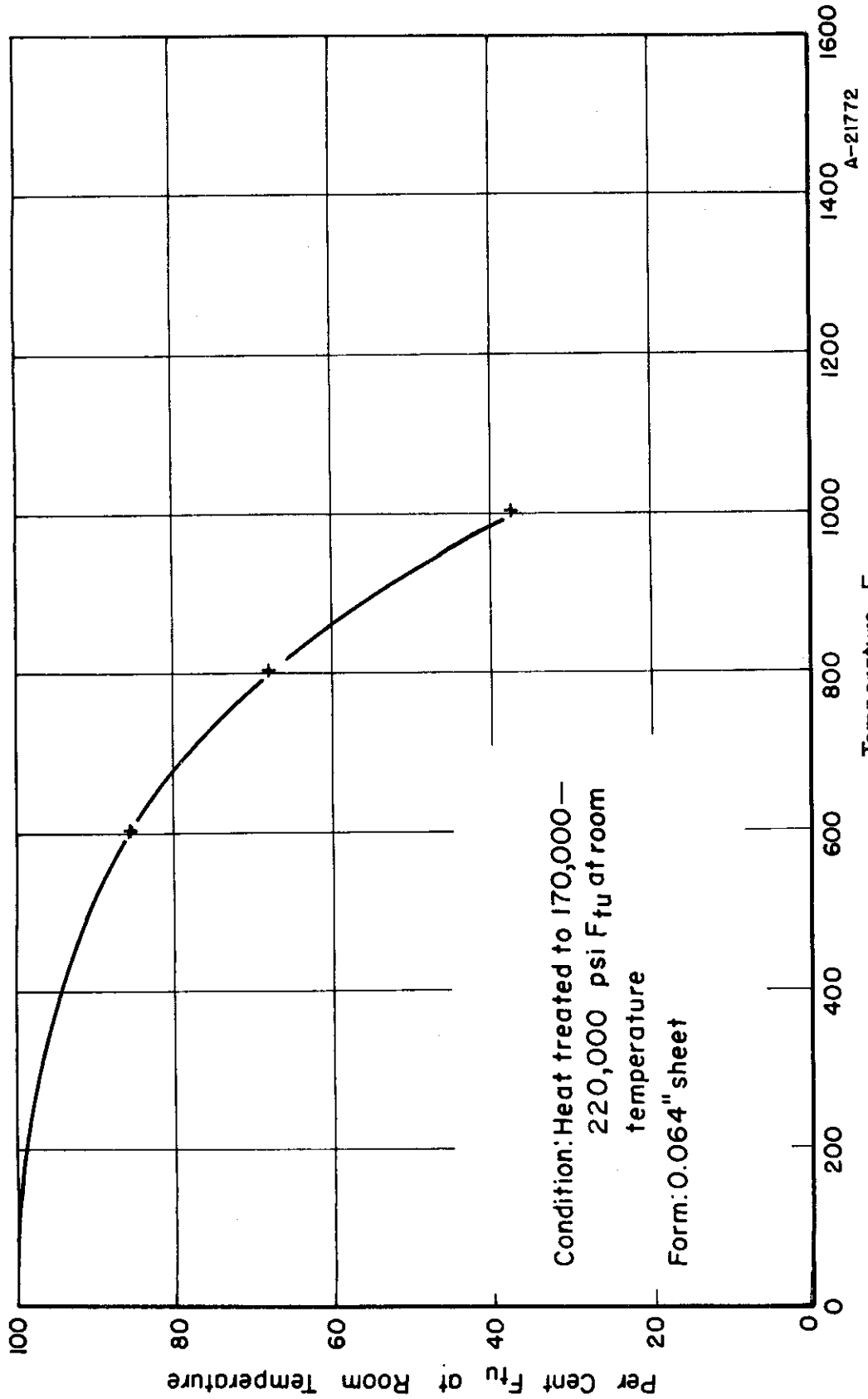

FIGURE 2. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF AISI 4340 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 361.

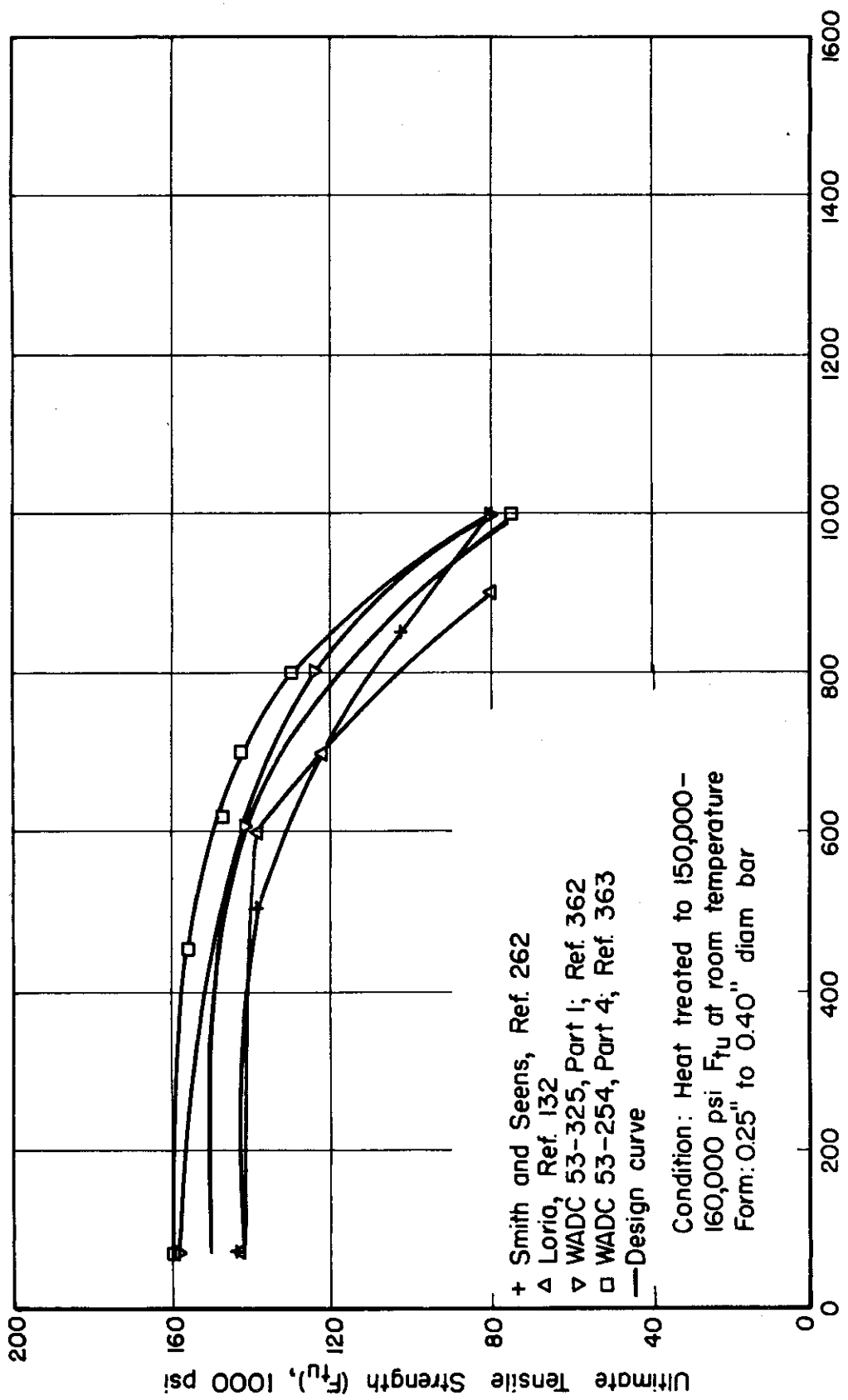

FIGURE 3. TENSILE STRENGTH (F_{tu}) OF AISI 4340 ALLOY STEEL (0.25 TO 0.40-INCH-DIAMETER BAR) AT ELEVATED TEMPERATURE

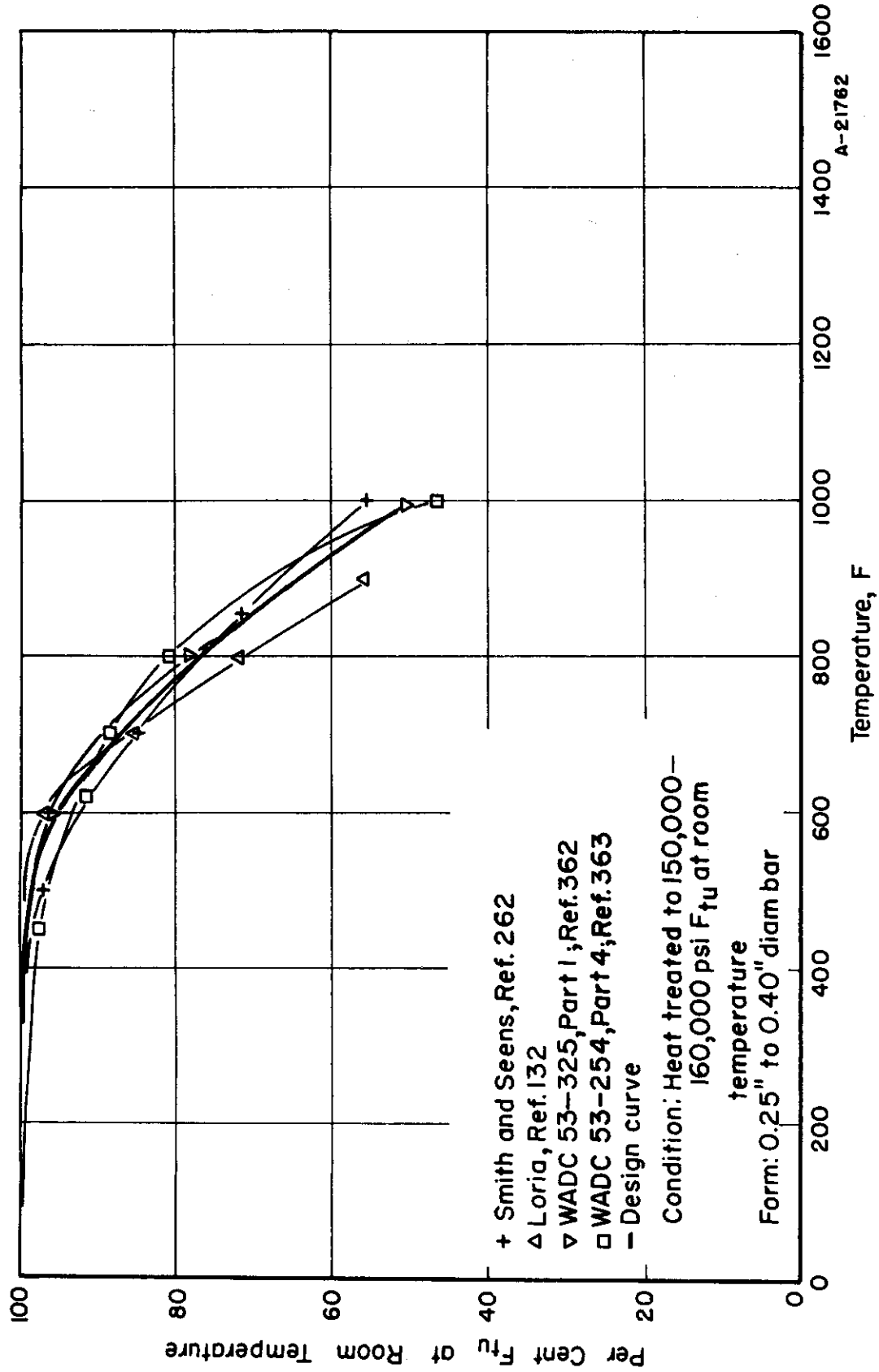

FIGURE 4. TENSILE STRENGTH (F_{tu}) EXPRESSED AS A PERCENTAGE OF ROOM-TEMPERATURE TENSILE STRENGTH OF AISI 4340 ALLOY STEEL (0.25 TO 0.40-INCH-DIAMETER BAR) AT ELEVATED TEMPERATURE

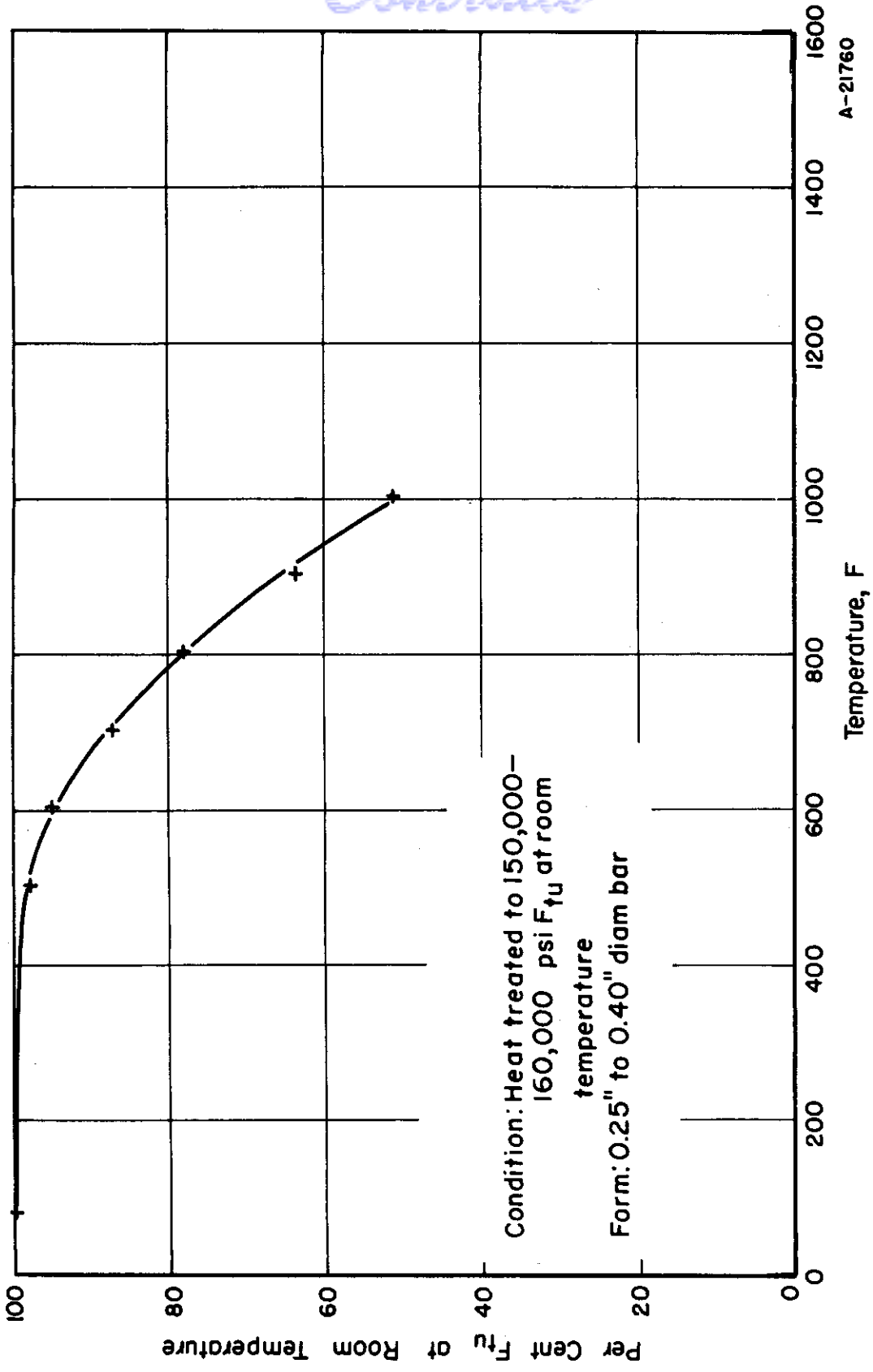

FIGURE 5. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF AISI 4340 ALLOY STEEL (0.25 TO 0.40-INCH-DIAMETER BAR) AT ELEVATED TEMPERATURE

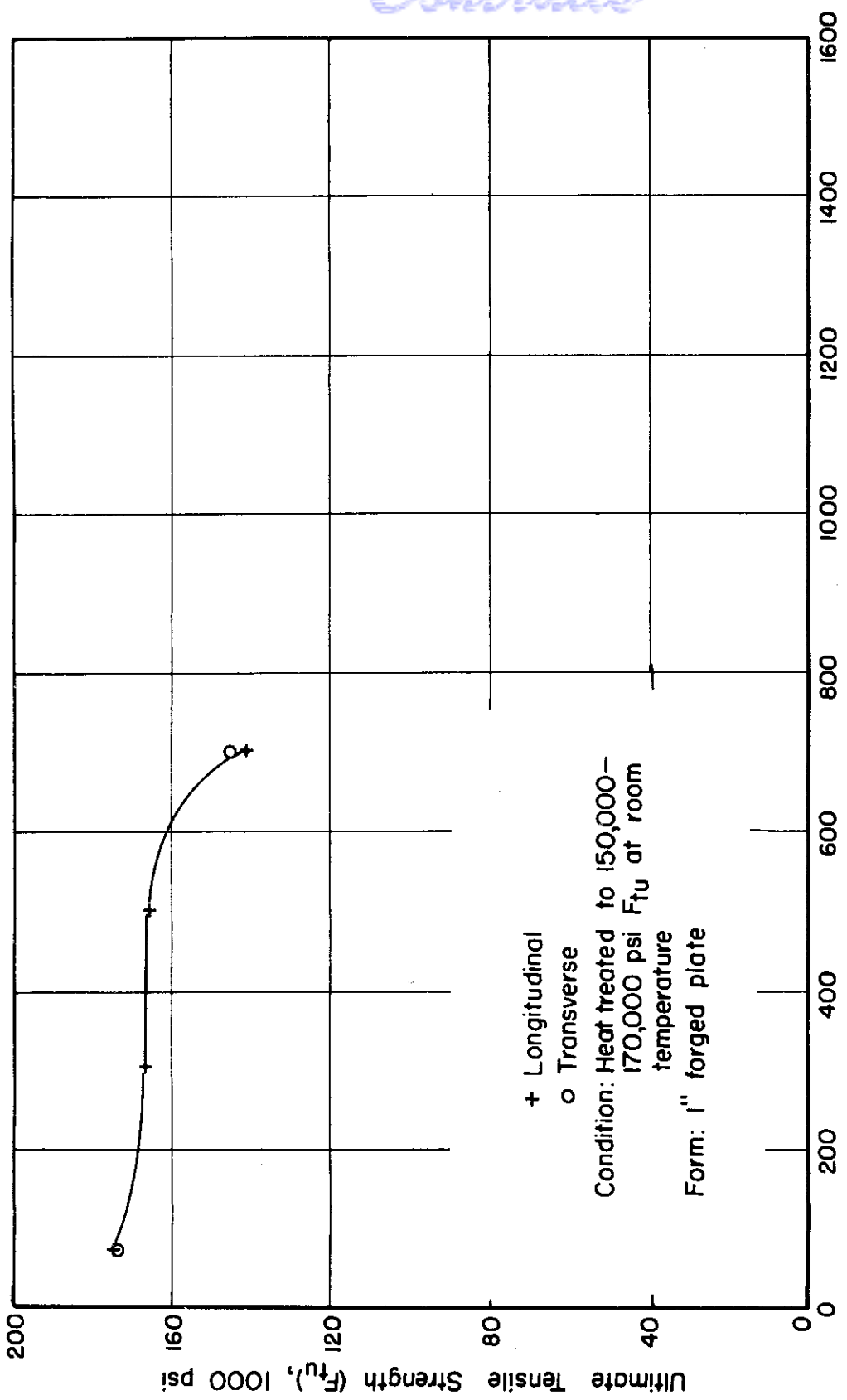

FIGURE 6. TENSILE STRENGTH (F_{tu}) OF AISI 4340 ALLOY STEEL (1-INCH FORGED PLATE) AT ELEVATED TEMPERATURE

Ref. 111.

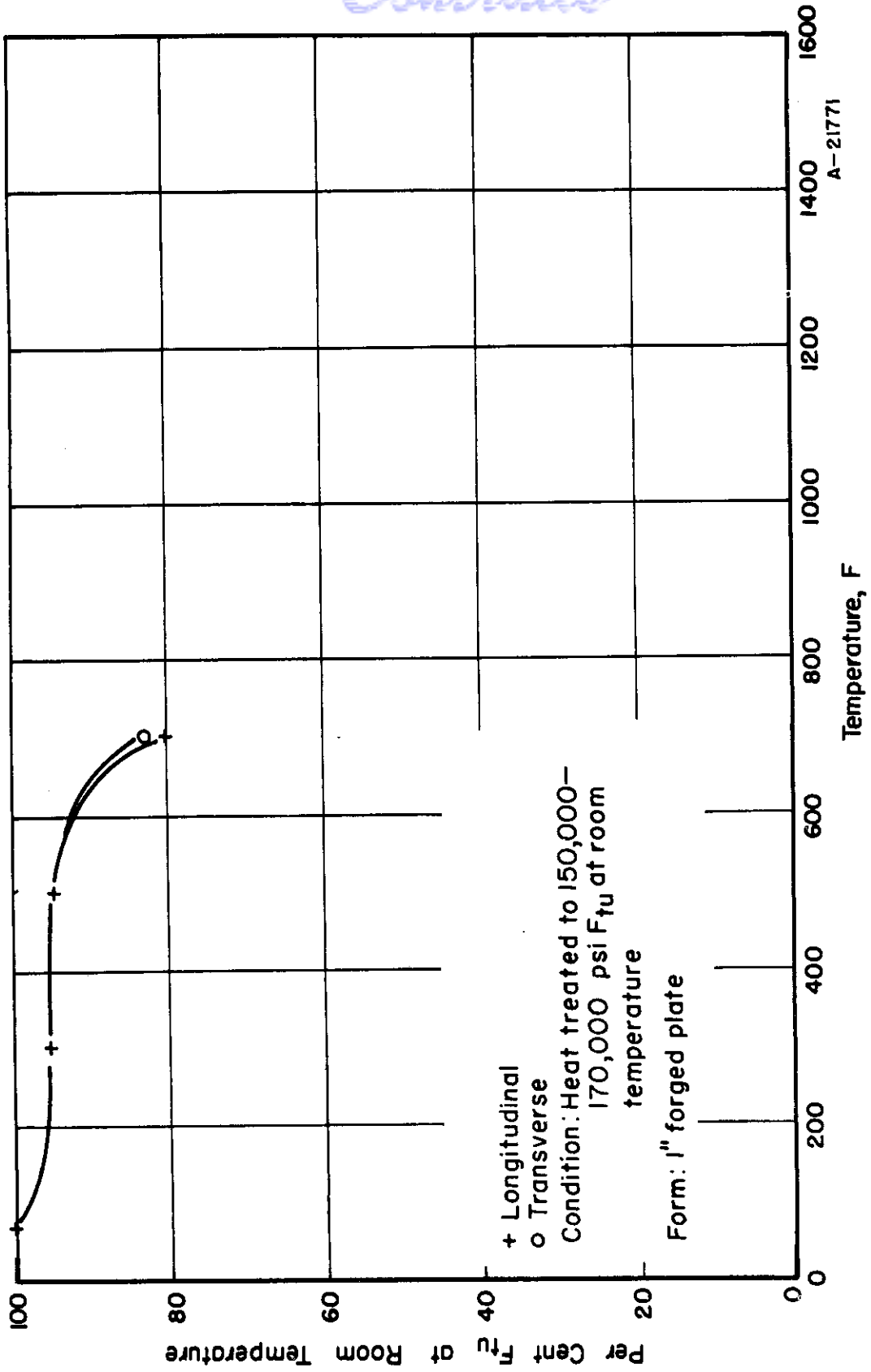

FIGURE 7. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF AISI 4340 ALLOY STEEL (1-INCH FORGED PLATE) AT ELEVATED TEMPERATURE

Ref. 111.

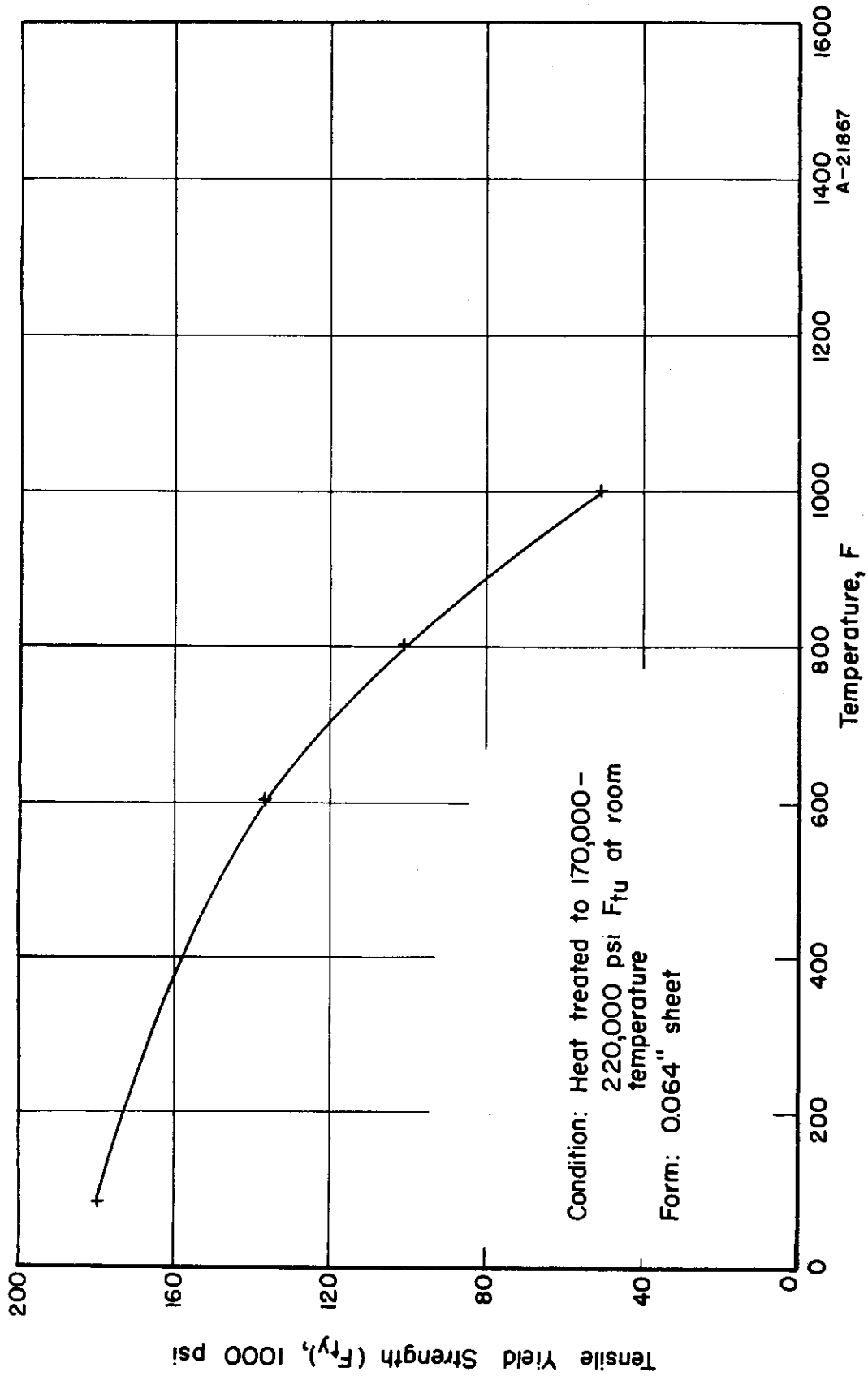

FIGURE 8. TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4340 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 361.

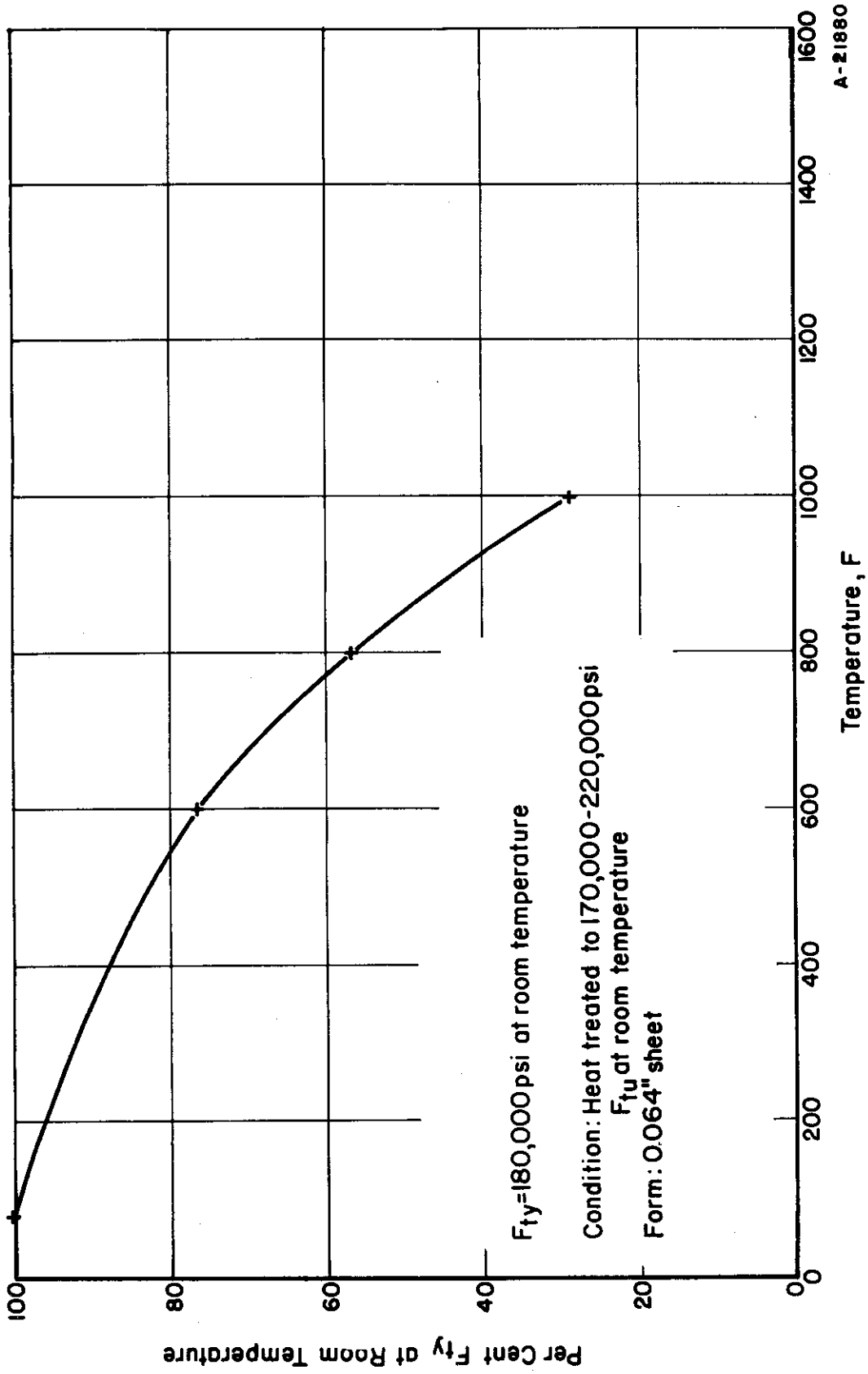

FIGURE 9. DESIGN CURVE FOR TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4340 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 361.

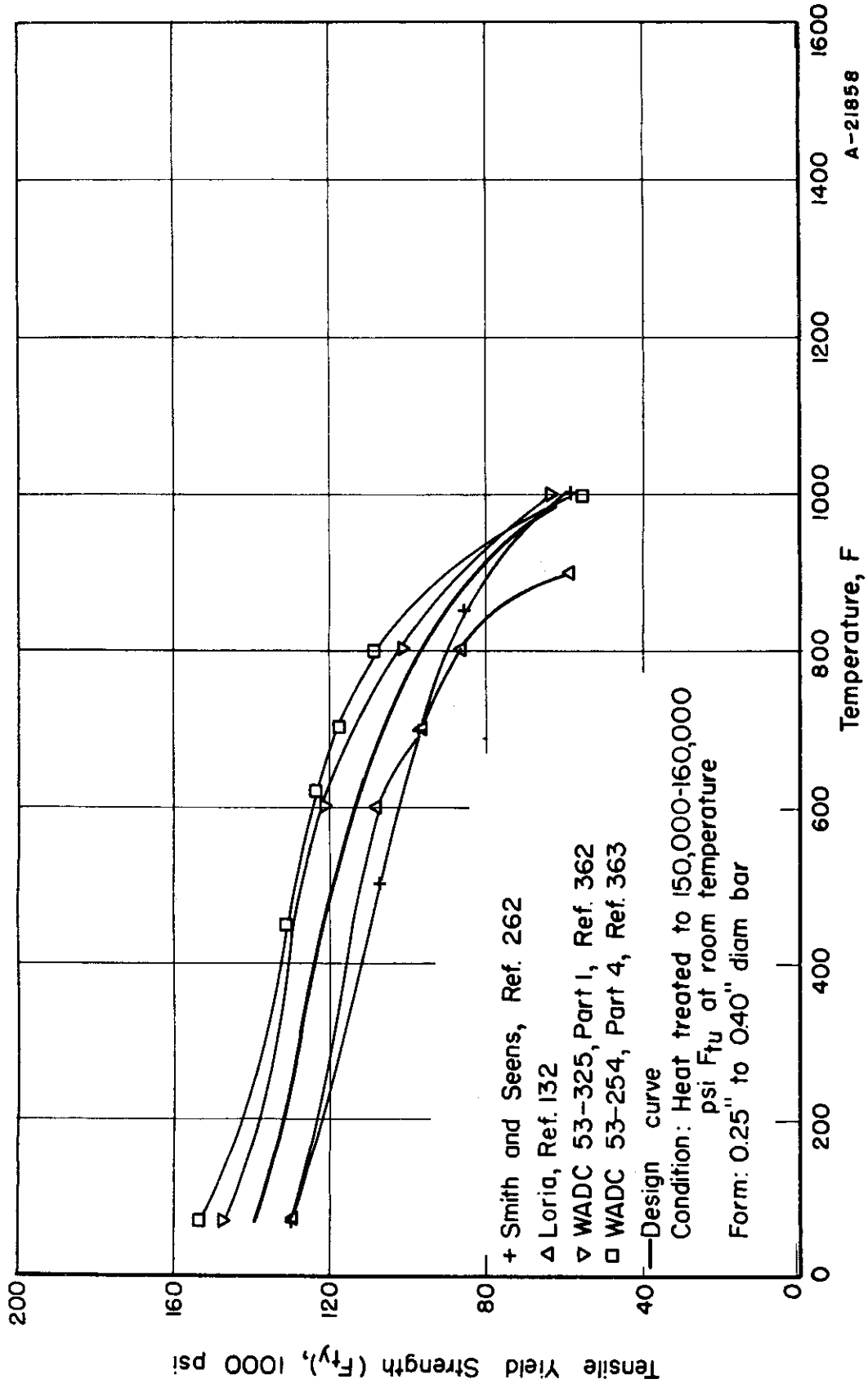

FIGURE 10. TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4340 ALLOY STEEL (0.25 TO 0.40-INCH-DIAMETER BAR) AT ELEVATED TEMPERATURE

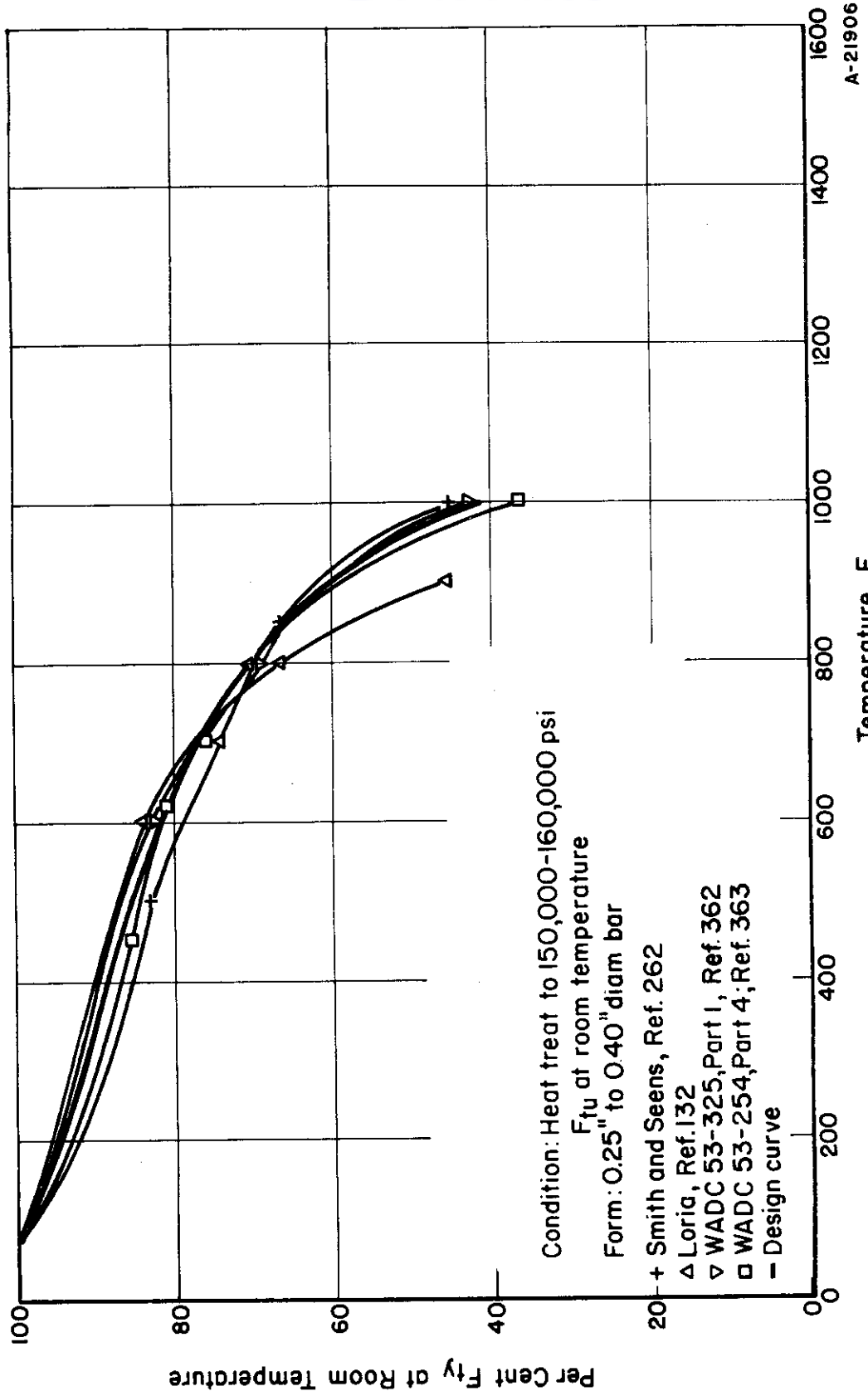

FIGURE 11. TENSILE YIELD STRENGTH (F_{ty}) EXPRESSED AS A PERCENTAGE OF ROOM-TEMPERATURE TENSILE YIELD STRENGTH OF AISI 4340 ALLOY STEEL (0.25 TO 0.40-INCH-DIAMETER BAR) AT ELEVATED TEMPERATURE

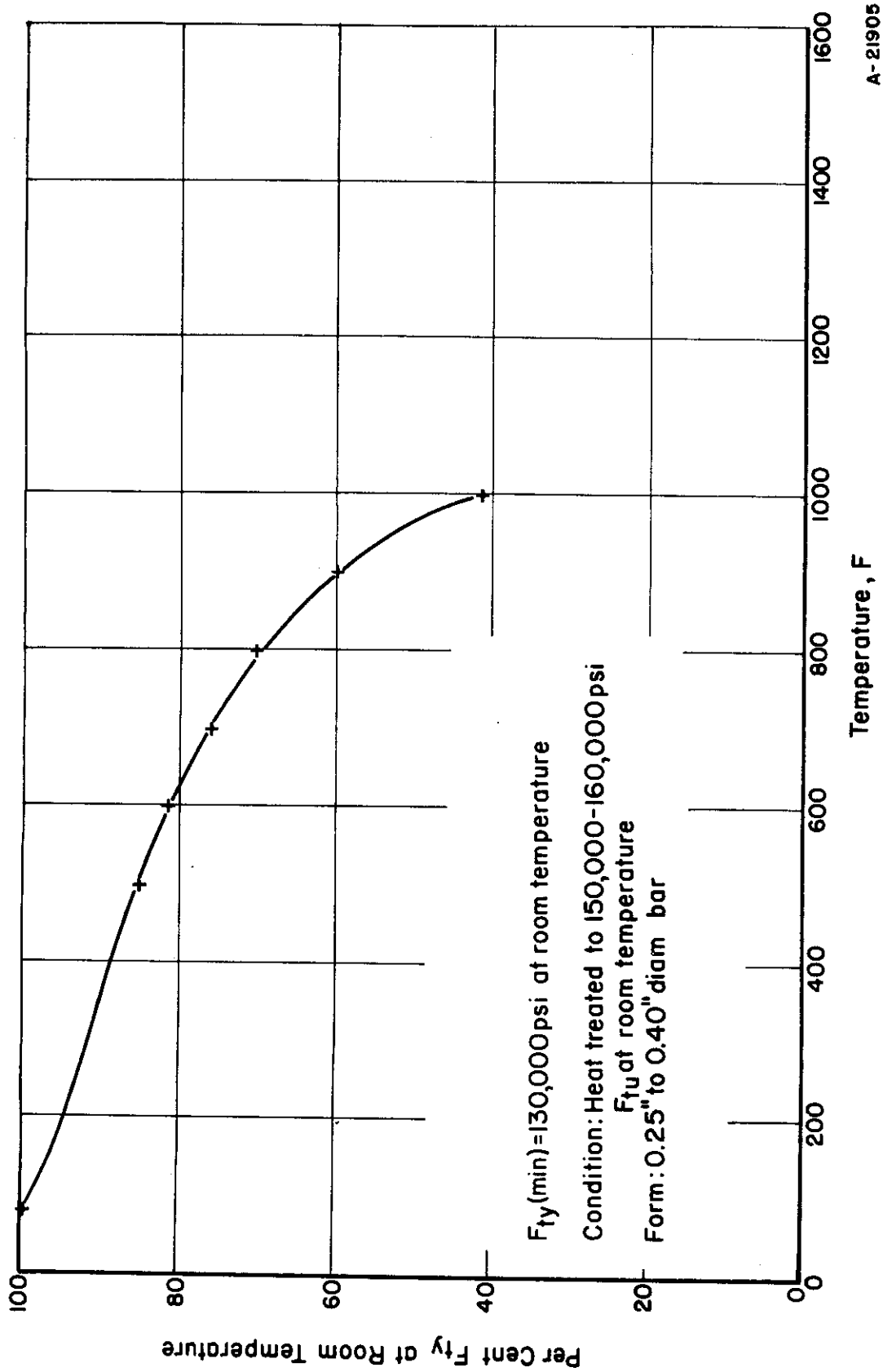

FIGURE 12. DESIGN CURVE FOR TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4340 ALLOY STEEL (0.25 TO 0.40-INCH-DIAMETER BAR) AT ELEVATED TEMPERATURE

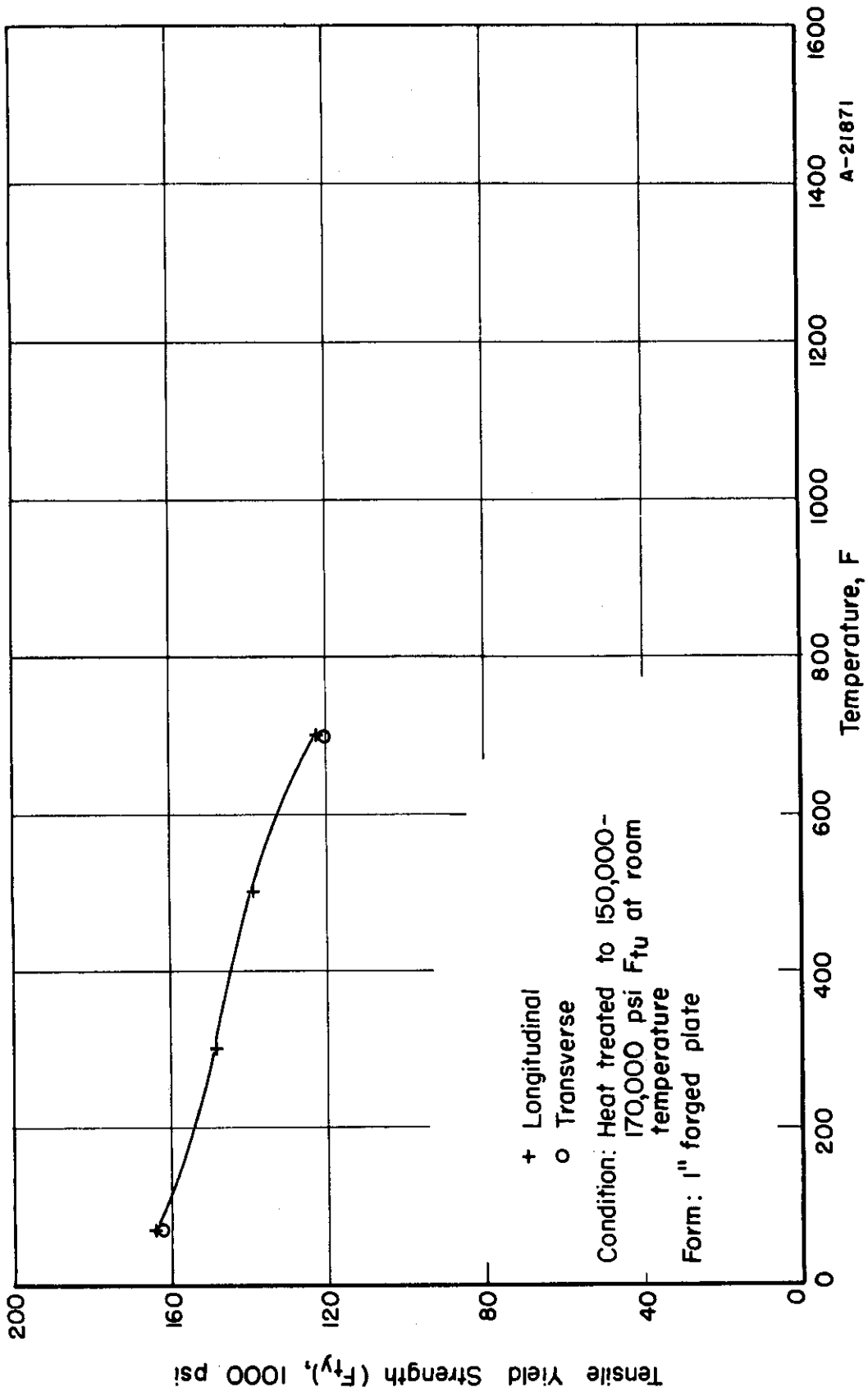

FIGURE 13. TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4340 ALLOY STEEL (1-INCH FORGED PLATE) AT ELEVATED TEMPERATURE

Ref. 111.

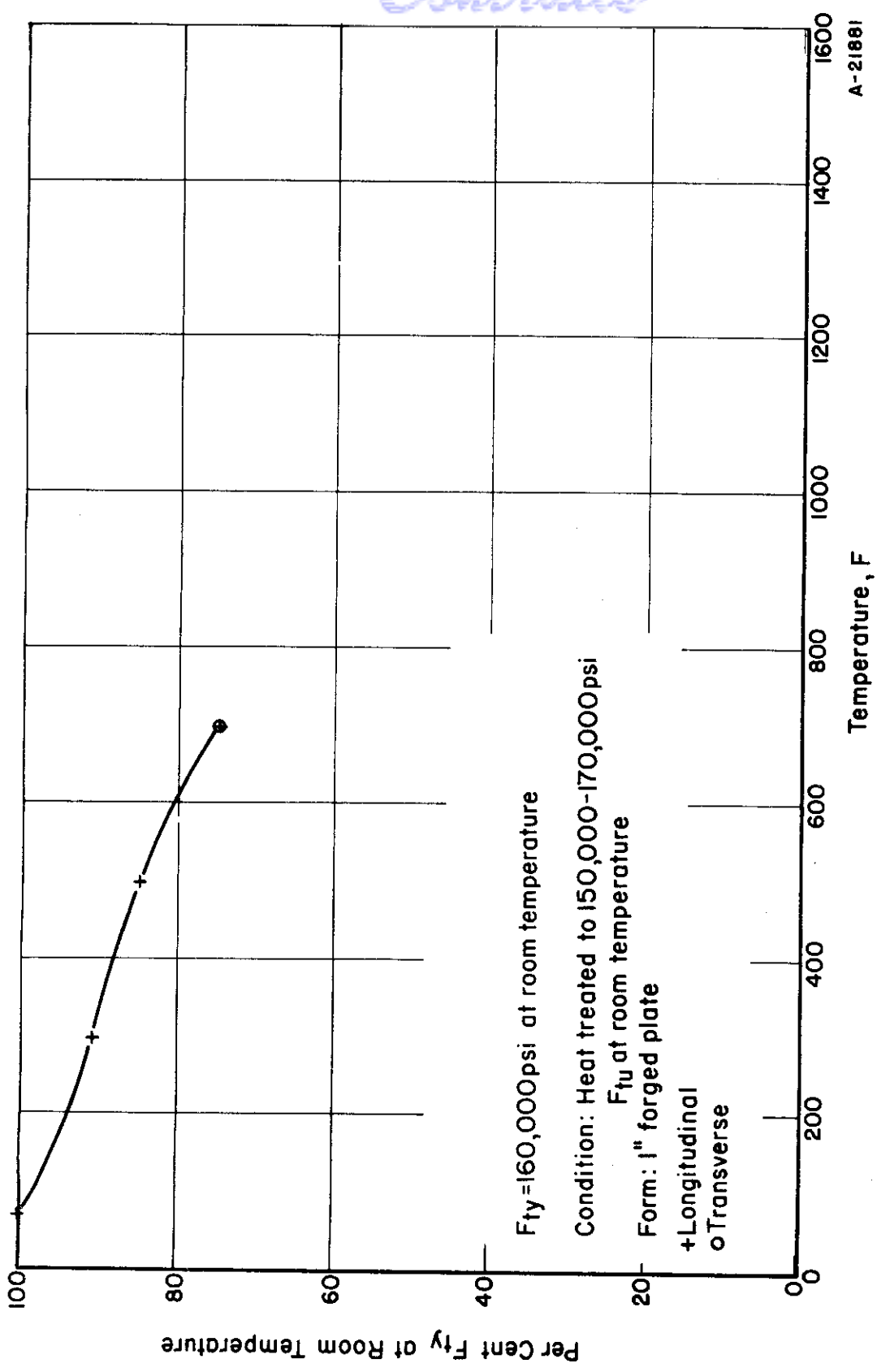

FIGURE 14. DESIGN CURVE FOR TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4340 ALLOY STEEL (1-INCH FORGED PLATE) AT ELEVATED TEMPERATURE

Ref. 111.

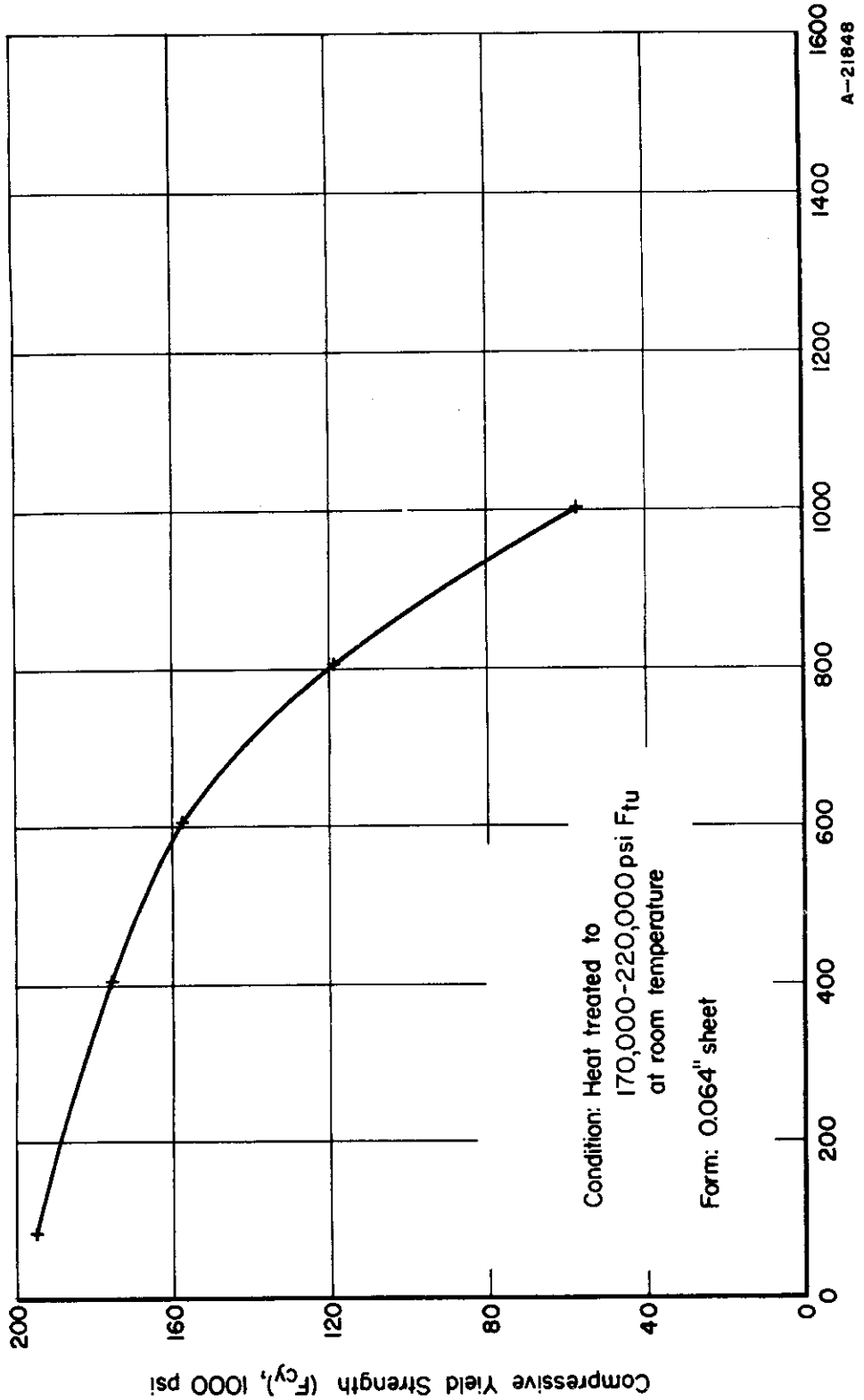

FIGURE 15. COMPRESSIVE YIELD STRENGTH (F_{cy}) OF AISI 4340 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 361.

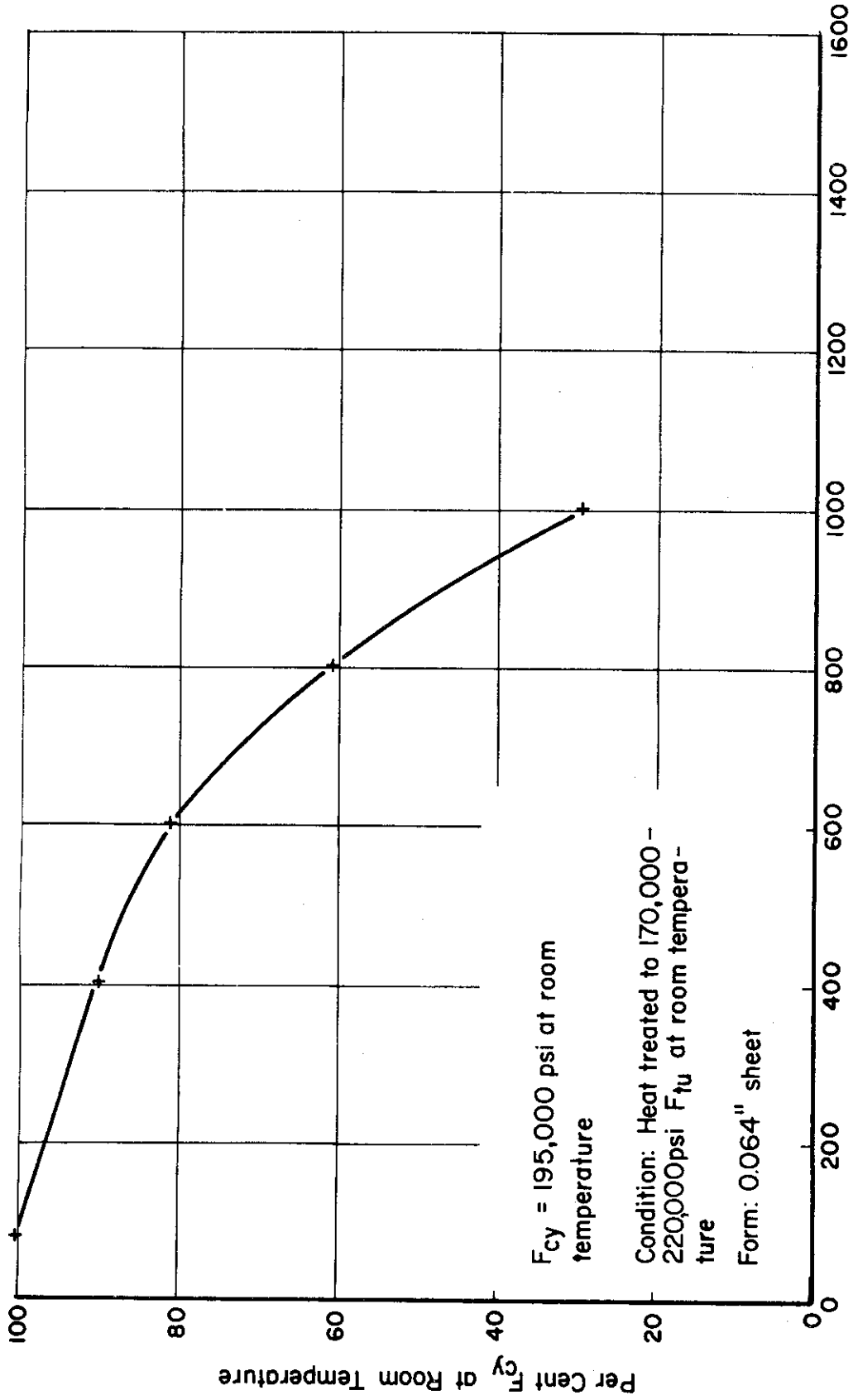

FIGURE 16. DESIGN CURVE FOR COMPRESSIVE YIELD STRENGTH (F_{cy}) OF AISI 4340 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 361.

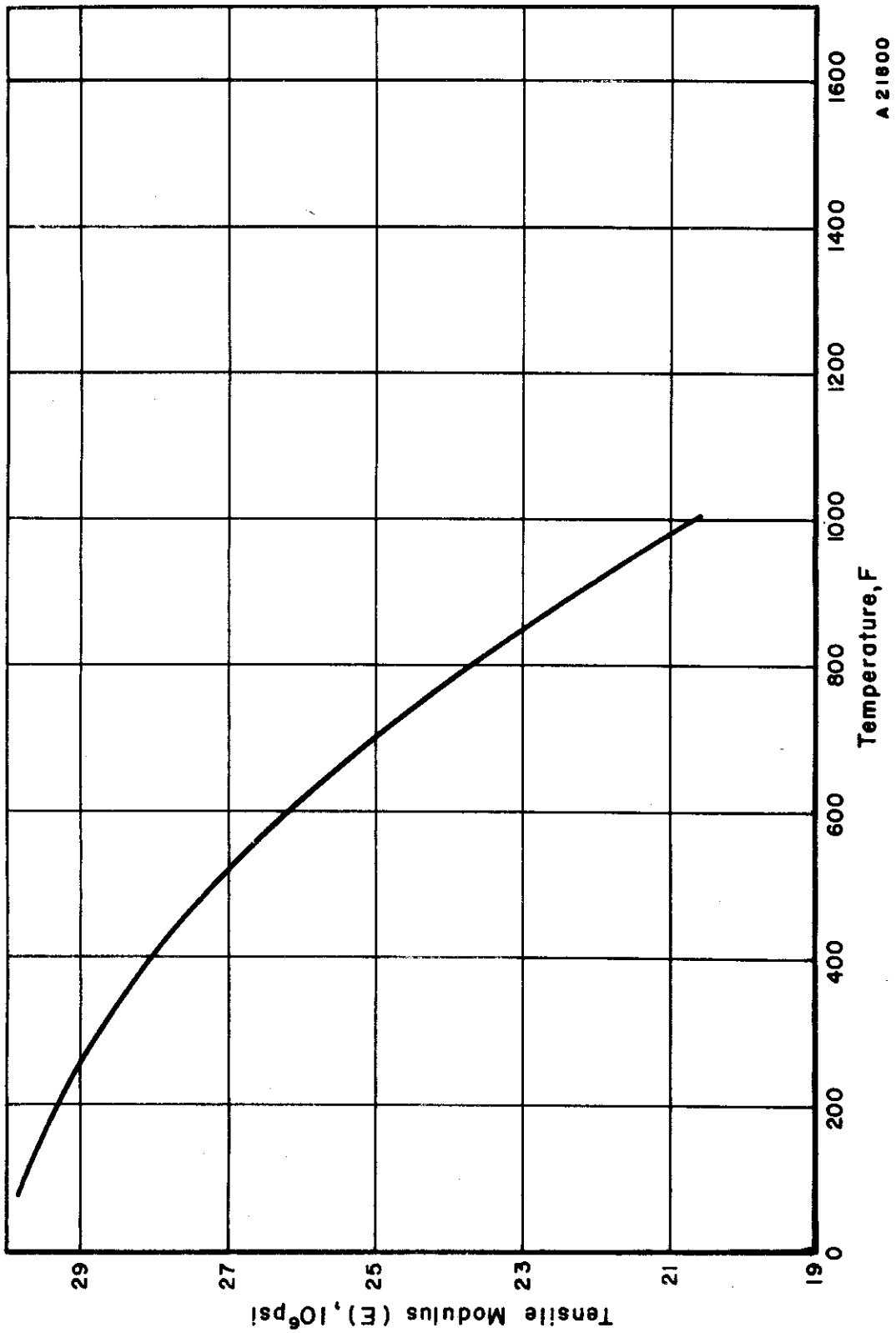

FIGURE 17. TENSILE MODULUS (E) FOR LOW AND MEDIUM ALLOY STEELS AT ELEVATED TEMPERATURE

Ref 178, 295, 296, 207, 192, 356.

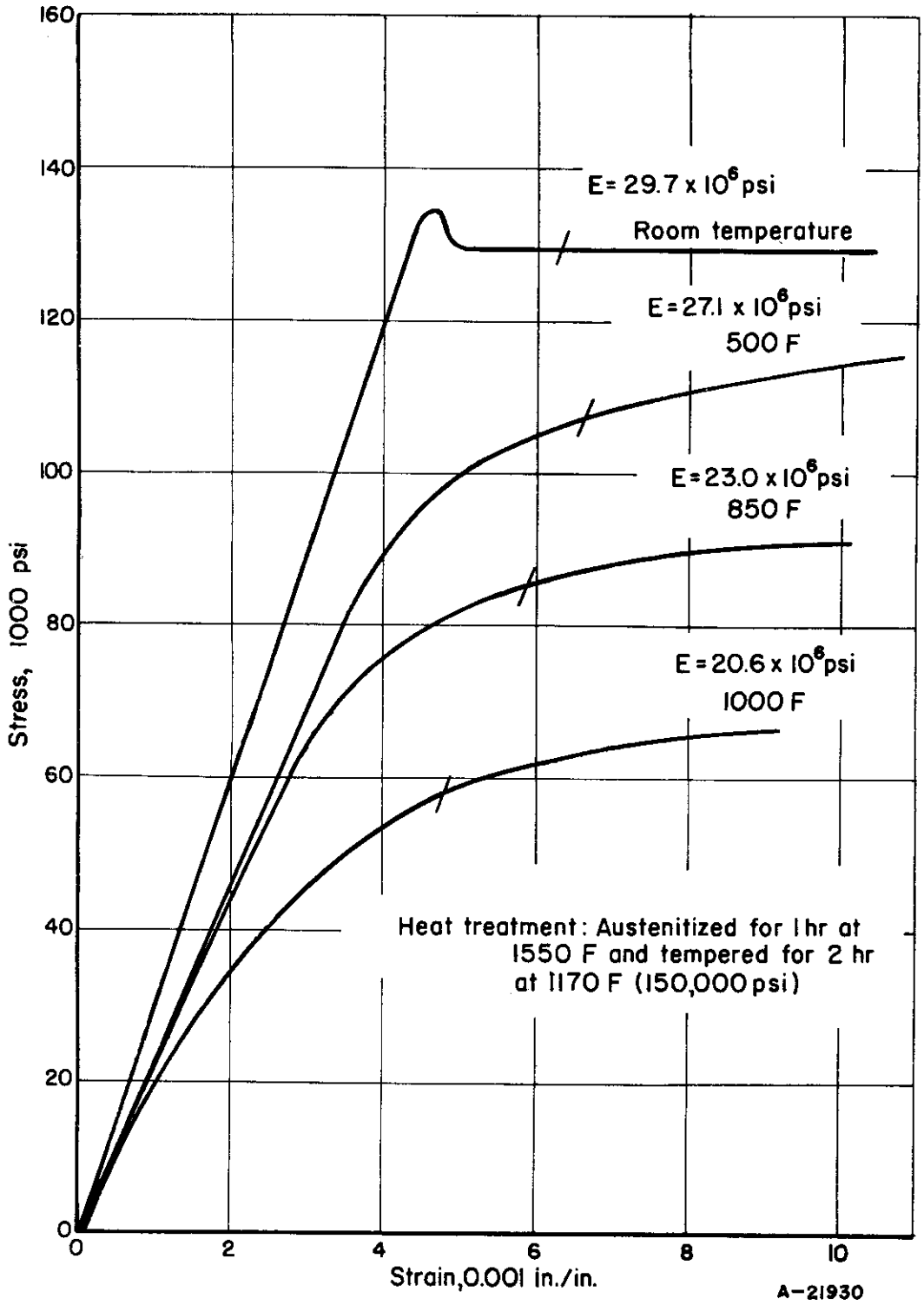

FIGURE 18. TENSILE STRESS-STRAIN CURVES FOR AISI 4340 ALLOY STEEL AT ROOM TEMPERATURE, 500 F, 850 F, AND 1000 F

Ref. 295.

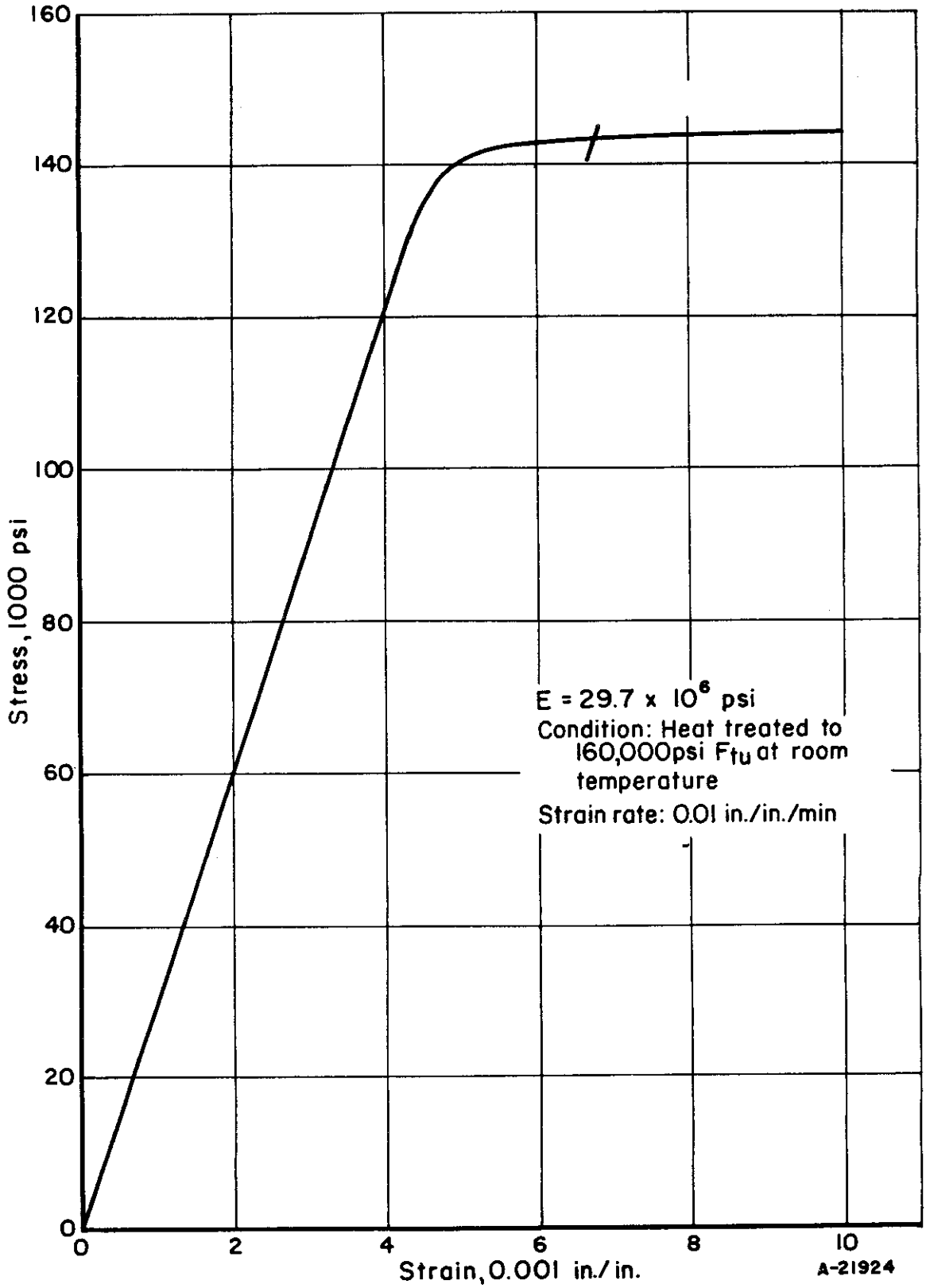

FIGURE 19. TENSILE STRESS-STRAIN CURVE FOR AISI 4340 ALLOY STEEL AT ROOM TEMPERATURE

Ref. 178.

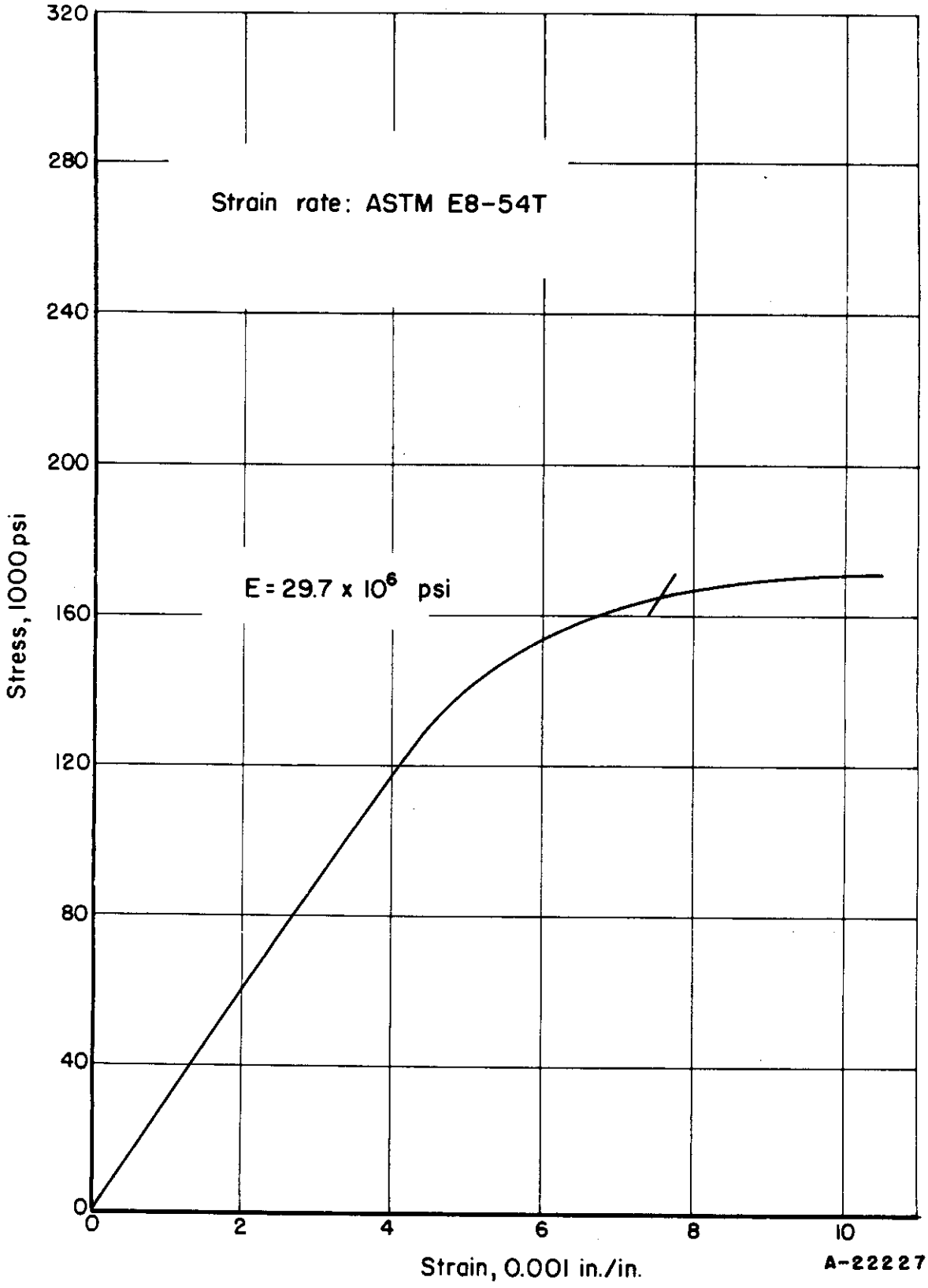

FIGURE 20. TENSILE STRESS-STRAIN CURVE FOR AISI 4340 ALLOY STEEL (180,000 PSI) AT ROOM TEMPERATURE

Ref. 207

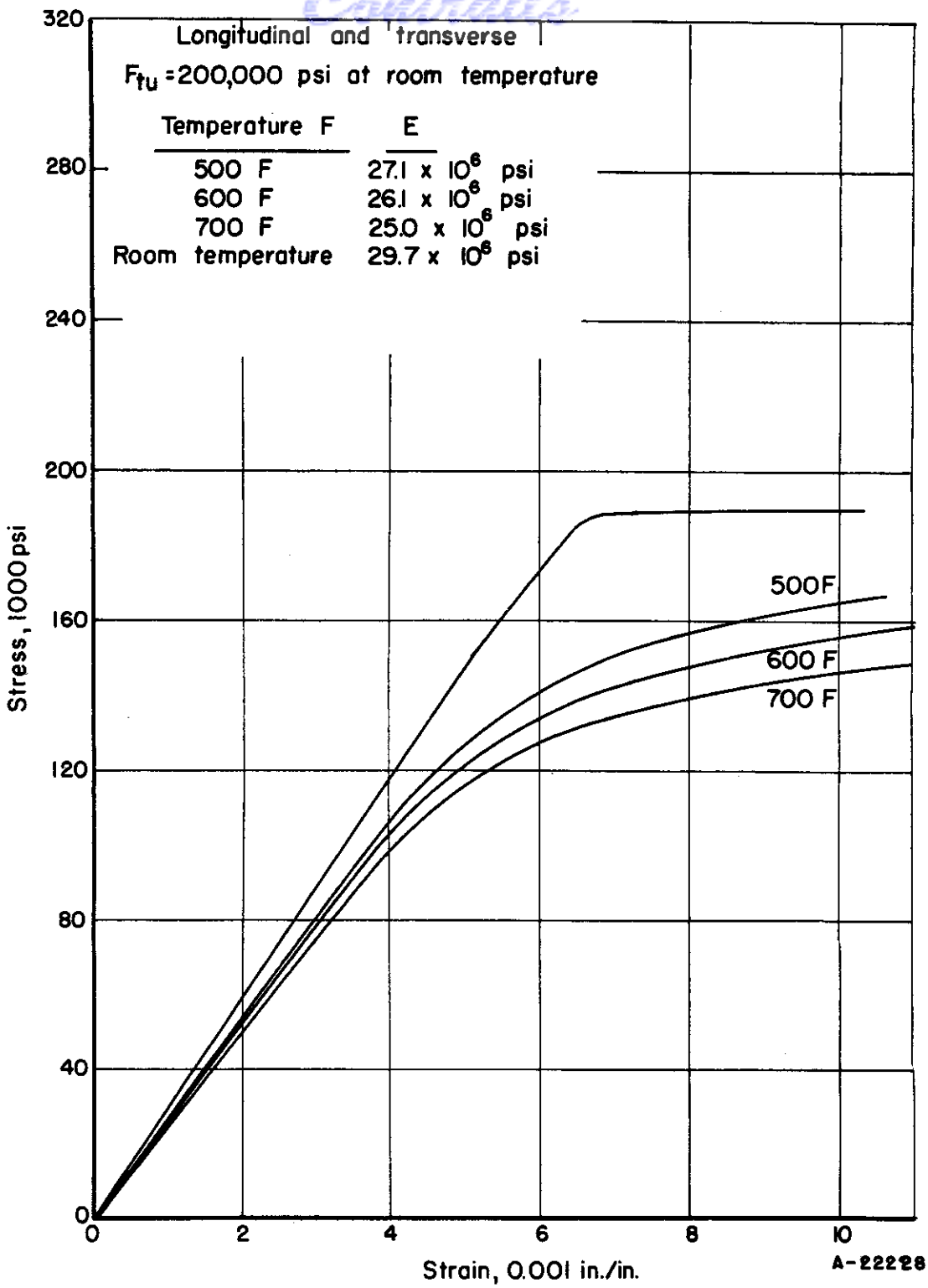

FIGURE 21. TENSILE STRESS-STRAIN CURVES FOR AISI 4340 ALLOY STEEL AT ROOM TEMPERATURE, 500 F, 600 F, AND 700 F

Ref. 296.

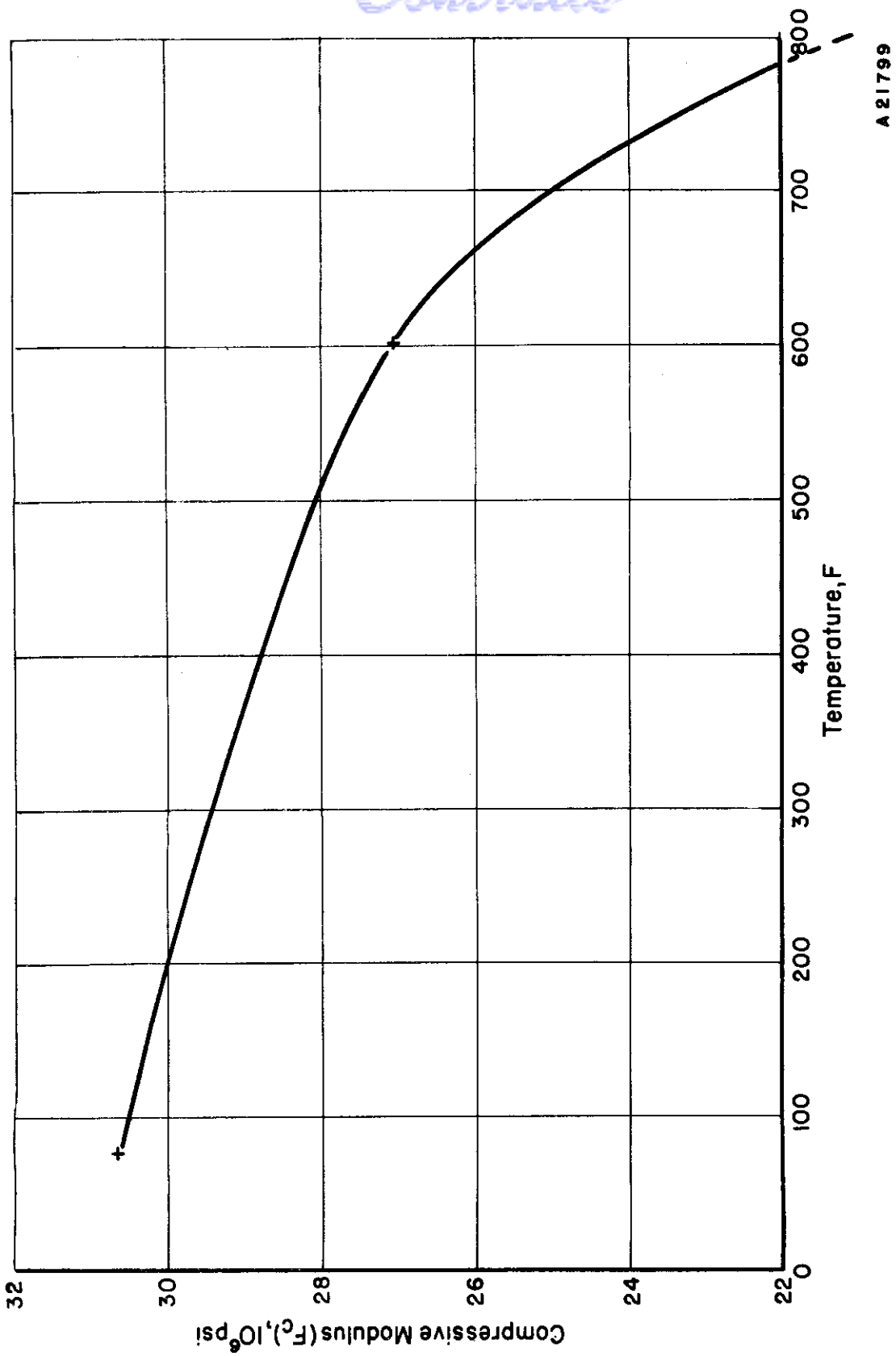

FIGURE 22. COMPRESSIVE MODULUS (E_c) OF AISI 4340 ALLOY STEEL AT ELEVATED TEMPERATURE

Ref. 207.

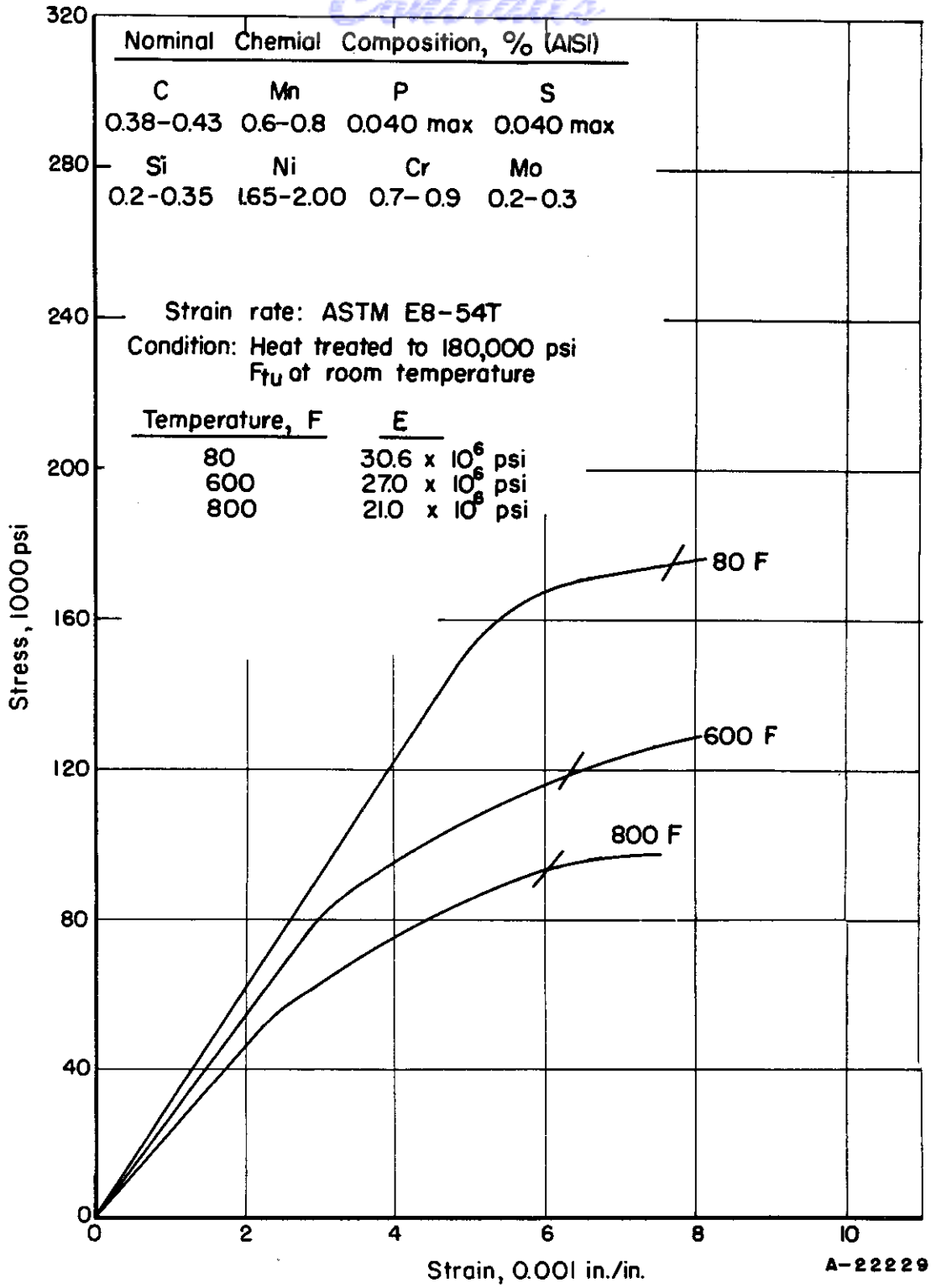

FIGURE 23. COMPRESSIVE STRESS-STRAIN CURVES FOR AISI 4340 ALLOY STEEL AT ROOM TEMPERATURE, 600 F, AND 800 F

Ref. 207.

AISI 4130
[QQ-S-00627 (Army Ord), FS 4130]
(AMS-6350C)

AISI 4130 is a chromium-molybdenum steel having lower hardenability than AISI 4340. AISI 4130 can be readily heat treated and utilized in the 125,000- to 180,000-psi strength range in small sections. It is not subject to temper embrittlement. AISI 4140 has hardenability characteristics similar to AISI 4130 and is comparable to AISI 4340 in maximum as-quenched hardness. The nominal chemical compositions of AISI 4037, 4130, and 4140 are given in Table 2.

TABLE 2. NOMINAL CHEMICAL COMPOSITION OF AISI 4037, 4130, AND 4140 STEELS

	Weight Per Cent		
Element	4037	4130	4140
Carbon	0.37	0.30	0.40
Manganese	0.80	0.50	0.85
Chromium	--	0.95	0.95
Molybdenum	0.25	0.20	0.20
Iron	Balance	Balance	Balance

The short-time, elevated-temperature properties of AISI 4130 are shown in the following curves:

(1) Tensile properties, Figures 24 through 39

(2) Compressive properties, Figures 40 and 41

(3) Bearing properties, Figures 42 through 45

(4) Shear properties, Figures 46 and 47

(5) Stress-strain curves, Figures 48 through 52, and 54 through 58

(6) Modulus of elasticity, Figure 53.

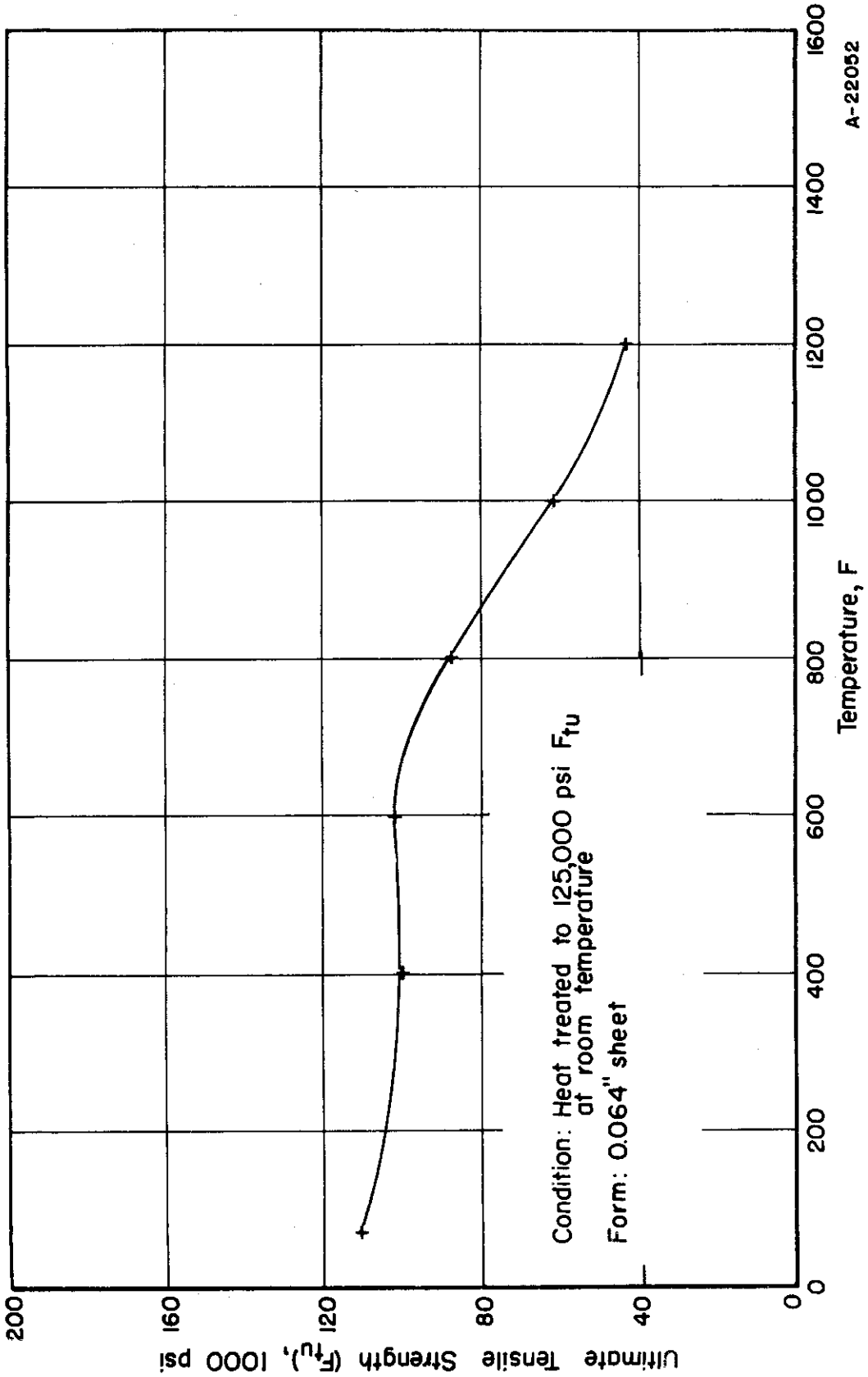

FIGURE 24. TENSILE STRENGTH (F_{tu}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

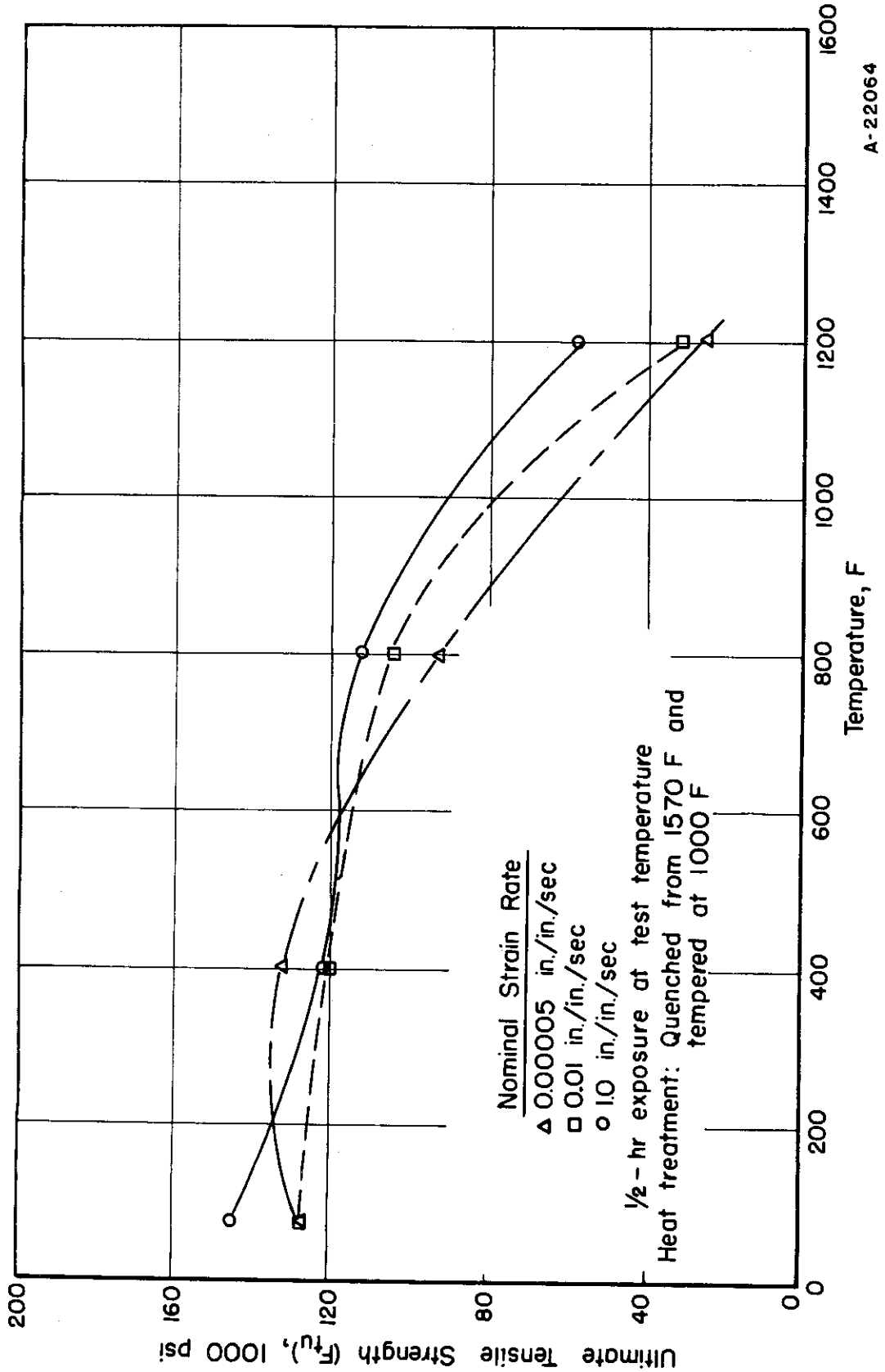

FIGURE 25. EFFECT OF STRAIN RATE ON THE TENSILE STRENGTH (F_{tu}) OF HEAT-TREATED AISI 4130 SHEET AT ELEVATED TEMPERATURE

Ref. WADC 55-199, Part 2, p88.

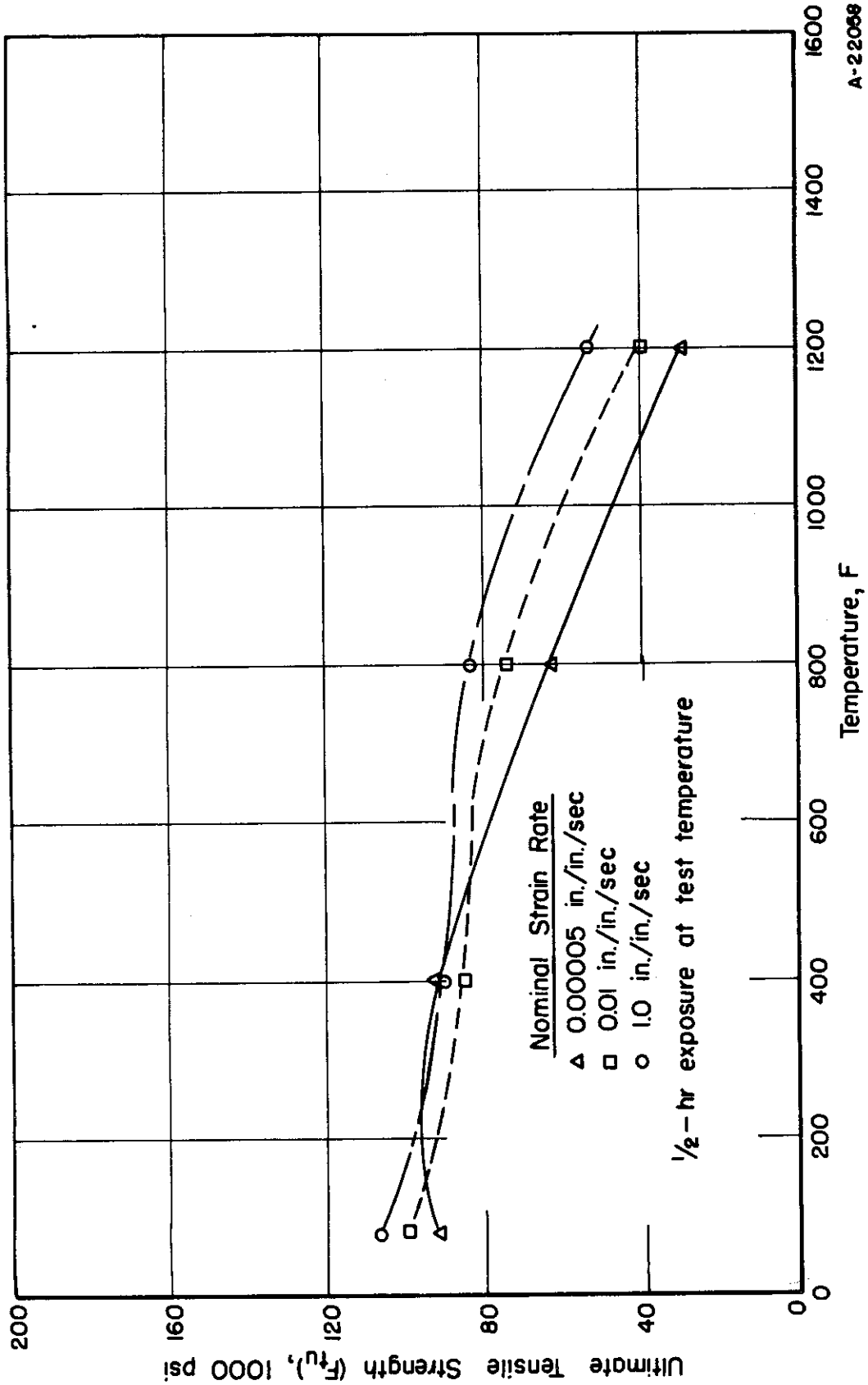

FIGURE 26. EFFECT OF STRAIN RATE ON THE TENSILE STRENGTH (F_{tu}) OF NORMALIZED AISI 4130 SHEET AT ELEVATED TEMPERATURE

Ref. WADC 55-199, Part 2 p 81.

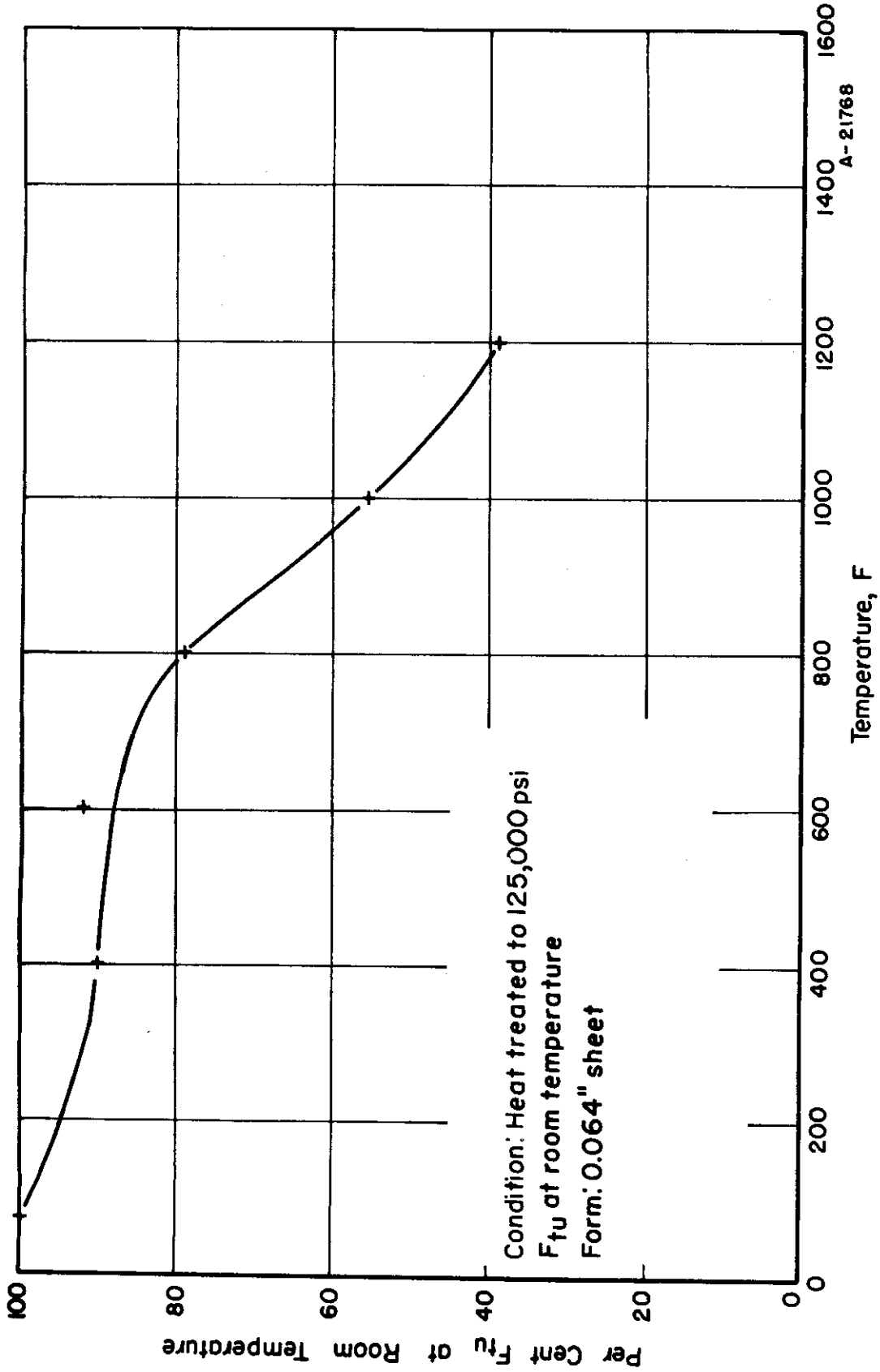

FIGURE 27. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

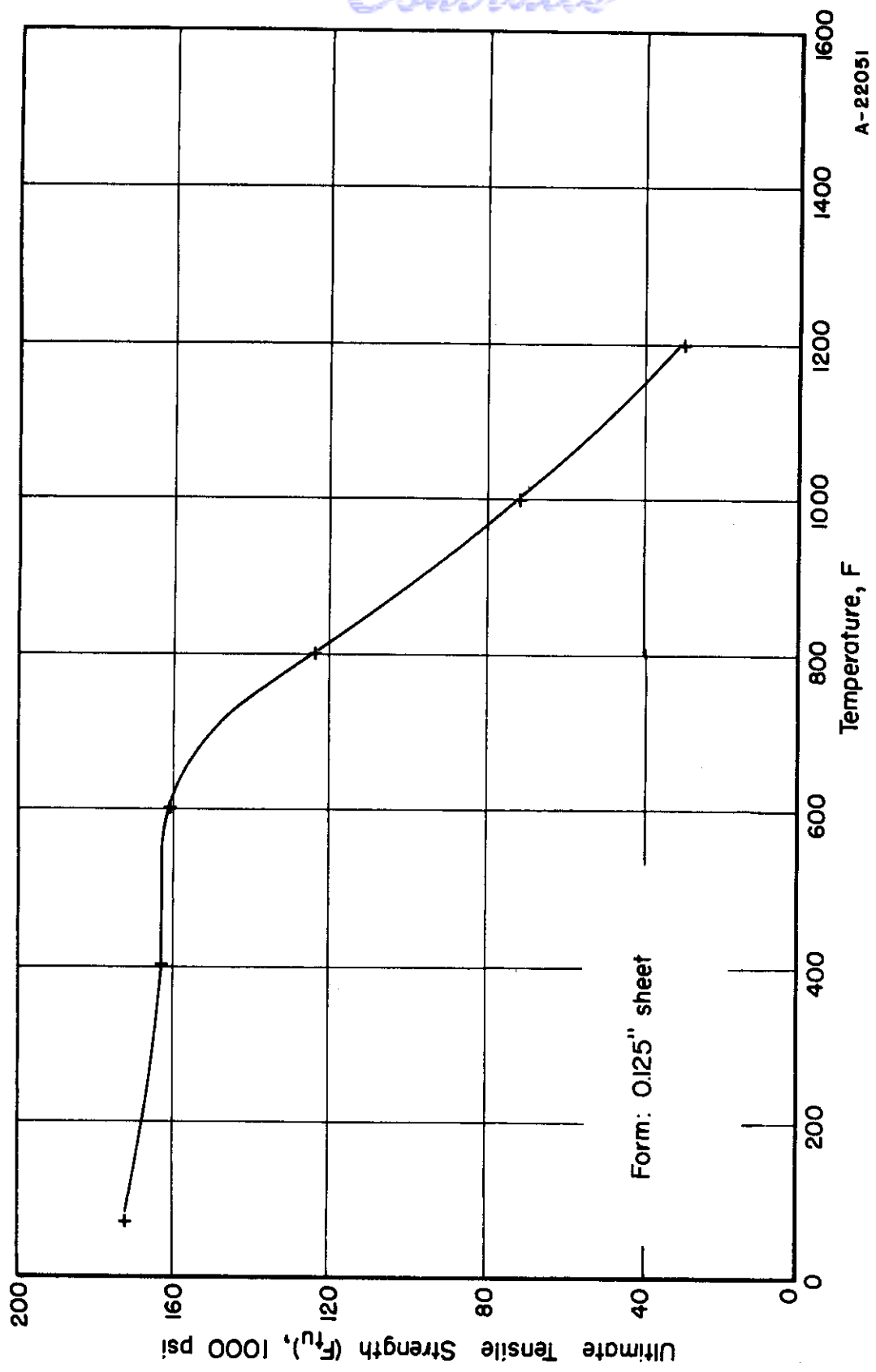

FIGURE 28. TENSILE STRENGTH (F_{tu}) OF AISI 4130 ALLOY STEEL (0.125-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 28.

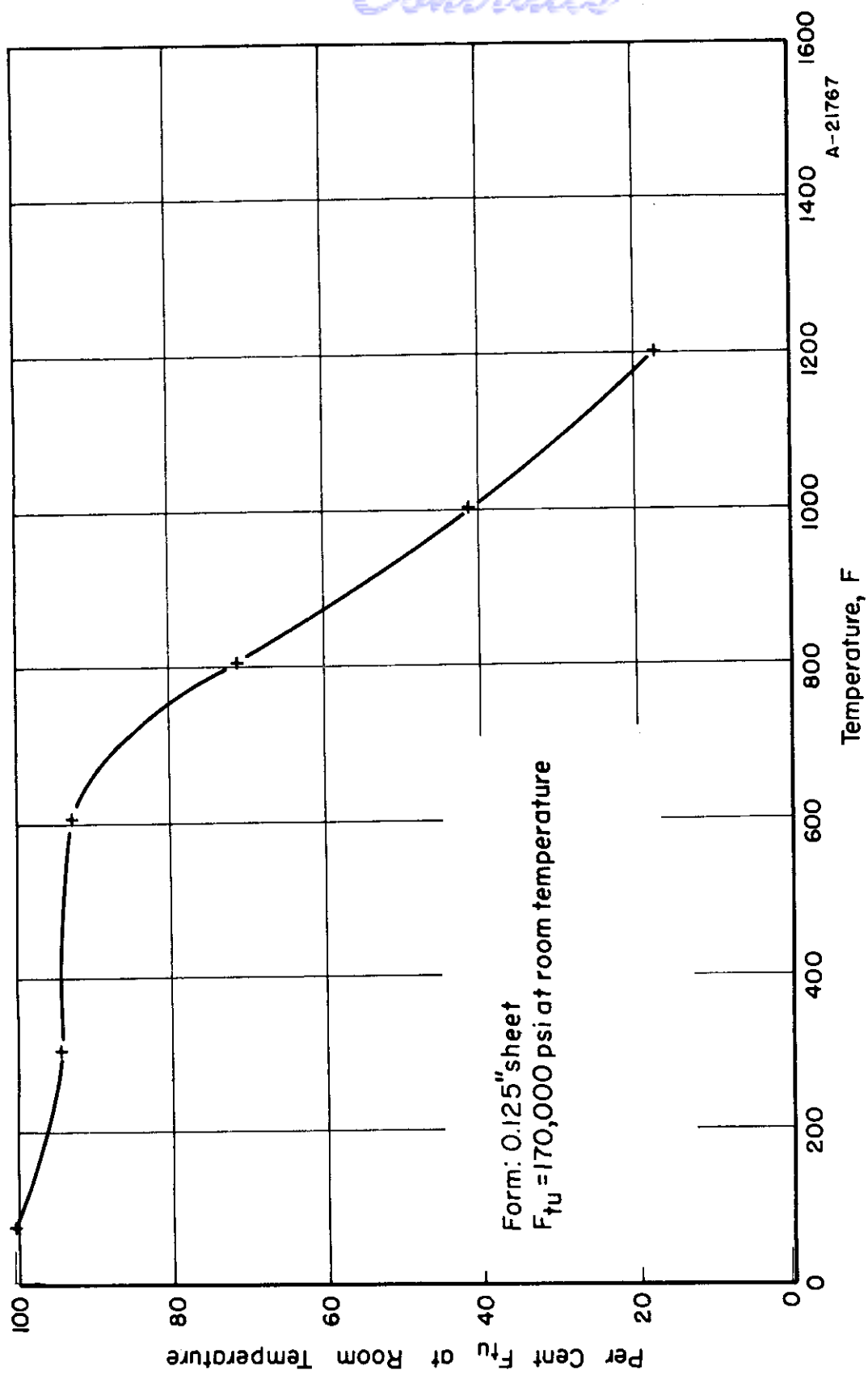

FIGURE 29. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF AISI 4130 ALLOY STEEL (0.125-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 28.

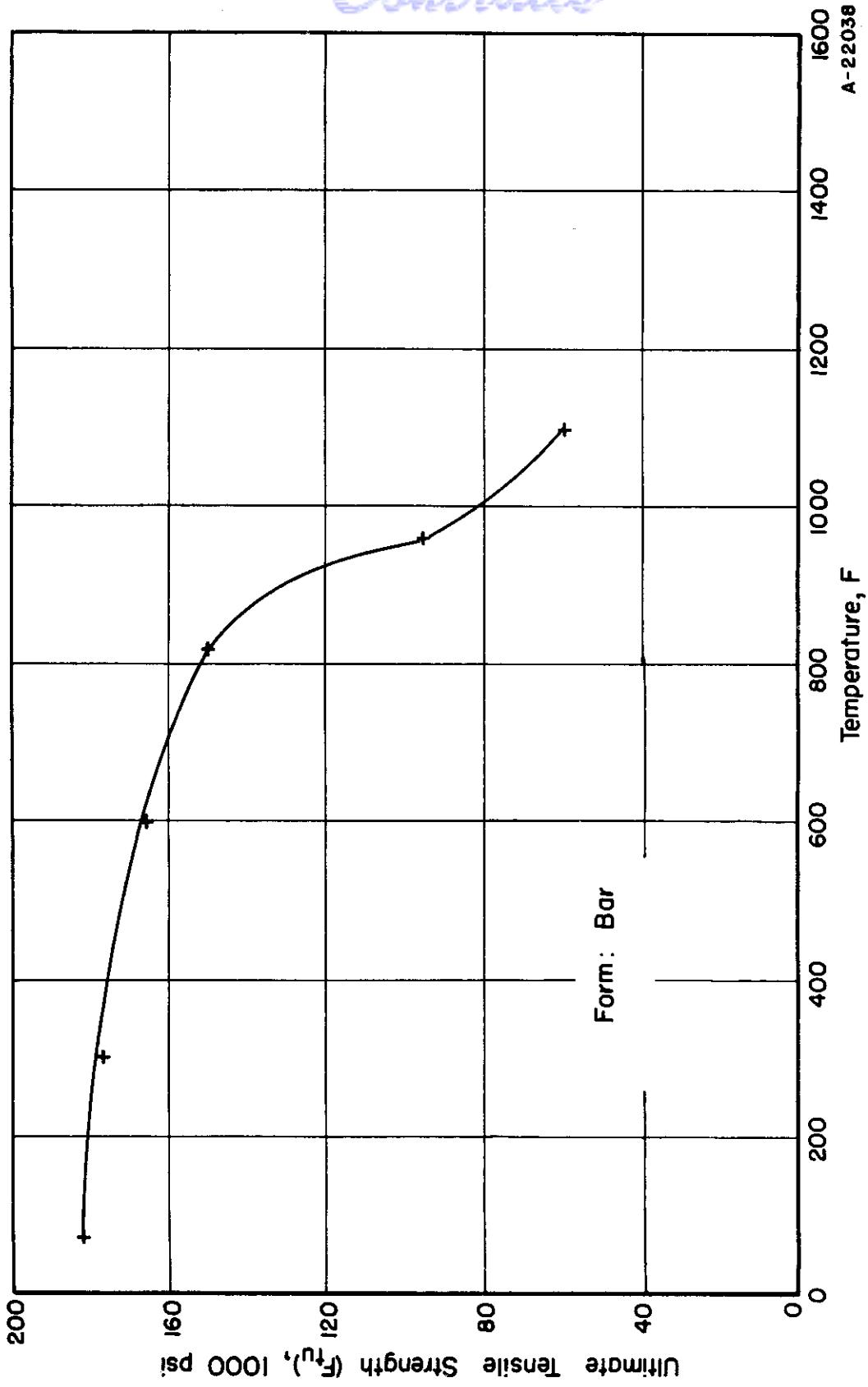

FIGURE 30. TENSILE STRENGTH (F_{tu}) OF AISI 4130 ALLOY STEEL (BAR) AT ELEVATED TEMPERATURE

Ref. 28.

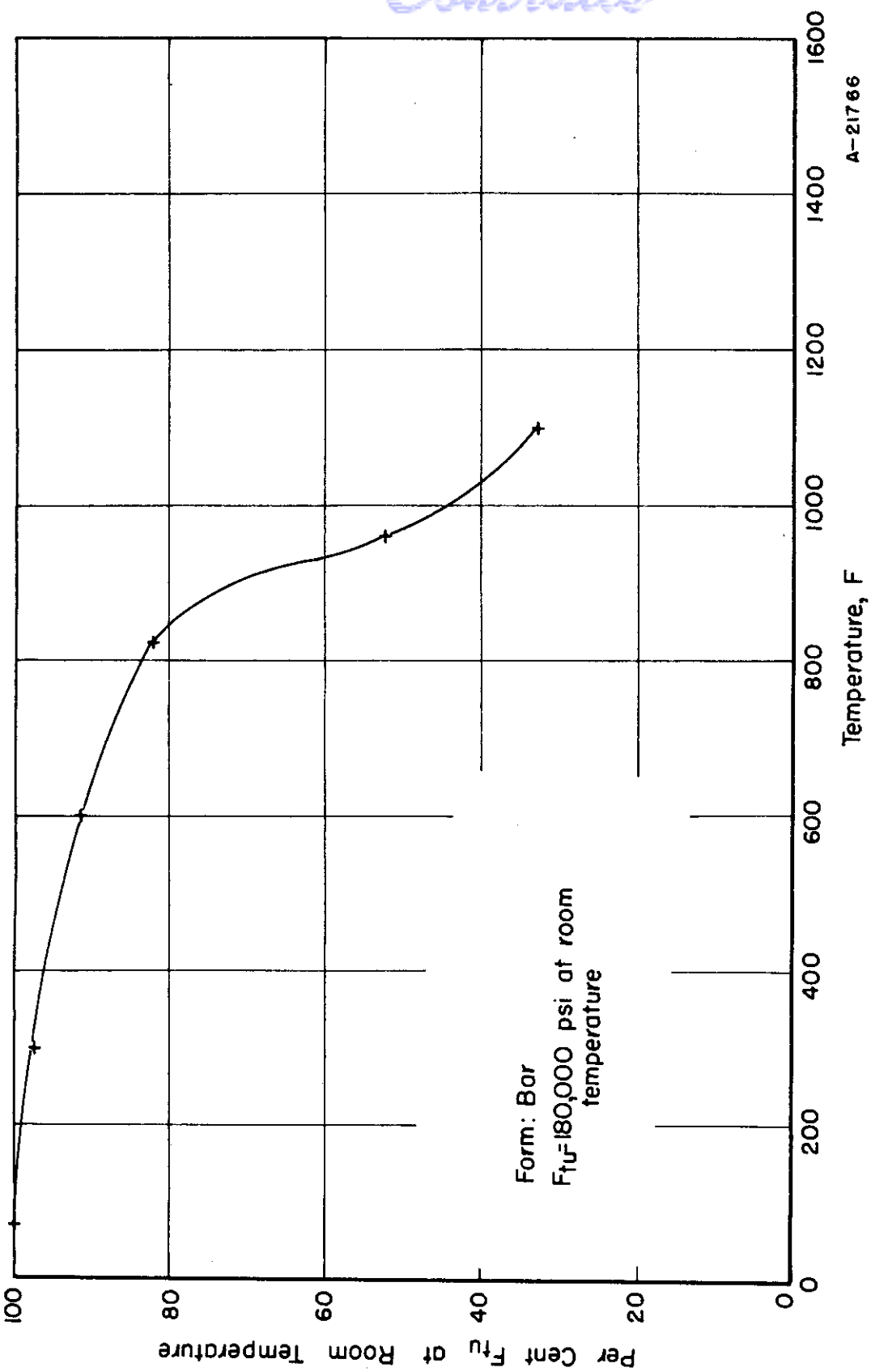

FIGURE 31. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF AISI 4130 ALLOY STEEL (BAR) AT ELEVATED TEMPERATURE

Ref. 28.

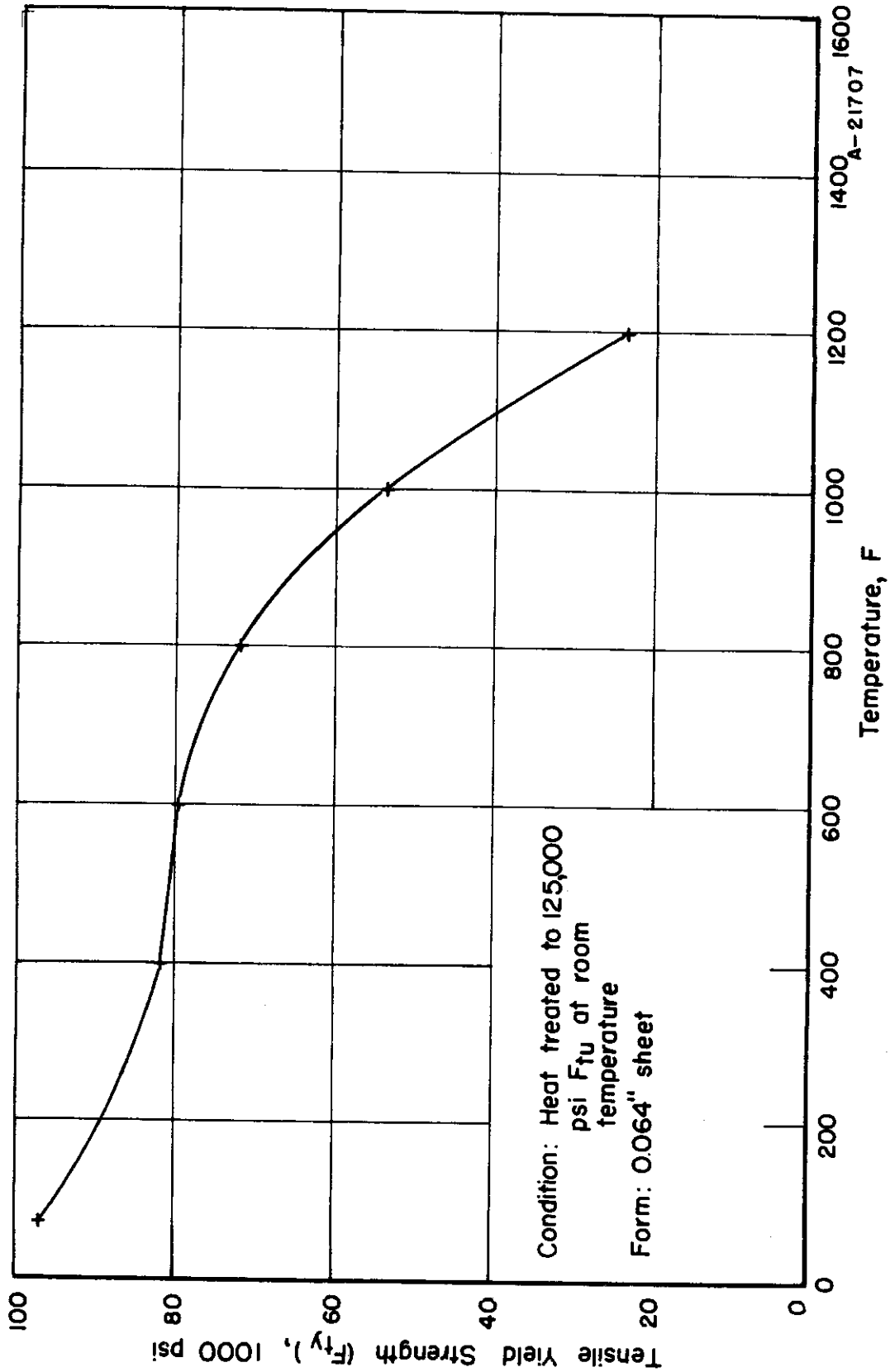

FIGURE 32. TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

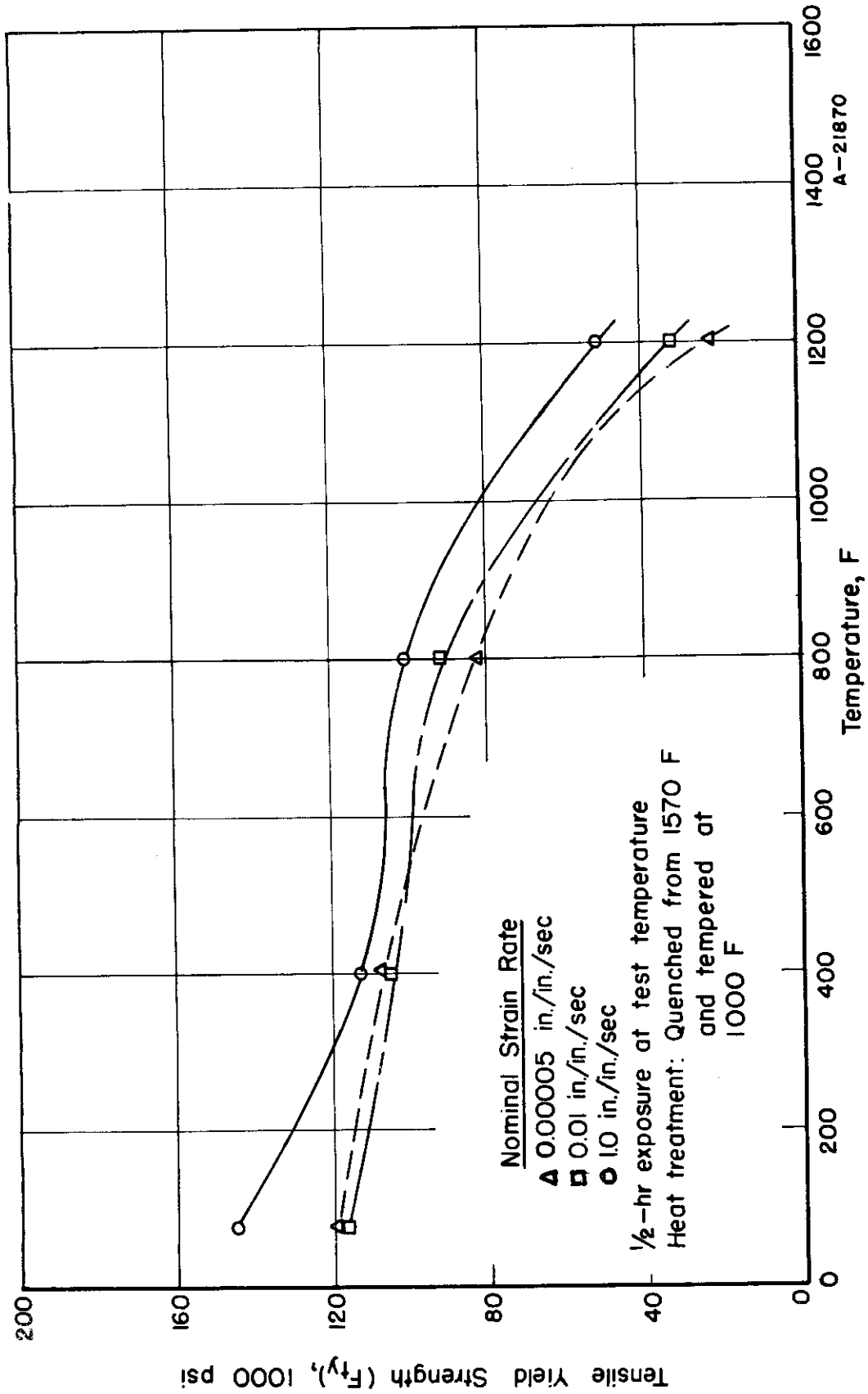

FIGURE 33. EFFECT OF STRAIN RATE ON THE TENSILE YIELD STRENGTH (F_{ty}) OF HEAT-TREATED AISI 4130 SHEET AT ELEVATED TEMPERATURE

Ref. WADC 55-199, Part 2, p 88.

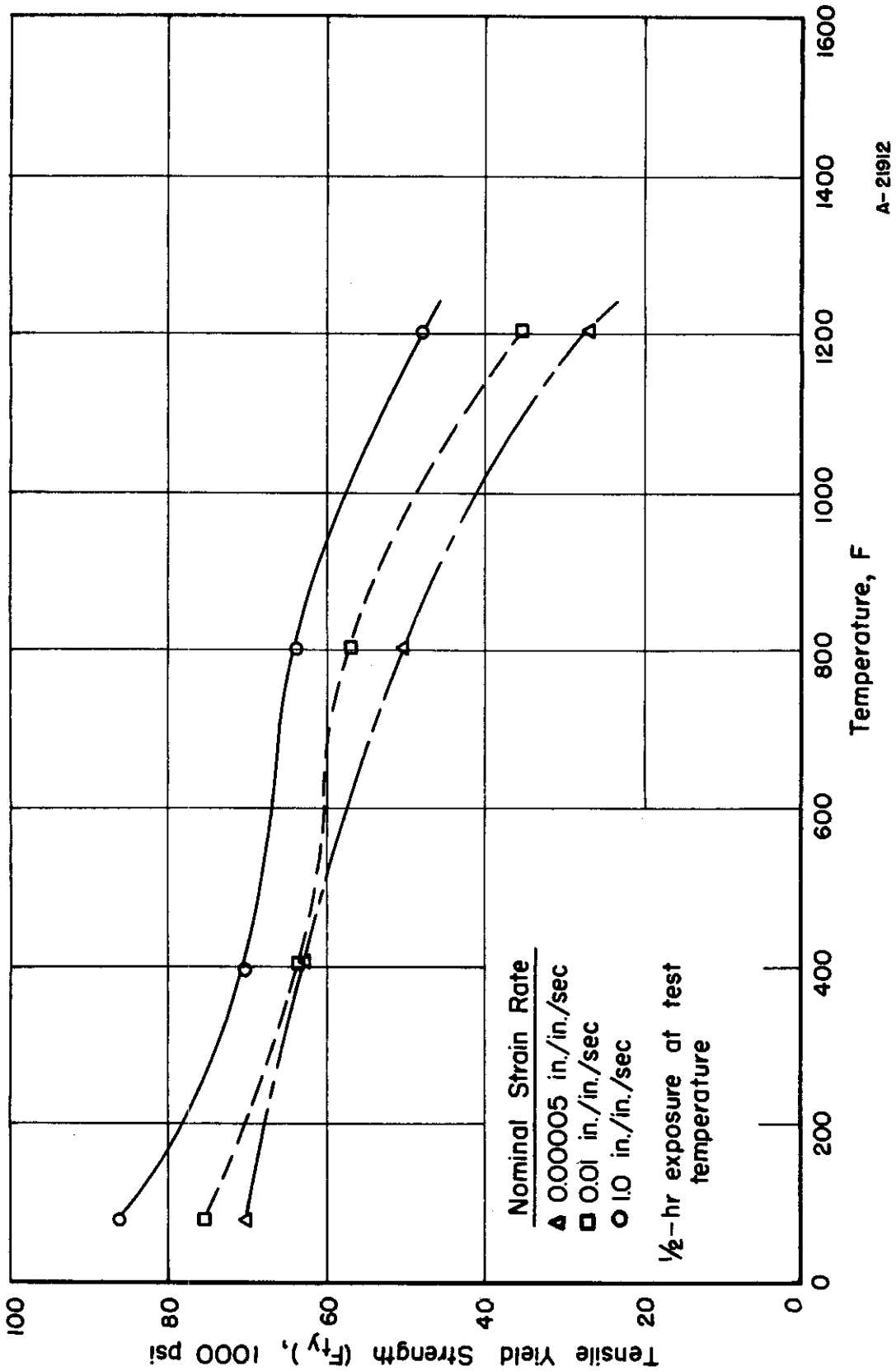

FIGURE 34. EFFECT OF STRAIN RATE ON THE TENSILE YIELD STRENGTH (F_{ty}) OF NORMALIZED AISI 4130 SHEET AT ELEVATED TEMPERATURE

WADC 55-199, Part 2, p 81.

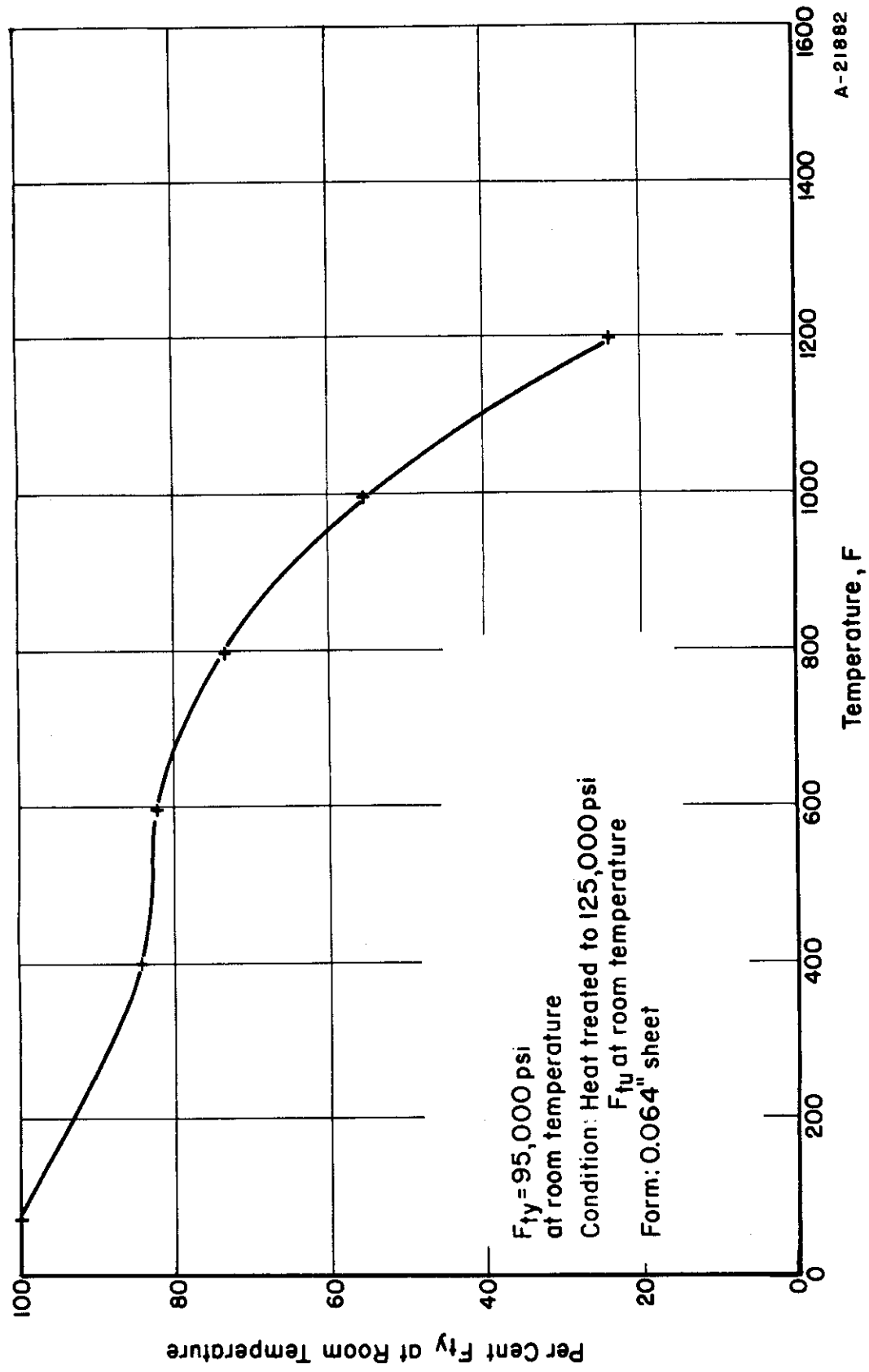

FIGURE 35. DESIGN CURVE FOR TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE Ref. 57.

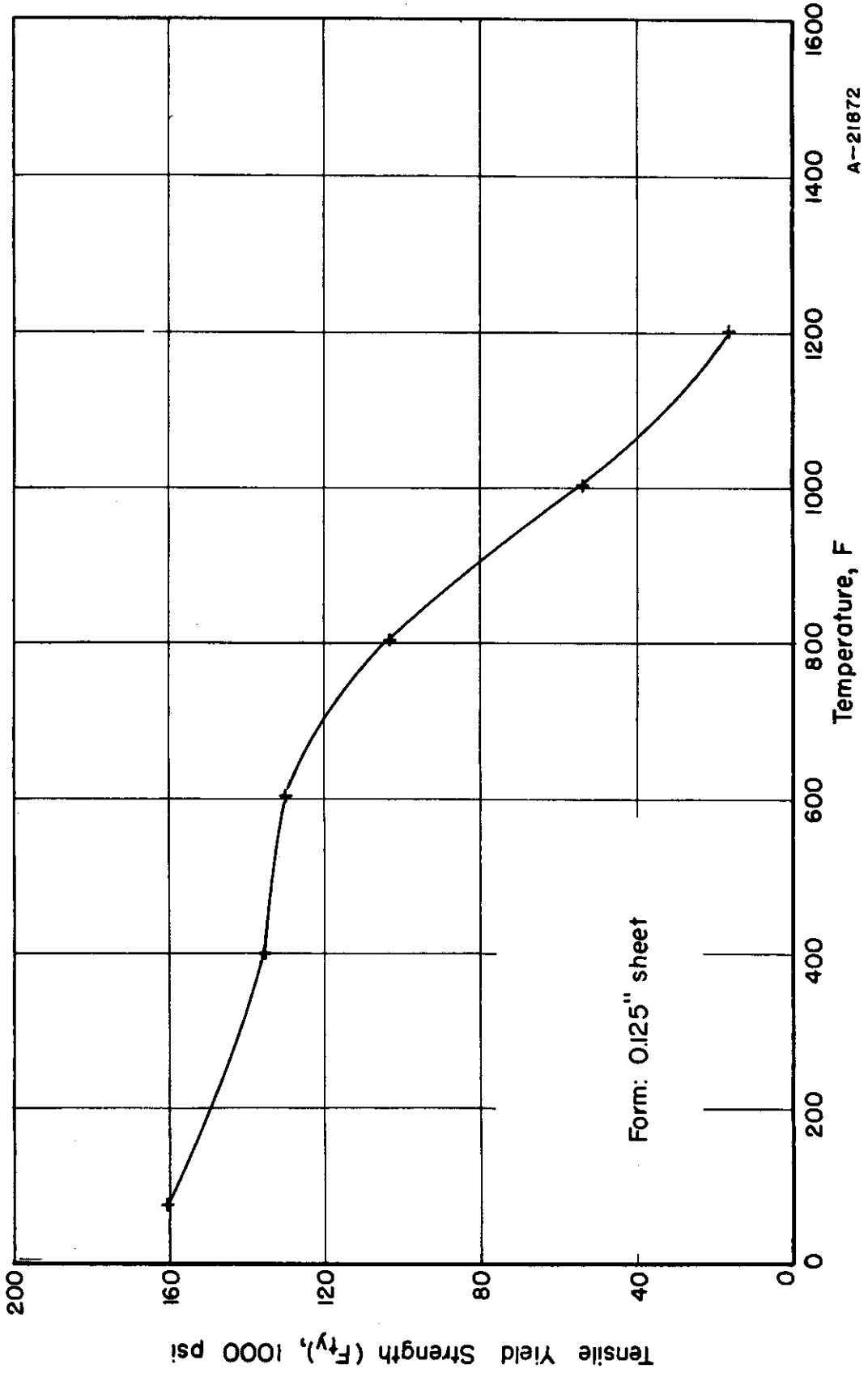

FIGURE 36. TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4130 ALLOY STEEL (0.125-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 28.

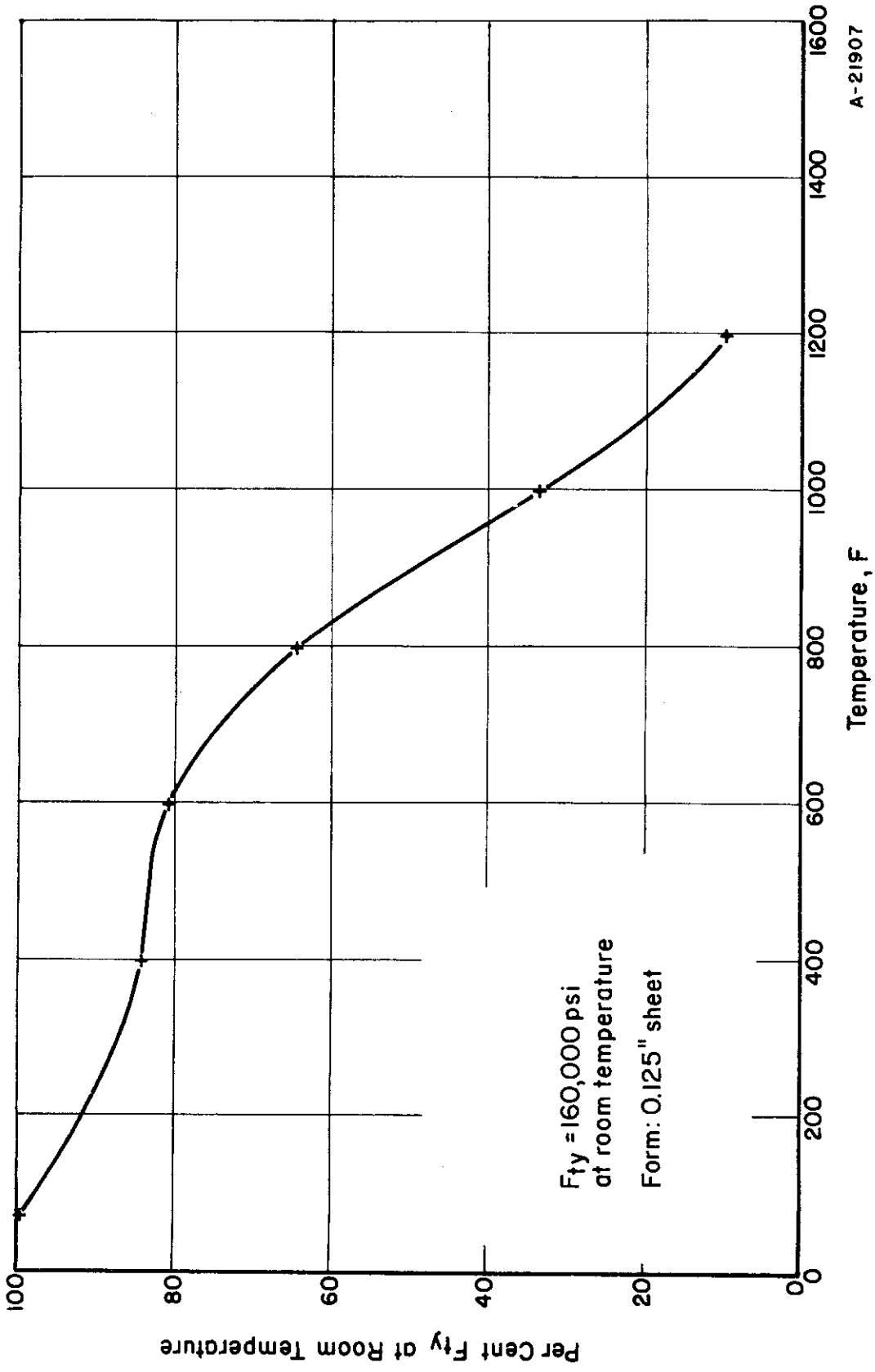

FIGURE 37. DESIGN CURVE FOR TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4130 ALLOY STEEL (0.125-INCH SHEET) AT ELEVATED TEMPERATURE
Ref. 28.

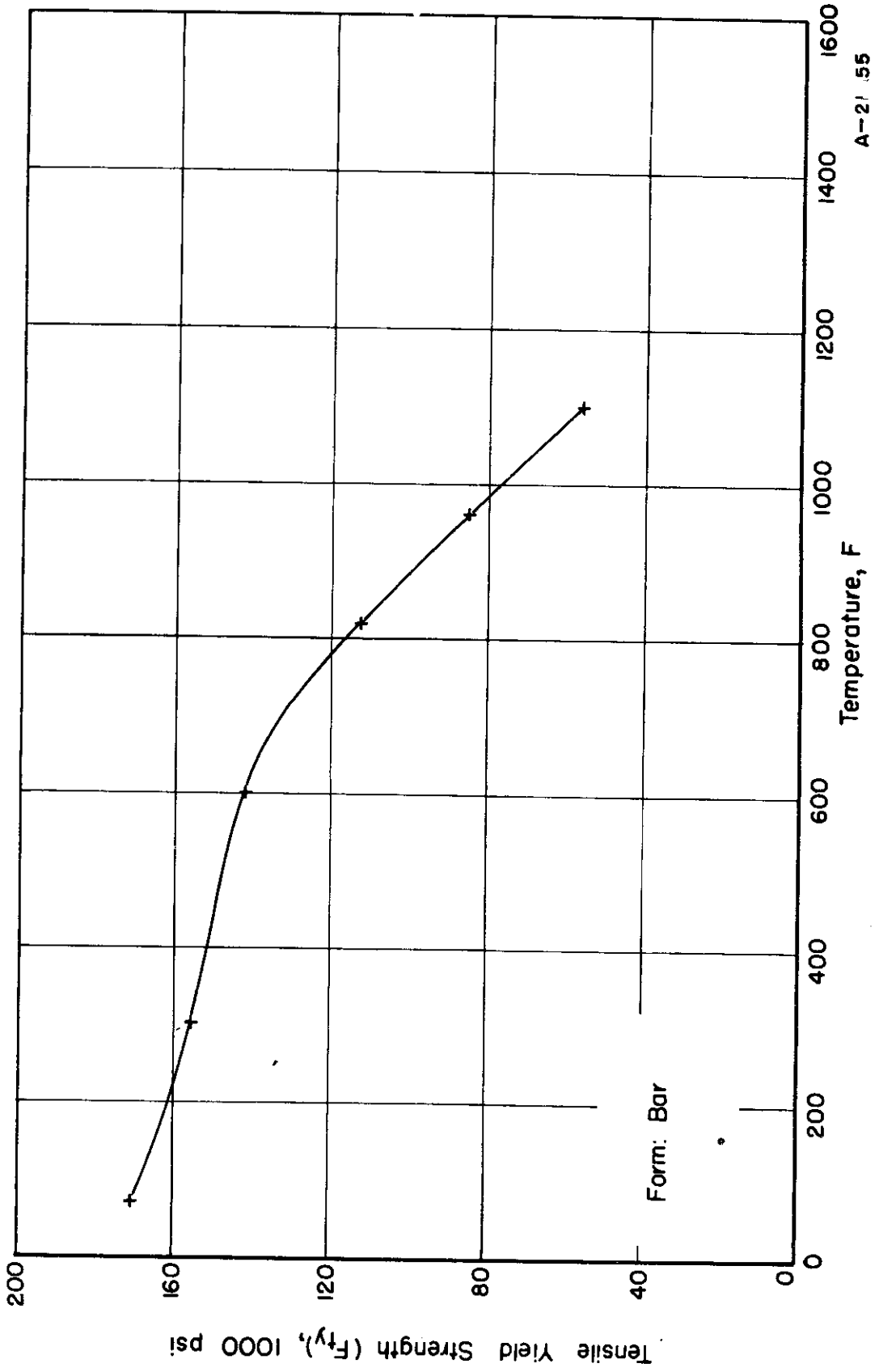

FIGURE 38. TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4130 ALLOY STEEL (BAR) AT ELEVATED TEMPERATURE

Ref. 28.

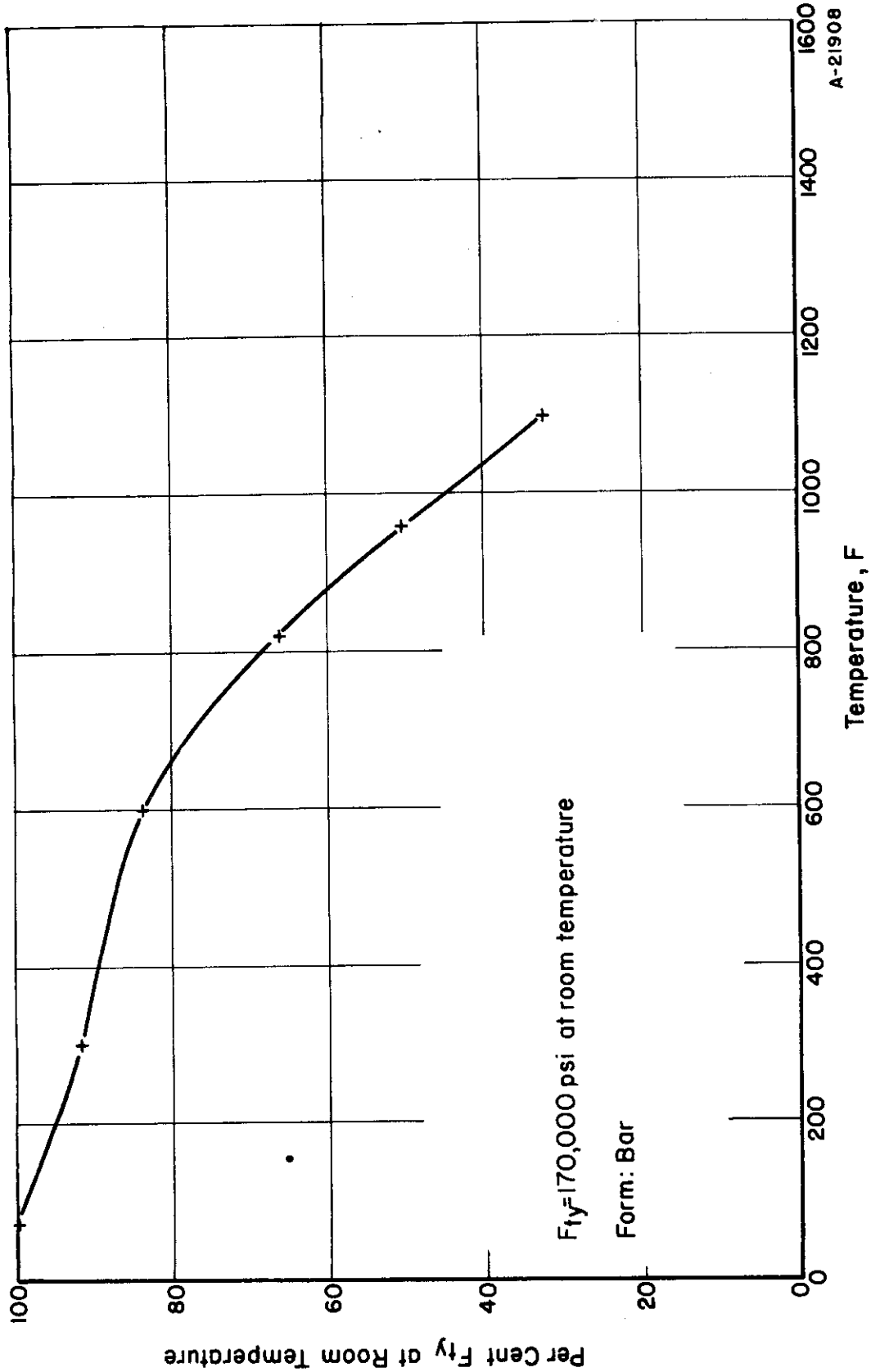

FIGURE 39. DESIGN CURVE FOR TENSILE YIELD STRENGTH (F_{ty}) OF AISI 4130 ALLOY STEEL (BAR) AT ELEVATED TEMPERATURE

Ref. 28.

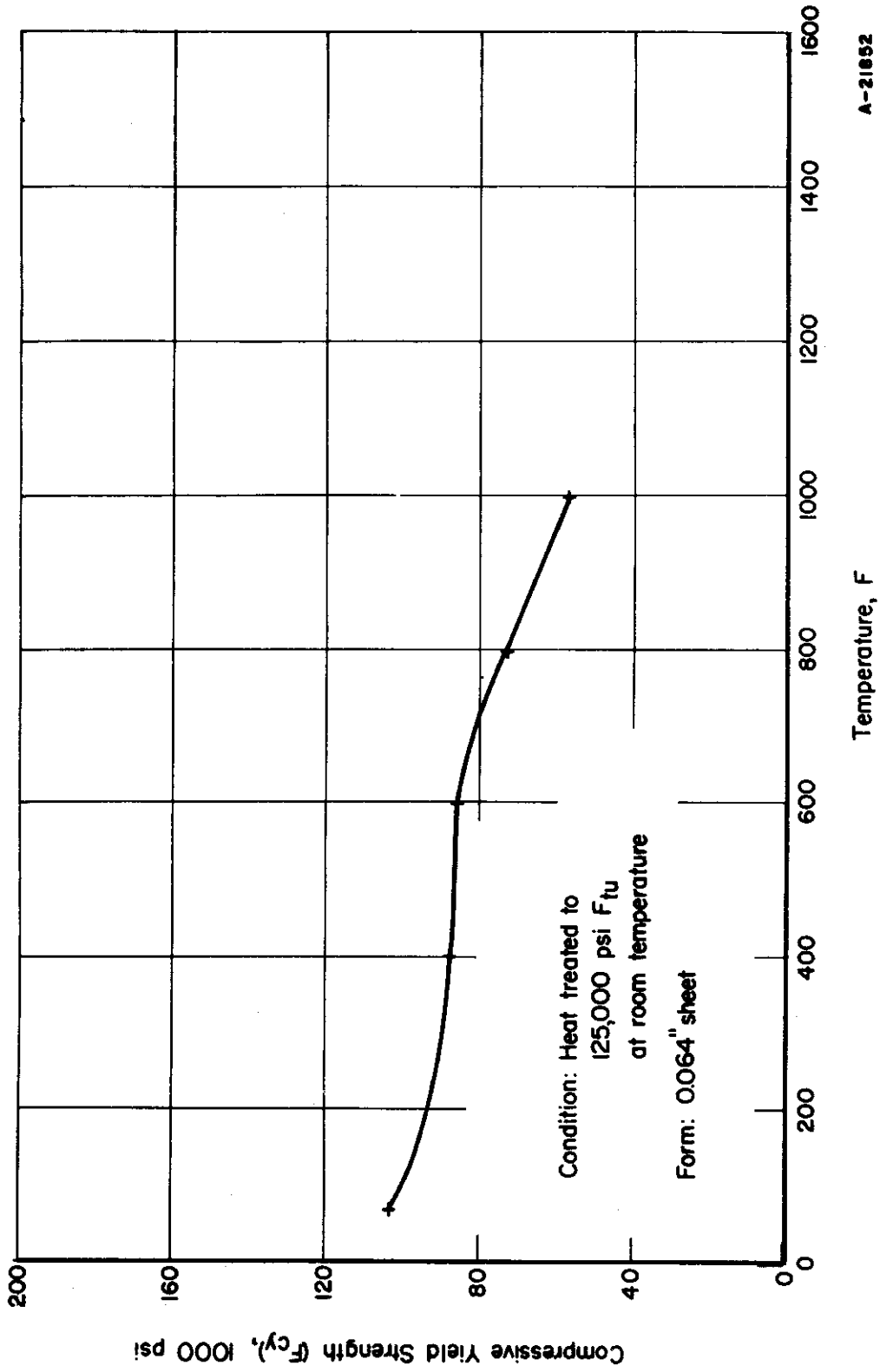

FIGURE 40. COMPRESSIVE YIELD STRENGTH (F_{cy}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

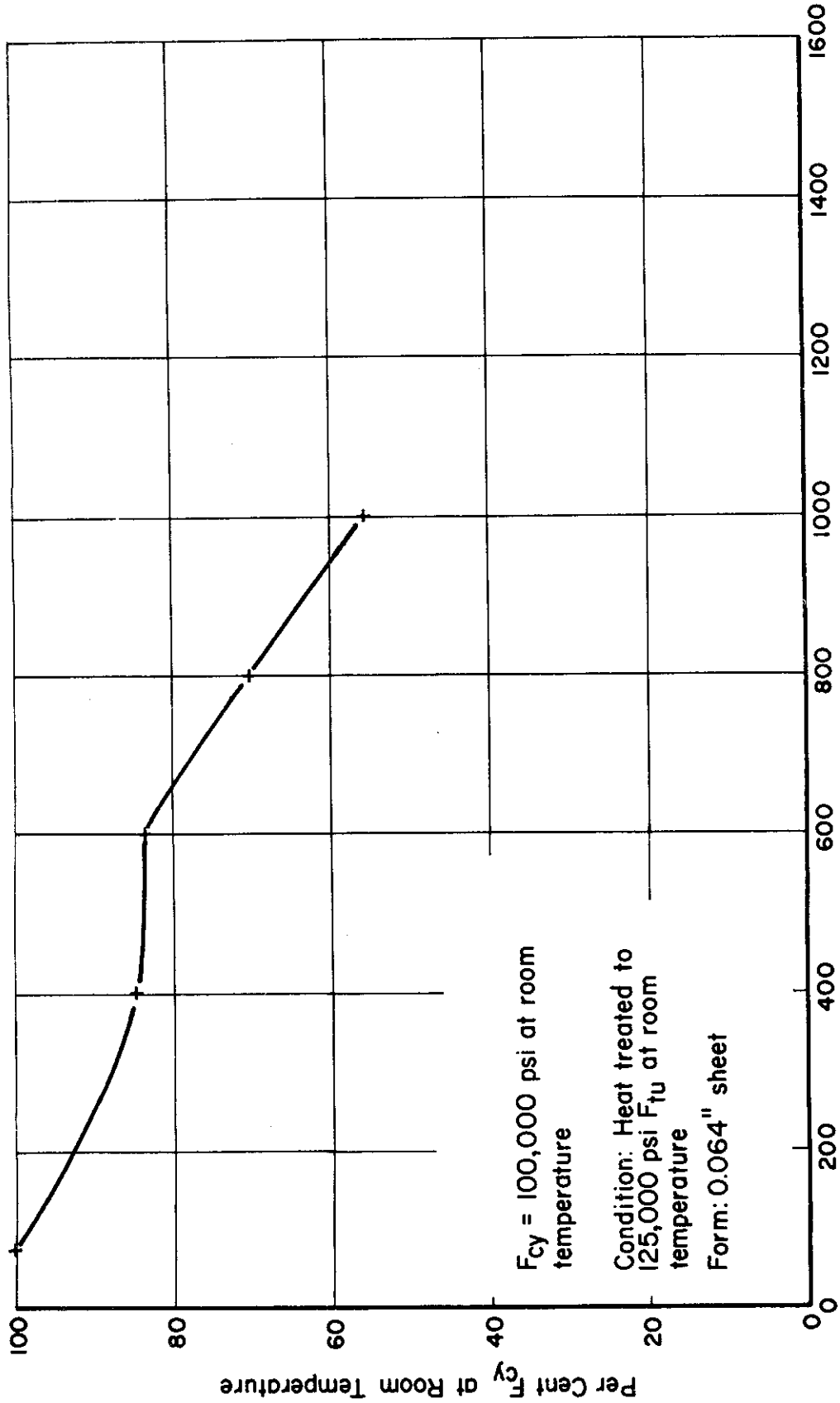

FIGURE 41. DESIGN CURVE FOR COMPRESSIVE YIELD STRENGTH (F_{cy}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

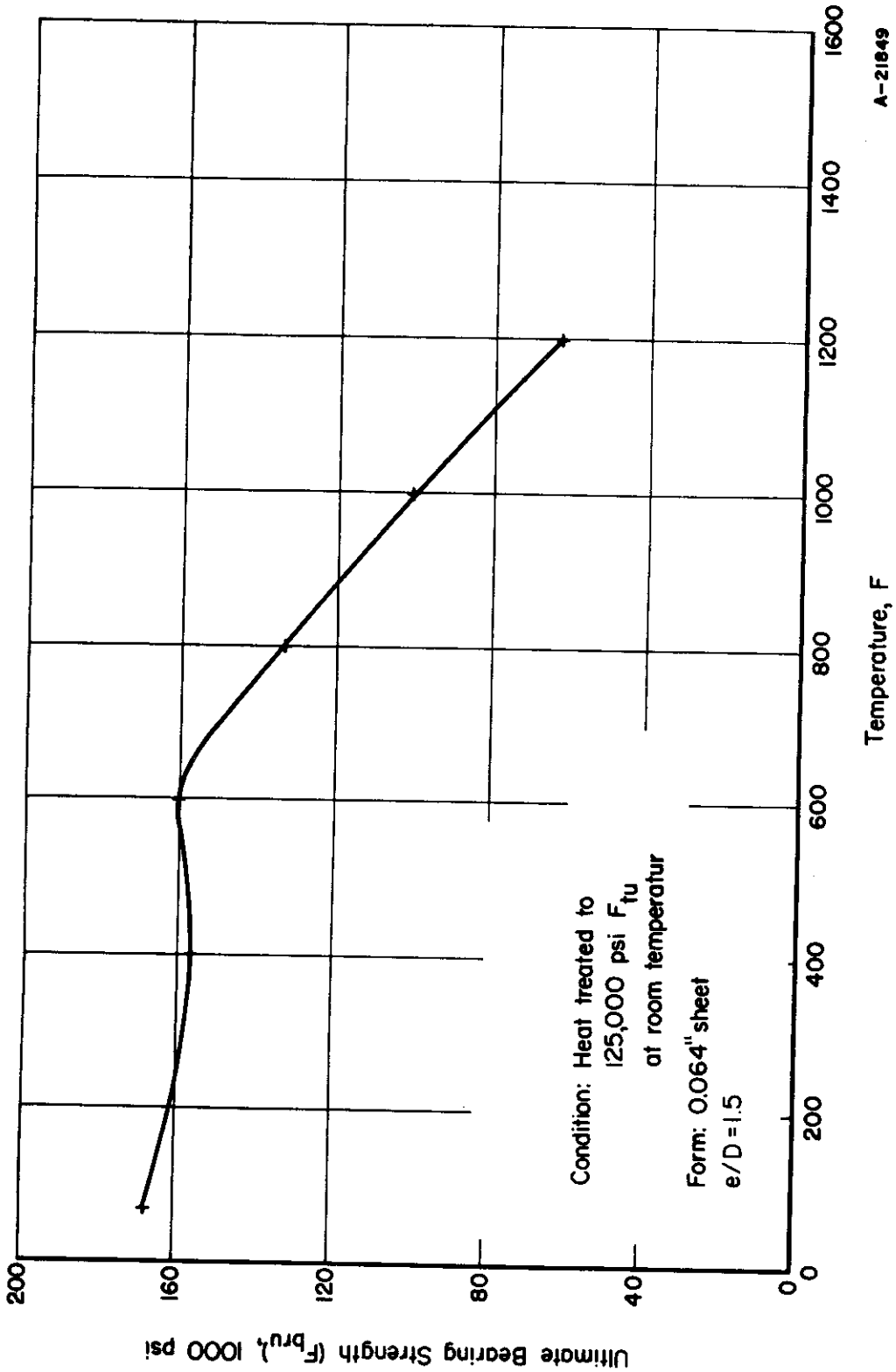

FIGURE 42. BEARING STRENGTH (F_{bru}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

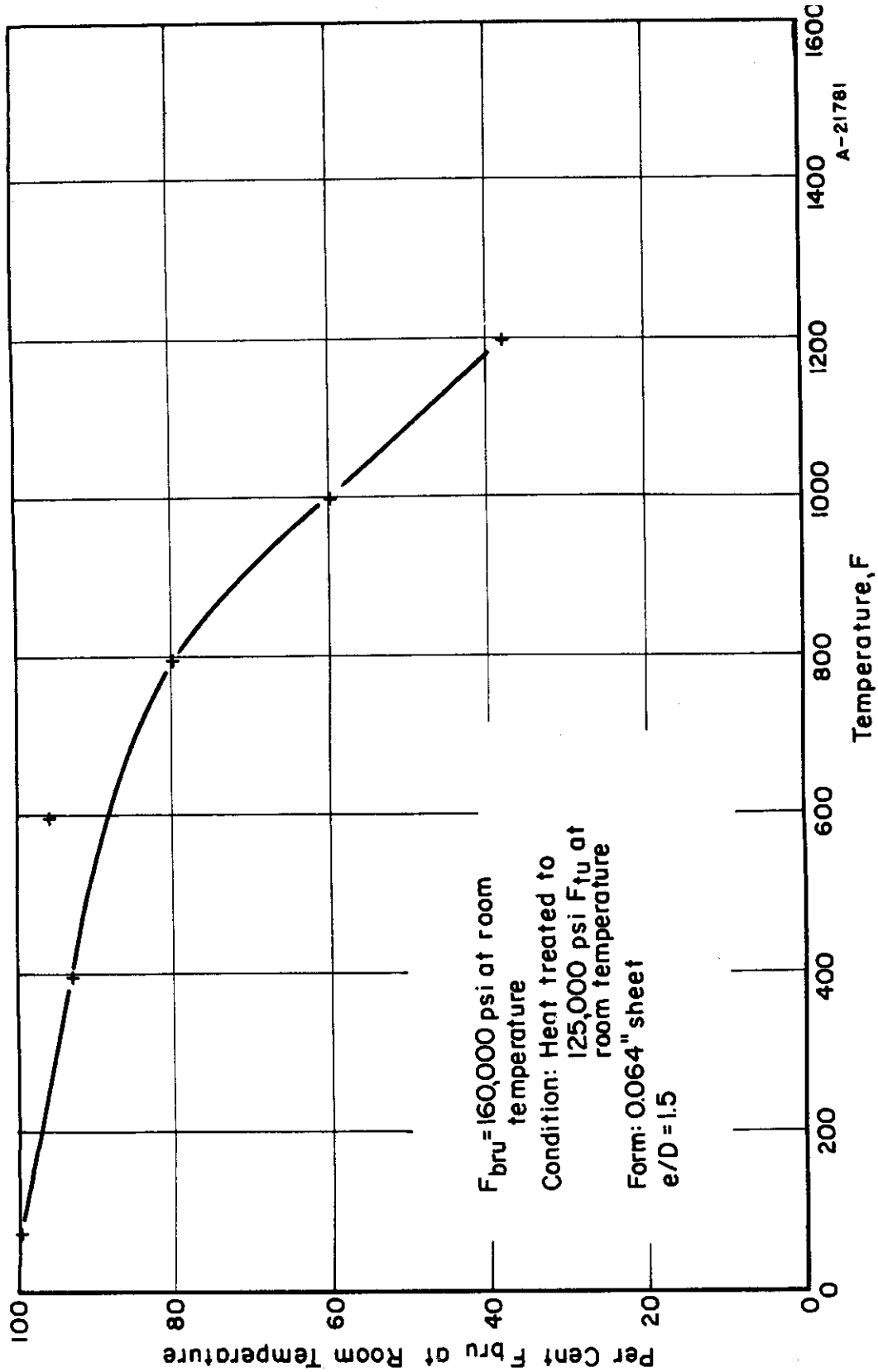

FIGURE 43. DESIGN CURVE FOR BEARING STRENGTH (F_{bru}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

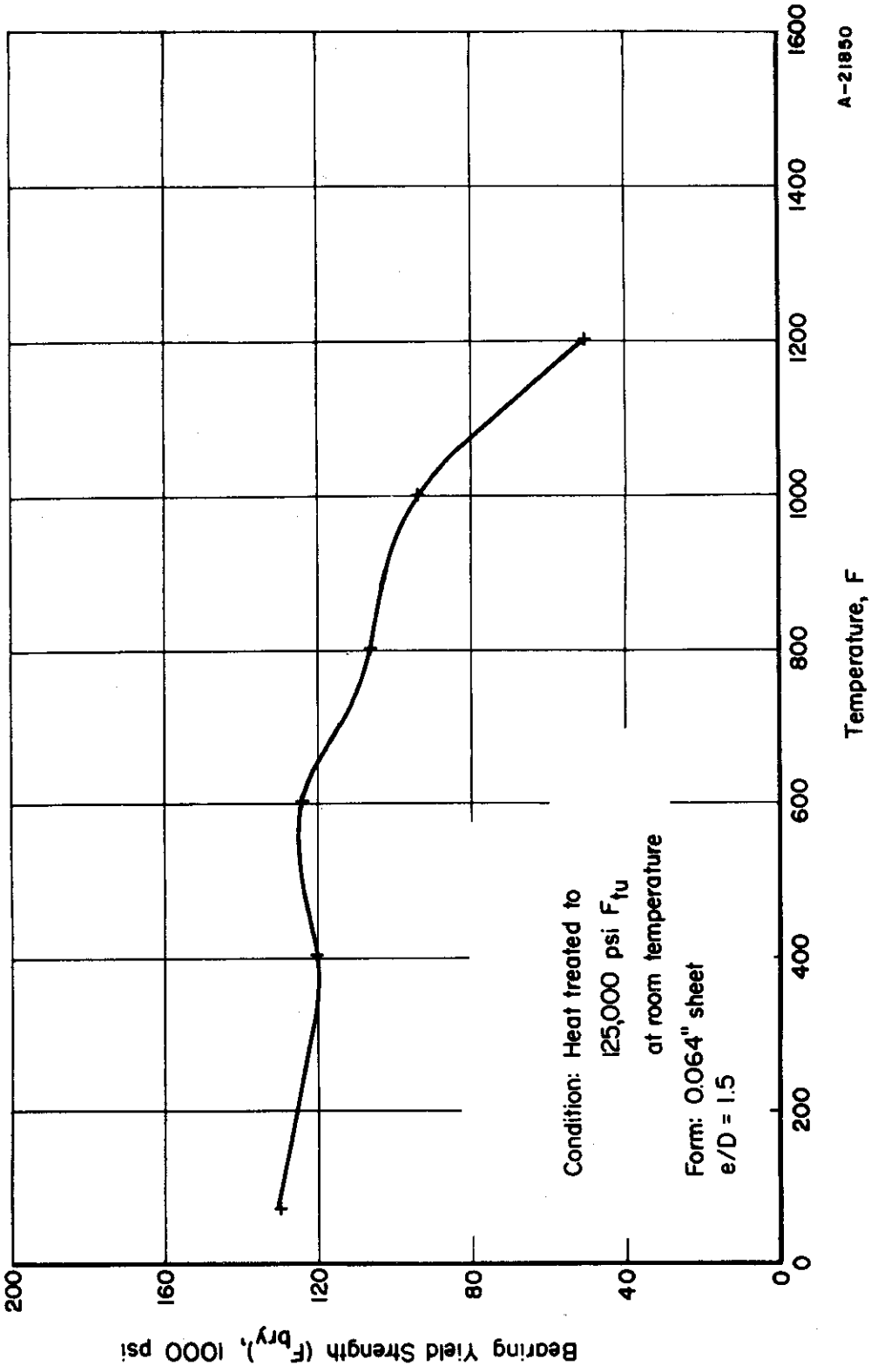

FIGURE 44. BEARING YIELD STRENGTH (F_{bry}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

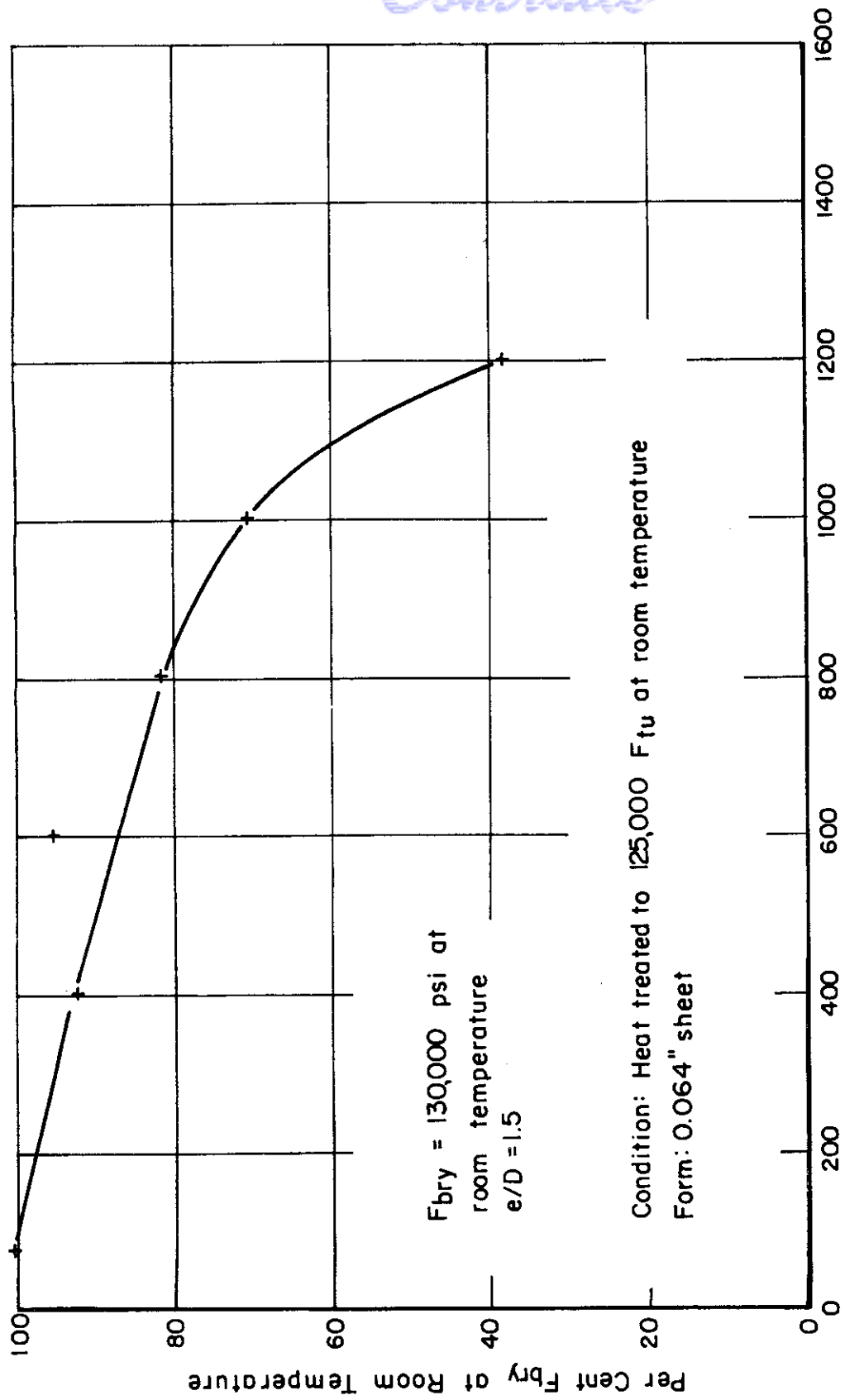

FIGURE 45. DESIGN CURVE FOR BEARING YIELD STRENGTH (F_{bry}) OF AISI 4130 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

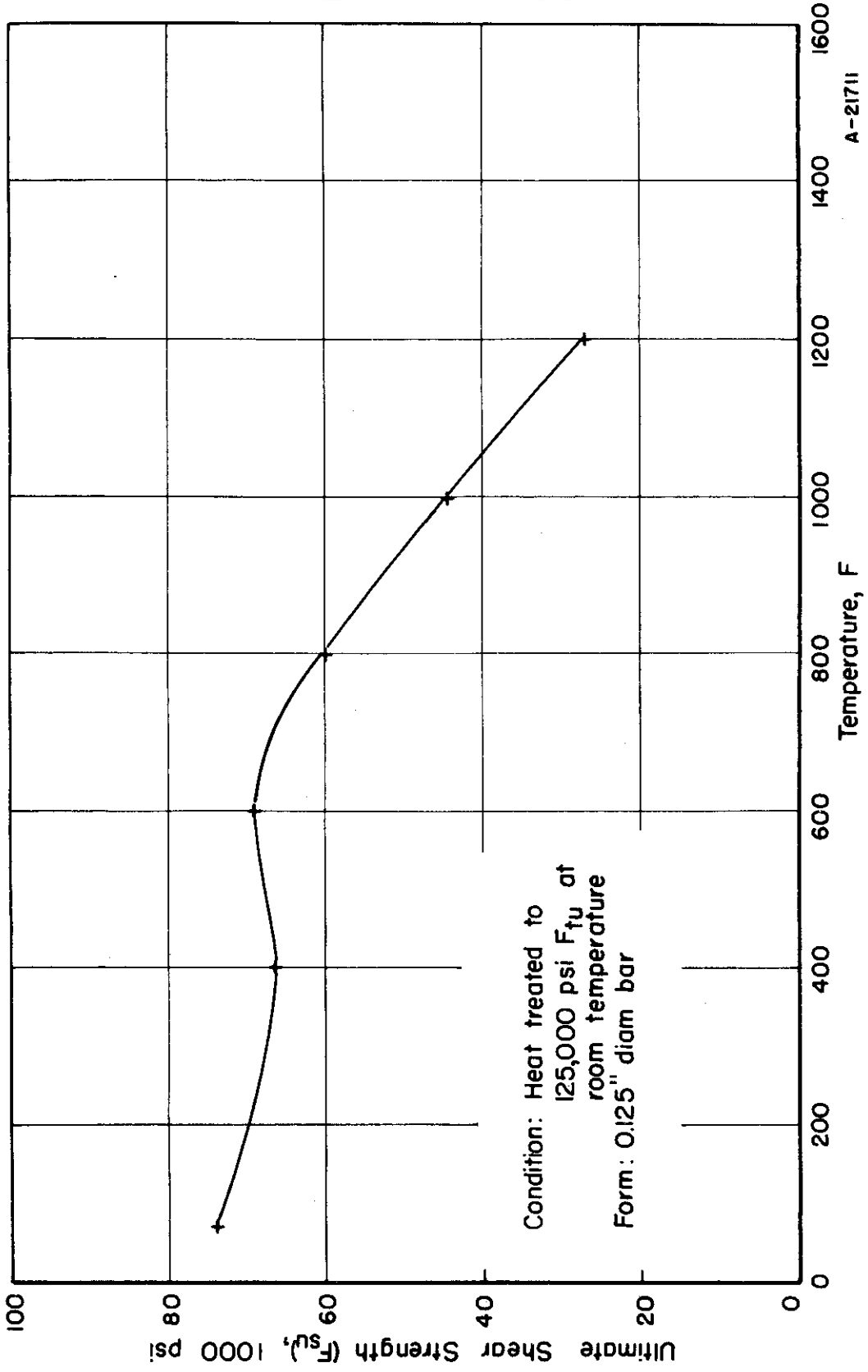

FIGURE 46. SHEAR STRENGTH (F_{su}) OF AISI 4130 ALLOY STEEL (0.125-INCH-DIAMETER BAR) AT ELEVATED TEMPERATURE

Ref. 57.

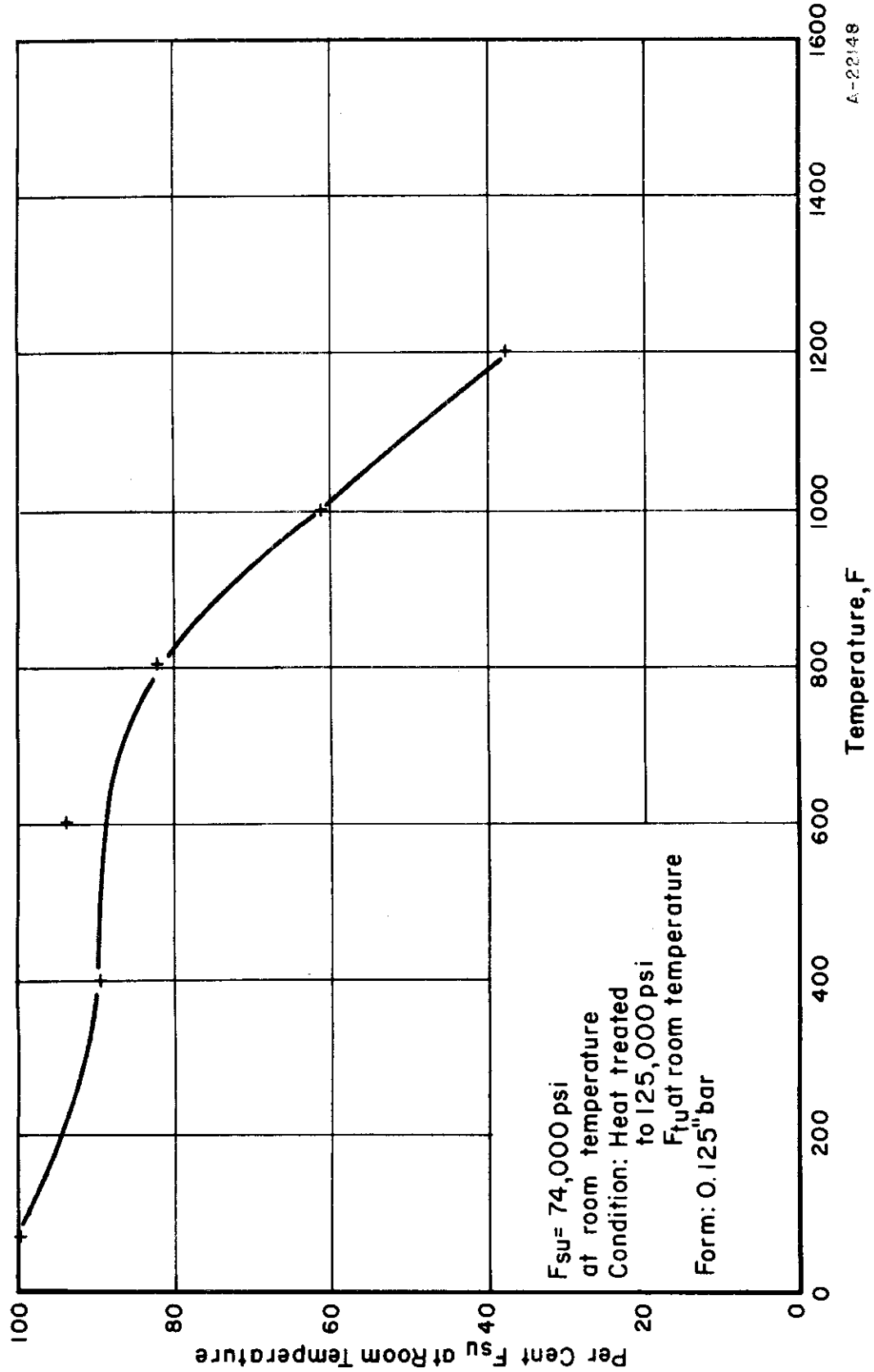

FIGURE 47. DESIGN CURVE FOR SHEAR STRENGTH (F_{su}) OF AISI 4130 ALLOY STEEL (0.125-INCH BAR) AT ELEVATED TEMPERATURE

Ref. 57.

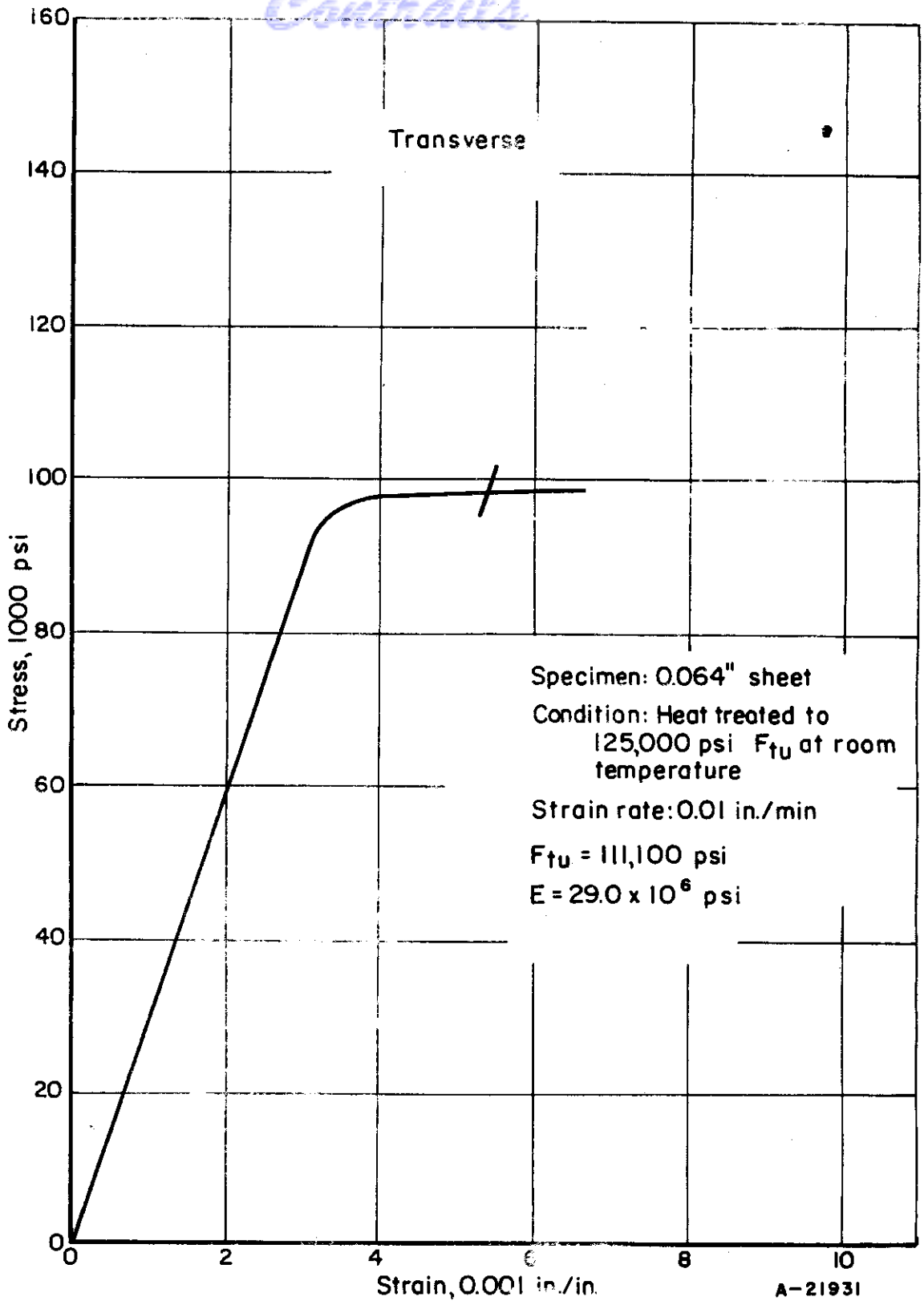

FIGURE 48. TENSILE STRESS-STRAIN CURVE FOR AISI 4130 ALLOY STEEL AT ROOM TEMPERATURE

[illegible] 57, p 132.

[illegible] TR 55-[illegible]

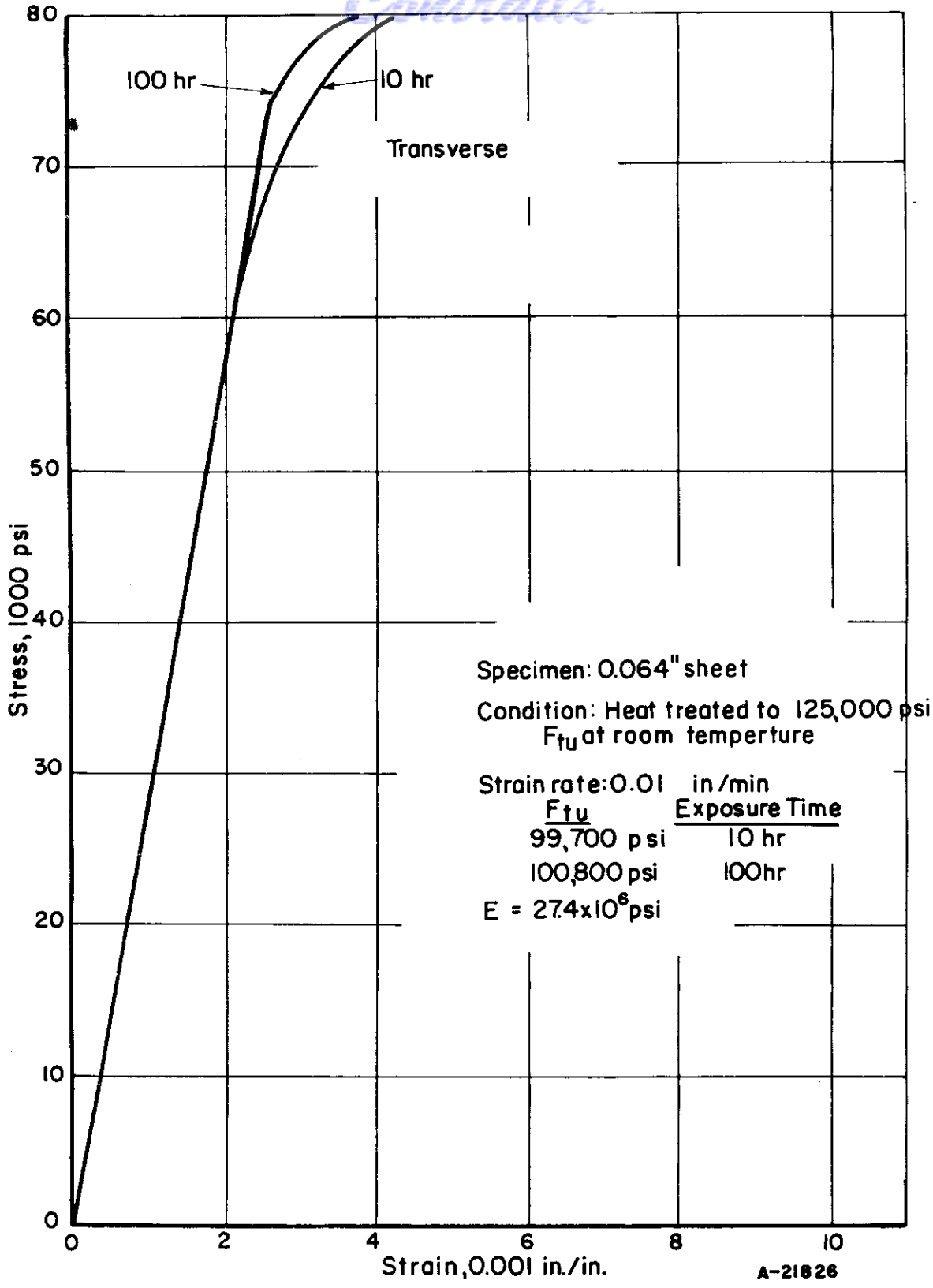

FIGURE 49. TENSILE STRESS-STRAIN CURVES FOR AISI 4130 ALLOY STEEL AT 400 F

Ref. 57, p 185.

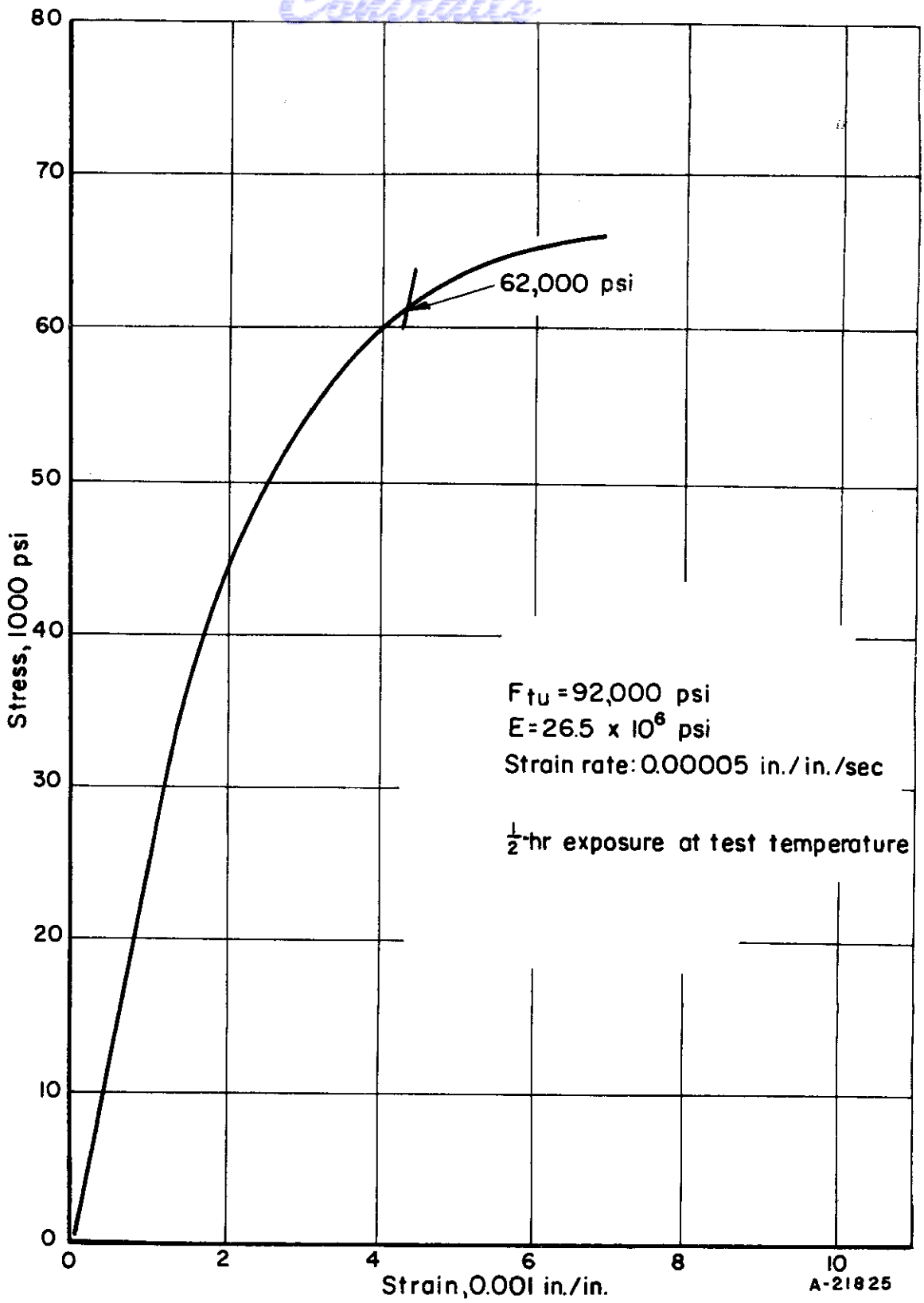

FIGURE 50. TENSILE STRESS-STRAIN CURVE FOR NORMALIZED AISI 4130 ALLOY STEEL (SHEET) AT 400 F

Ref. WADC 55-199, Part 2, p 87.

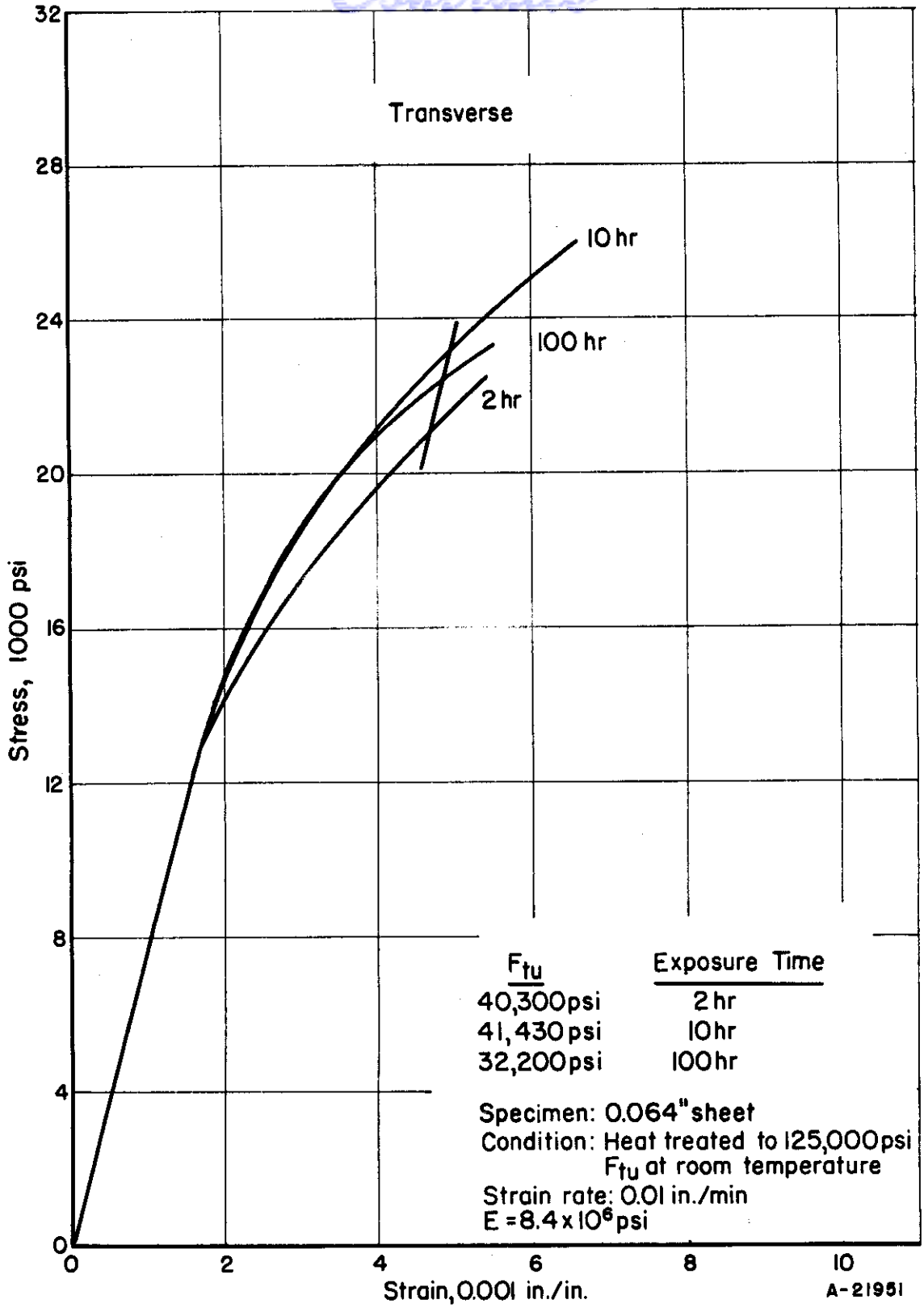

FIGURE 51. TENSILE STRESS-STRAIN CURVES FOR AISI 4130 ALLOY STEEL (SHEET) AT 1200 F

Ref. 57, p 187.

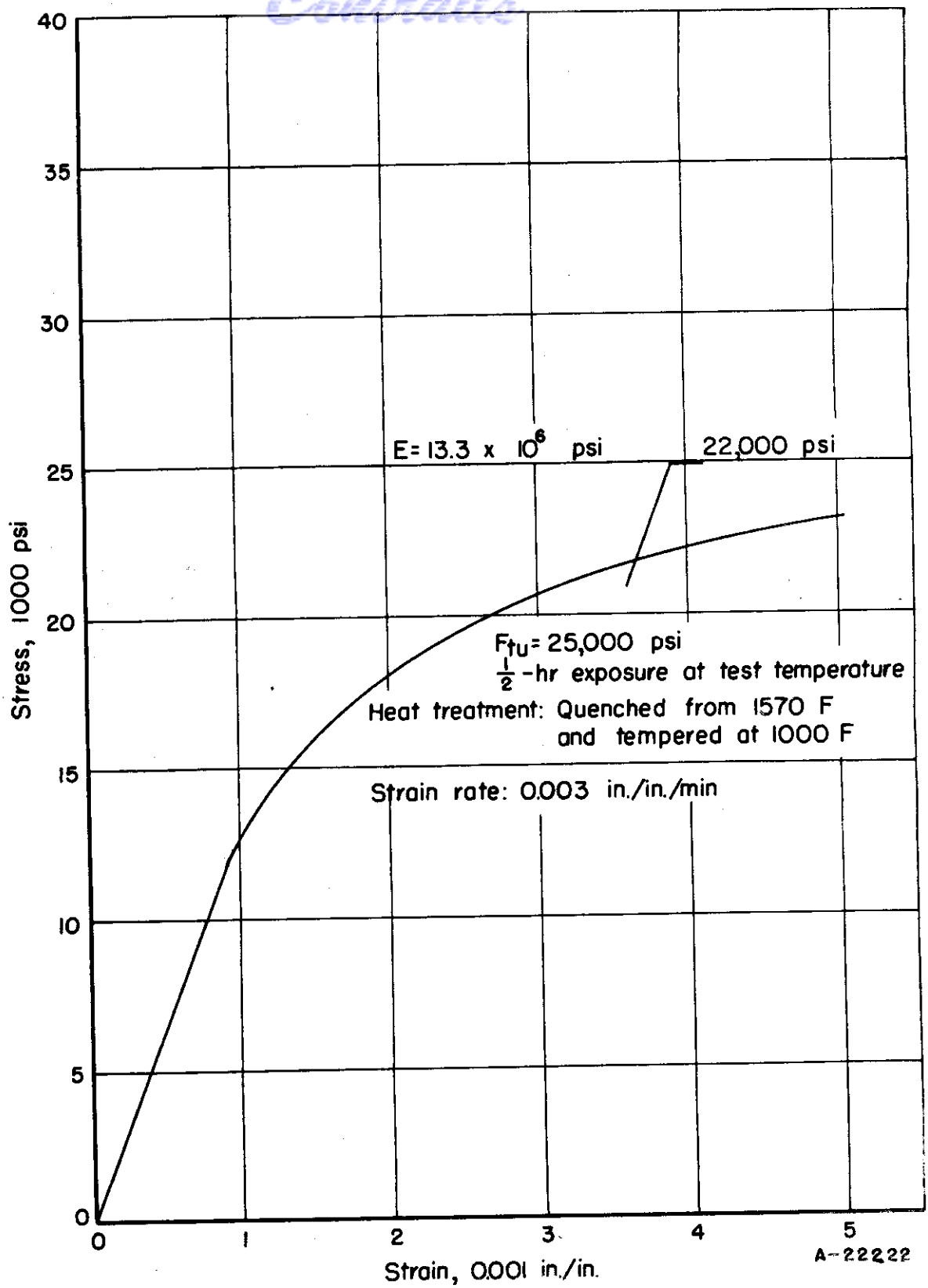

FIGURE 52. TENSILE STRESS-STRAIN CURVE FOR AISI [illegible] ALLOY STEEL AT 1200 F

Ref. WADC 55-199, Part 2, p 94.

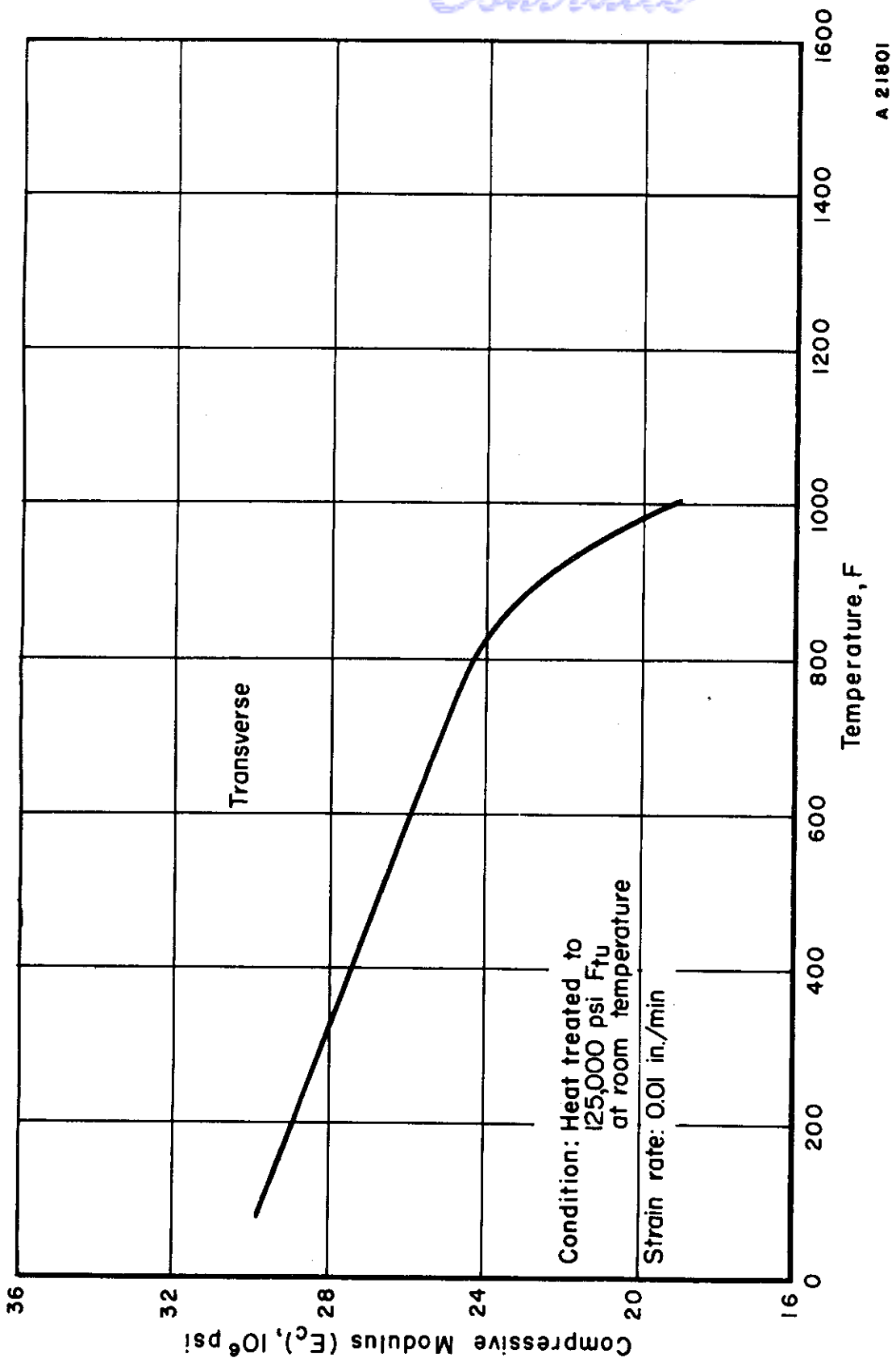

FIGURE 53. COMPRESSIVE MODULUS (E_c) OF AISI 4130 ALLOY STEEL AT ELEVATED TEMPERATURE

Ref. 57.

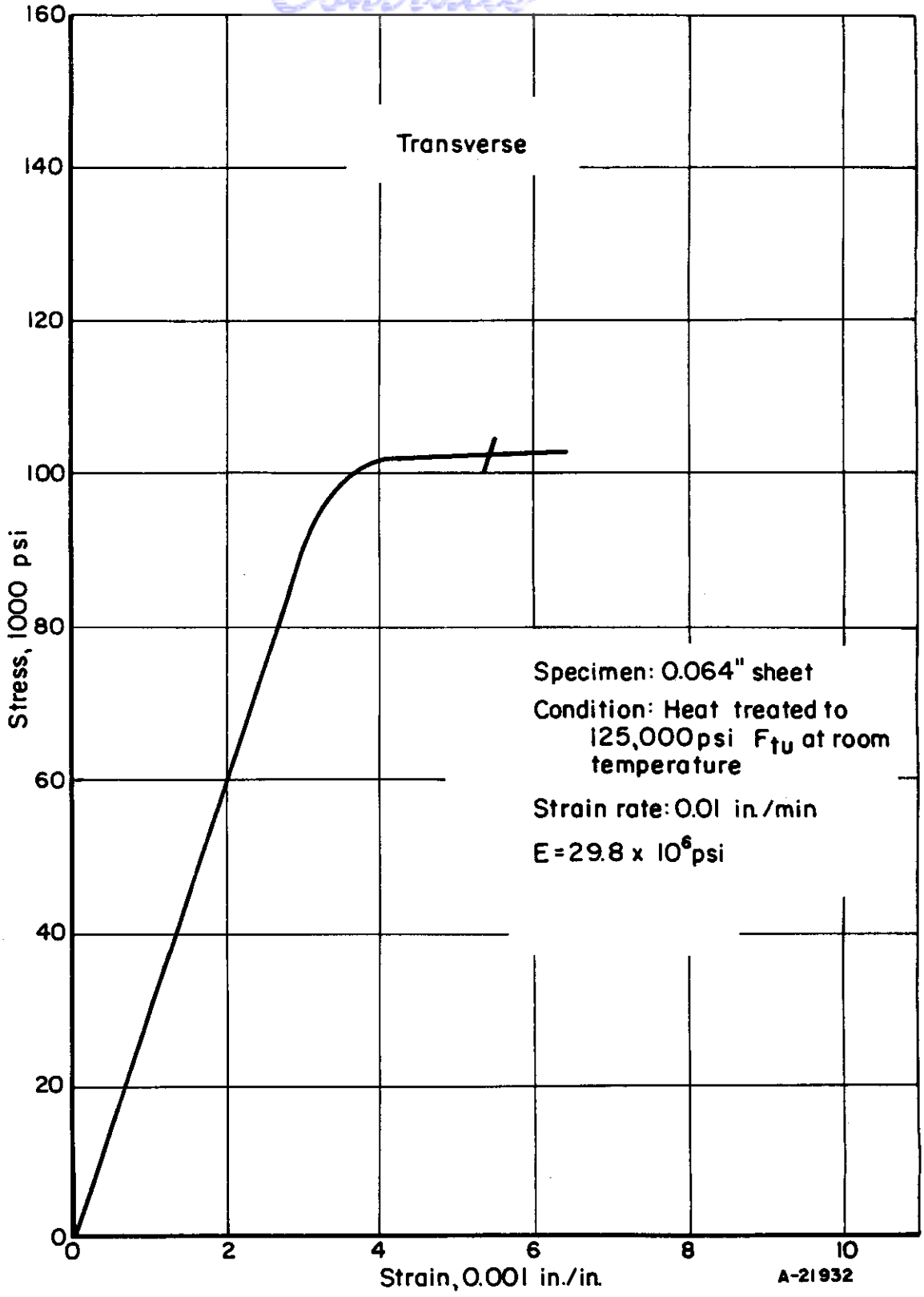

FIGURE 54. COMPRESSIVE STRESS-STRAIN CURVE FOR AISI 4130 ALLOY STEEL AT ROOM TEMPERATURE

Ref. 57, p 188.

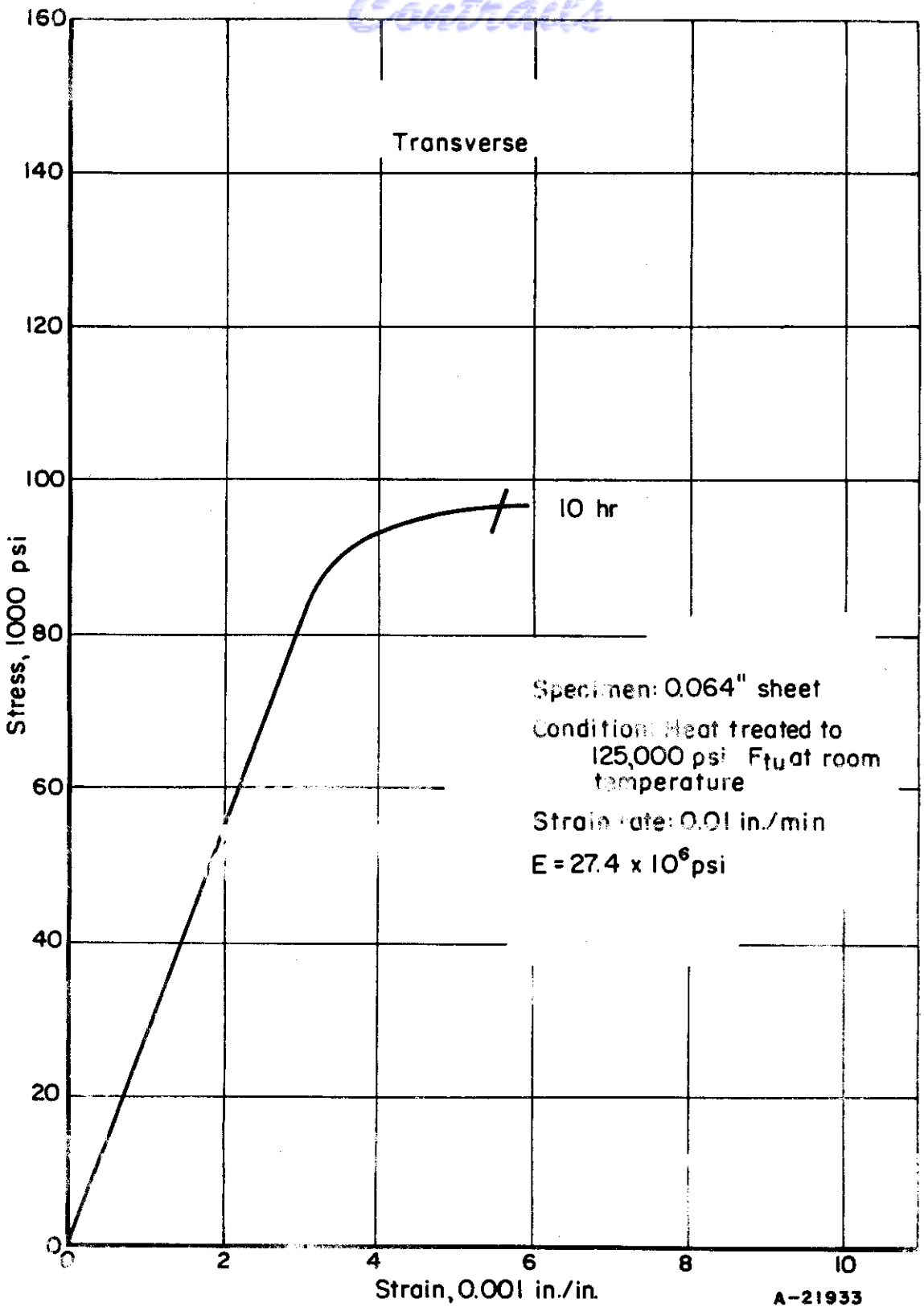

FIGURE 55. COMPRESSIVE STRESS-STRAIN CURVE FOR AISI 4130 ALLOY STEEL AT 400 F

Ref. 57.

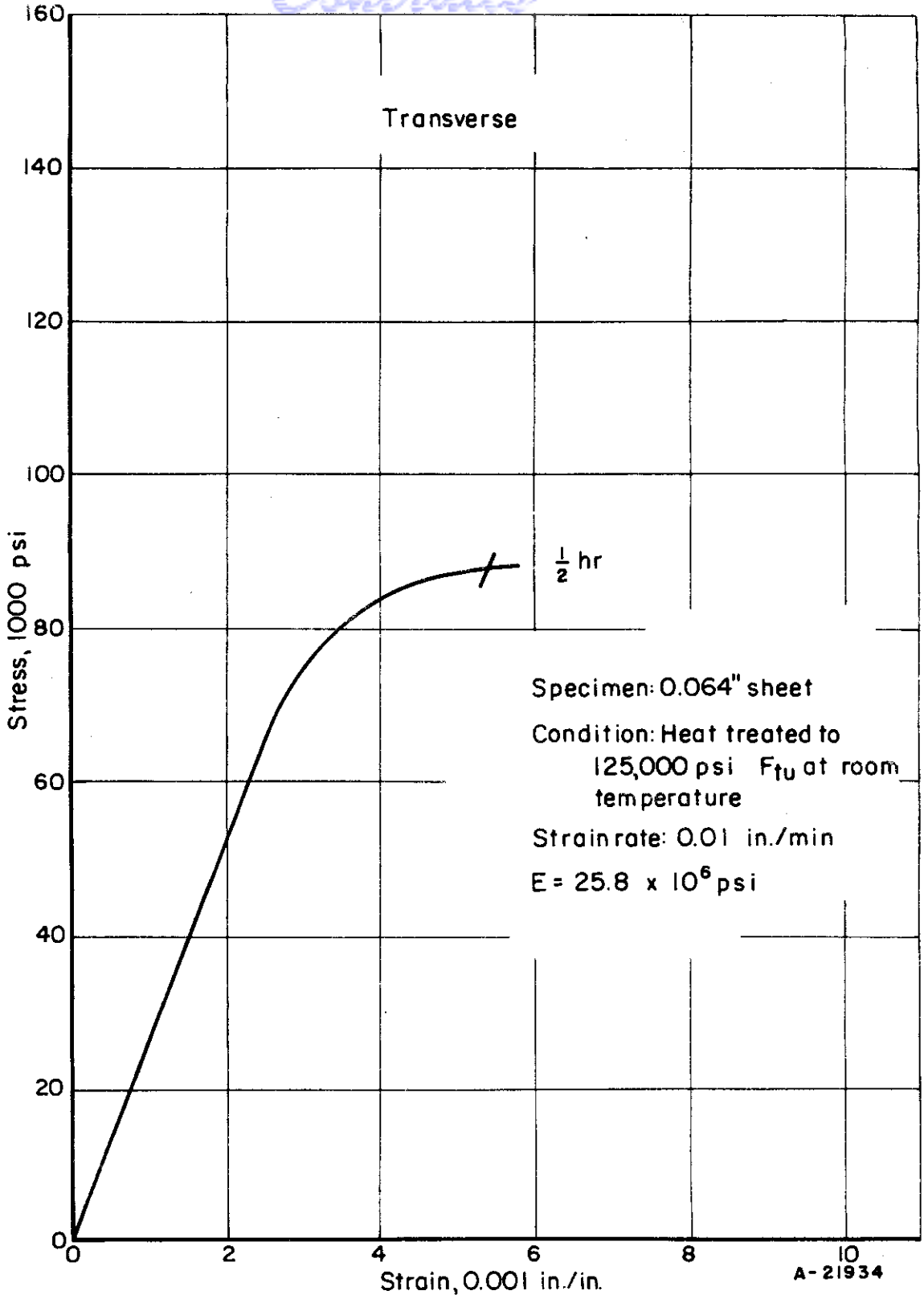

FIGURE 56. COMPRESSIVE STRESS-STRAIN CURVE FOR AISI 4130 ALLOY STEEL AT 600 F

Ref. 57, p 190.

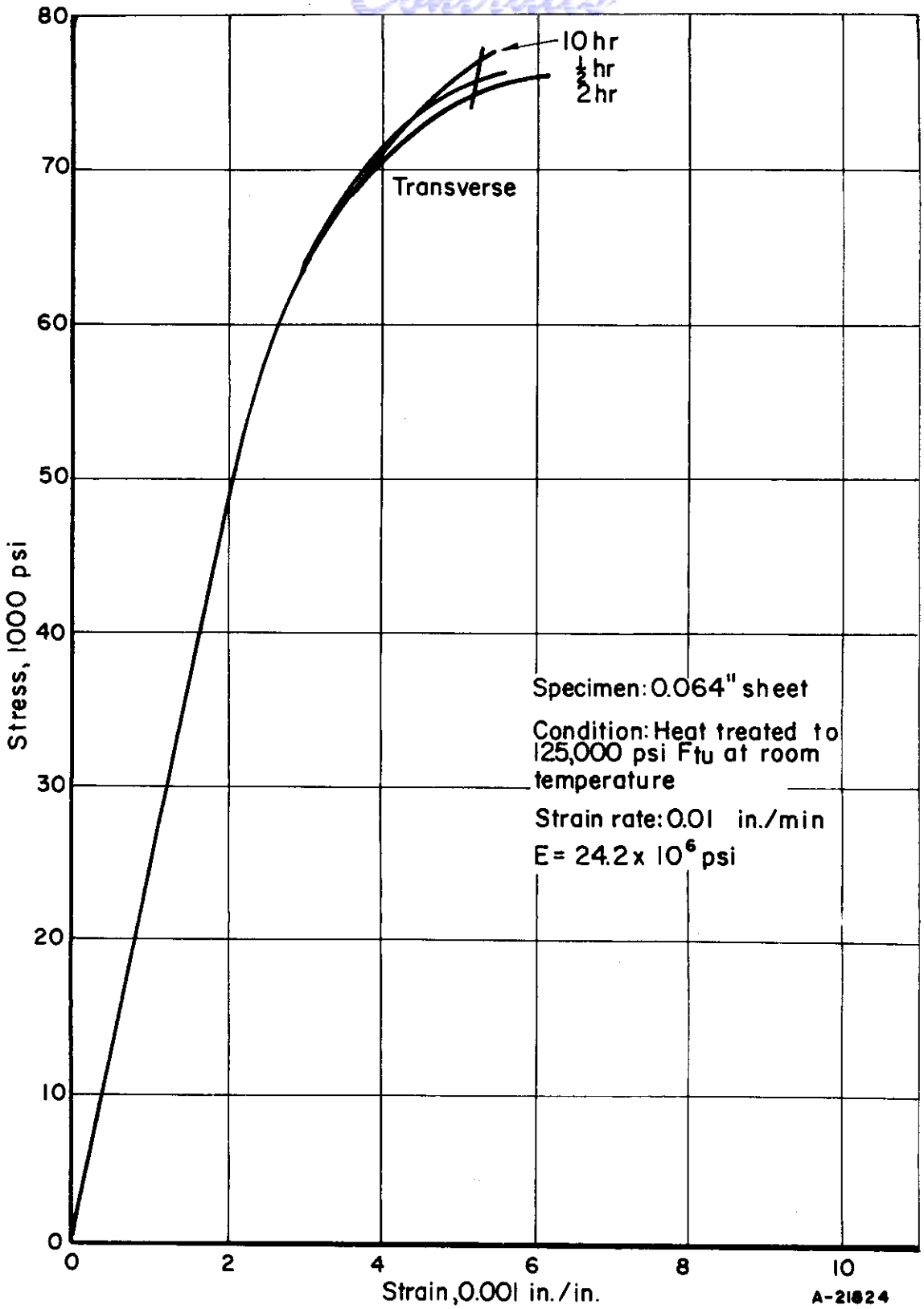

FIGURE 57. COMPRESSIVE STRESS-STRAIN CURVES FOR AISI 4130 ALLOY STEEL AT 800 F

Ref. 57, p 191.

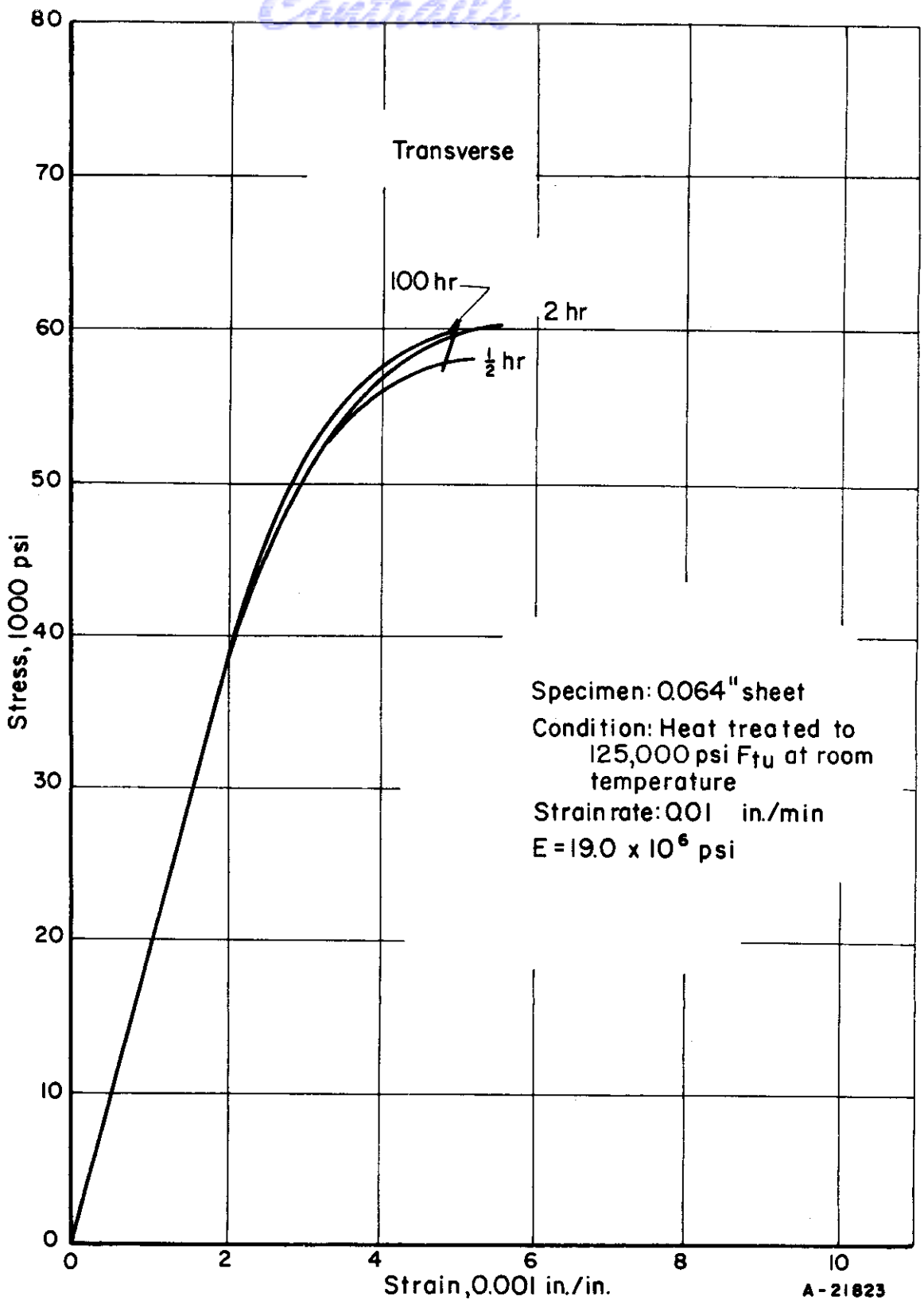

FIGURE 58. COMPRESSIVE STRESS-STRAIN CURVES FOR AISI 4130 ALLOY STEEL AT 1000 F

Ref. 57, p 192.

AISI 8630
(AMS-6355E)

AISI 8630 is a chromium-nickel-molybdenum steel and is similar to AISI 4130 in its metallurgical characteristics. Its nominal chemical composition is given in Table 3.

High toughness results from tempering 8630 at high temperatures. This material begins to show thermal unstability or time dependency under load at about 600 F. Data are given for the 160,000- to 180,000-psi strength range.

TABLE 3. NOMINAL CHEMICAL COMPOSITION OF AISI 8630 STEEL (AMS-6355E)

Element	Weight Per Cent
Carbon	0.30
Manganese	0.80
Nickel	0.55
Chromium	0.50
Molybdenum	0.20
Iron	Balance

The short-time, elevated-temperature properties of AISI 8630 are shown in the following curves:

(1) Tensile properties, Figures 59 through 64

(2) Compressive properties, Figures 65 and 66

(3) Bearing properties, Figures 67 through 70

(4) Shear properties, Figures 71 and 72

(5) Stress-strain curves, Figures 73 through 82, 84 through 88, 90 through 94

(6) Modulus of elasticity, Figures 83 and 89

All surveyed strength properties were available for AISI 8630.

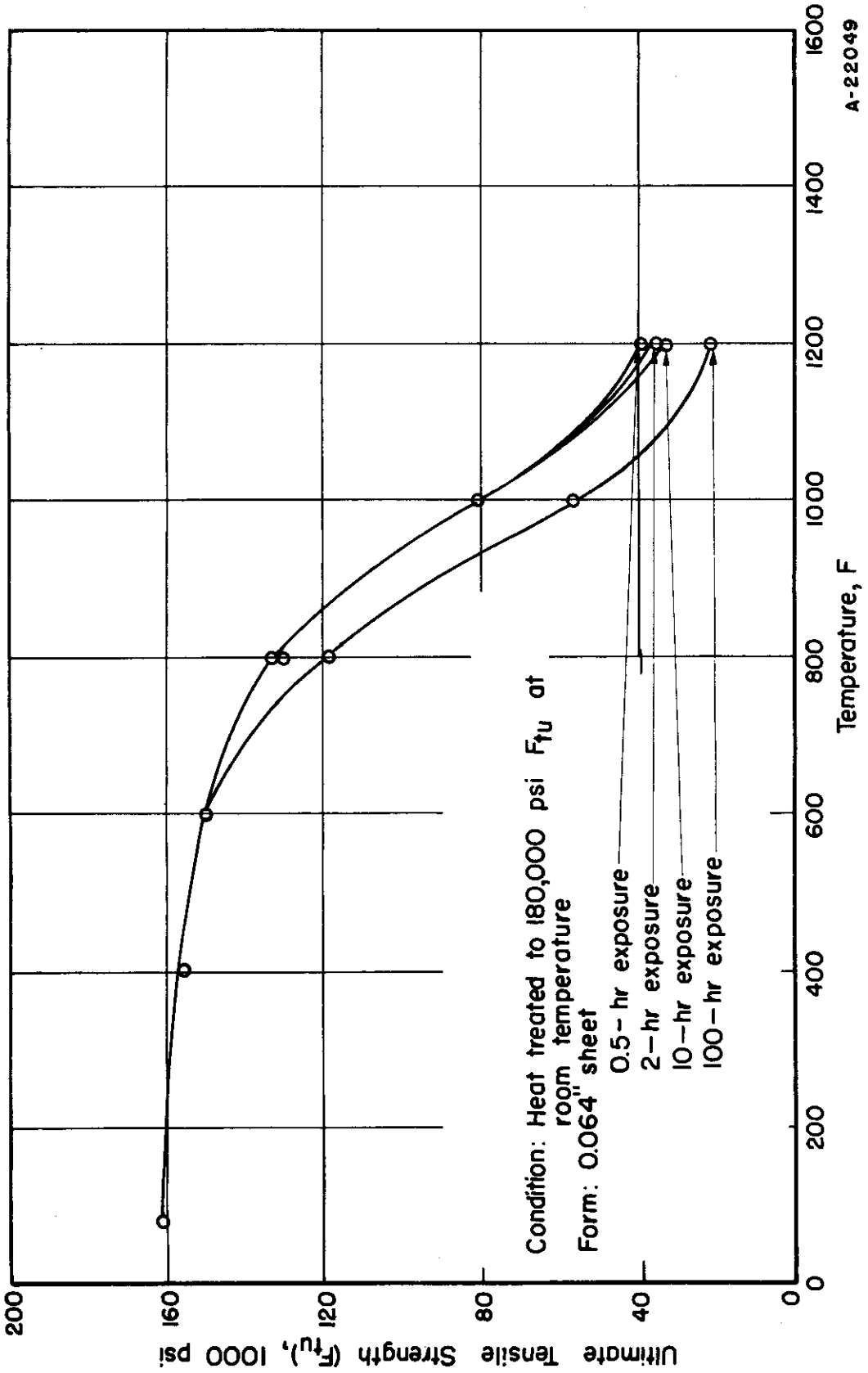

FIGURE 59. TENSILE STRENGTH (F_{tu}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

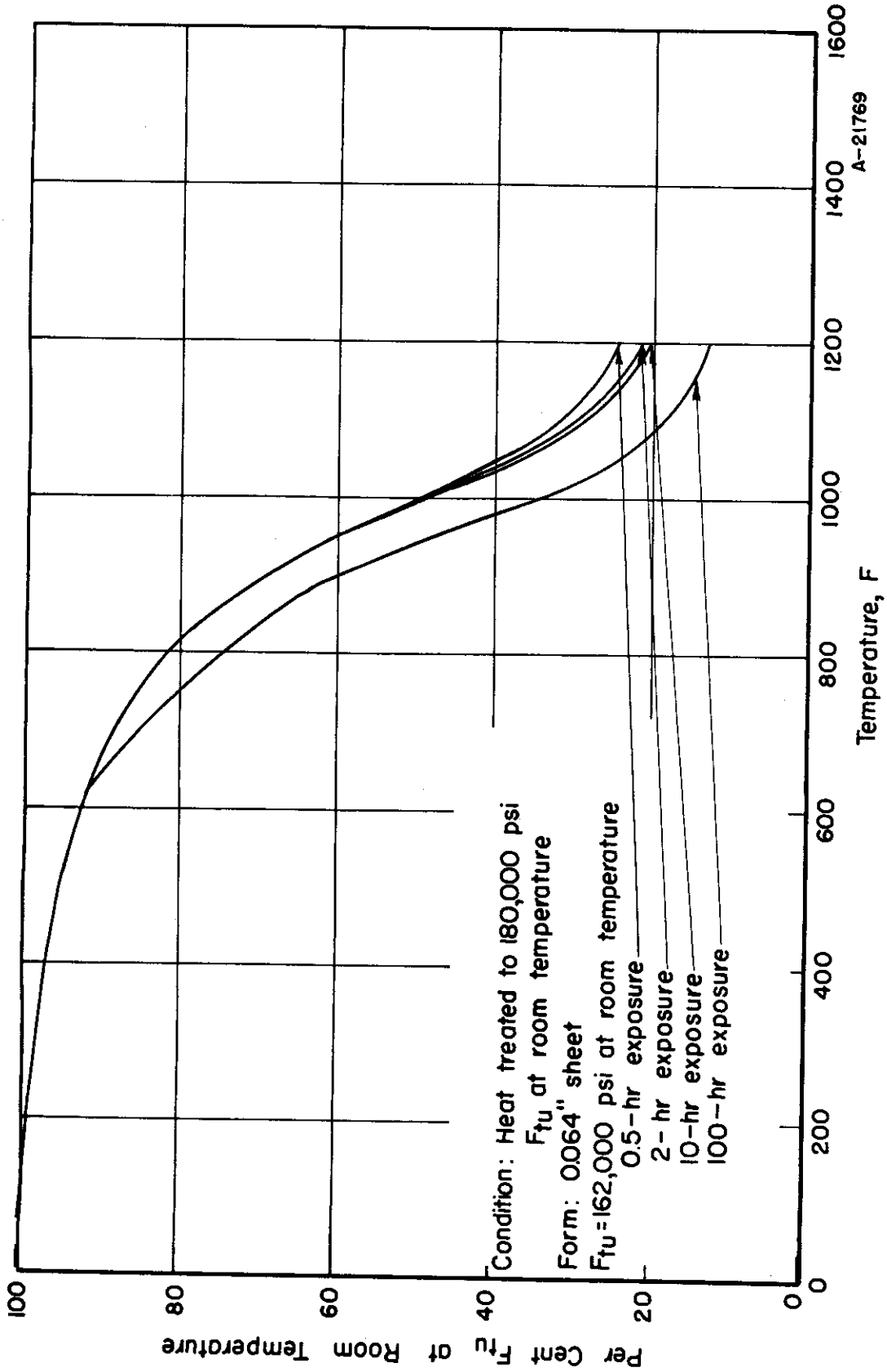

FIGURE 60. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

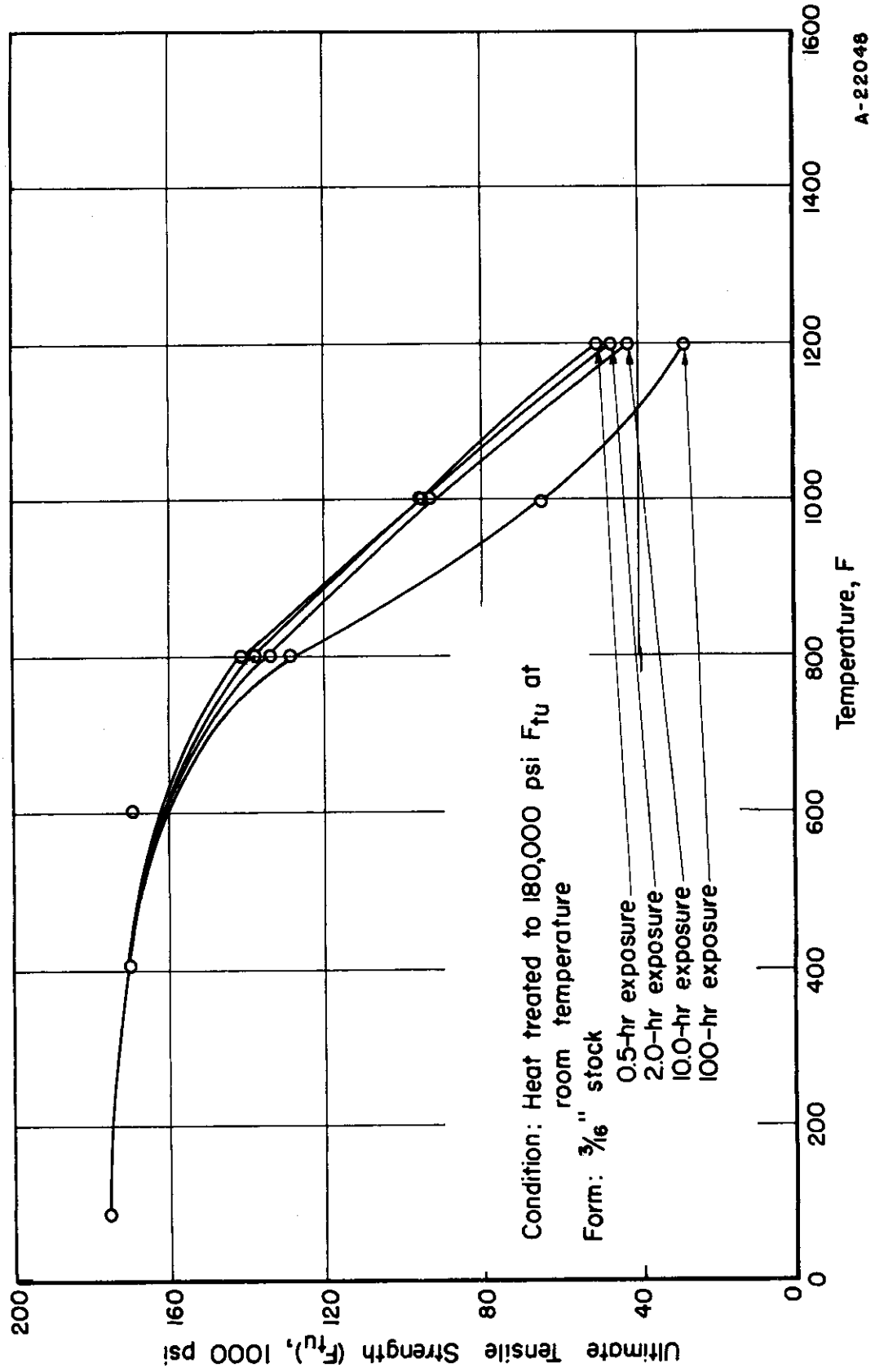

FIGURE 61. TENSILE STRENGTH (F_{tu}) OF AISI 8630 ALLOY STEEL (3/16-INCH STOCK) AT ELEVATED TEMPERATURE

Ref. 57.

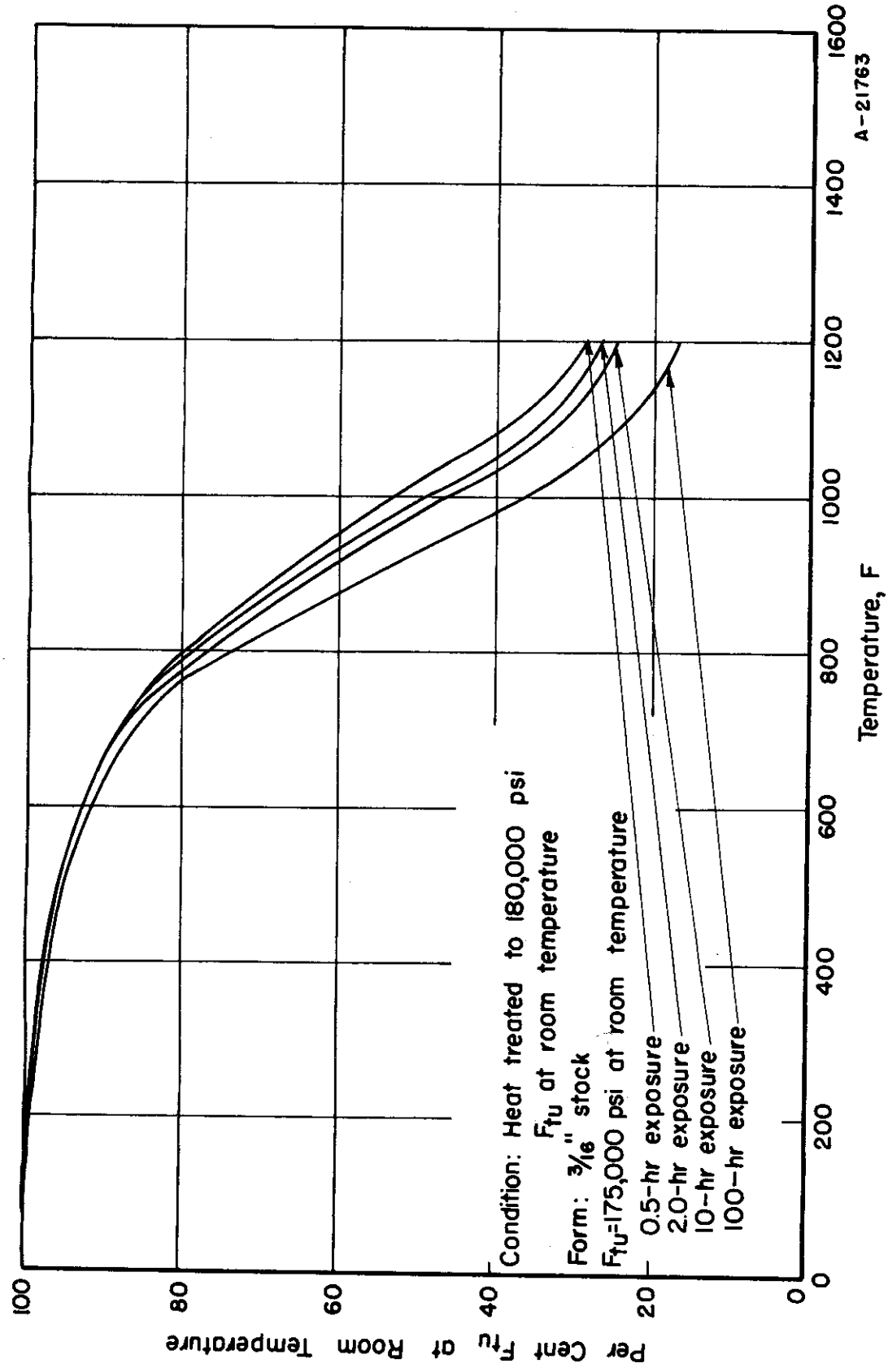

FIGURE 62. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF AISI 8630 ALLOY STEEL (3/16-INCH STOCK) AT ELEVATED TEMPERATURE

Ref. 57.

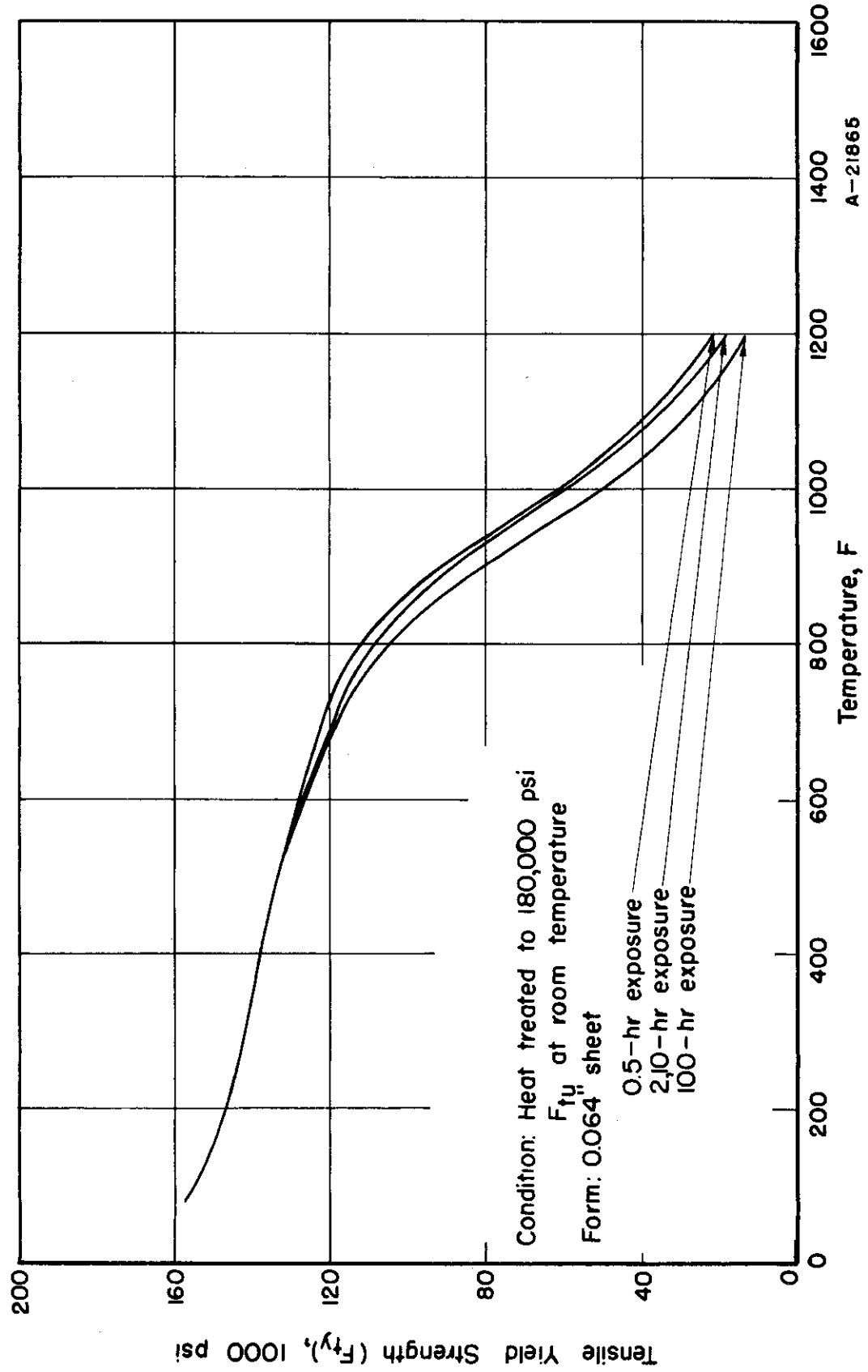

FIGURE 63. TENSILE YIELD STRENGTH (F_{ty}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

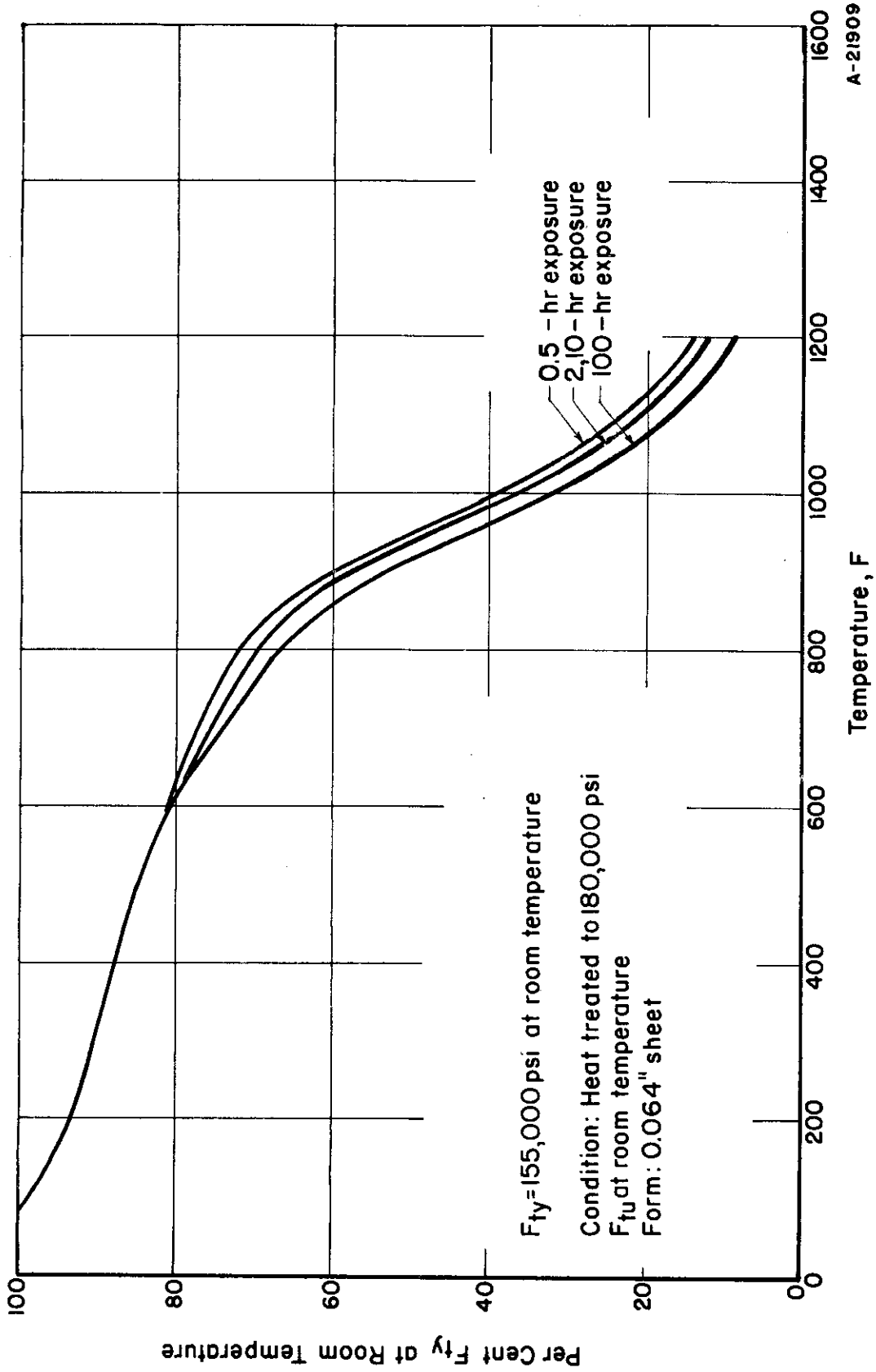

FIGURE 64. DESIGN CURVES FOR TENSILE STRENGTH (F_{ty}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

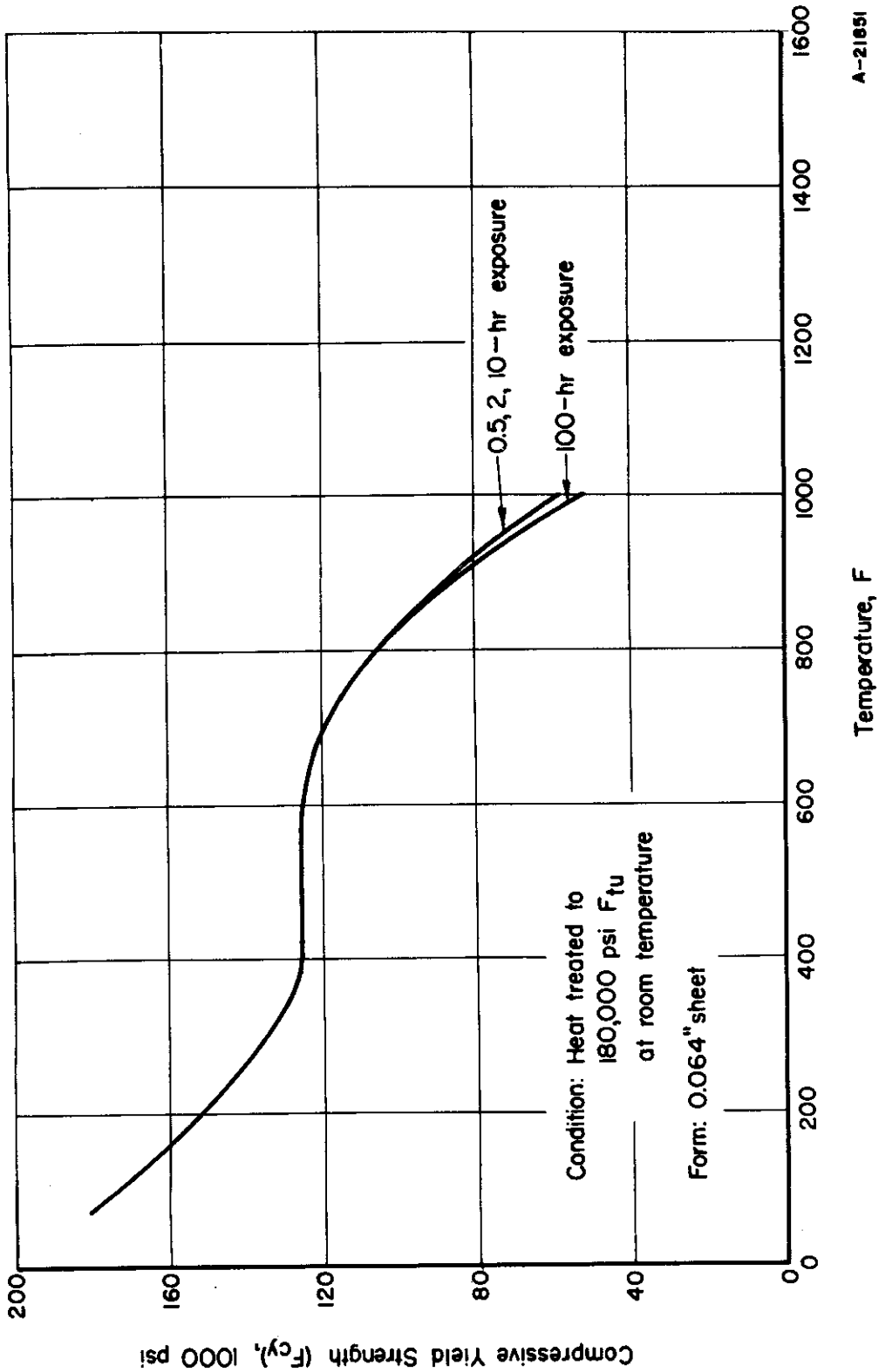

FIGURE 65. COMPRESSIVE YIELD STRENGTH (F_{cy}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

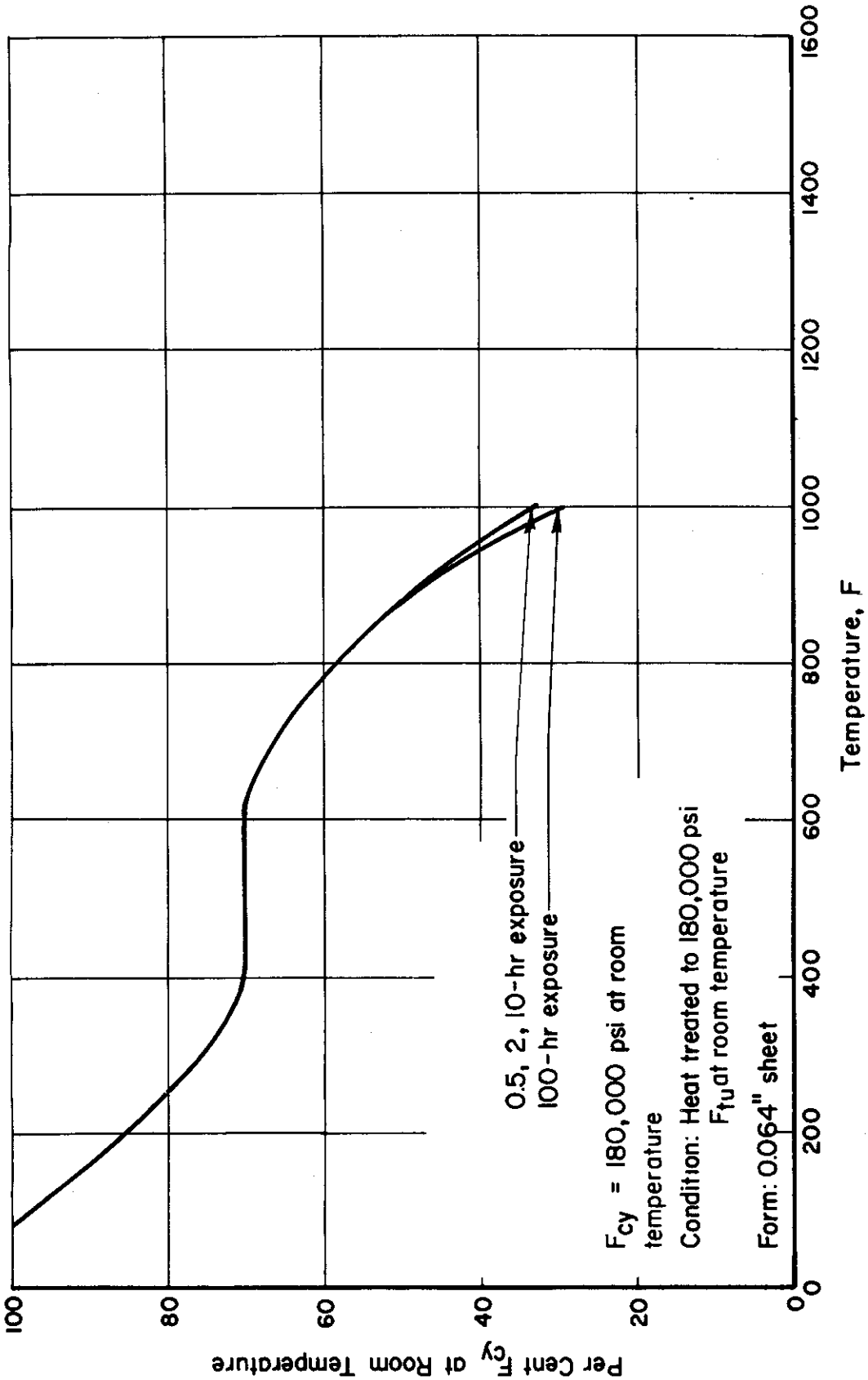

FIGURE 66. DESIGN CURVE FOR COMPRESSIVE YIELD STRENGTH (F_{cy}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE
Ref. 57.

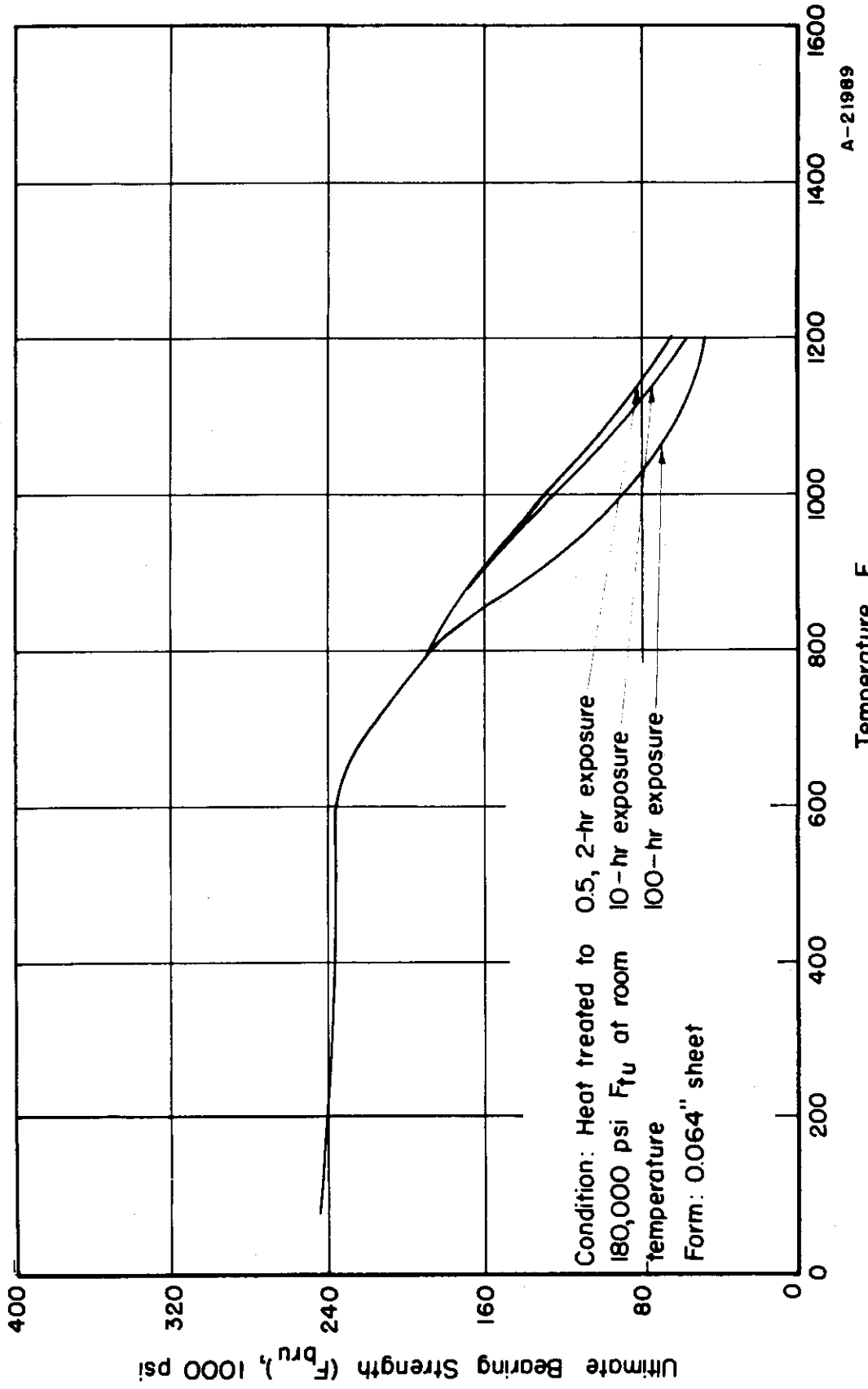

FIGURE 67. BEARING STRENGTH (F_{bru}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

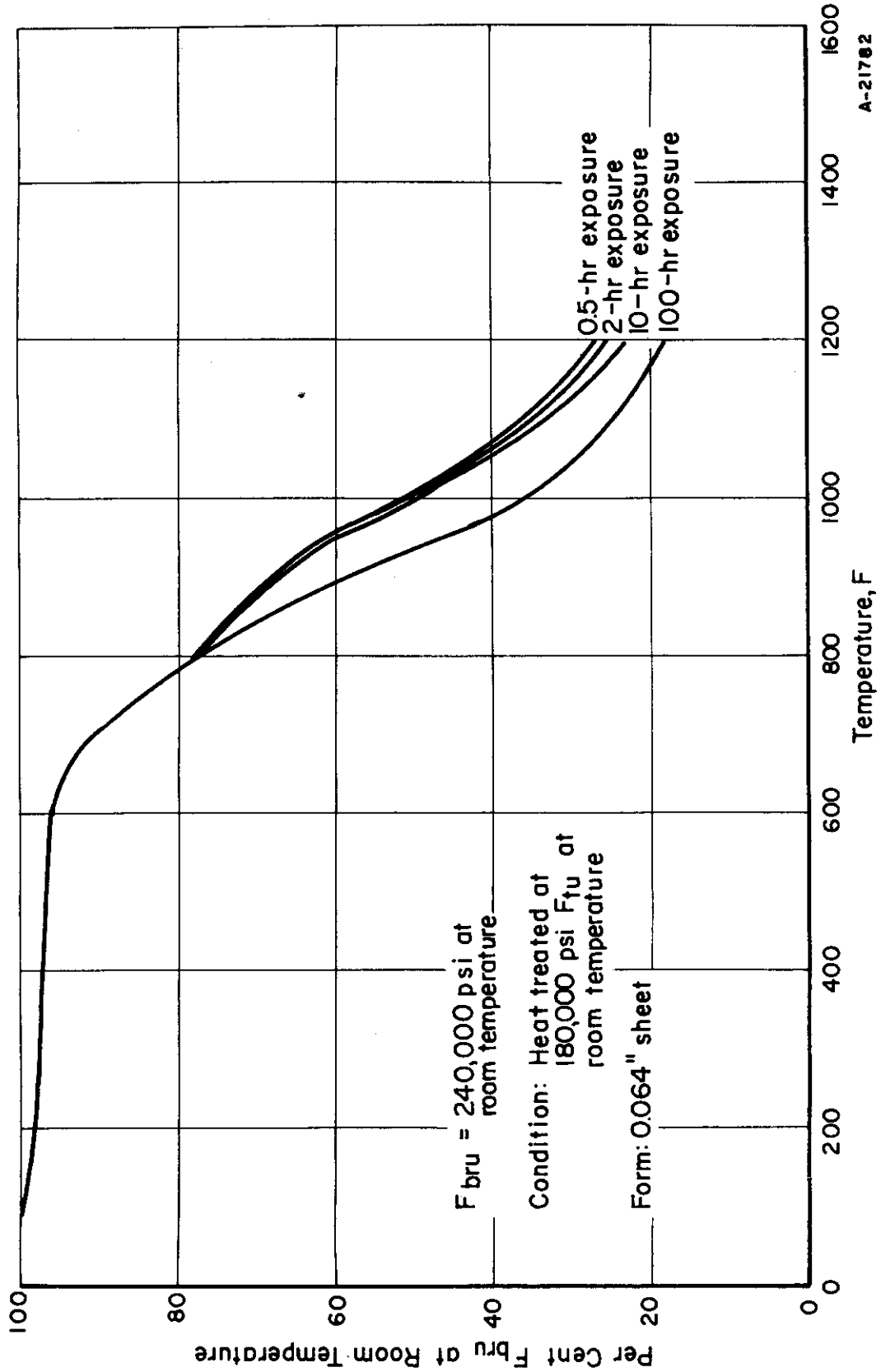

FIGURE 68. DESIGN CURVE FOR BEARING STRENGTH (F_{bru}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

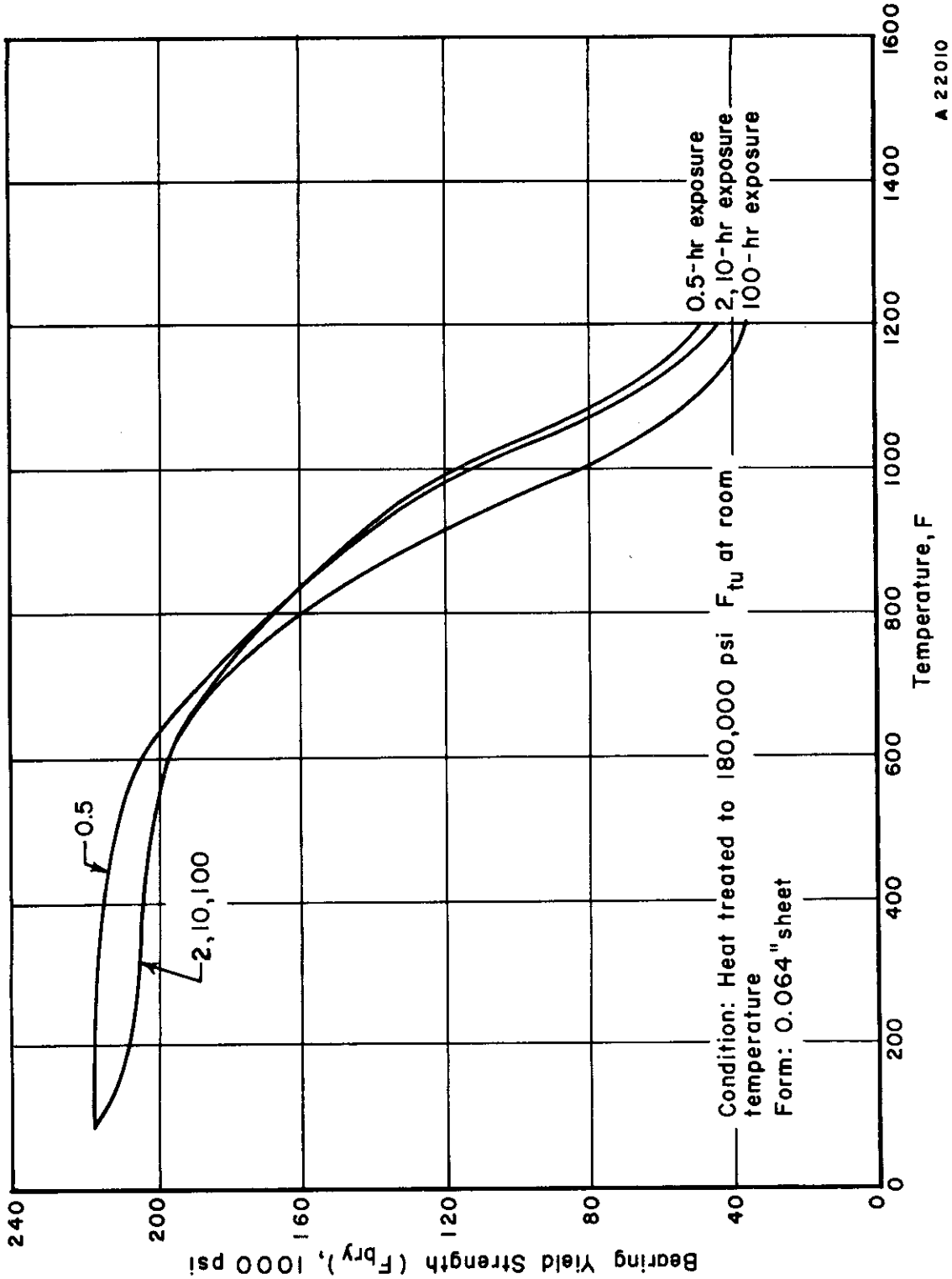

FIGURE 69. BEARING YIELD STRENGTH (F_{bry}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE

Ref. 57.

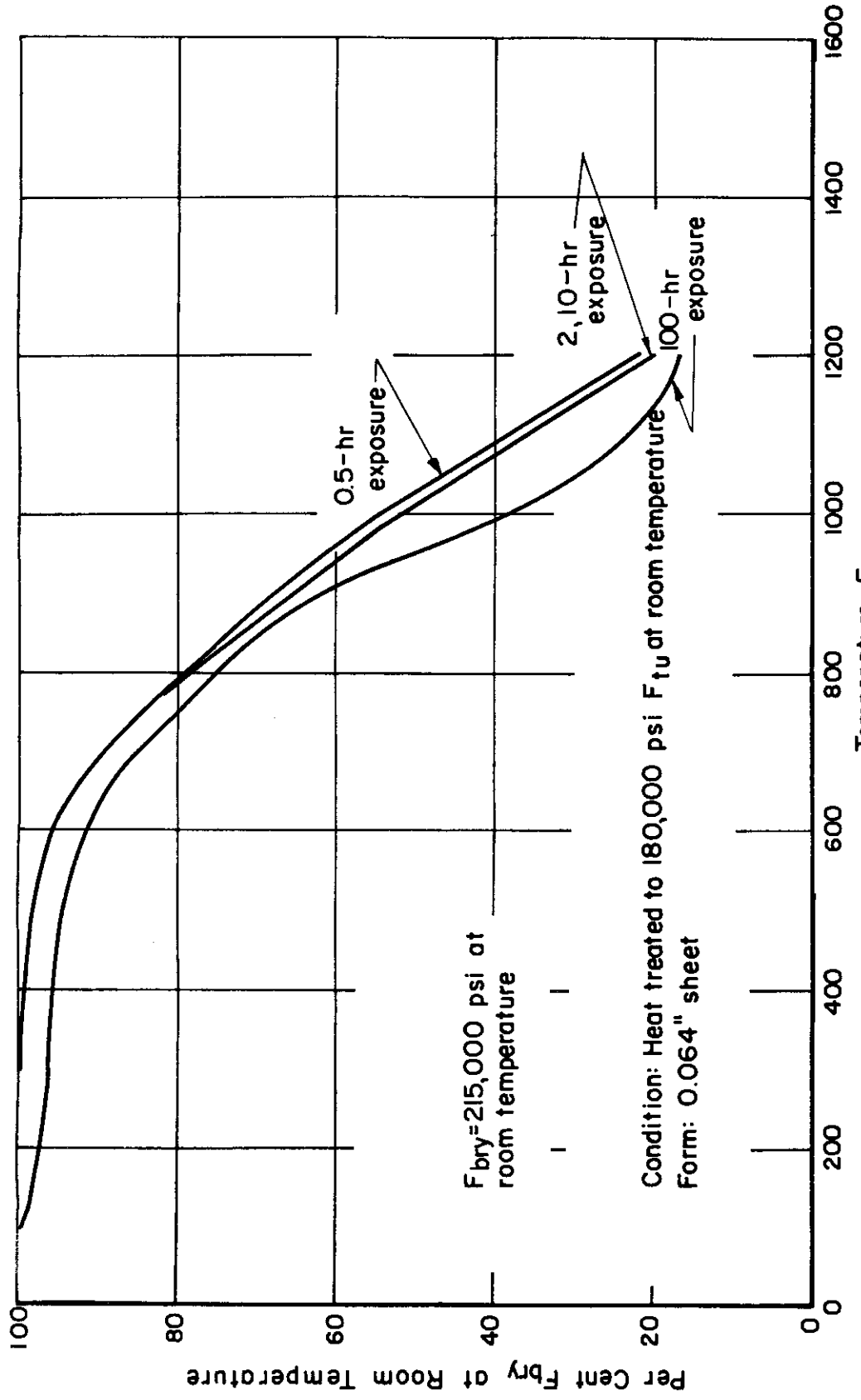

FIGURE 70. DESIGN CURVE FOR BEARING YIELD STRENGTH (F_{bry}) OF AISI 8630 ALLOY STEEL (0.064-INCH SHEET) AT ELEVATED TEMPERATURE[57]

Ref. 57.

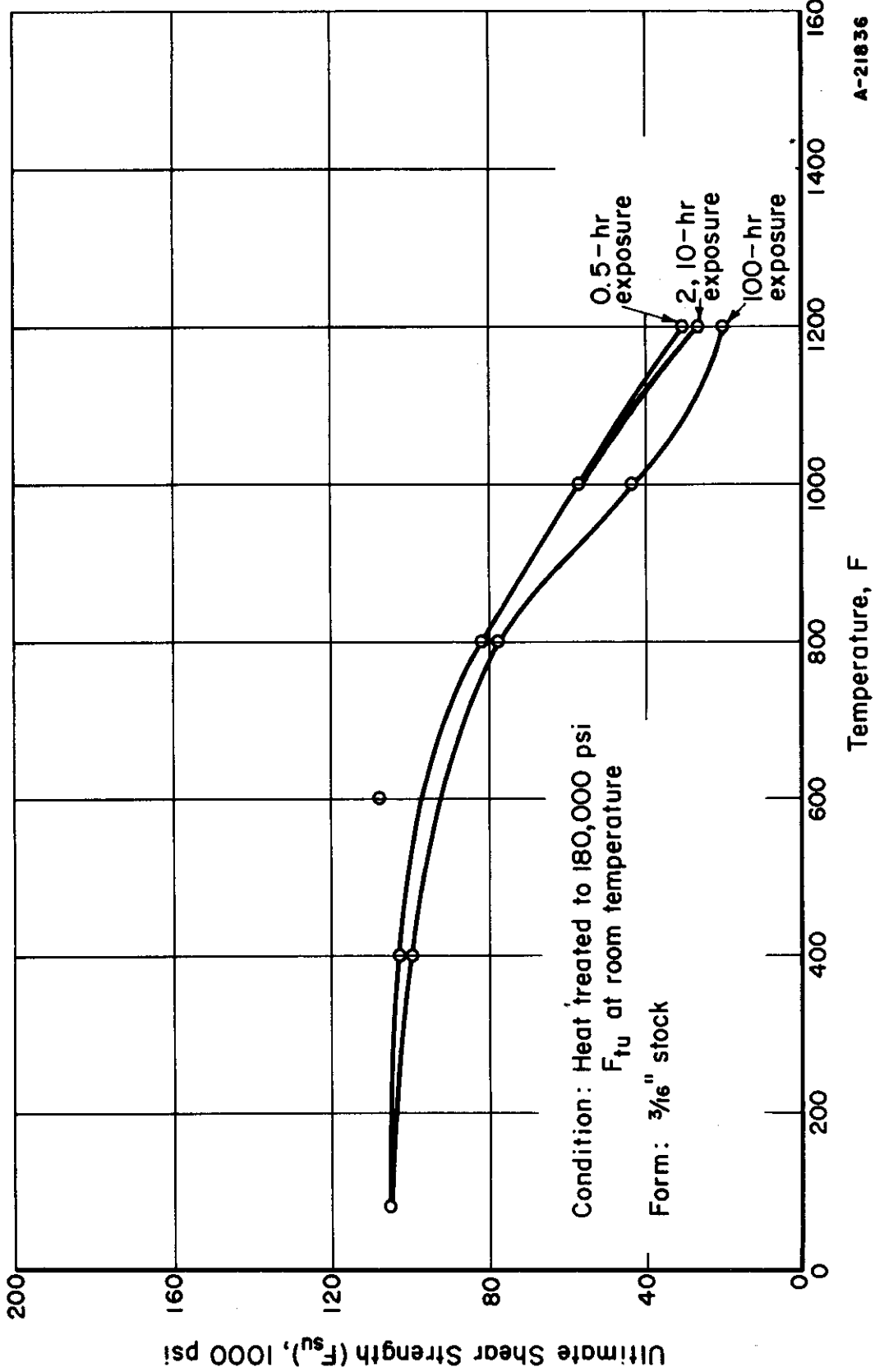

FIGURE 71. SHEAR STRENGTH (F_{su}) OF AISI 8630 ALLOY STEEL (3/16-INCH STOCK) AT ELEVATED TEMPERATURE

Ref. 57.

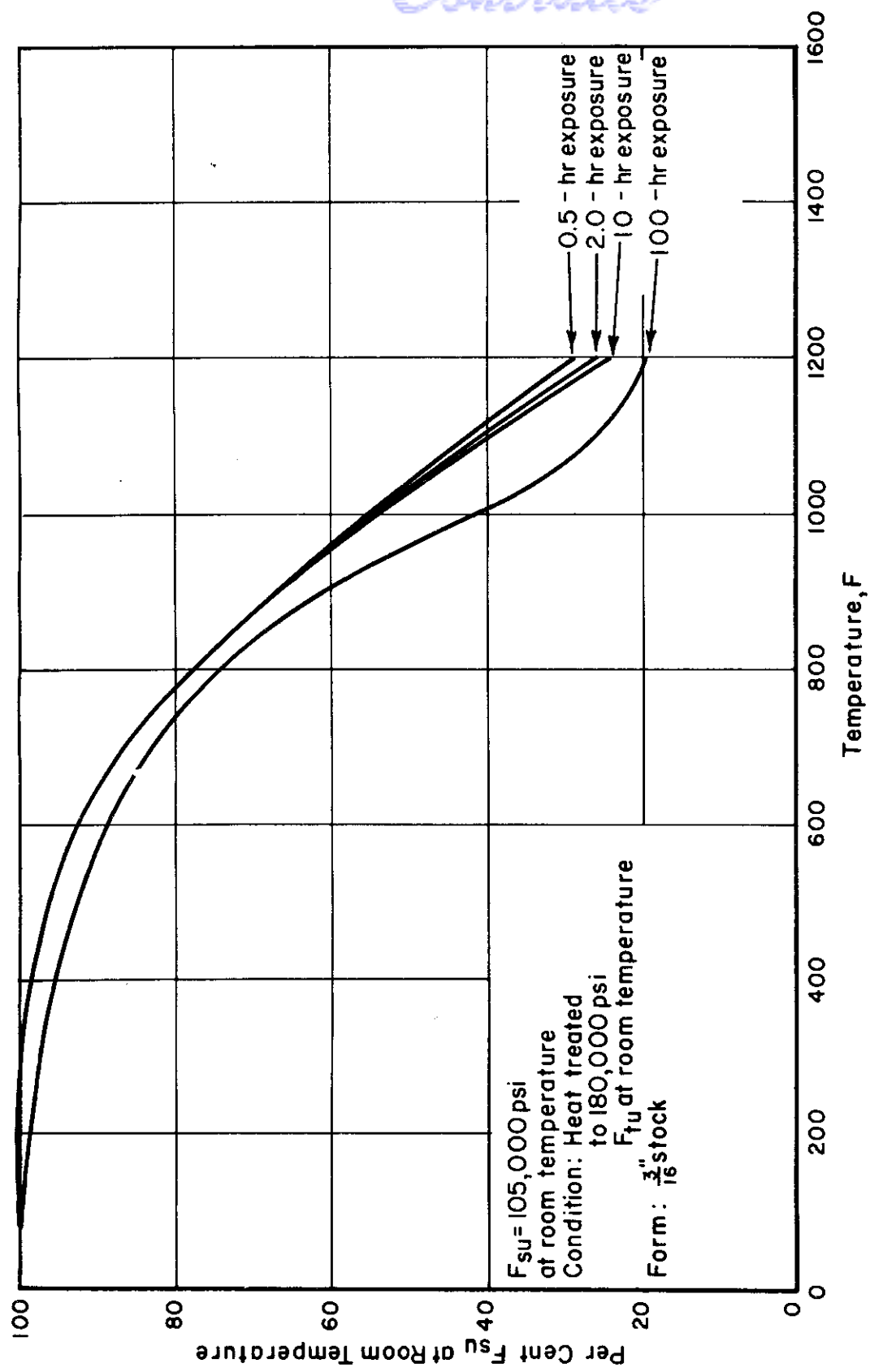

FIGURE 72. DESIGN CURVE FOR SHEAR STRENGTH (F_{su}) OF AISI 8630 ALLOY STEEL (3/16-INCH STOCK) AT ELEVATED TEMPERATURE

Ref. 57.

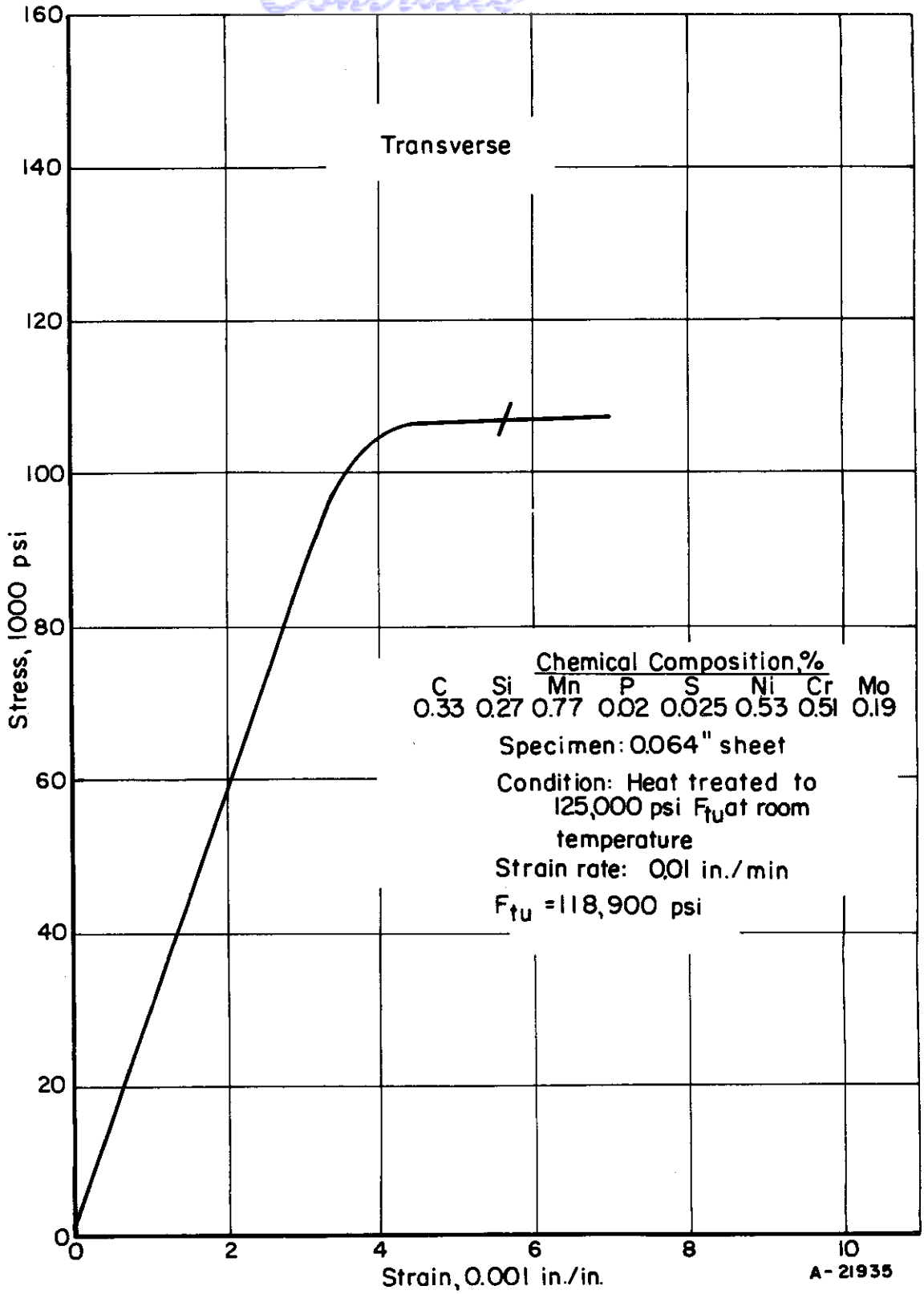

FIGURE 73. TENSILE STRESS-STRAIN CURVE FOR AISI 8630 ALLOY STEEL AT ROOM TEMPERATURE

Ref. 57, p 148.

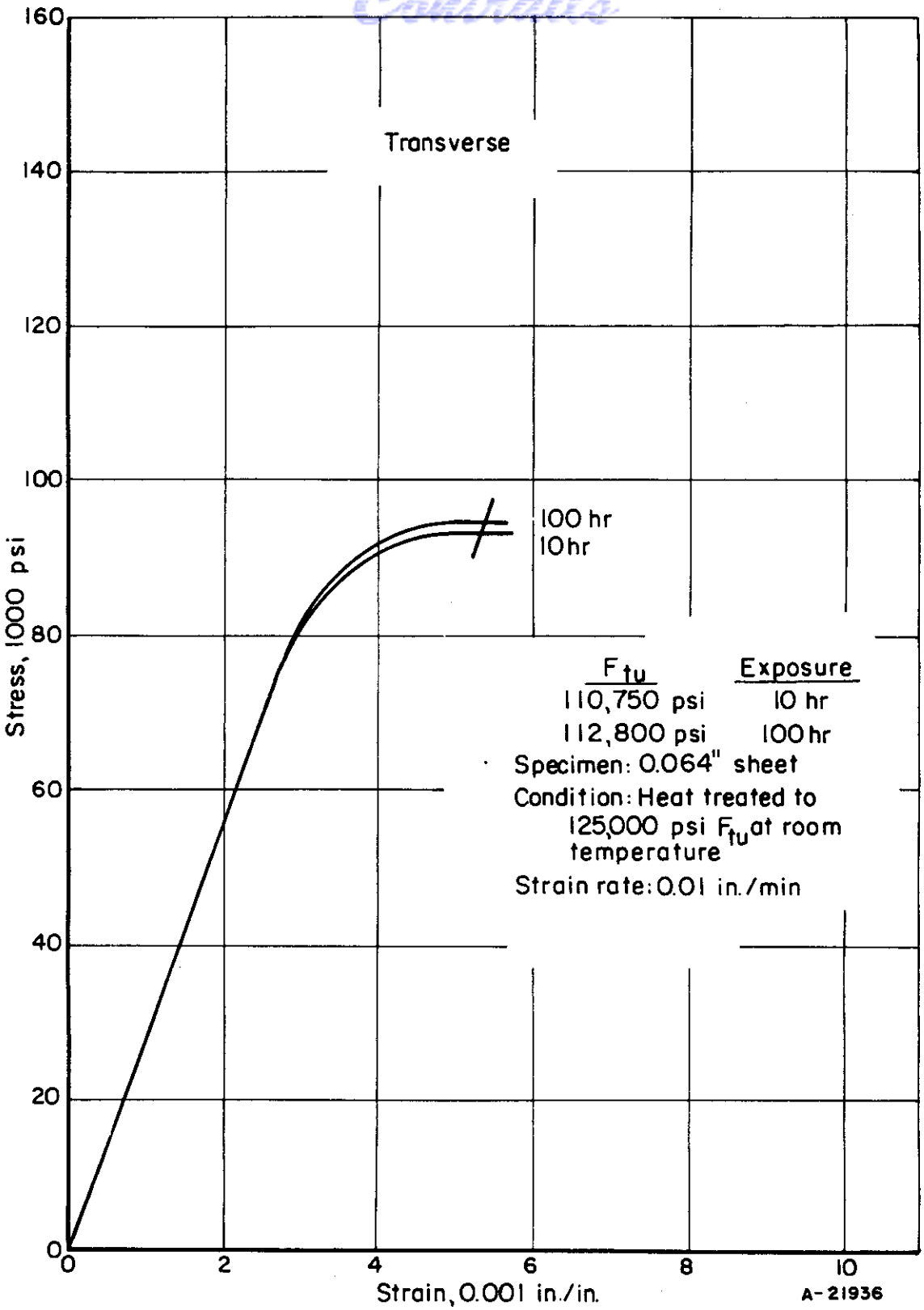

FIGURE 74. TENSILE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 400 F

Ref. 57, p 149.

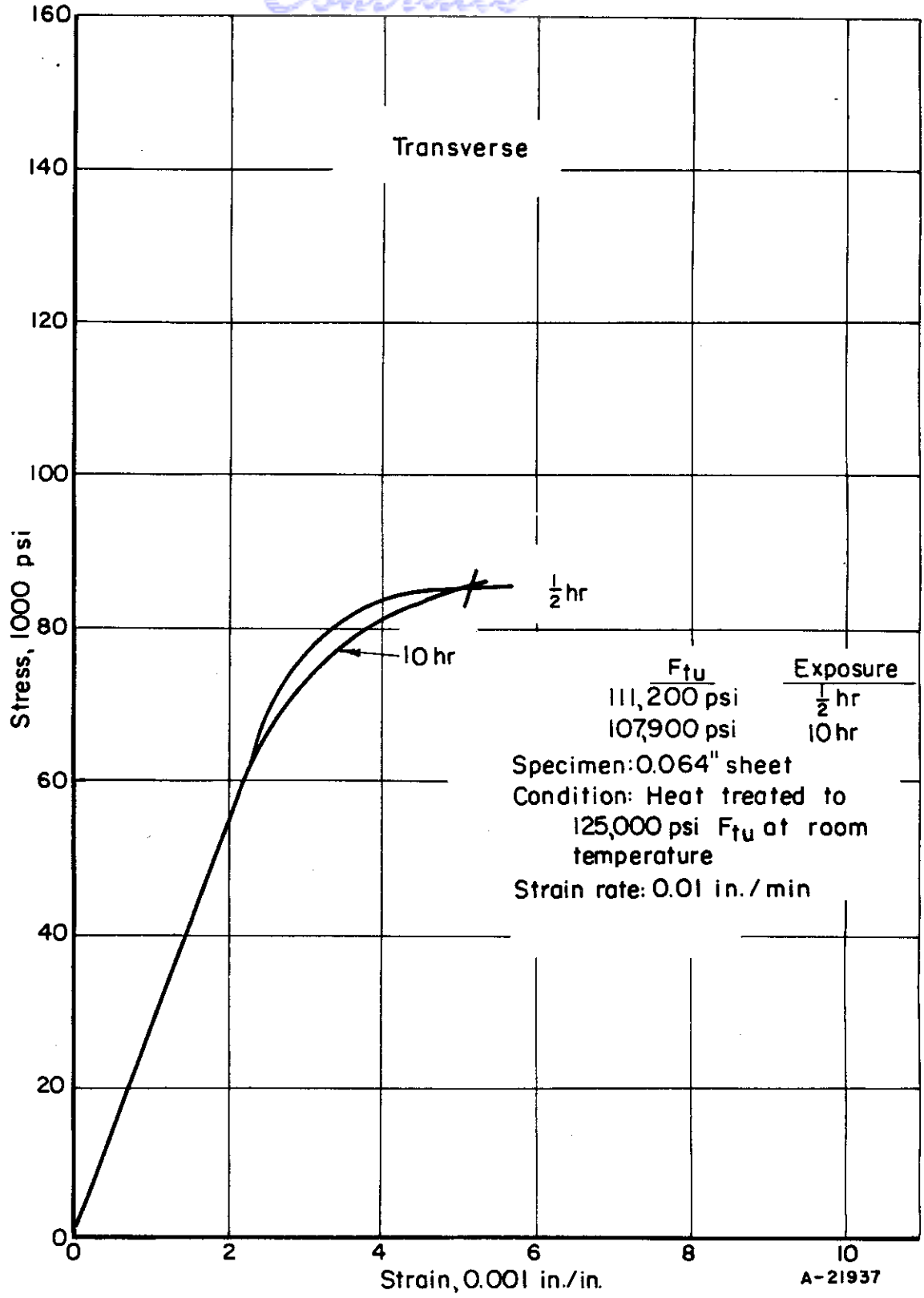

FIGURE 75. TENSILE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 600 F

Ref. 57, p 150.

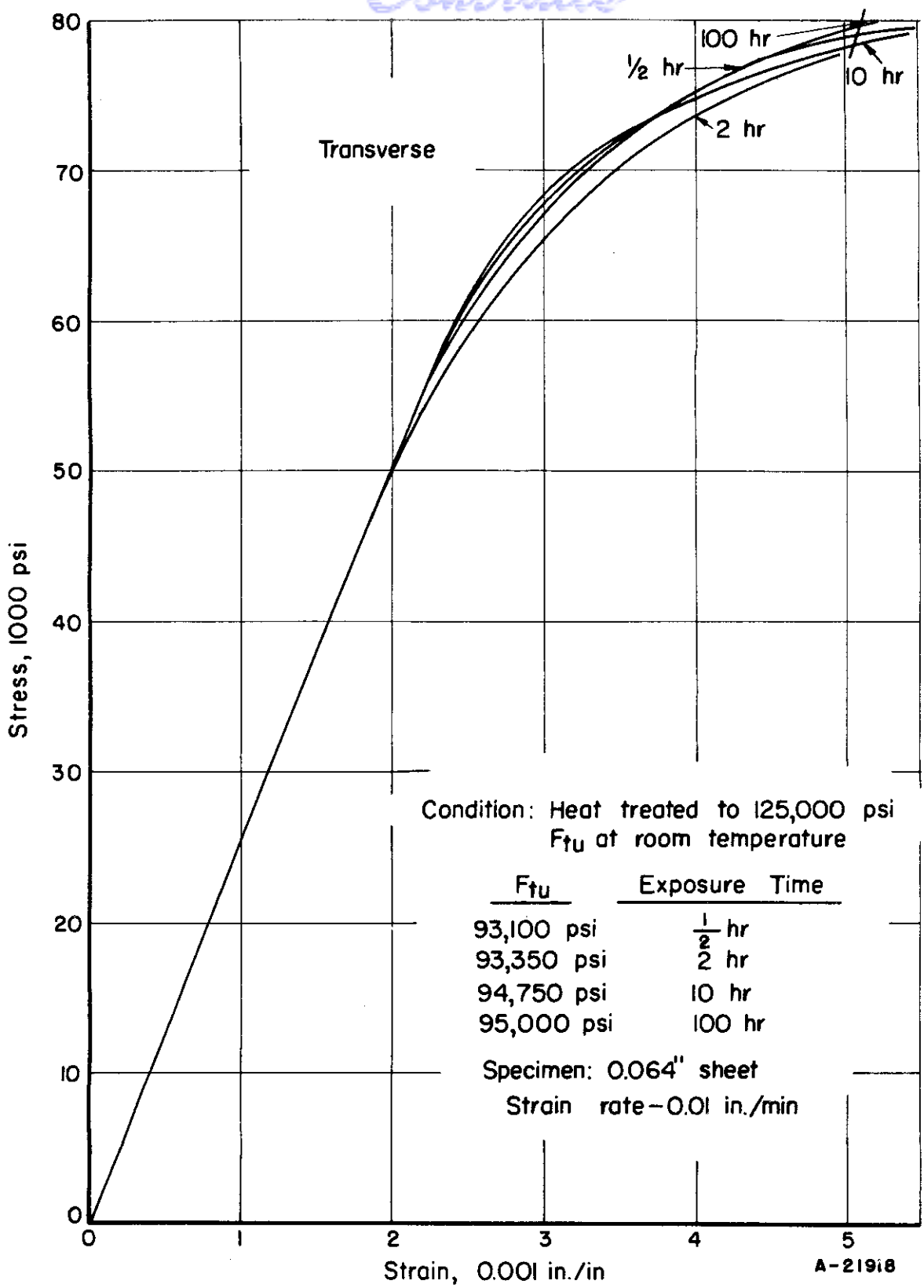

FIGURE 76. TENSILE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 800 F

Ref. 57, p 151.

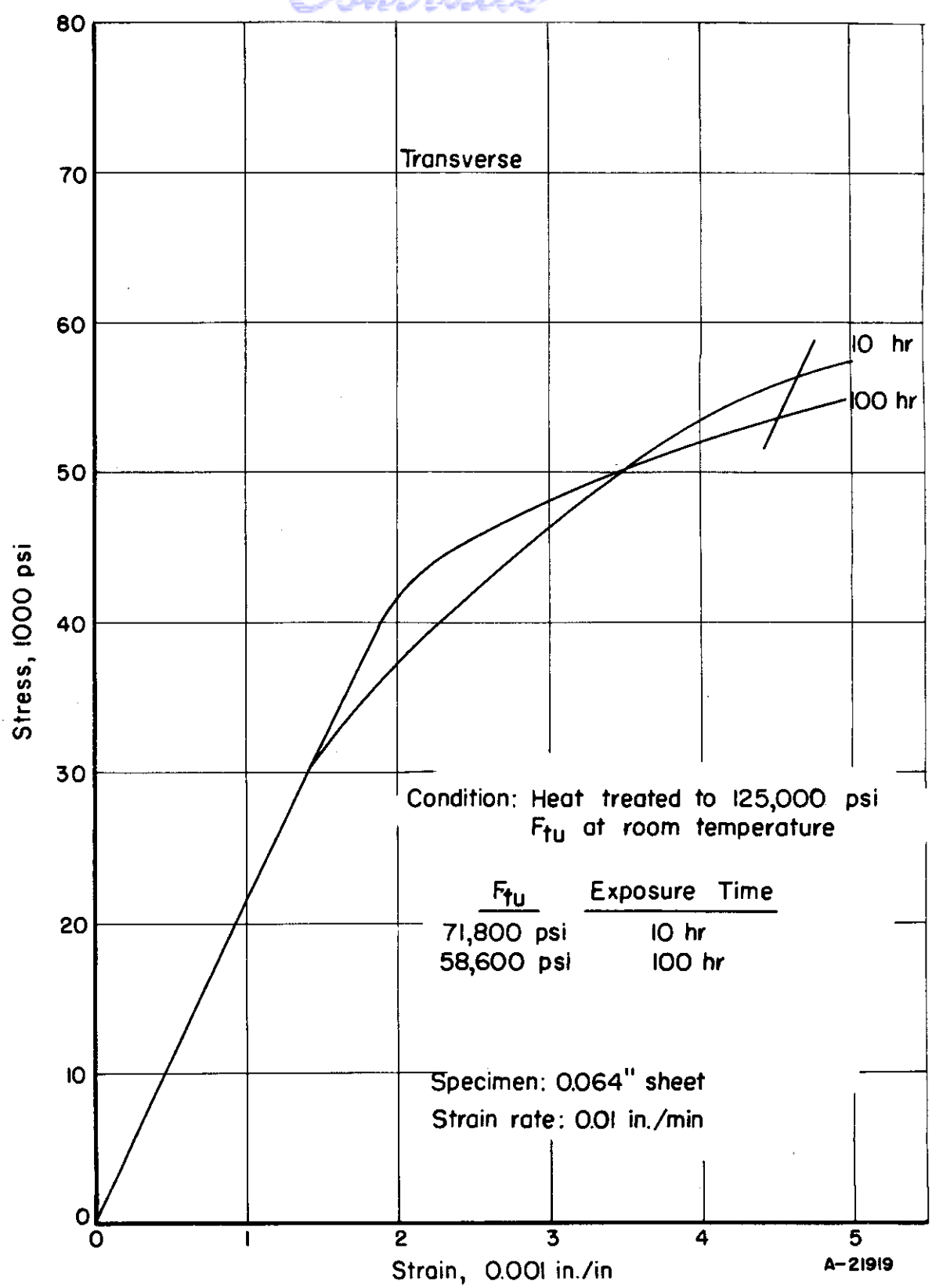

FIGURE 77. TENSILE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 1000 F

Ref. 57, p 152.

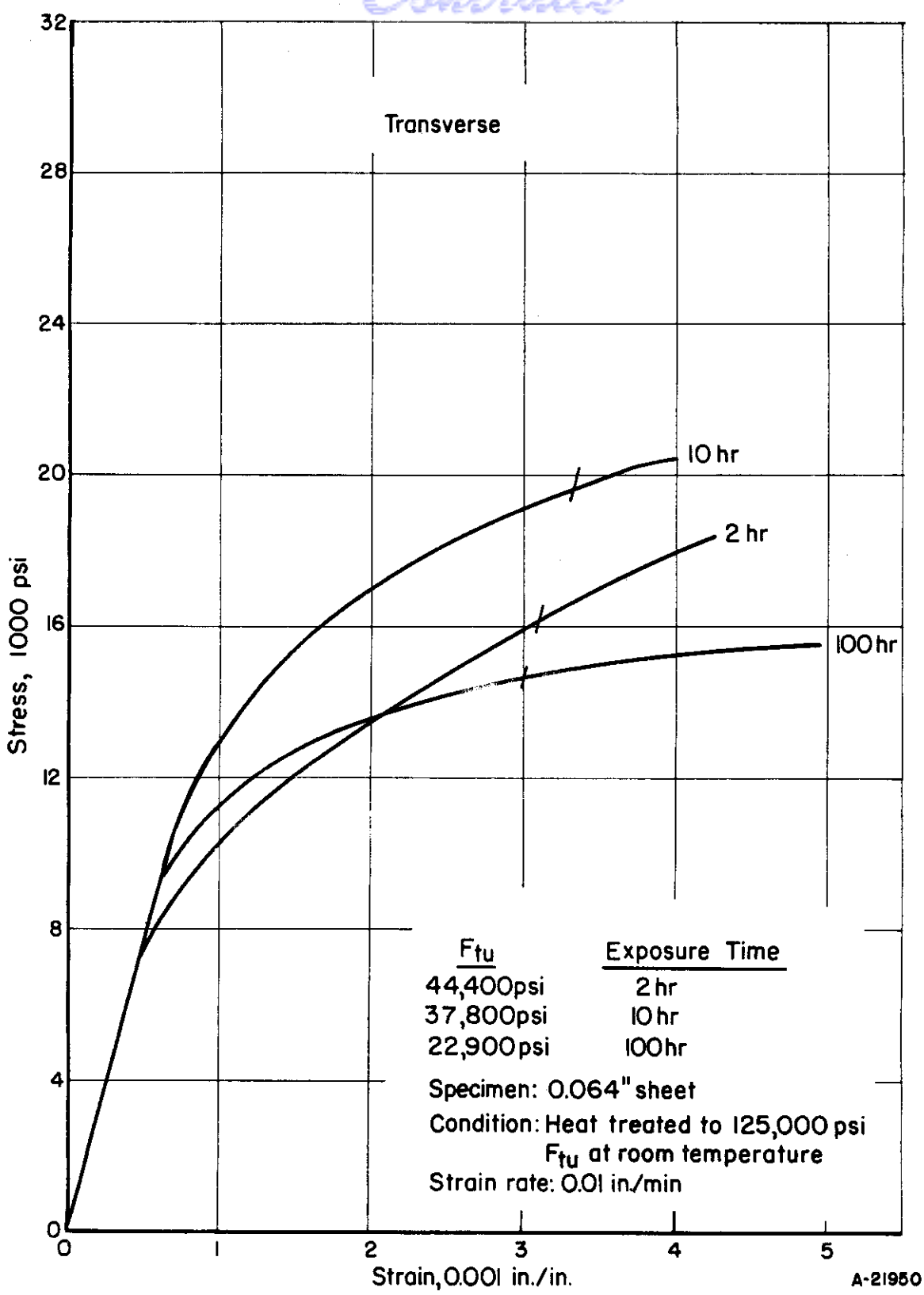

FIGURE 78. TENSILE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 1200 F

Ref. 57, p 153.

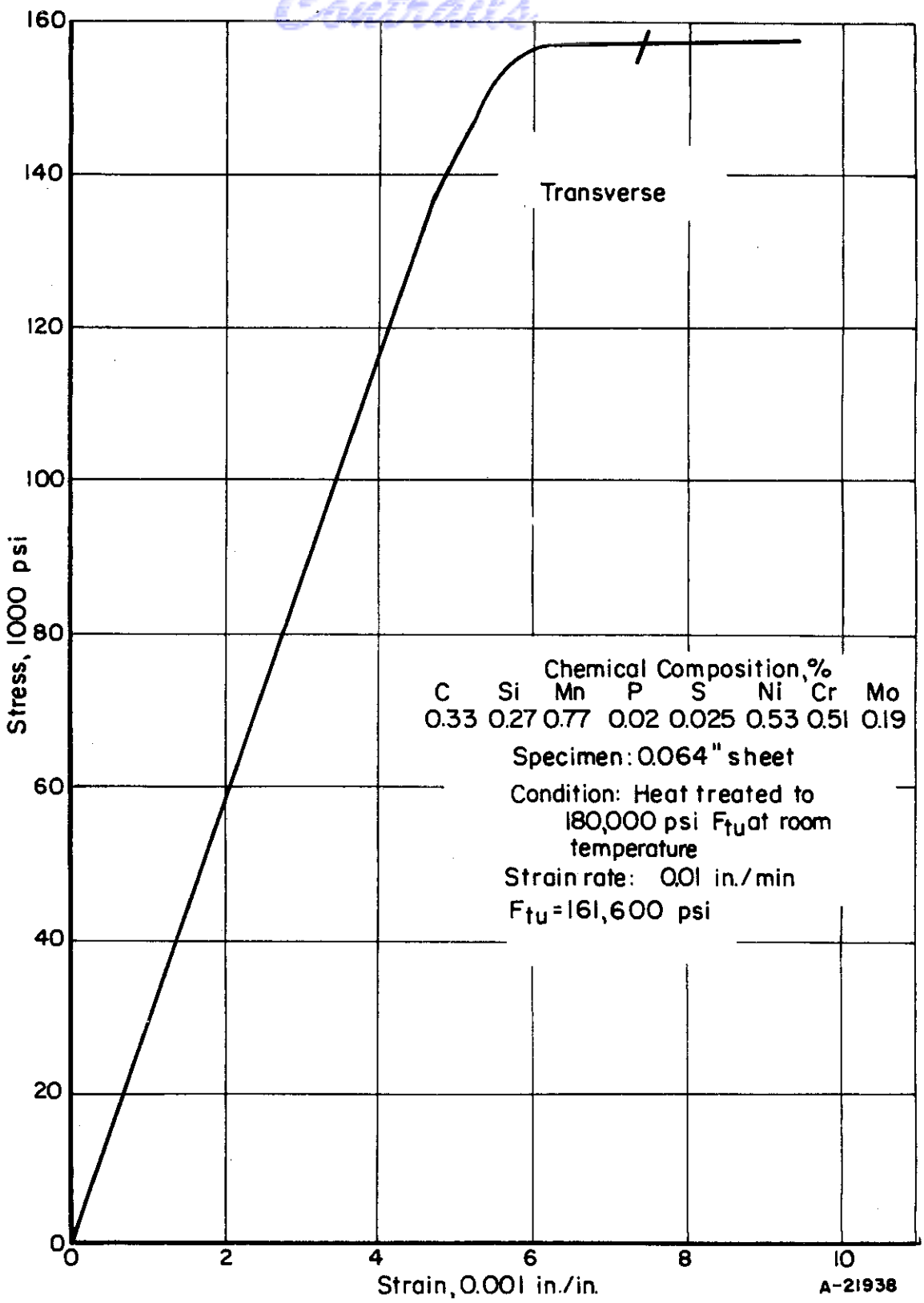

FIGURE 79. TENSILE STRESS-STRAIN CURVE FOR AISI 8630 ALLOY STEEL AT ROOM TEMPERATURE

Ref. 57, p 165.

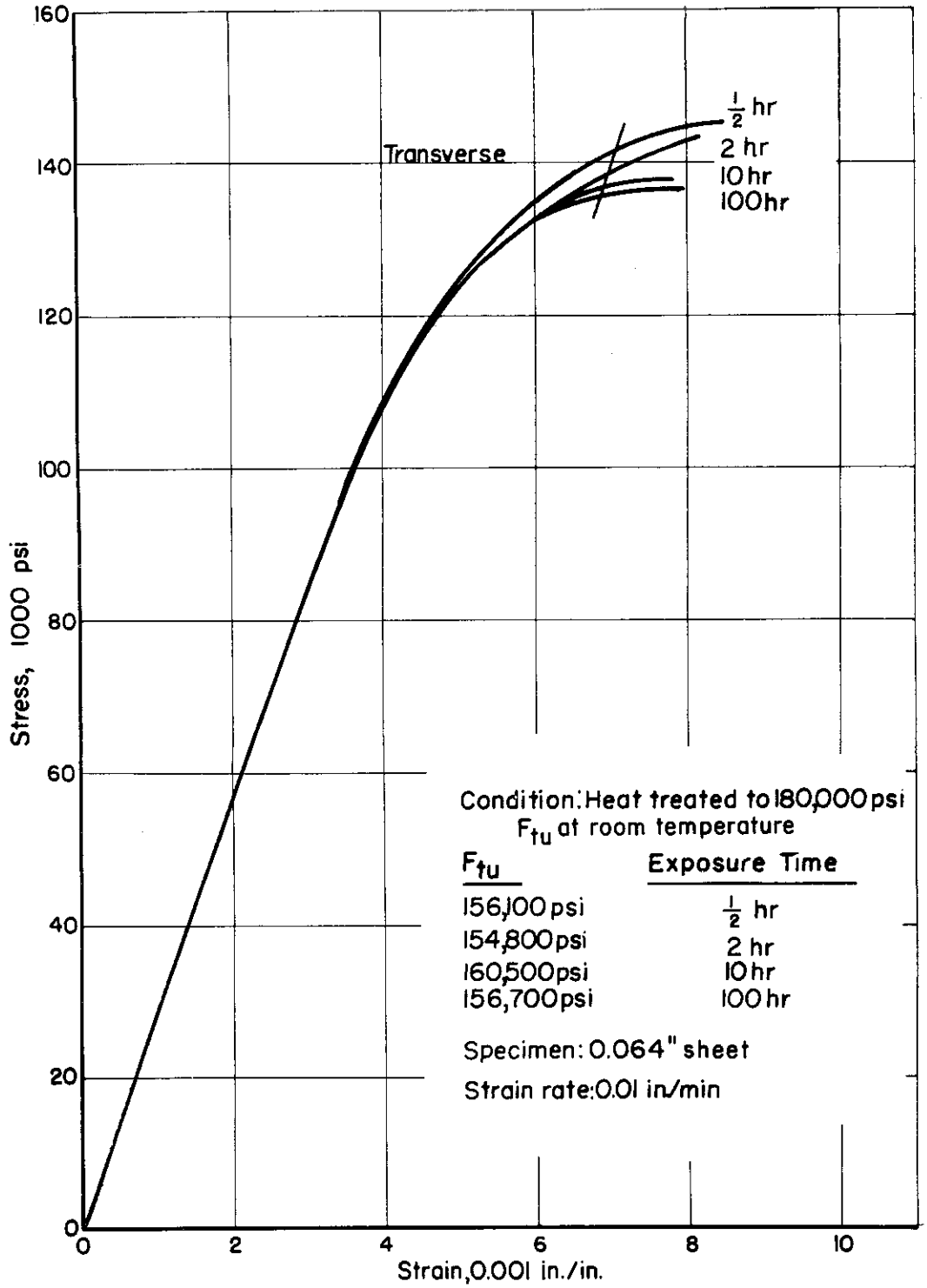

FIGURE 80. TENSILE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 400 F

Ref. 57, p 166.

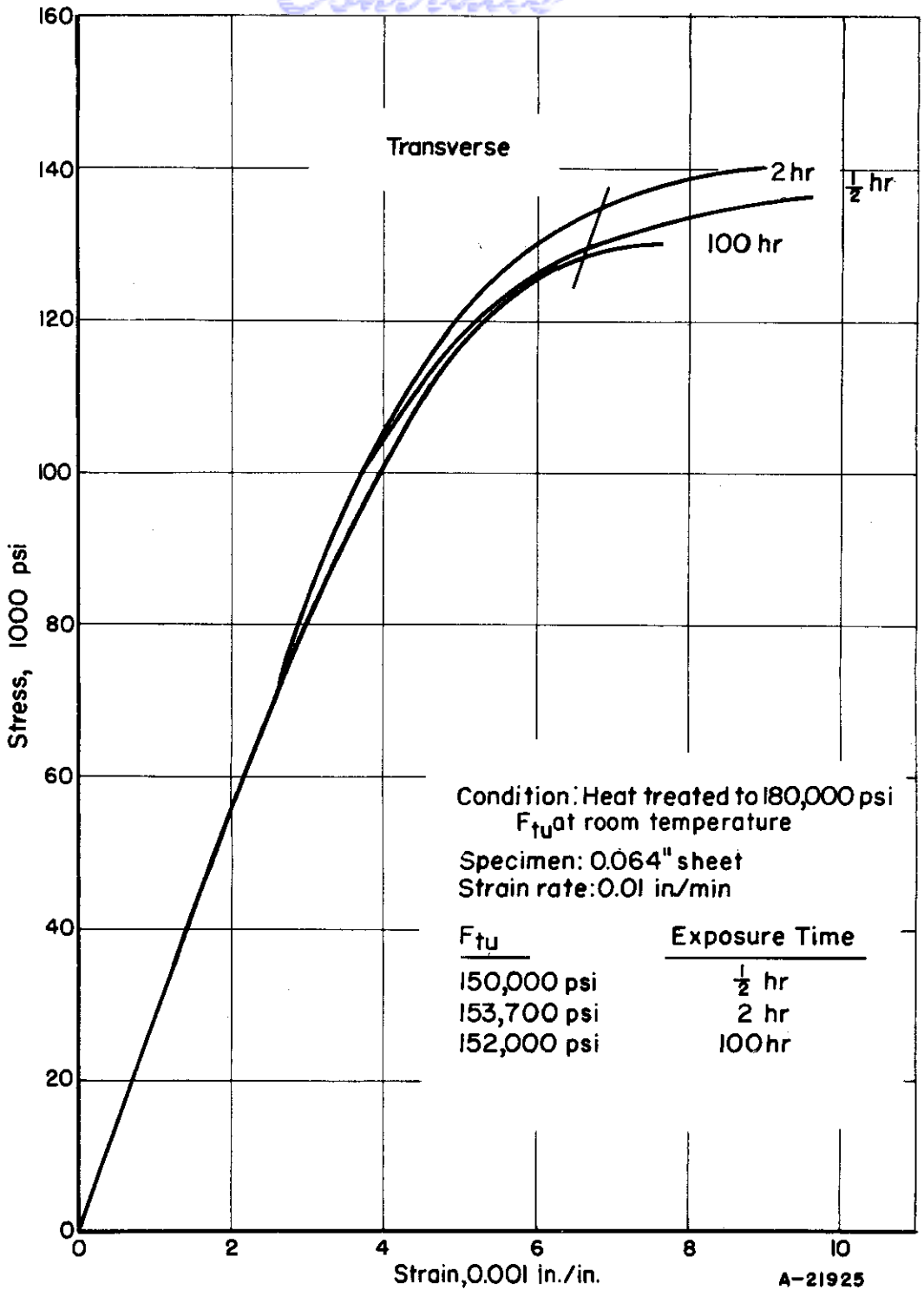

FIGURE 81. TENSILE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 600 F

Ref. 57, p 167.

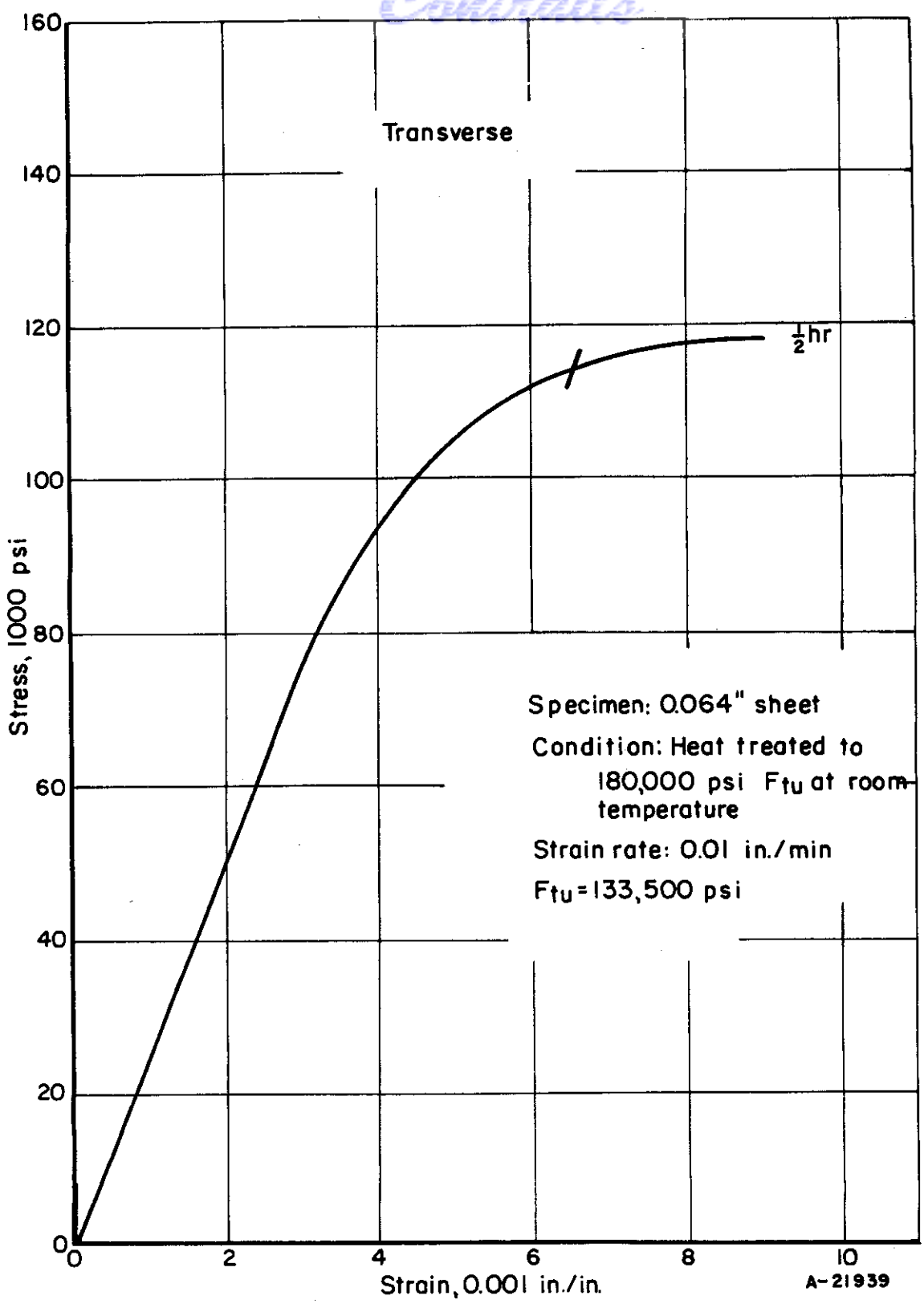

FIGURE 82. TENSILE STRESS-STRAIN CURVE FOR AISI 8630 ALLOY STEEL AT 800 F

Ref. 57, p 168.

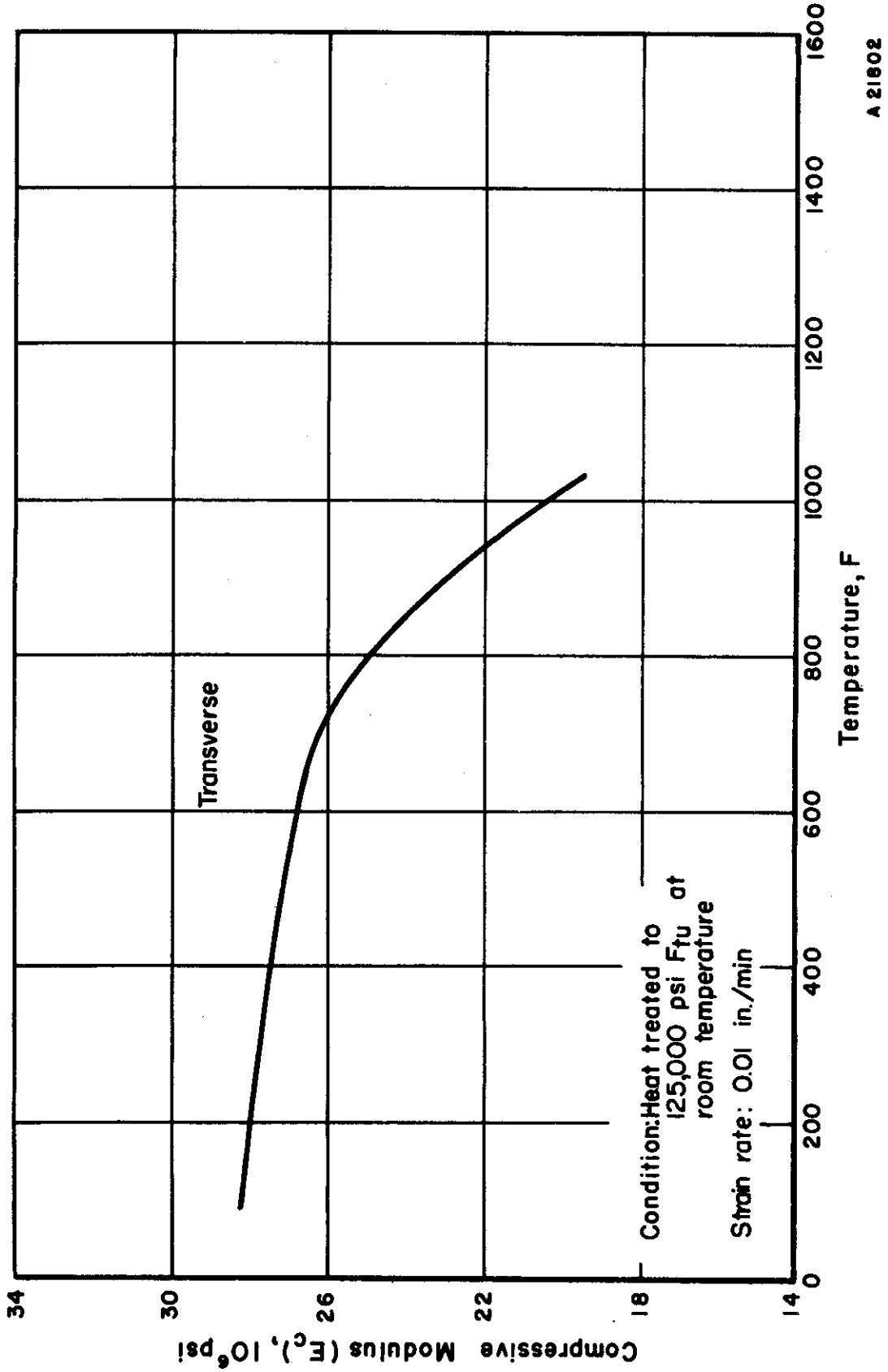

FIGURE 83. COMPRESSIVE MODULUS (E_c) OF AISI 8630 ALLOY STEEL AT ELEVATED TEMPERATURE

Ref. 57.

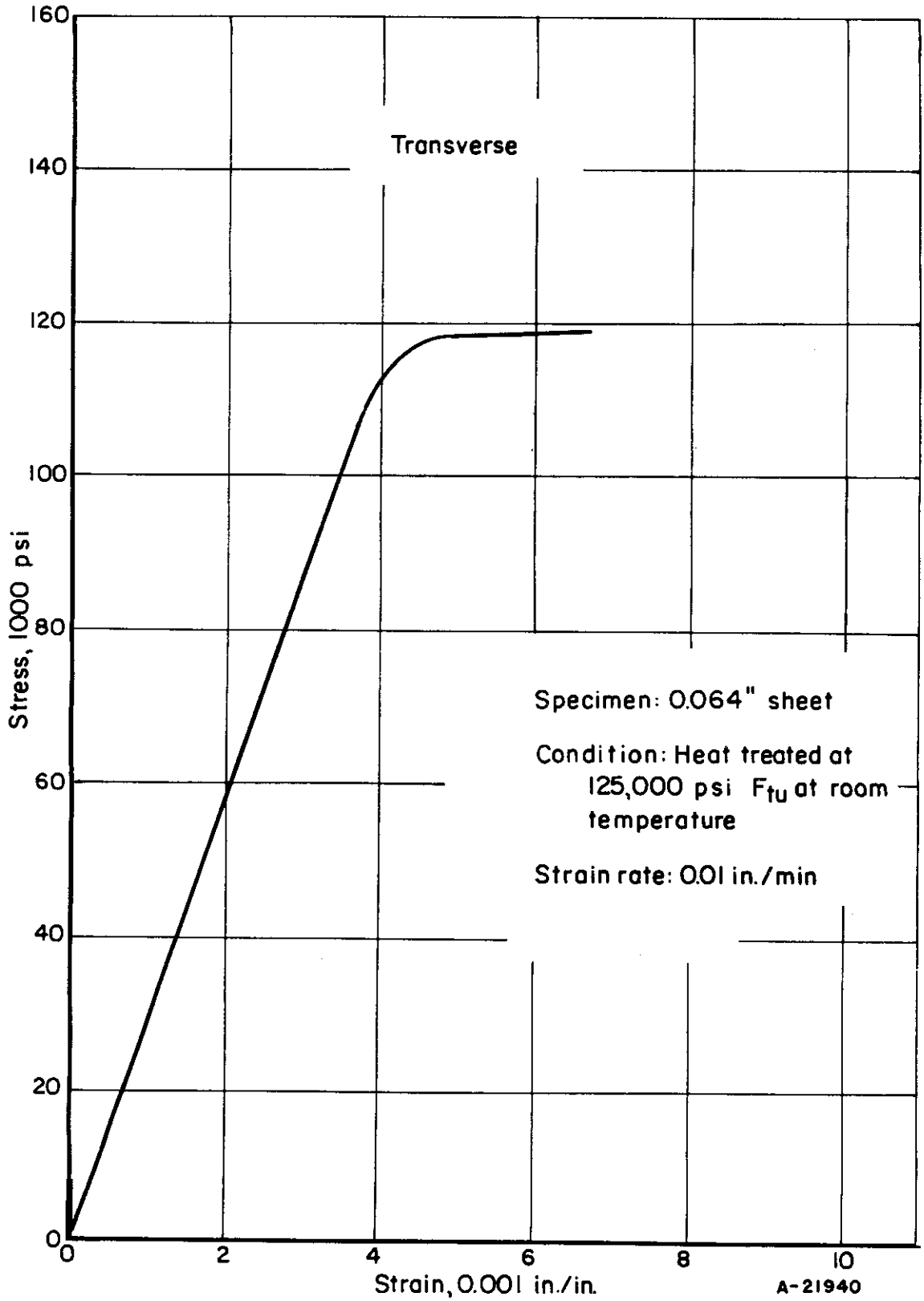

FIGURE 84. COMPRESSIVE STRESS-STRAIN CURVE FOR AISI 8630 ALLOY STEEL AT ROOM TEMPERATURE

Ref. 57, p 154.

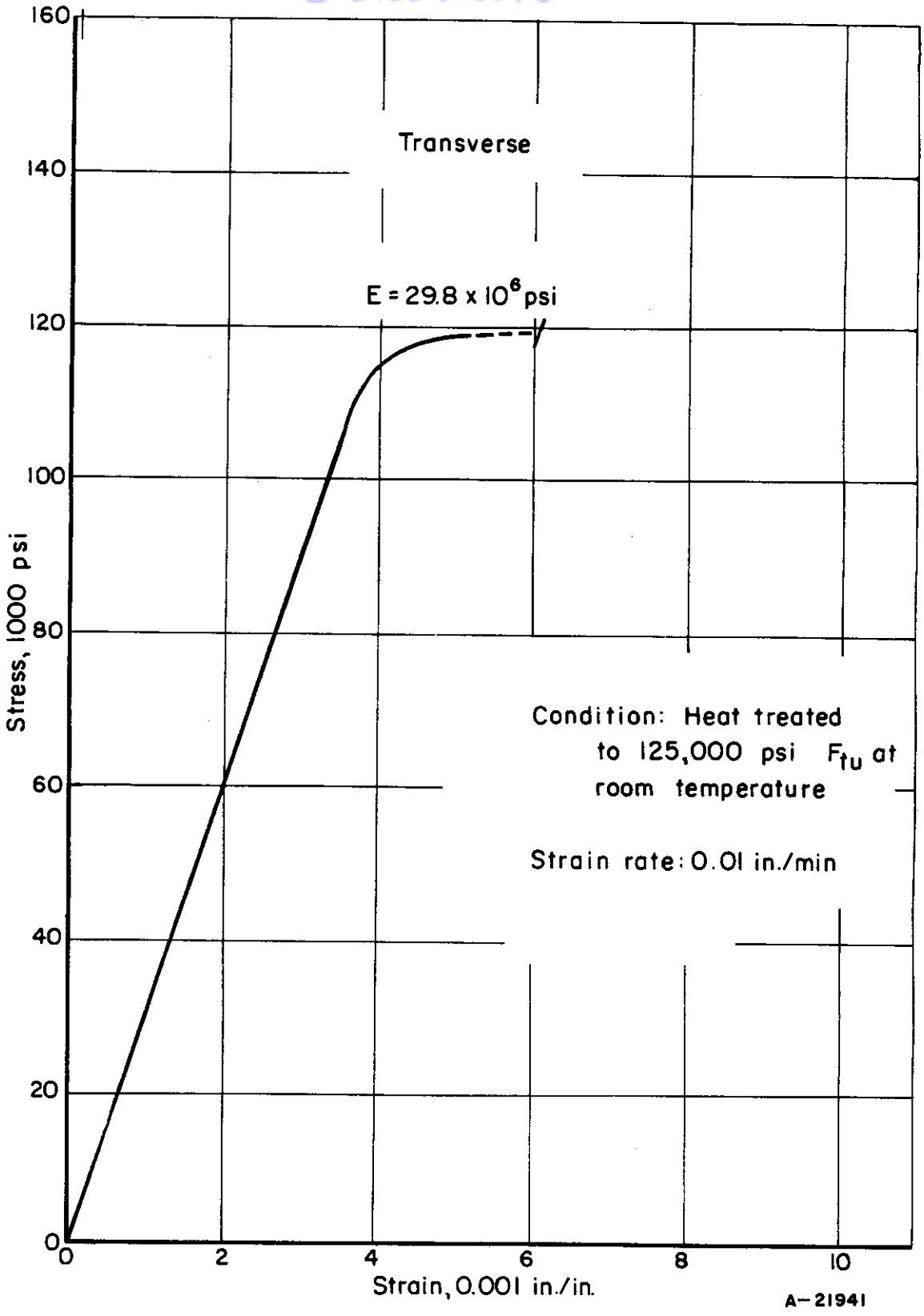

FIGURE 85. COMPRESSIVE STRESS-STRAIN CURVE FOR AISI 8630 ALLOY STEEL AT 78 F

Ref. 57, p 154.

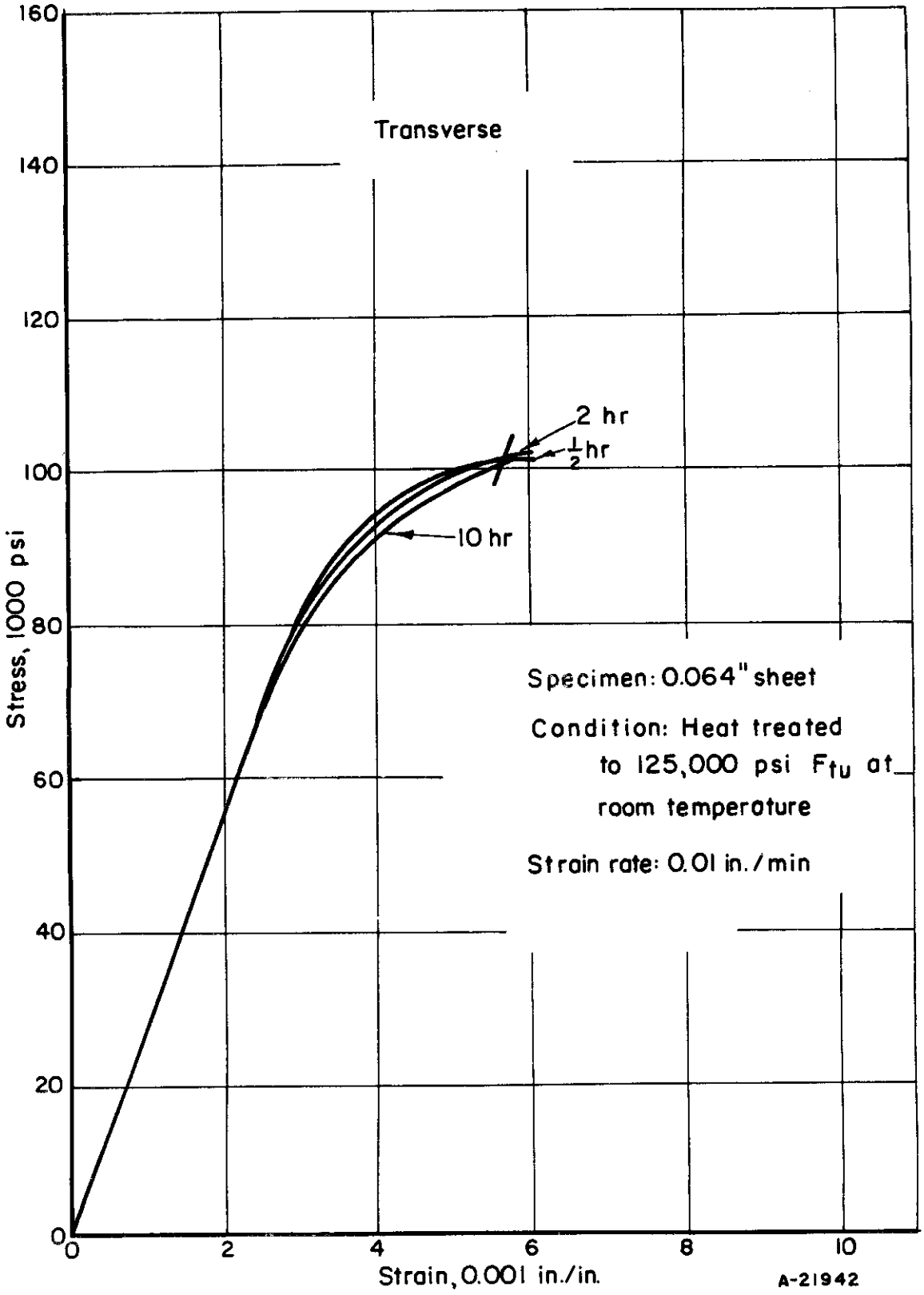

FIGURE 86. COMPRESSIVE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 600 F

Ref. 57, p 156.

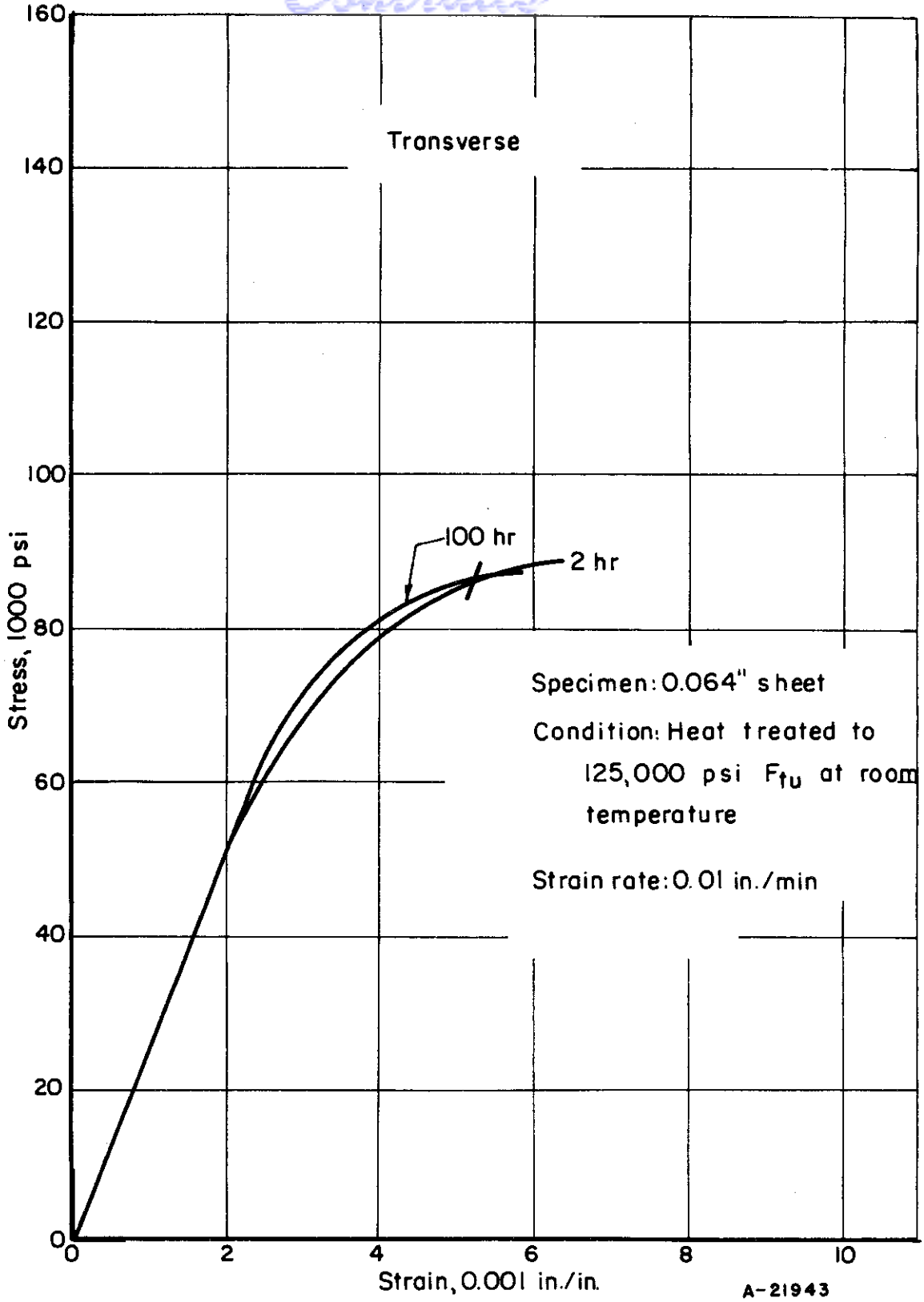

FIGURE 87. COMPRESSIVE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 800 F

Ref. 57, p 157.

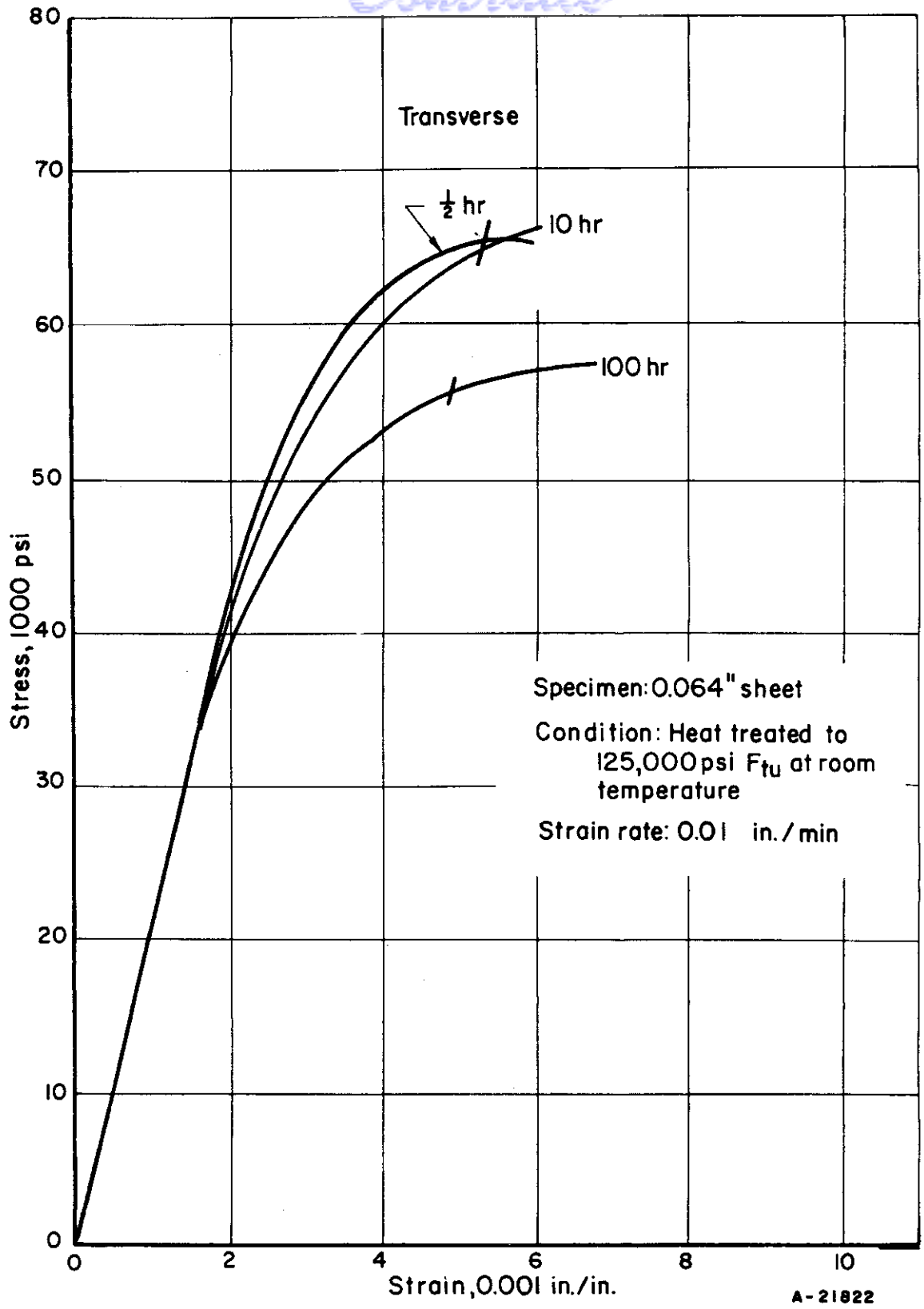

FIGURE 88. COMPRESSIVE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 1000 F

Ref. 57, p 158.

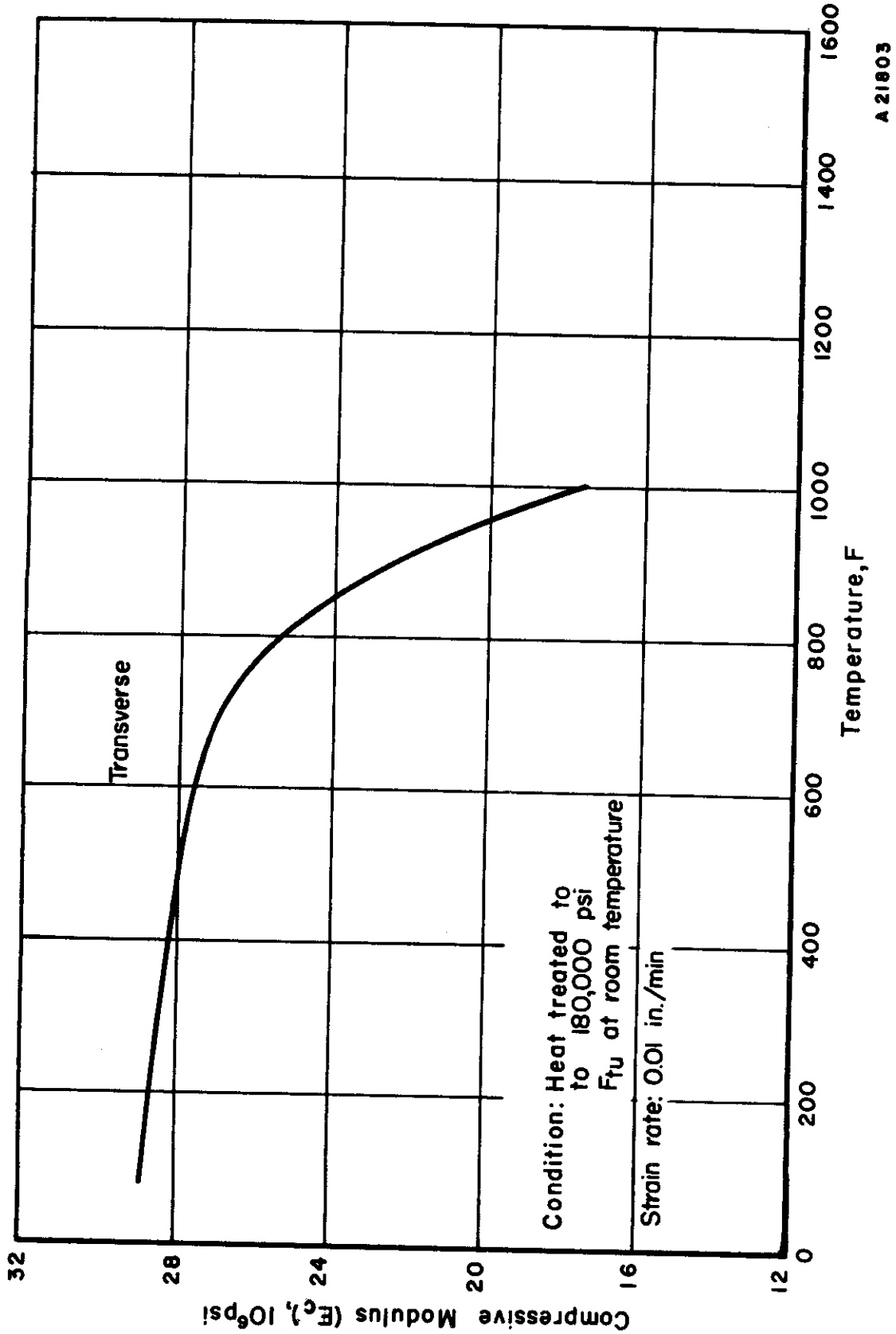

FIGURE 89. COMPRESSIVE MODULUS (E_c) OF 8630 ALLOY STEEL AT ELEVATED TEMPERATURE

Ref. 57.

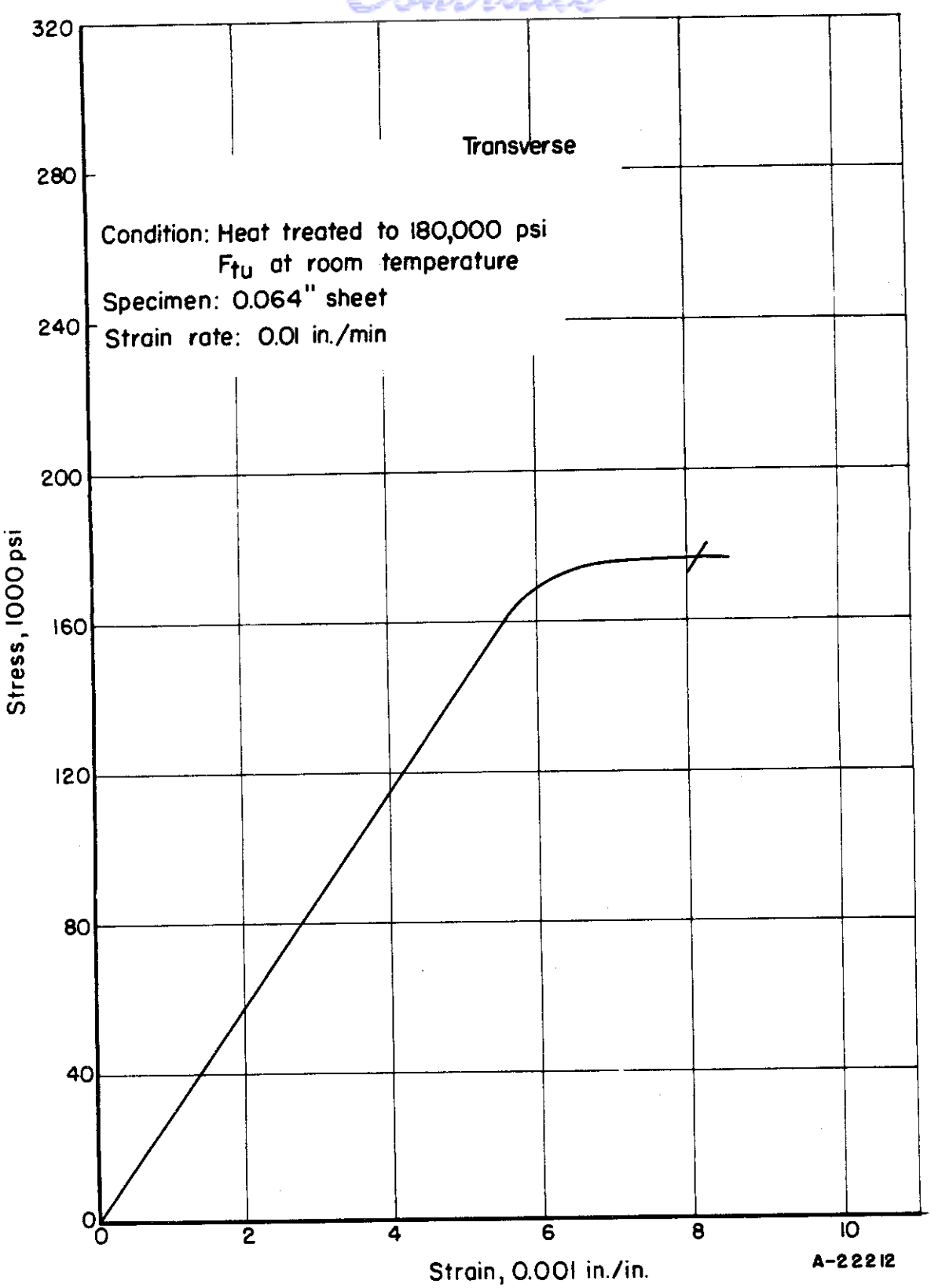

FIGURE 90. COMPRESSIVE STRESS-STRAIN CURVE FOR AISI 8630 ALLOY STEEL AT ROOM TEMPERATURE

Ref. 57, p 171.

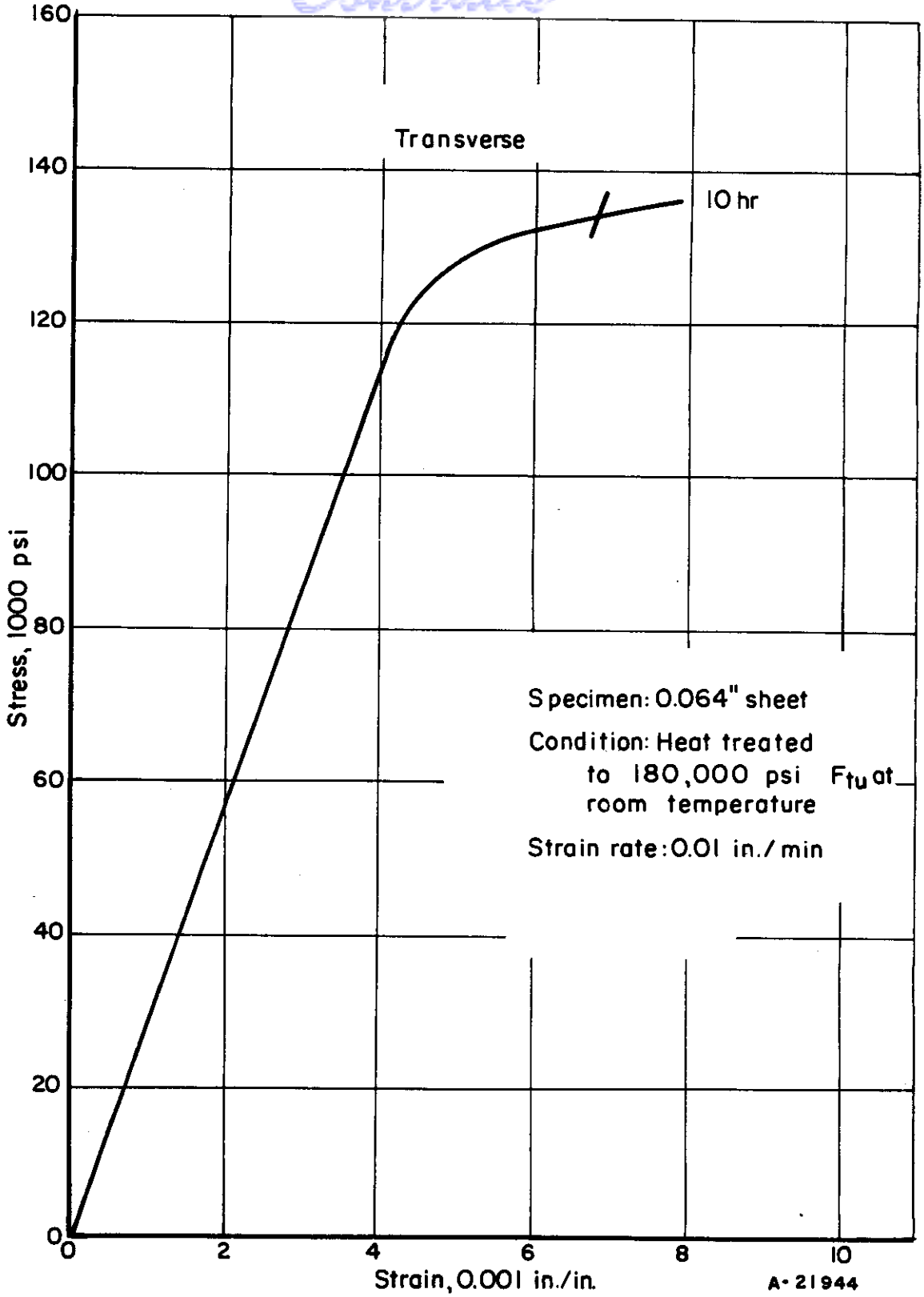

FIGURE 91. COMPRESSIVE STRESS-STRAIN CURVE FOR AISI 8630 ALLOY STEEL AT 400 F

Ref. 57, p 172.

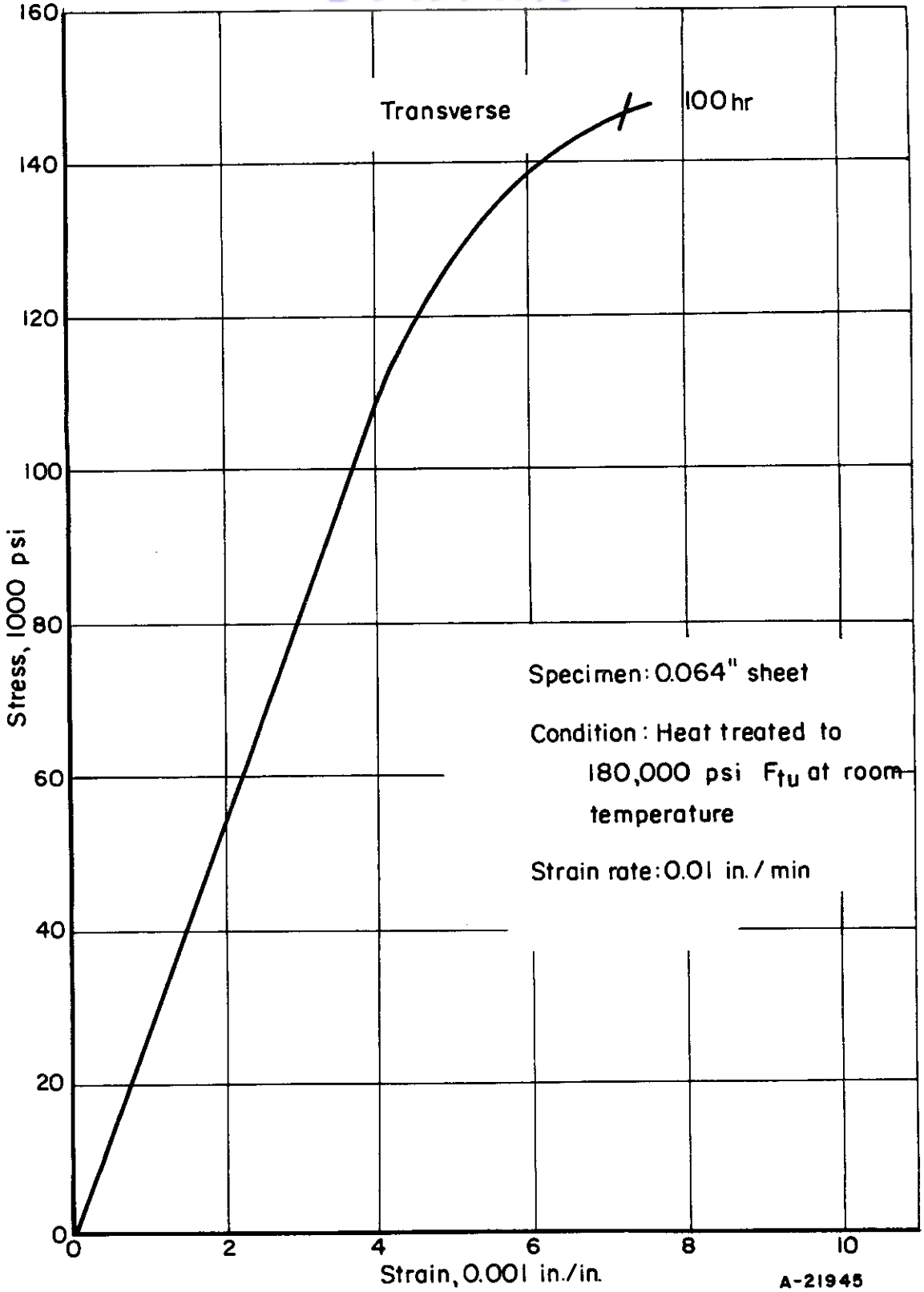

FIGURE 92. COMPRESSIVE STRESS-STRAIN CURVE FOR AISI 8630 ALLOY STEEL AT 600 F

Ref. 57, p 173.

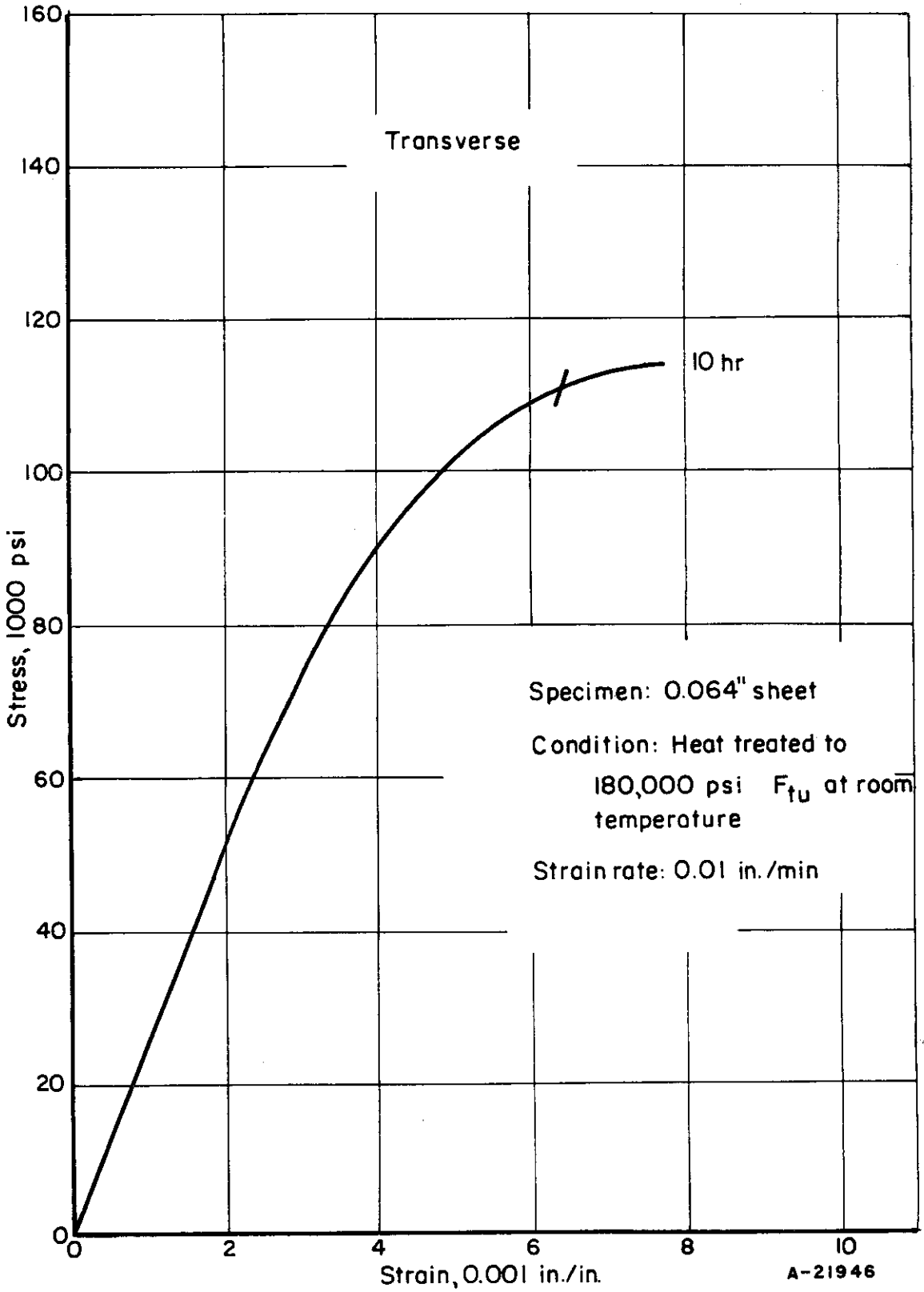

FIGURE 93. COMPRESSIVE STRESS-STRAIN CURVE FOR AISI 8630 ALLOY STEEL AT 800 F

Ref. 57, p 174.

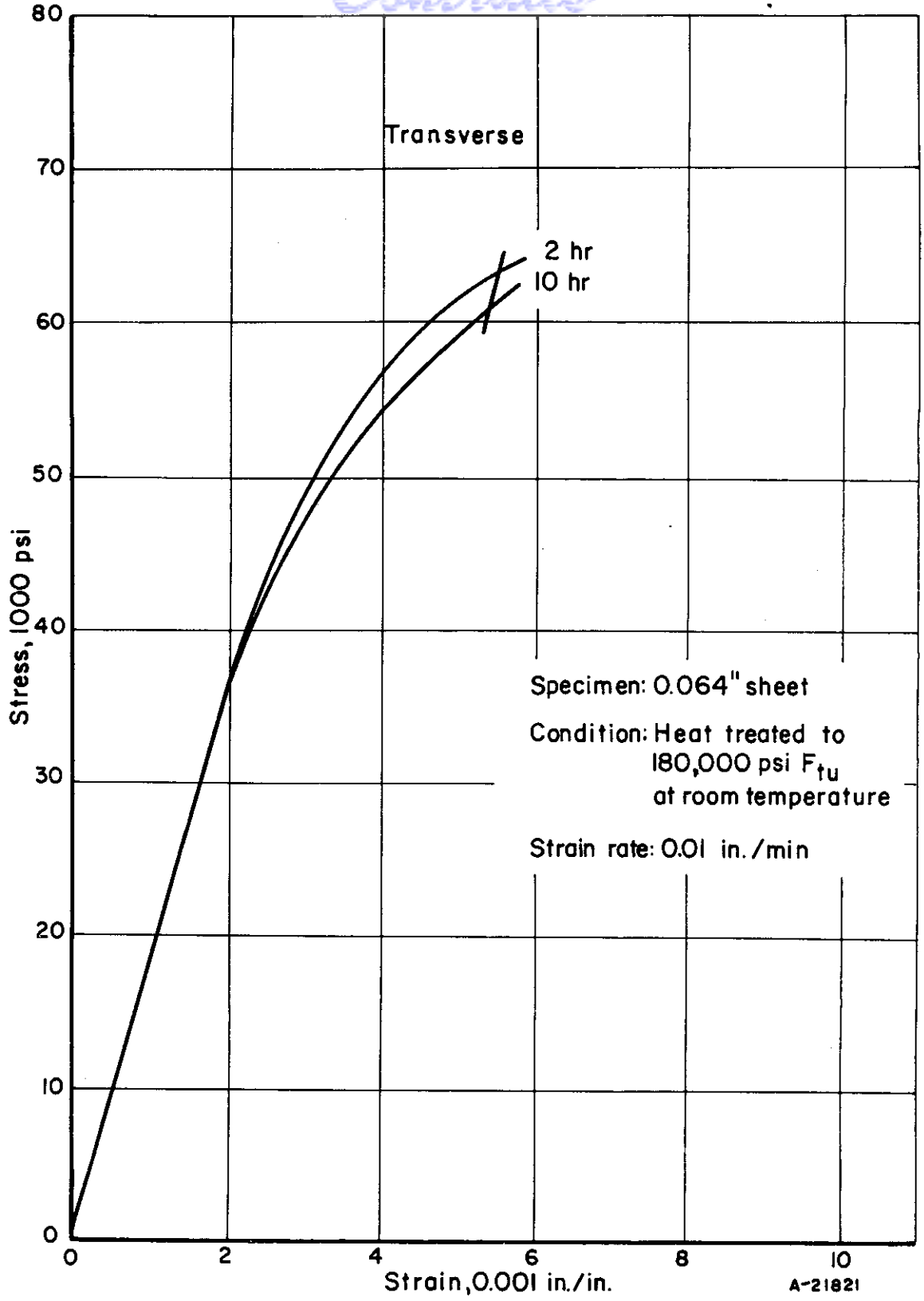

FIGURE 94. COMPRESSIVE STRESS-STRAIN CURVES FOR AISI 8630 ALLOY STEEL AT 1000 F

Ref. 57, p 175.

The 17-22A alloy is a silicon-chromium-molybdenum-vanadium steel having high resistance to thermal cracking and heat checking even in the hardened condition. The nominal chemical composition is given in Table 4.

TABLE 4. NOMINAL CHEMICAL COMPOSITION OF 17-22A STEEL

Element	Weight Per Cent
Carbon	0.43
Manganese	0.55
Silicon	0.65
Chromium	1.25
Molybdenum	0.50
Vanadium	0.25

Heat treating procedures are given below.

Annealing

Heat to 1550 F and furnace cool.

Normalizing

Heat to 1725 F and air cool. Temper as desired.

Hardening

Heat to 1550 F, oil quench, and temper to desired hardness.

Typical room-temperature mechanical properties of 17-22A alloy are given in Table 5.

TABLE 5. TYPICAL ROOM TEMPERATURE PROPERTIES OF 17-22A ALLOY STEEL

Property	
Ultimate tensile (F_{tu})	150,000 psi
Tensile yield (F_{ty})	141,000 psi
Elongation (e) in 2 inches	16 per cent
Reduction of area	48 per cent
Brinell hardness number	302

This alloy has sufficient strength to resist hot upsetting under rapidly applied stresses at extreme temperatures. It can be seen from the following short-time, elevated-temperature curves that 17-22A alloy can find application up to 1000 F.

(1) Tensile properties, Figures 95 through 102

Only tensile properties were available for 17-22A.

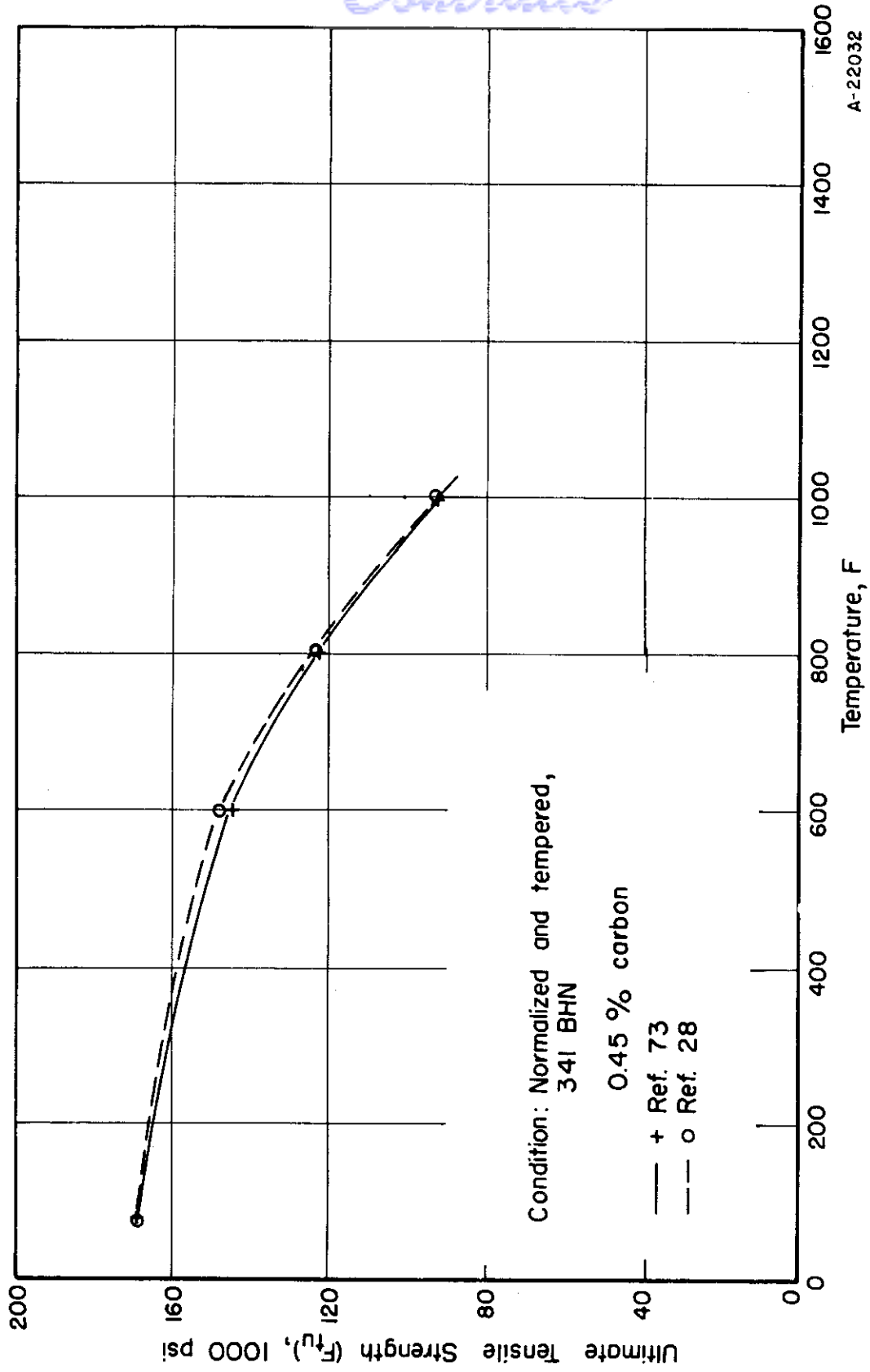

FIGURE 95. TENSILE STRENGTH (F_{tu}) OF 17-22A ALLOY STEEL (NORMALIZED AND TEMPERED) AT ELEVATED TEMPERATURE

Ref. 73, 28.

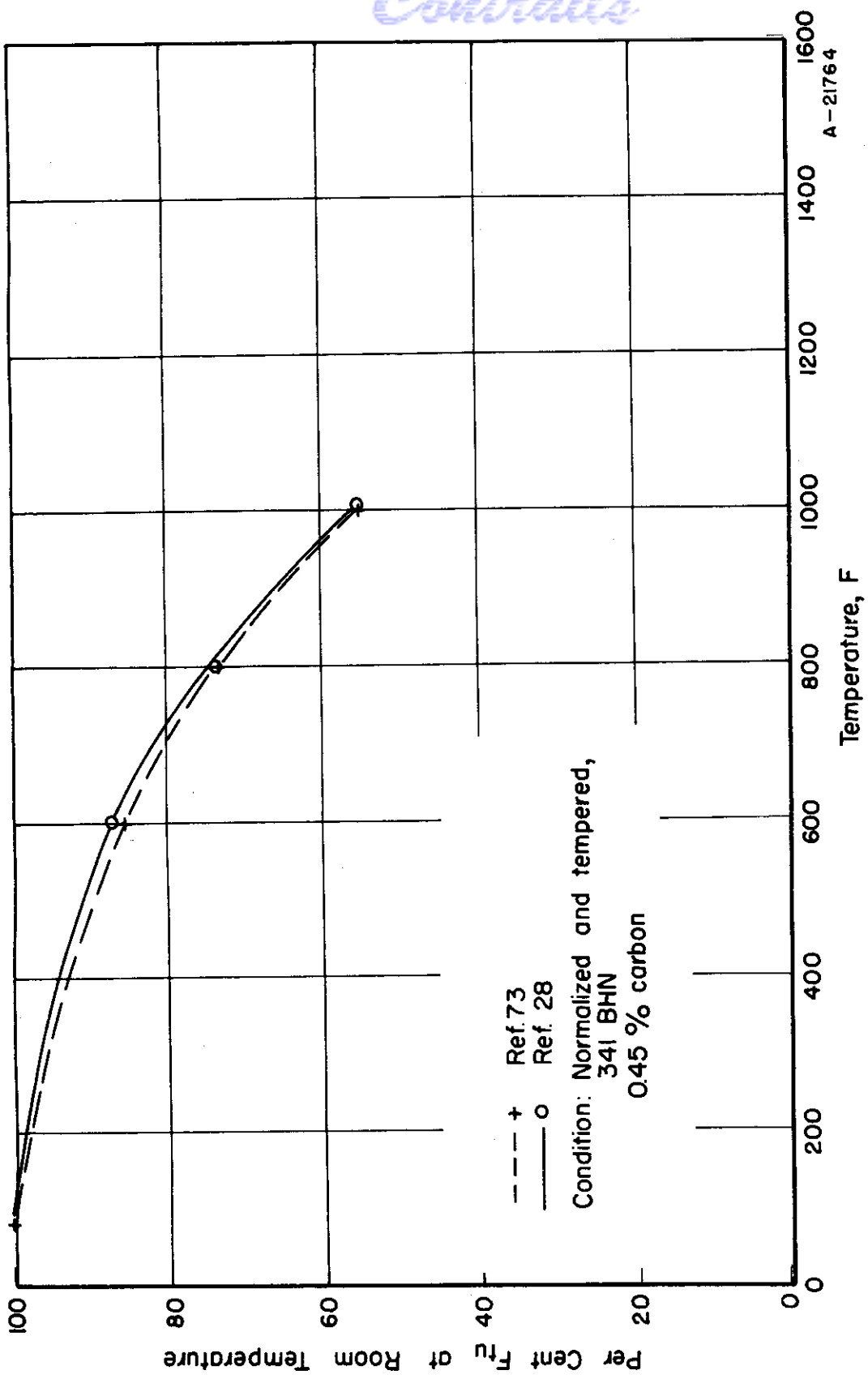

FIGURE 96. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF 17-22A ALLOY STEEL (NORMALIZED AND TEMPERED) AT ELEVATED TEMPERATURE

Ref. 73, 28.

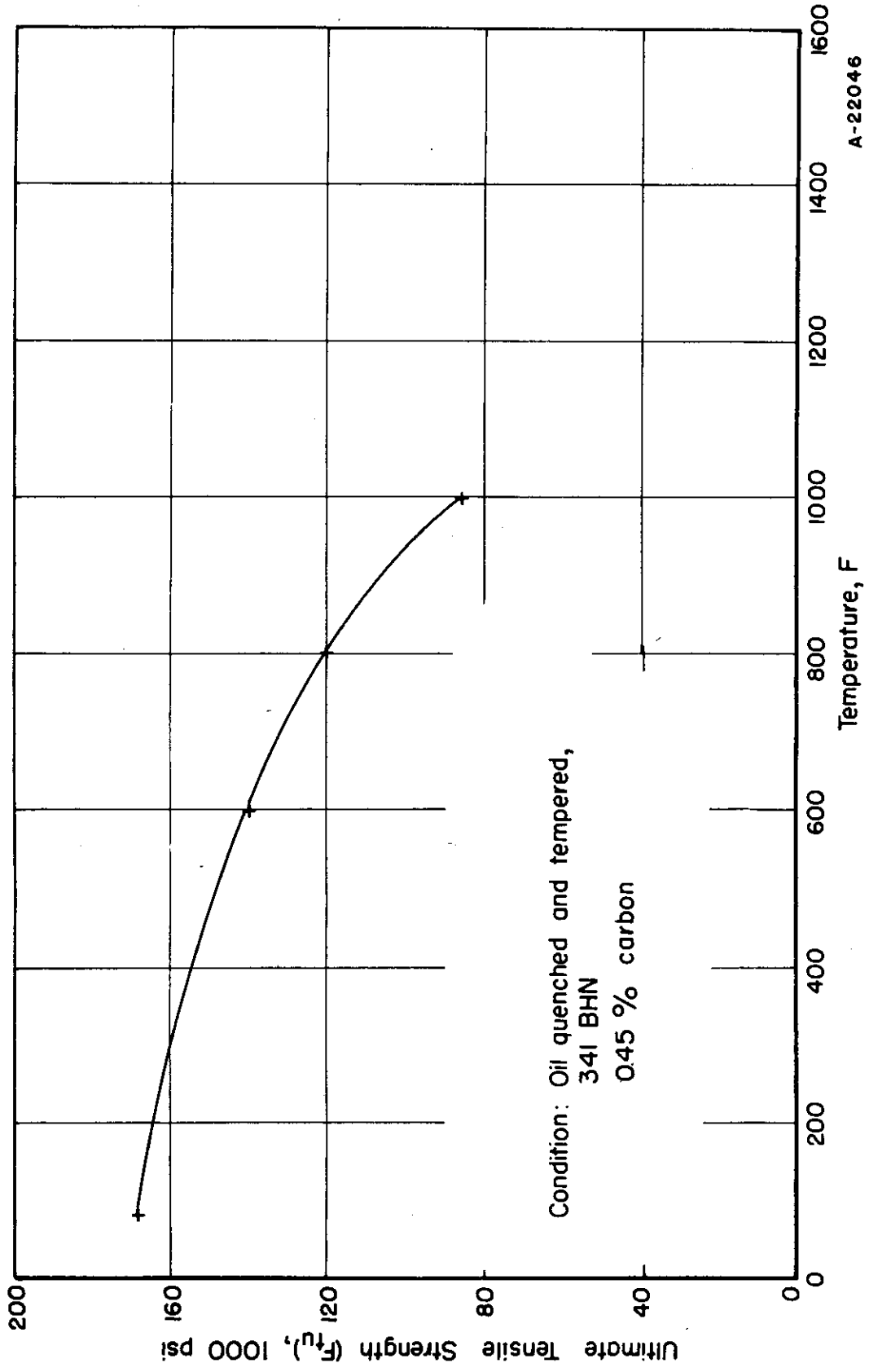

FIGURE 97. TENSILE STRENGTH (F_{tu}) OF 17-22A ALLOY STEEL (QUENCHED AND TEMPERED) AT ELEVATED TEMPERATURE

Ref. 73.

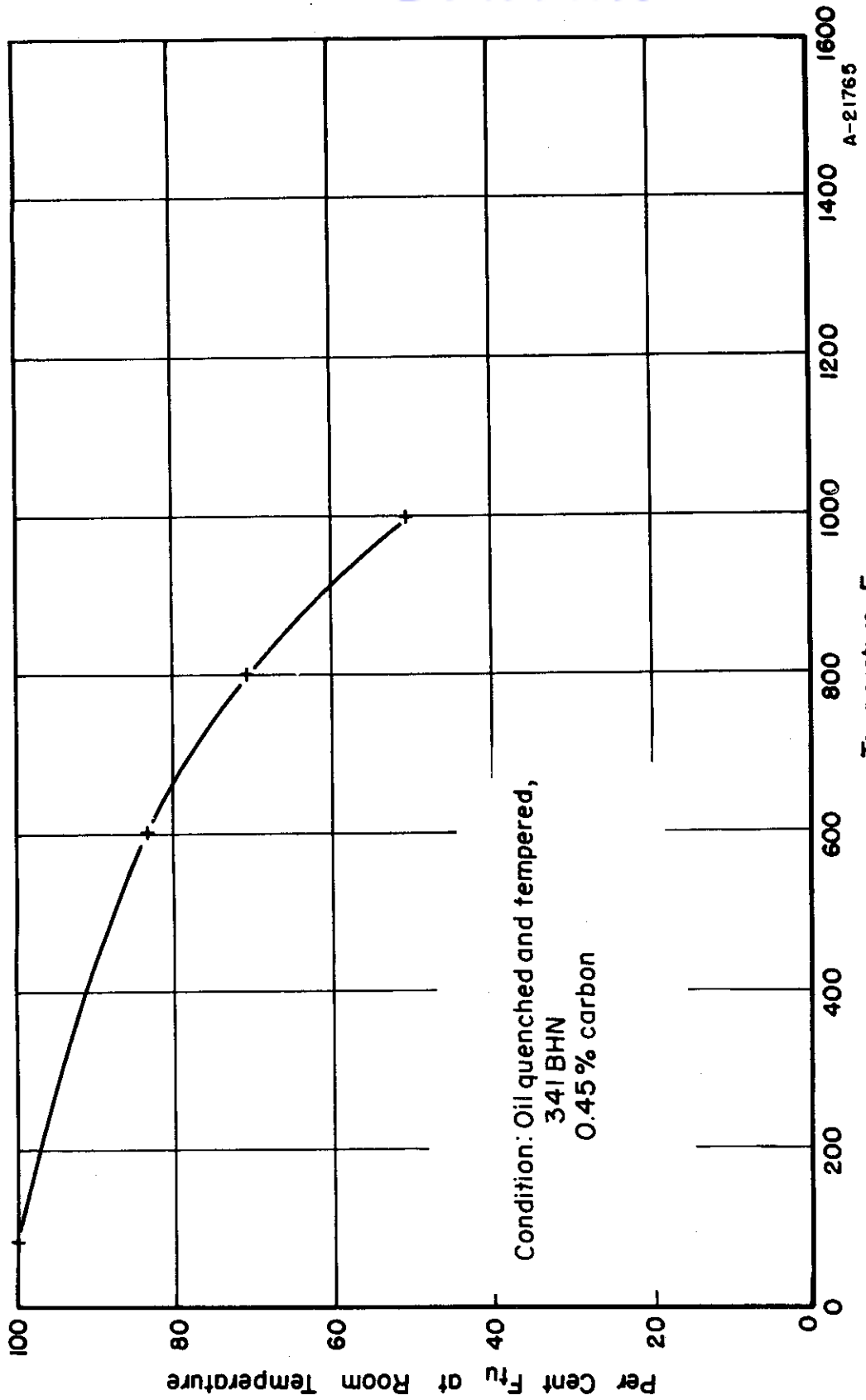

FIGURE 98. DESIGN CURVE FOR TENSILE STRENGTH (F_{tu}) OF 17-22A ALLOY STEEL (QUENCHED AND TEMPERED) AT ELEVATED TEMPERATURE

Ref. 73.

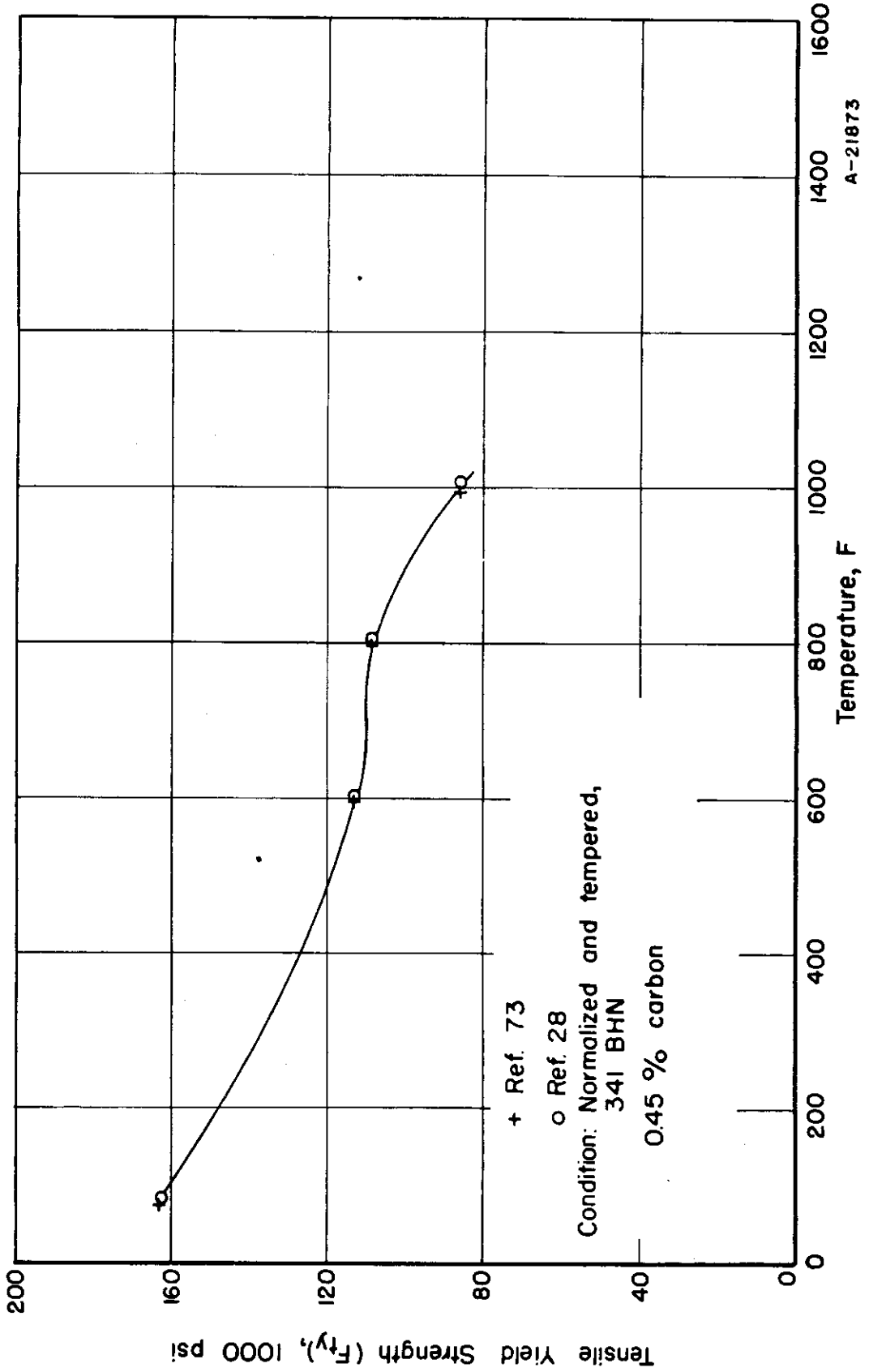

FIGURE 99. TENSILE YIELD STRENGTH (F_{ty}) OF 17-22A ALLOY STEEL (NORMALIZED AND TEMPERED) AT ELEVATED TEMPERATURE

Ref. 73, 28.

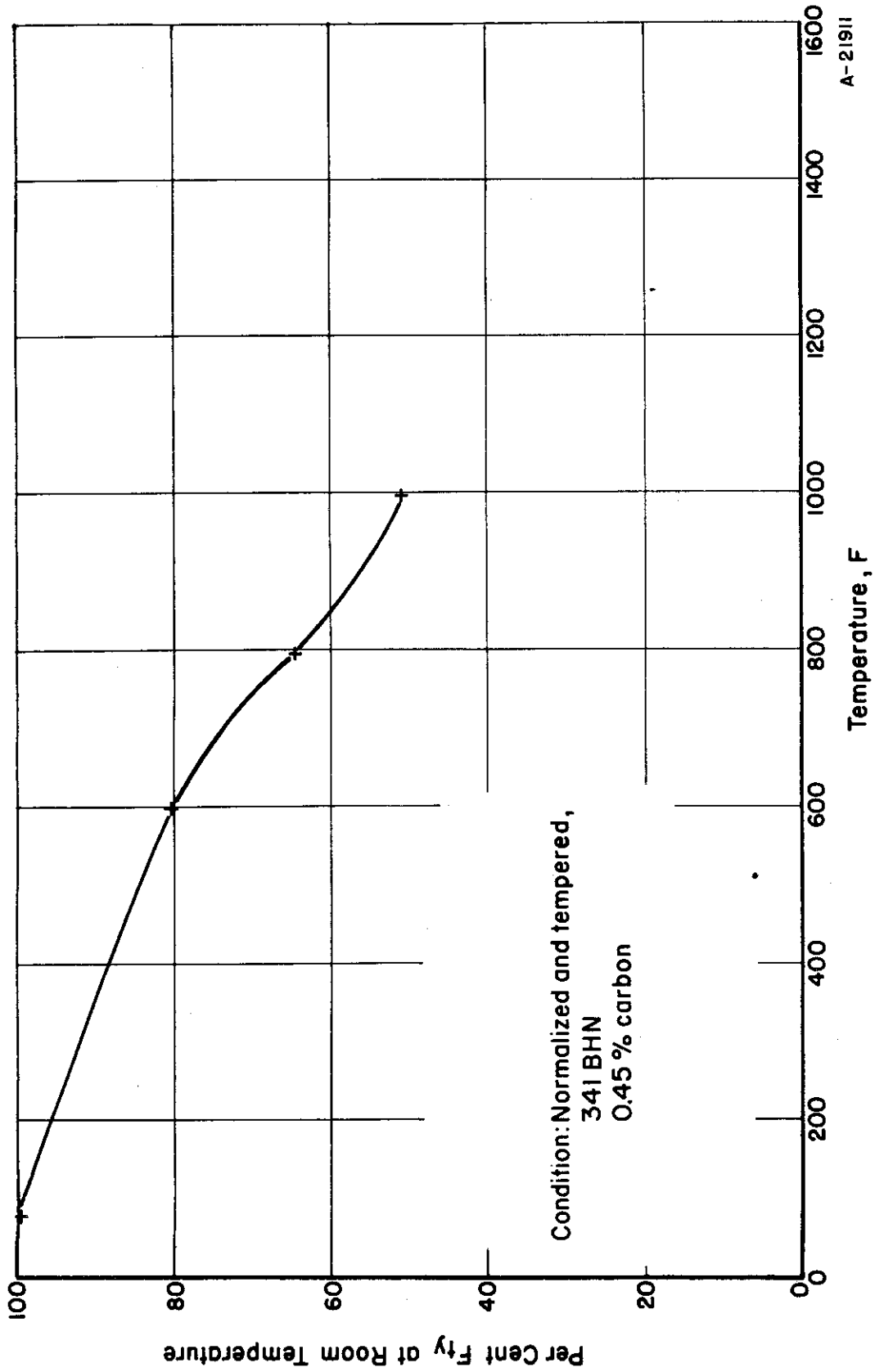

FIGURE 100. DESIGN CURVE FOR TENSILE YIELD STRENGTH (F_{ty}) OF 17-22A ALLOY STEEL (NORMALIZED AND TEMPERED) AT ELEVATED TEMPERATURE

Ref. 73, 28.

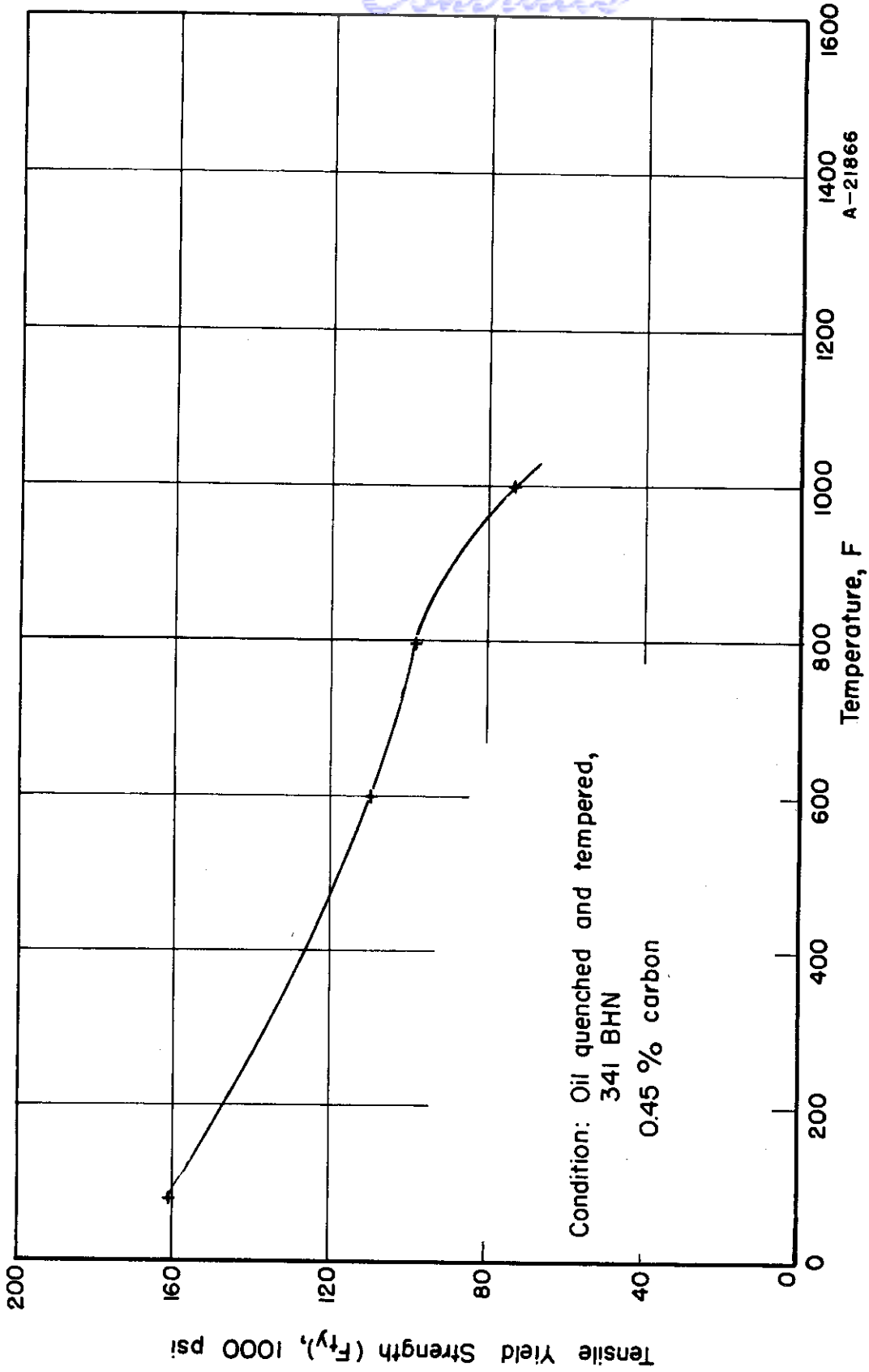

FIGURE 101. TENSILE YIELD STRENGTH (F_{ty}) OF 17-22A ALLOY STEEL (QUENCHED AND TEMPERED) AT ELEVATED TEMPERATURE

Ref. 73.

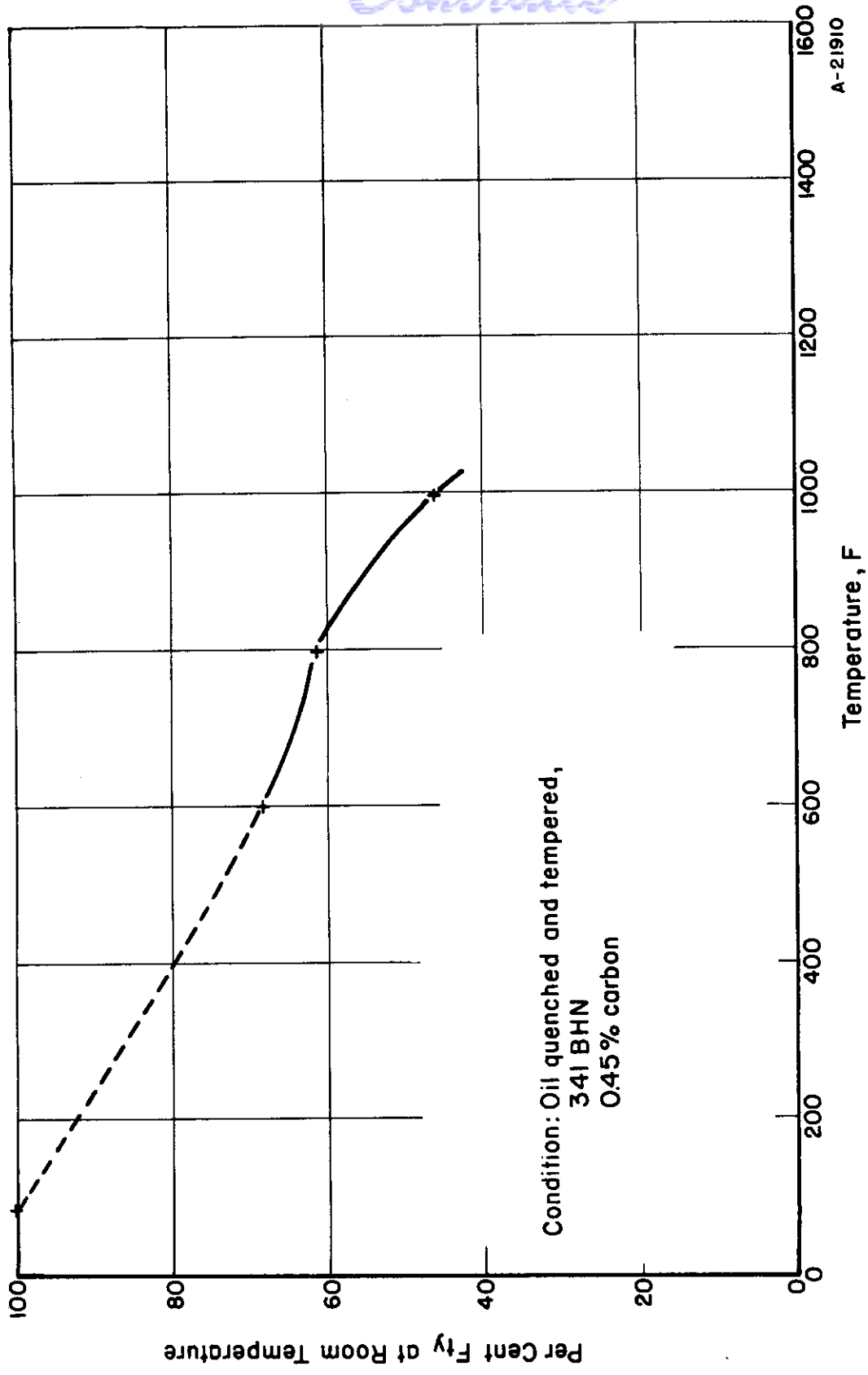

FIGURE 102. DESIGN CURVE FOR TENSILE YIELD STRENGTH (F_{ty}) OF 17-22A ALLOY STEEL (QUENCHED AND TEMPERED) AT ELEVATED TEMPERATURE

Ref. 73.

APPENDIX I

MATERIAL COMPARISON CURVES

For convenience, the following curves have been plotted to show the relative strengths of the various alloys discussed in this report.

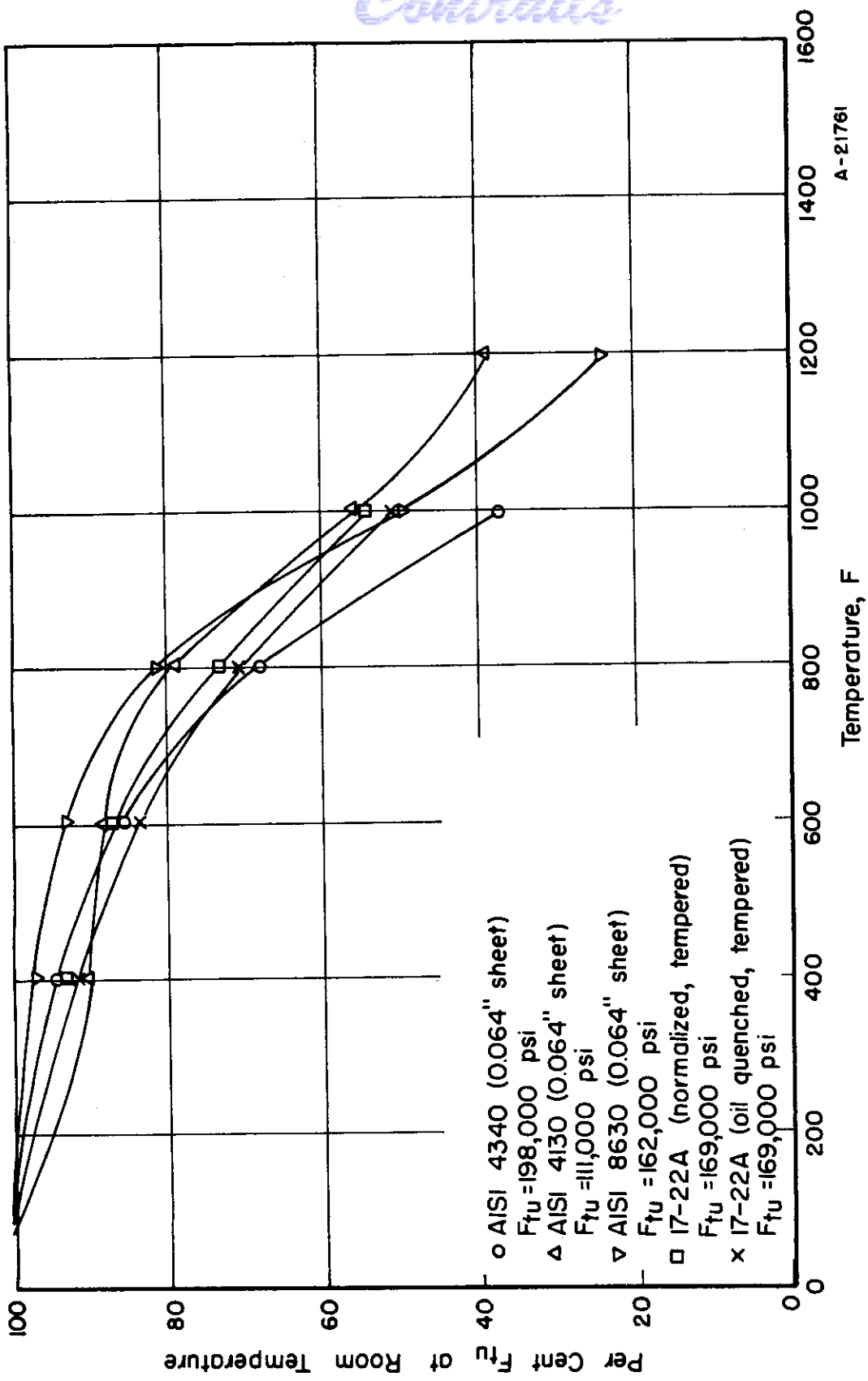

FIGURE 103. COMPARISON OF TENSILE STRENGTHS (F_{tu}) OF MEDIUM ALLOY STEELS AT ELEVATED TEMPERATURE

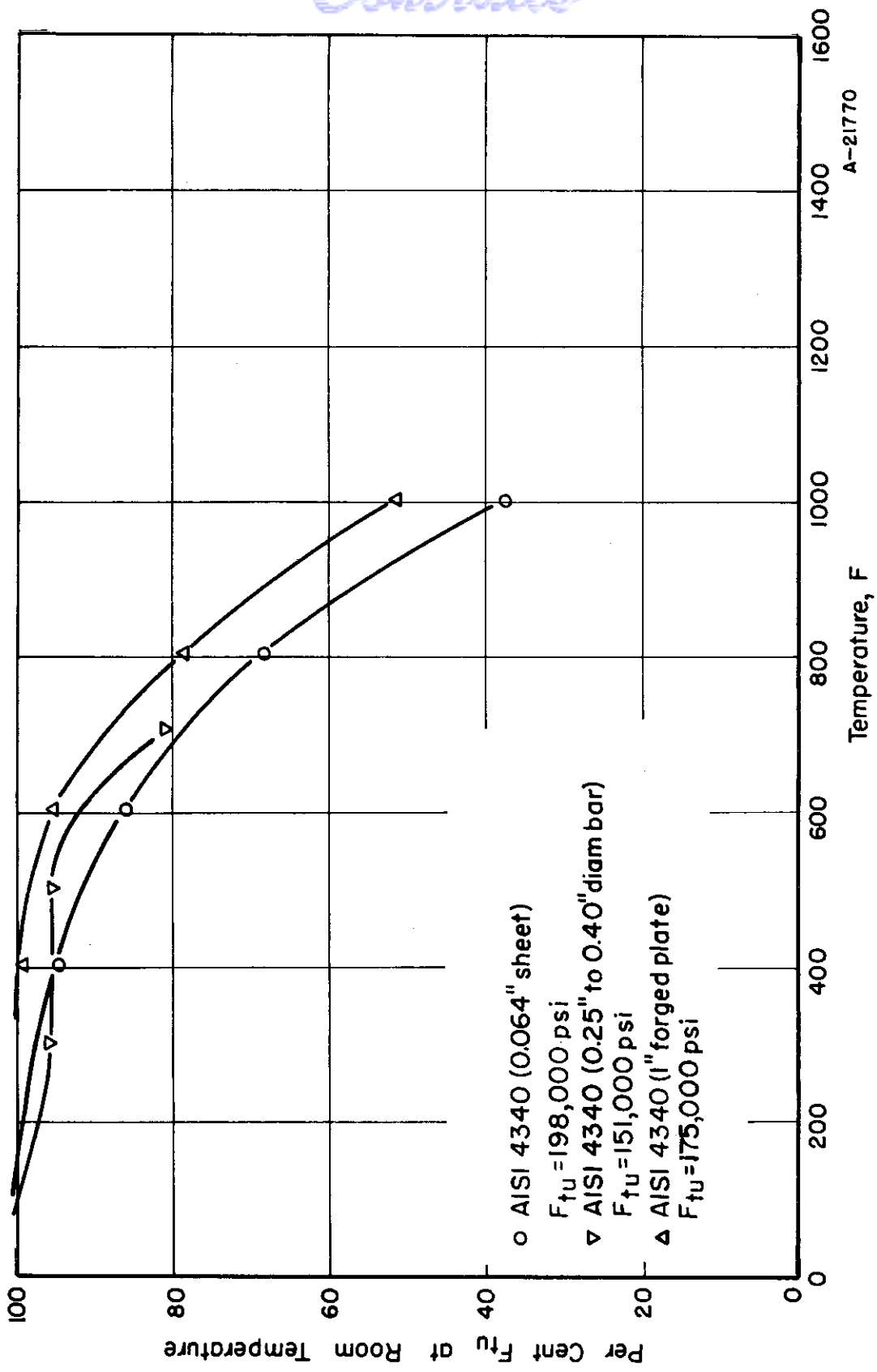

FIGURE 104. COMPARISON OF TENSILE STRENGTHS (F_{tu}) OF AISI 4340 ALLOY STEEL AT ELEVATED TEMPERATURE

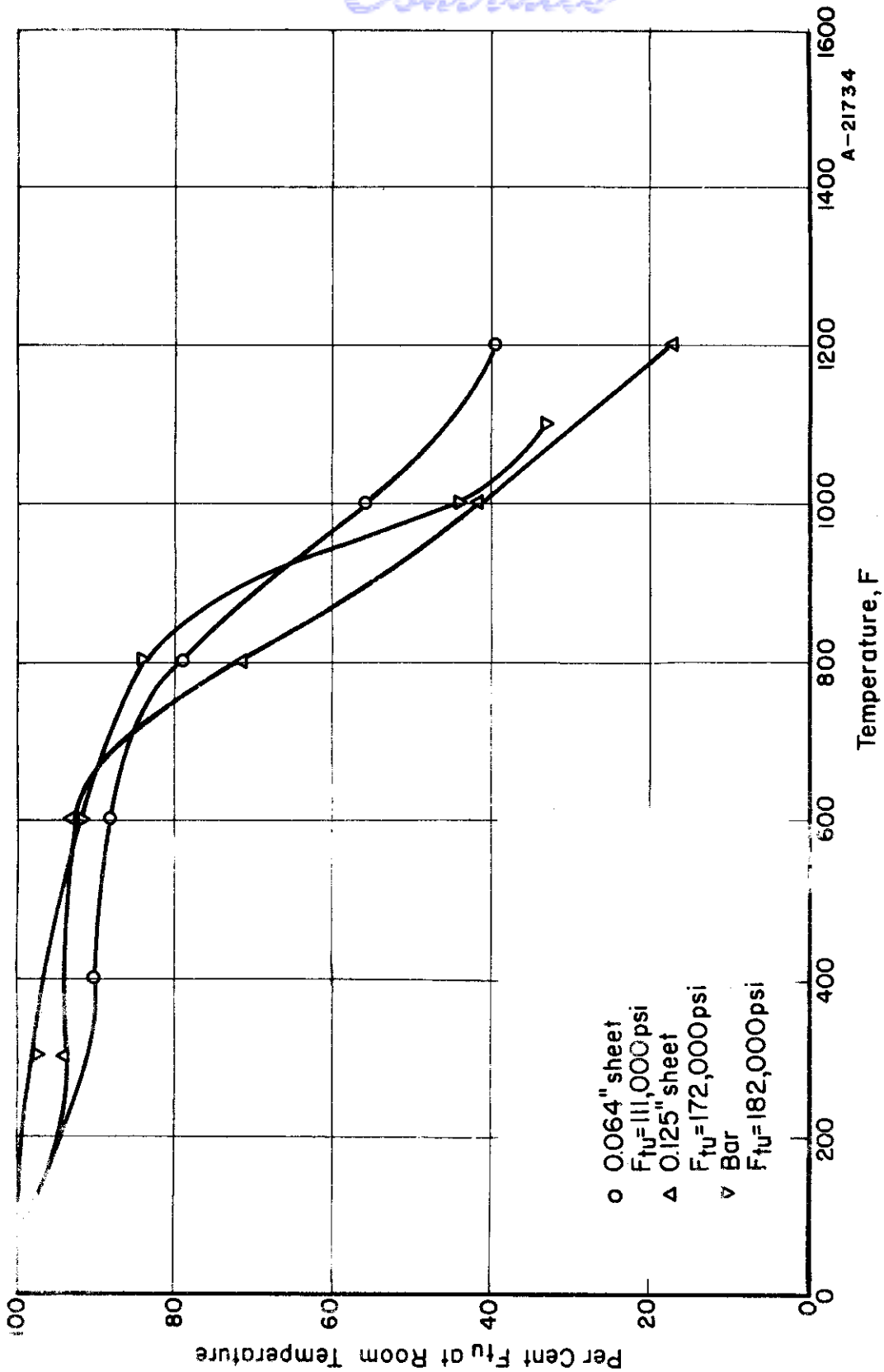

FIGURE [illegible]. COMPARISON OF TENSILE STRENGTHS (F_{tu}) OF AISI 4130 ALLOY STEEL AT ELEVATED TEMPERATURE

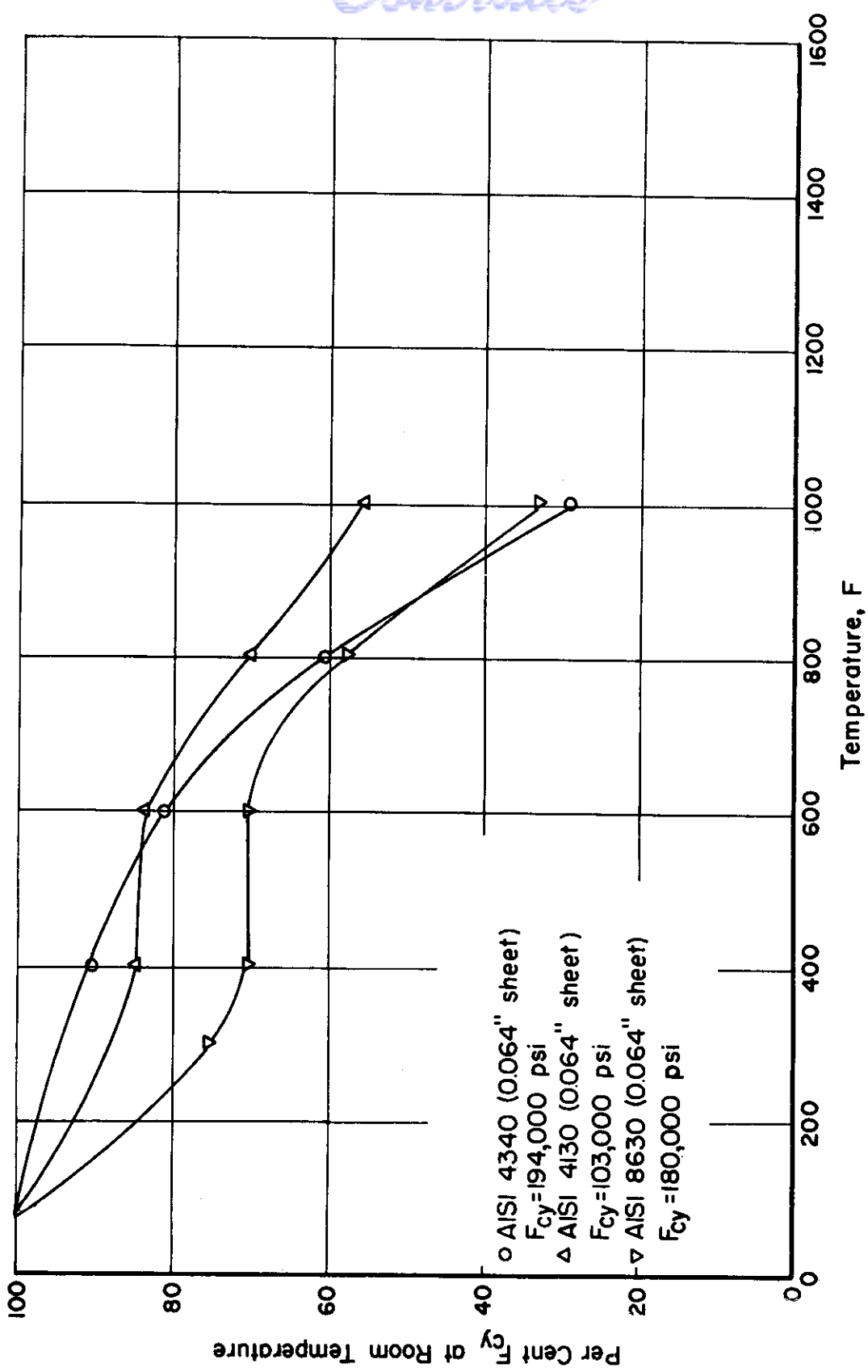

FIGURE 106. COMPARISON OF COMPRESSIVE YIELD STRENGTHS (F_{cy}) OF MEDIUM ALLOY STEELS AT ELEVATED TEMPERATURE

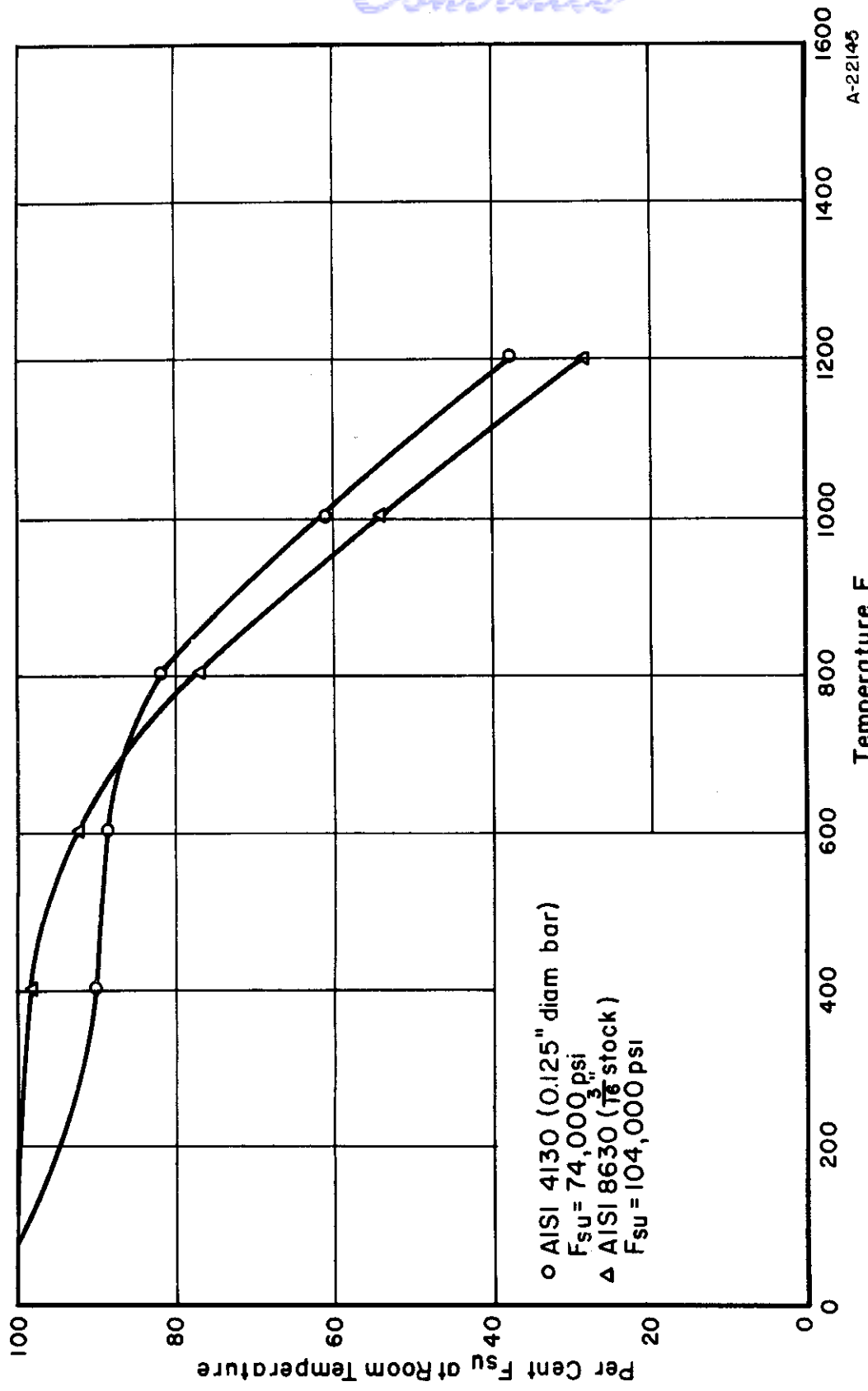

FIGURE 107. COMPARISON OF SHEAR STRENGTHS (F_{su}) OF MEDIUM ALLOY STEELS AT ELEVATED TEMPERATURE

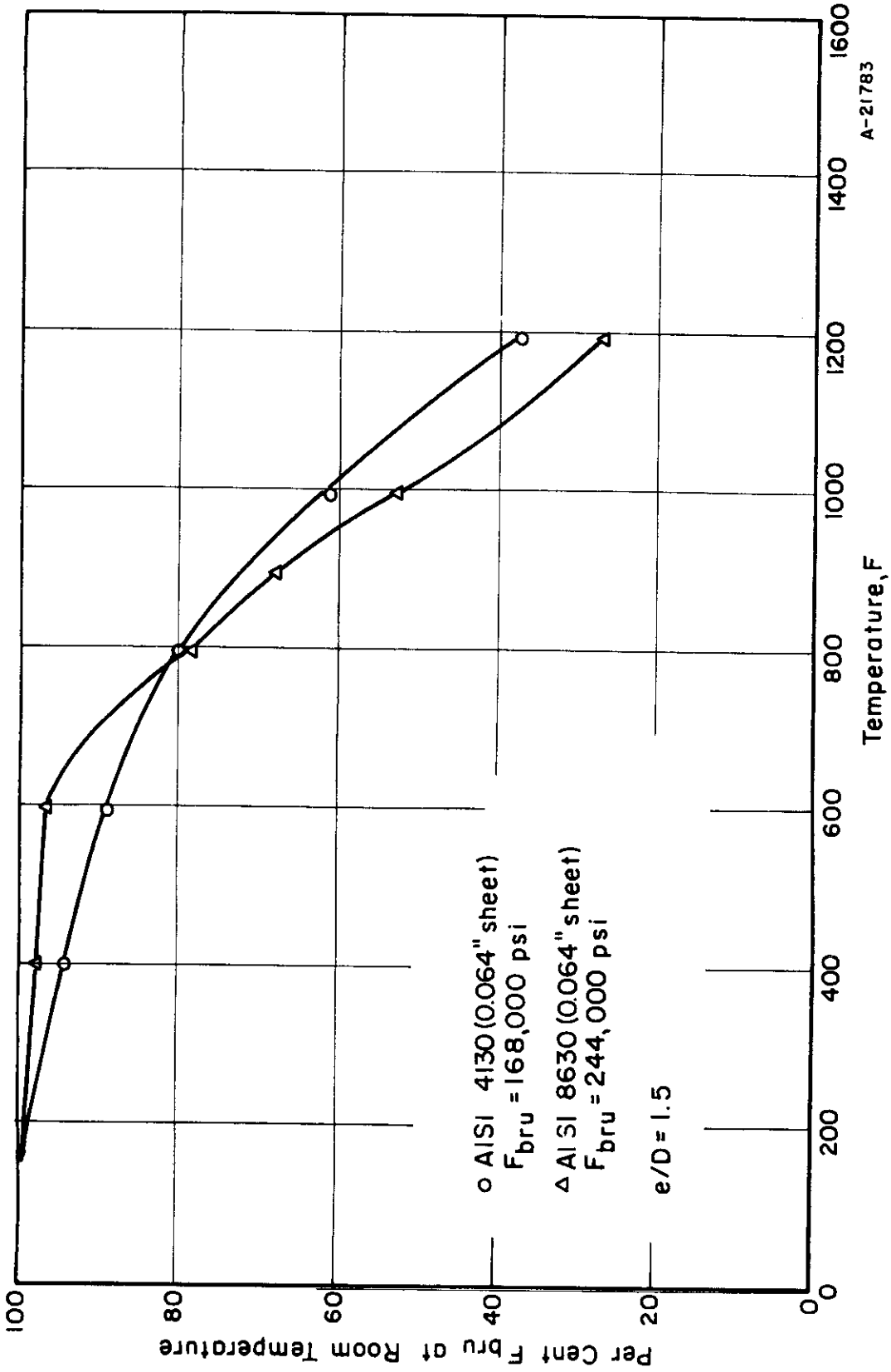

FIGURE 108. COMPARISON OF BEARING STRENGTHS (F_{bru}) OF MEDIUM ALLOY STEELS AT ELEVATED TEMPERATURE