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THE EFFECT OF GRAIN SIZE AND STRUCTURAL VARIABLES ON THE STABILIZATION OF TITANIUM ALLOYS

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FOREWORD

This report was prepared by Battelle Memorial Institute under USAF Contract No. AF 33(616)-412. This contract was initiated under Project No. 7351, "Metallic Materials", Task No. 73510, "Titanium Metals and Alloys", formerly RDO No. 615-11, "Titanium Metals and Alloys", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Lt. D. Wruck acting as project engineer.

This report covers period of work from September, 1954, to June, 1955.

ABSTRACT

Studies have been made on the effects of alloy composition and heat treatment on the thermal stability of titanium alloys. Additions of molybdenum increase thermal stability of an alpha-beta alloy, whereas chromium decreases stability. Eutectoid decomposition products were observed in the microstructures of a Ti-5Cr alloy after 200-hour aging at 800 or 1000 F. Oxygen additives increase strength and lower ductility, without a pronounced effect on thermal stability.

Heat treatments to produce a thermally stable condition are most effective when the alloy has an acicular-type structure. This is most effectively accomplished by starting the stabilizing heat treatment in the beta field, although some improvement was observed when the alloy was originally worked in the beta field and stabilized in the alpha-beta.

Exposure to a stress of 25,000 psi during aging at 600 F did not affect thermal stability.

Stress-rupture tests did not indicate a strain-aging process in the conditions tested.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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THE EFFECT OF GRAIN SIZE AND STRUCTURAL VARIABLES ON THE STABILIZATION OF TITANIUM ALLOYS

INTRODUCTION

This report is a Summary Report on a study of the effect of grain size and structural variables on the stability of titanium alloys. It covers the period from September 1, 1954, to June 1, 1955.

The object of this research was to study the factors which affect the stabilization of titanium alloys. In this report, the thermal stability of an alloy is considered as the ability to maintain an initial set of mechanical properties during exposure at elevated temperatures. Stabilization is the process involved in approaching a condition of thermal stability. Thus, the evaluation of thermal stability is a means of determining the effectiveness of the stabilizing treatments. In this work, the evaluation of thermal stability was made by hardness, bend, and tensile tests on specimens before and after exposure at elevated temperatures. These data are presented graphically to supplement the text of the report. Complete tabular data are included in the Appendix.

EXPERIMENTAL PROCEDURES

Preparation of Alloys

Melting Procedures

Twelve 275-gram ingots were prepared for use in the study of compositional effects on thermal stability. Duplicate ingots were made at three basic alloy levels, Ti-5Cr, Ti-5Mo, and Ti-2.5Cr-2.5Mo. In addition, duplicate ingots also were prepared from titanium melting stock containing an addition of 0.1 per cent oxygen. The oxygen additions were made to the sponge-titanium melting stock in a Sieverts-type apparatus. Each ingot was melted three times to insure homogeneity.

Stabilizing treatments were studied with Ti-2.5Cr-2.5Mo and Ti-5.0Cr-5.0Mo alloys prepared as 6-pound ingots. These ingots were arc-melted, fabricated to 60-mil sheet, descaled, and sheared into melting stock for the second melt. Examination of microstructures did not reveal any evidence of segregation in these alloys.

A part of the initial study on effects of stabilization treatments on thermal stability was made by using material available from previous work. This alloy (Ti-2.5Cr-2.5Mo) originally had been prepared in the form of 3/4-inch-diameter rod stock.

Fabrication

Fabrication temperature is an important factor in determining the final microstructure in an alpha-beta titanium alloy. Thus, the alloys to be used in the stabilization program were fabricated both in the beta and alpha-beta fields. Also, the duplicate alloys to be used in the composition program were fabricated both in the alpha-beta and beta fields.

All the ingots were forged at 1600 to 1700 F. Alloys were fabricated in the beta field by rolling or swaging at 1600 F, and in the alpha-beta field by rolling or swaging at 1300 to 1400 F. Following fabrication, all the alloys were cooled in air to room temperature.

Heat Treatments

The test-specimen blanks were heat treated in potentiometer-controlled electric resistance furnaces. Specimens annealed at temperatures above 750 C were encapsulated in Vycor under a partial pressure of argon to prevent contamination; short-time annealing at lower temperatures was done in air.

The 200-hour stability checks were made in air, with the exception of the 1000 F treatments for which the specimens were encapsulated. The specimens given the 200-hour stability check at 600 F under stress were placed in a dead-weight loading rack that was fitted into a forced-air furnace. Tensile-test specimens were given this treatment before cutting the reduced section or notch. The stress level used for this exposure (25,000 psi) was estimated at 50 per cent of the 200-hour rupture life as determined by using the Larson-Miller equation and data from an 800 F test. No appreciable strain was observed as a result of this exposure.

Mechanical Testing

Bend Testing

Duplicate bend tests were conducted at room temperature. The specimens used were approximately 1-1/2 inches long by 3/8 inch wide, and about 40 mils thick. The specimens were prepared for testing by grinding the faces through 400 grit paper. The specimens were tested by bending over dies of progressively decreasing radii through an angle of 75 degrees. Test results are reported as T units, obtained by dividing the radius of the last good die (immediately preceding a visible crack) by the thickness of the specimen.

Tensile Testing

Test specimens were machined from sections of 1/4-inch-diameter rod after heat treatment. Specifications for the unnotched and notched specimens and general testing procedures have been presented in a previous report*. Testing was done on standard Baldwin-Southwark universal testing machines at a uniform crosshead speed of 0.005 inch per minute. Strain on the unnotched specimens was measured with electric resistance gages (SR4 Type A-7) to about 1 per cent strain; a lever extensometer was used from 1 per cent strain to maximum load.

The notched specimens also were tested at a uniform crosshead speed of 0.005 inch per minute. Tests at other than room temperature were made by immersing the specimen in the cooling or heating medium. The initial and final root diameters were measured by tracing the profiles on a 50X Shadowgraph.

COMPOSITION PROGRAM

This study was made to determine the effects of alloy composition on thermal stability and rate of stabilization. Two separate investigations were made; alloys of the same nominal composition and identical methods of evaluation were used. In the first study, the alloys were fabricated and stabilized in the alpha-beta field, so the final microstructures were composed of equiaxed alpha-beta grains. The second series of alloys was fabricated in the beta field, and the stabilizing heat treatment also was initiated in the beta field. This provided a series of specimens in which the microstructures were of the transformed or acicular alpha-beta type.

Three basic alpha-beta-type alloys were prepared for this work. These included two binary alloys, one containing a beta-eutectoid element (Ti-5Cr) and one containing a beta-isomorphous element (Ti-5Mo). In addition, a ternary alloy containing both beta-eutectoid and beta-isomorphous additives (Ti-2.5Cr-2.5Mo) was prepared.

These three basic alloys were melted from both untreated sponge titanium and titanium to which 0.1 per cent oxygen had been added. Thus,

* Holden, F. C., Ogden, H. R., and Jaffee, R. I., "The Effect of Grain Size on the Mechanical Properties of Titanium and Its Alloys", WADC Technical Report 54-487, Contract No. AF 33(616)-412 (August, 1954).

a comparison of the three basic alloys at two levels of interstitial content could be made.

The thermal stability was checked by comparing the properties of as-stabilized specimens with those of specimens exposed 200 hours at 600, 800, and 1000 F (unstressed), and at 600 F under an applied stress of 25, 000 psi. The stabilizing treatments were evaluated by testing duplicate unnotched tensile specimens, notched tensile specimens over a temperature range from -196 C to 200 C, and notched, incrementally loaded stress-rupture specimens at room temperature.

Results of these tests are presented graphically in Figures 1, 3, and 4. Complete tabular data are included in the Appendix.

The effect of alloy composition on room-temperature tensile properties of specimens as stabilized and after aging at 800 F is shown in Figure 1. Tensile strengths before and after the 800 F stability check diverge as the quantity of chromium in the alloy is increased. For the binary Ti-5Mo alloy, tensile strength is virtually unchanged after the aging treatment, even in the alloy containing 0. 1 per cent oxygen. Tensile ductility, measured by reduction in area, also is dependent on alloy content. Ductility is lowered by the 800 F aging treatment, with the greatest loss of ductility occurring for the Ti-5Cr alloy.

Examination of microstructures reveals that in the Ti-5Cr alloy transformation of the beta to alpha plus $TiCr_2$ takes place during the 200-hour aging treatment at 800 or 1000 F. The transformation to alpha plus $TiCr_2$ was not observed in the microstructures of specimens aged at 600 F, nor was it apparent in any of the Ti-2. 5Cr-2. 5Mo alloy specimens. Typical microstructures of the equiaxed alpha-beta specimens are shown in Figure 2.

The thermal stability of these alloys also is shown by the notched tensile properties, as shown in Figures 3 and 4. Tensile strength and ductility of the Ti-5Mo alloys are affected only slightly by the 200-hour aging treatments, whereas those for the Ti-5Cr alloys are lowered considerably. The loss of strength and ductility is particularly marked at low testing temperatures. The behavior of the Ti-2. 5Cr-2. 5Mo alloy is intermediate between that of the Ti-5Cr and Ti-5Mo alloys.

From these data, it may be concluded that the alloy containing only an isomorphous additive (Ti-5Mo) can be effectively stabilized by proper heat treatment. Because no eutectoid decomposition is involved, any thermal instability must be associated with the transformation of the beta phase to omega or alpha. The data obtained show that, for the stability checks involved in this program, both stabilizing treatments used are effective for this alloy.

The Ti-2. 5Cr-2. 5Mo alloy also shows very good thermal stability. Tensile strengths are, in general, only slightly changed after the 200-hour

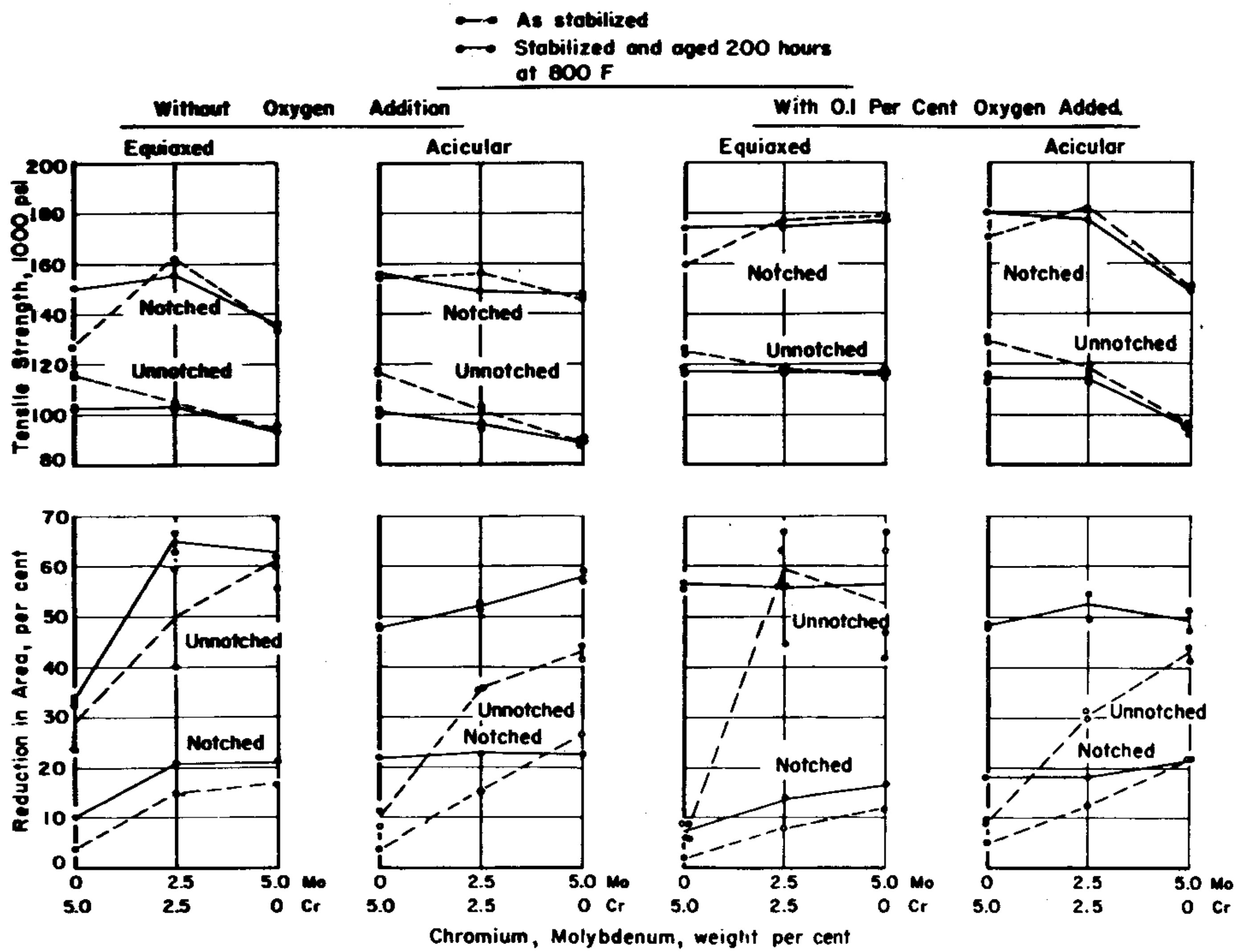

FIGURE I. EFFECT OF COMPOSITION ON TENSILE PROPERTIES OF ALPHA-BETA TITANIUM ALLOYS
Specimens in equiaxed and acicular conditions are from different ingots of same nominal composition.

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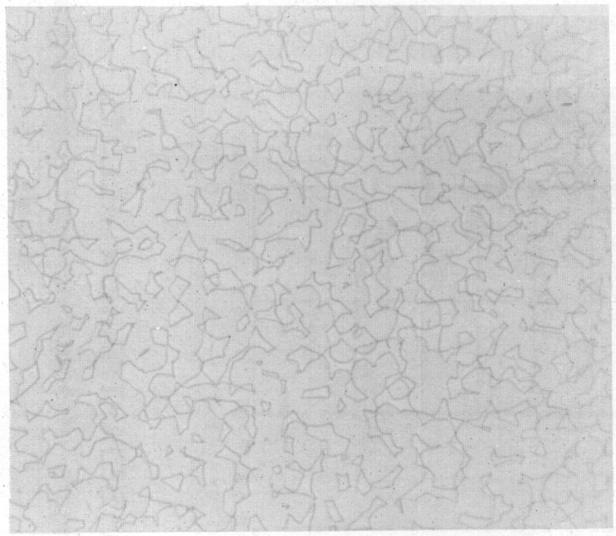
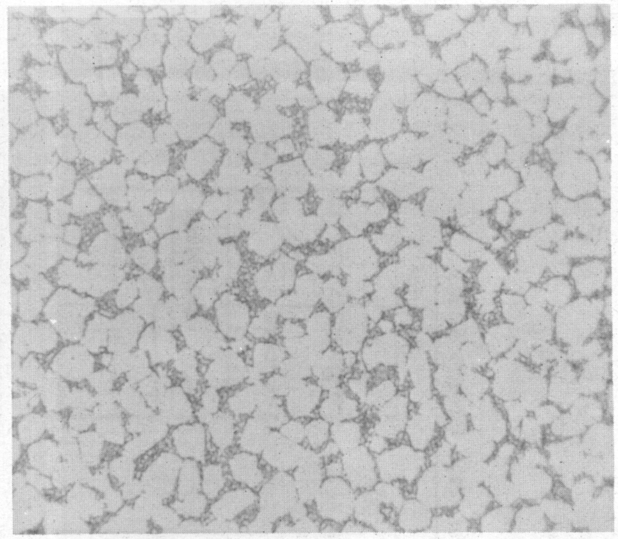


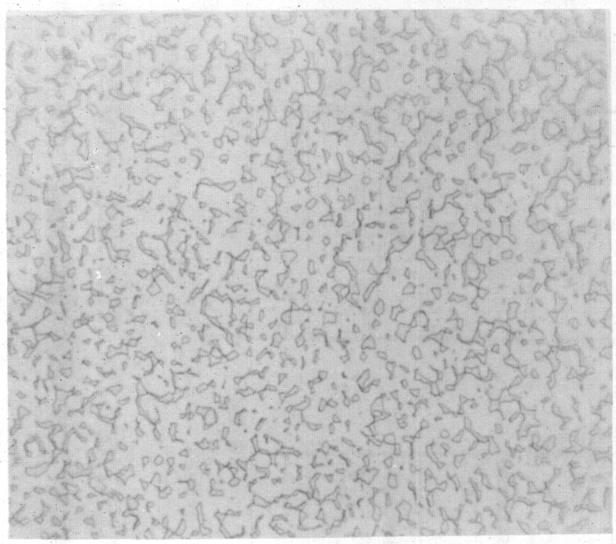
1500X N18893

a. Ti-5Cr Alloy, As Heat Treated



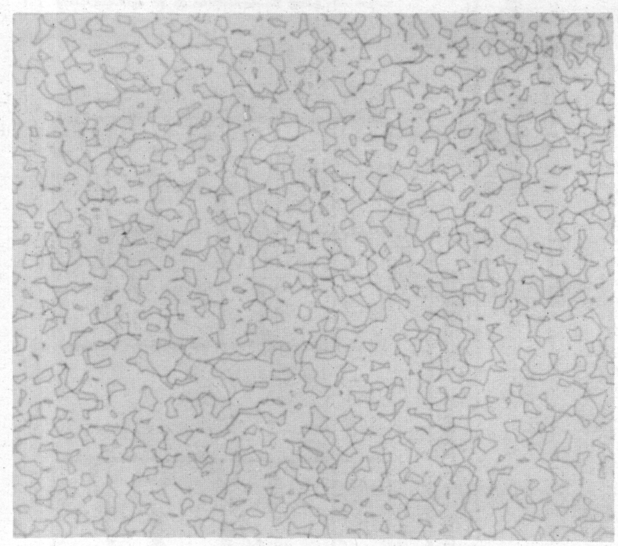
1500X N18896

b. Ti-5Cr Alloy, As Heat Treated and Aged 200 Hours at 1000 F



1500X N18897

c. Ti-5Mo Alloy, As Heat Treated and Aged 200 Hours at 1000 F



1500X N18898

d. Ti-2.5Cr-2.5Mo Alloy, As Heat Treated and Aged 200 Hours at 1000 F

Initial heat treatment: Annealed 1 hour at 750 C; furnace cooled to 700 C, held 1 hour; furnace cooled to 650 C, held 2 hours; furnace cooled to 600 C, held 2 hours, and air cooled

FIGURE 2. MICROSTRUCTURES OF TITANIUM ALLOYS SHOWING EFFECTS OF AGING AT 1000 F

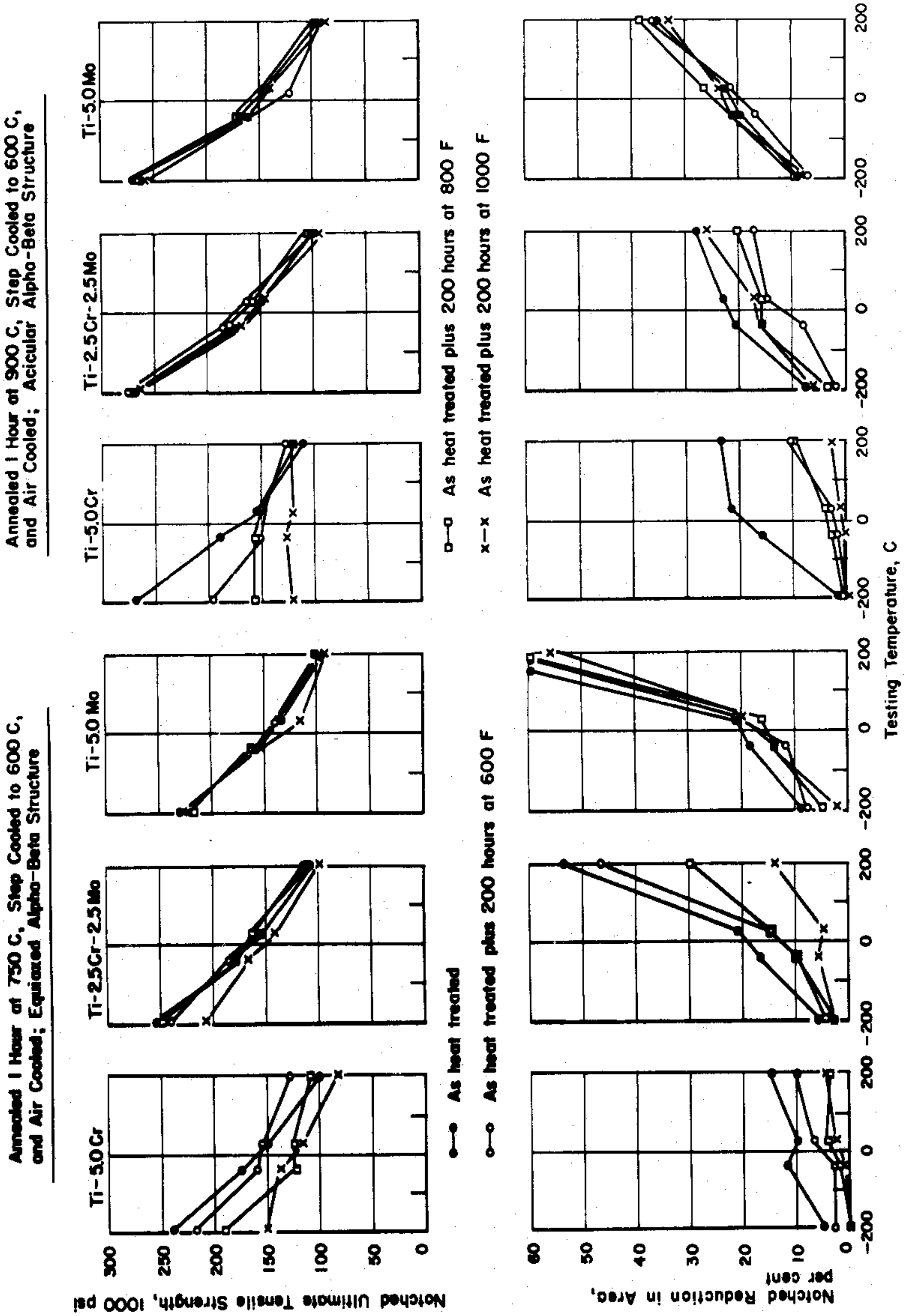


FIGURE 3. EFFECT OF TESTING TEMPERATURE ON THE NOTCHED TENSILE PROPERTIES OF TITANIUM ALLOYS

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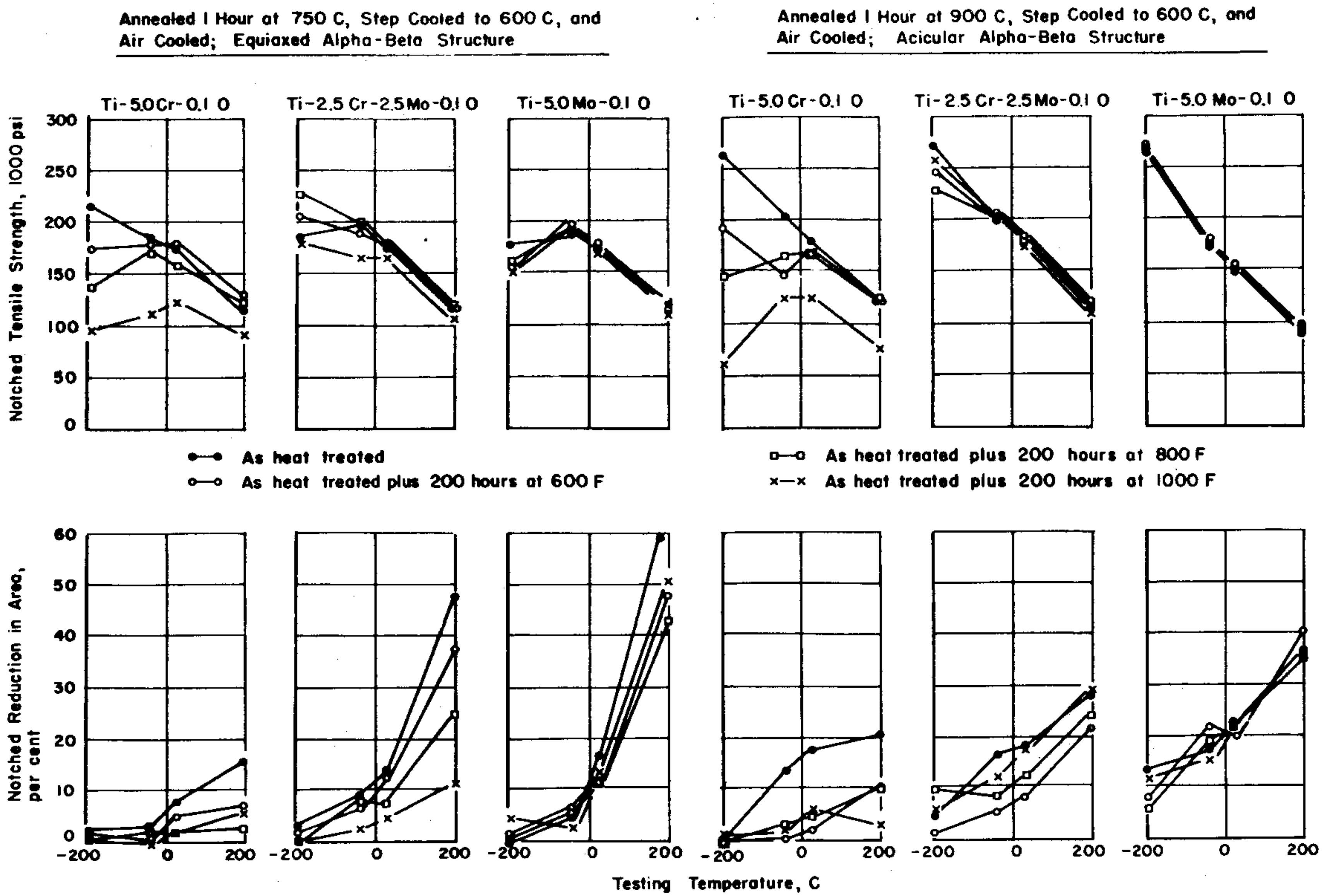

FIGURE 4. EFFECT OF TESTING TEMPERATURE ON THE NOTCHED TENSILE PROPERTIES OF TITANIUM ALLOYS CONTAINING AN OXYGEN ADDITION

A-18164

aging treatments. Tensile ductilities, however, do show that this alloy is not completely stable. An eventual loss of ductility, particularly at low testing temperatures, becomes apparent as the aging temperature is increased. The loss of ductility in this alloy may be caused by transformation of the beta phase to alpha or omega, or by the formation of eutectoid products. No apparent changes in microstructure were observed, however.

The thermal instability of the Ti-5Cr alloy is demonstrated by a loss of both tensile strength and ductility, particularly at low testing temperatures, after exposure at elevated temperature. These changes in properties probably are caused mainly by the observed formation of eutectoid products.

The alloys containing the 0.1 per cent oxygen addition are stronger and less ductile than those without the addition. Behavior of these alloys after aging is similar to that found without the oxygen addition. The loss of ductility, particularly at low temperatures, is most apparent in the specimens with equiaxed microstructures, and was observed both before and after aging.

It may be expected that oxygen (an interstitial alpha-stabilizing element) will partition to the alpha phase in an alpha-beta alloy. Thus, in the stabilized condition, the matrix beta phase in the alloys containing oxygen may be nearly free of dissolved oxygen. Because the stability of the beta phase determines the thermal stability of the alloy, this could account for the similar thermal stability of the two alloys.

STABILIZATION PROGRAM

This phase of the research was directed toward an understanding of the principles that govern the stabilization of an alpha-beta alloy. As defined earlier, stabilization is considered as the process of approaching a condition of thermal stability. Two alloys, Ti-2.5Cr-2.5Mo and Ti-5.0Cr-5.0Mo, were used in this study. The principal variables studied were, in addition to alloy composition, fabrication temperature, grain size and shape, and heat treatment. Stability was evaluated by the use of data obtained from bend tests and from notched and unnotched tensile tests. The specimens were tested in the as-stabilized condition and after aging 200 hours at 600, 800, and 1000 F (unstressed), and at 600 F under stress.

Preliminary Tests

A preliminary test program, using bend test and hardness as criteria, was carried out to determine the most promising stabilizing treatments. The data obtained from these tests are presented in the Appendix, and bend test data for the conditions selected are shown in graphical form in Figures 5 and 7. The principal observations made from these data are summarized below:

(1) The alloy containing larger quantities of beta-stabilizing additions (Ti-5.0Cr-5.0Mo) is more unstable than is the Ti-2.5Cr-2.5Mo alloy.

(2) For heat treatments initiated in the beta field, no difference was observed between beta- and alpha-beta-rolled materials.

(3) The acicular alpha-beta structure is stabilized more rapidly than is the equiaxed alpha-beta structure for a given equilibration condition. This grain-shape effect was observed in both alloys, and is considered to be an important factor in the stabilization process.

(4) The other variables studied, including beta grain size, equilibration time and temperature, or stabilizing time and temperature, have relatively little influence on the stabilization process.

Full-Scale Test Program

For the full-scale program, four heat treatments were used:

(1) Anneal 1 hour at 750 C, furnace cool to 600 C, hold 2 hours, and air cool.

(2) Anneal 1 hour at 900 C, furnace cool to 600 C, hold 2 hours, and air cool.

(3) Anneal 1 hour at 900 C, step cool* to 600 C, hold 2 hours, and air cool.

(4) Anneal 24 hours at 600 C and air cool.

Specimens given the heat treatments that are started in the alpha-beta field (1 and 4) were separated according to fabrication temperature. The specimens receiving heat treatments initiated in the beta field (2 and 3) were not separated with respect to fabrication temperature. Thus, for each alloy, a total of six combinations of fabrication temperature and heat treatment were tested. The thermal stability was evaluated from the comparison of properties obtained from specimens in the as-heat-treated condition with

* The step-cool includes a furnace cool to 750 C, hold 1 hour; furnace cool to 700 C, hold 2 hours; furnace cool to 650 C, hold 2 hours; furnace cool to 600 C.

properties obtained following 200-hour exposures at 600, 800, and 1000 F, and 600 F under stress. Tests were made on duplicate unnotched tensile-test specimens (tested at room temperature) and on notched (K_t = 3) tensile-test specimens tested at -196, -40, 25, and 200 C. Complete tabular data are included in the Appendix, and graphical illustrations are used to supplement the text.

Ti-2.5Cr-2.5Mo Alloy

It was shown in the study of effects of alloy composition that the Ti-2.5Cr-2.5Mo alloy can be heat treated to a condition of good thermal stability. This is further demonstrated by the mechanical properties, as shown in Figures 5 and 6. For all the conditions tested, tensile strength, tensile ductility, and bend ductility remain reasonably good after 200-hour exposures up to 1000 F. Bend ductility appears to be one of the more sensitive parameters in the evaluation of thermal stability. This is shown by the effect of rolling temperature in Figures 5a and 5b, in which the specimens with equiaxed structures (rolled at 1400 F) are shown to be less stable than are those with acicular structures (rolled at 1600 F). In addition, the improvement in reduction in area of the specimens with equiaxed structures is lost as the aging treatment is carried out at higher temperatures. The advantage of the acicular structures also is pointed out by comparing Figure 5a with Figures 5c and 5d. For the acicular specimens, the better equilibration obtained by slow cooling from the beta field results in very good thermal stability, as measured both by tensile and bend properties. The thermal instability of specimens given the 24-hour anneal at 600 C is pointed up by the drop in tensile strength and ductility shown in Figures 5e and 5f. Bend ductility was not measured for specimens in this condition.

Results of the notched tensile tests for the same conditions are presented in Figure 6. The relation between heat treatment and thermal stability is shown here in terms of the grouping of strength and ductility curves. Specimens initially heated into the beta field (Figures 6c and 6d) were more stable, and thus the curves are more closely grouped. The scatter in ductility values is most pronounced for the specimens fabricated and annealed in the alpha-beta field.

Ti-5.0Cr-5.0Mo Alloy

This alloy contains a total of 10 per cent beta-stabilizing additions, and the high-temperature beta phase is very unstable. The results of mechanical tests are presented in Figures 7 and 8. The behavior of these alloy specimens is generally similar to that of the Ti-2.5Cr-2.5Mo alloy, but the response to aging (degree of thermal instability) is greater. The loss of bend ductility with aging temperature is apparent for the specimens in the equiaxed condition (Figure 7a). The sharp peaks in tensile strength

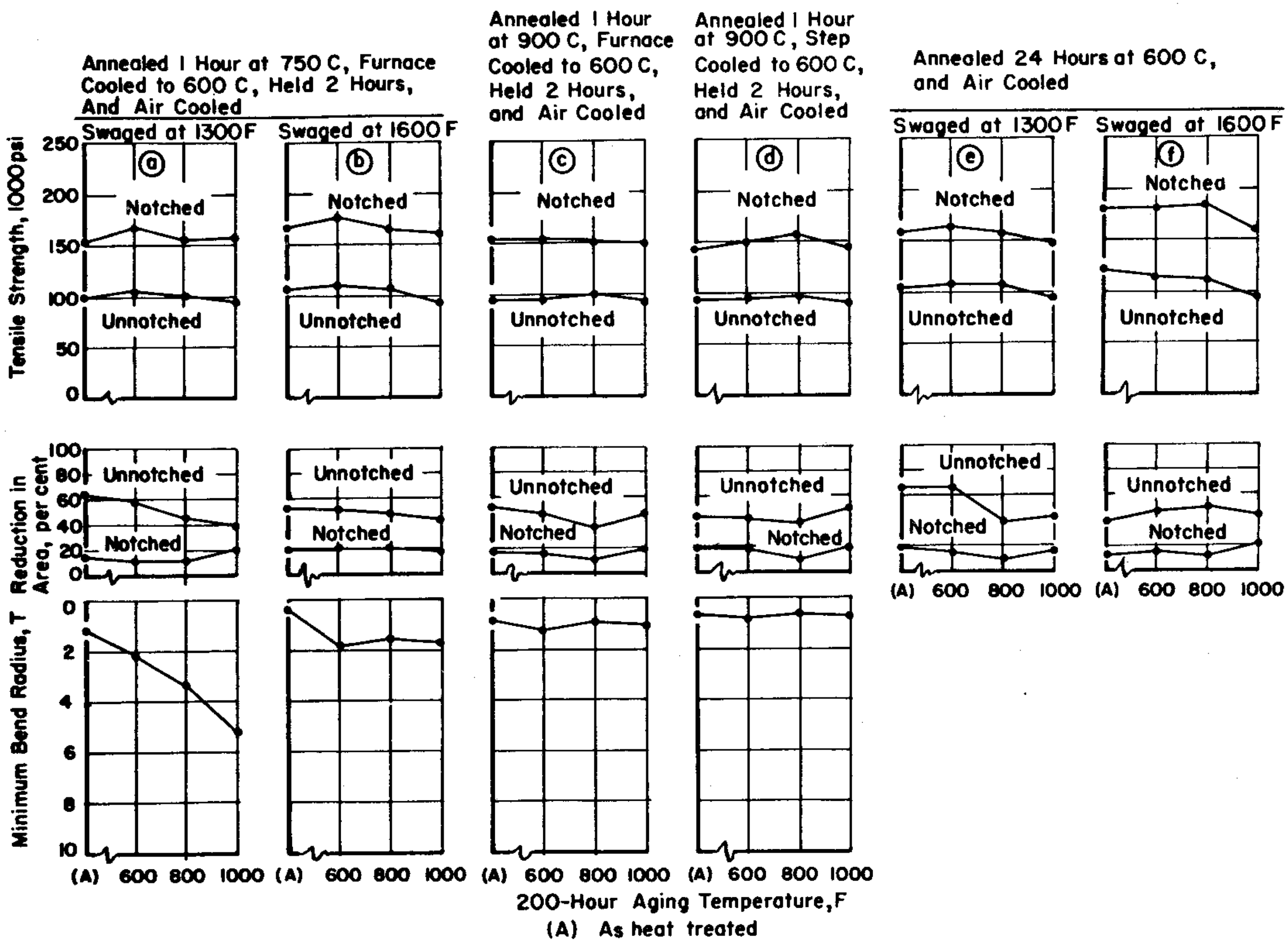

FIGURE 5. EFFECT OF FABRICATION TEMPERATURE AND STABILIZING TREATMENT ON THE MECHANICAL PROPERTIES OF A Ti-2.5Cr-2.5Mo ALLOY

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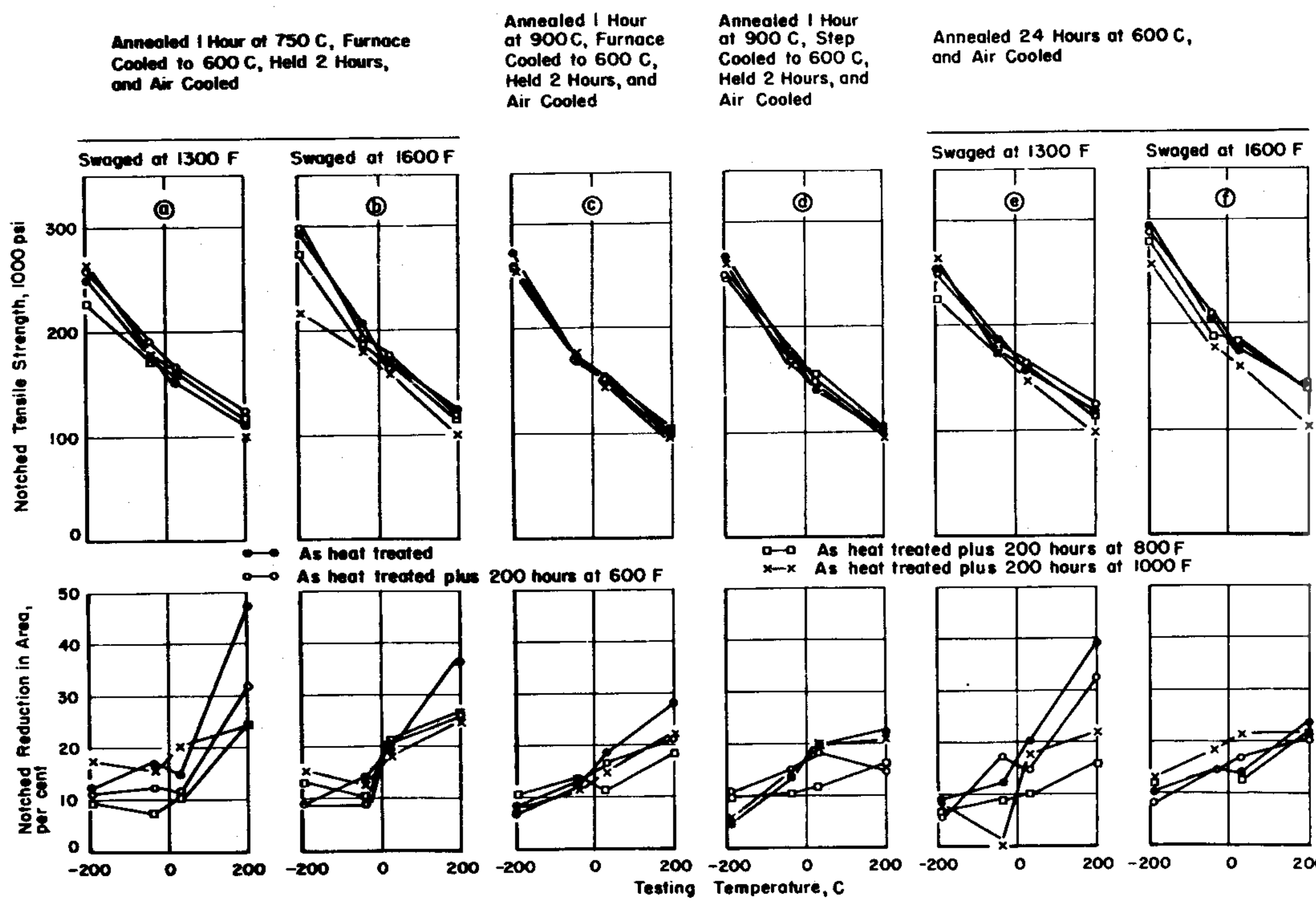

FIGURE 6. EFFECT OF TESTING TEMPERATURE ON THE NOTCHED TENSILE PROPERTIES OF A Ti-2.5 Cr-2.5 Mo ALLOY

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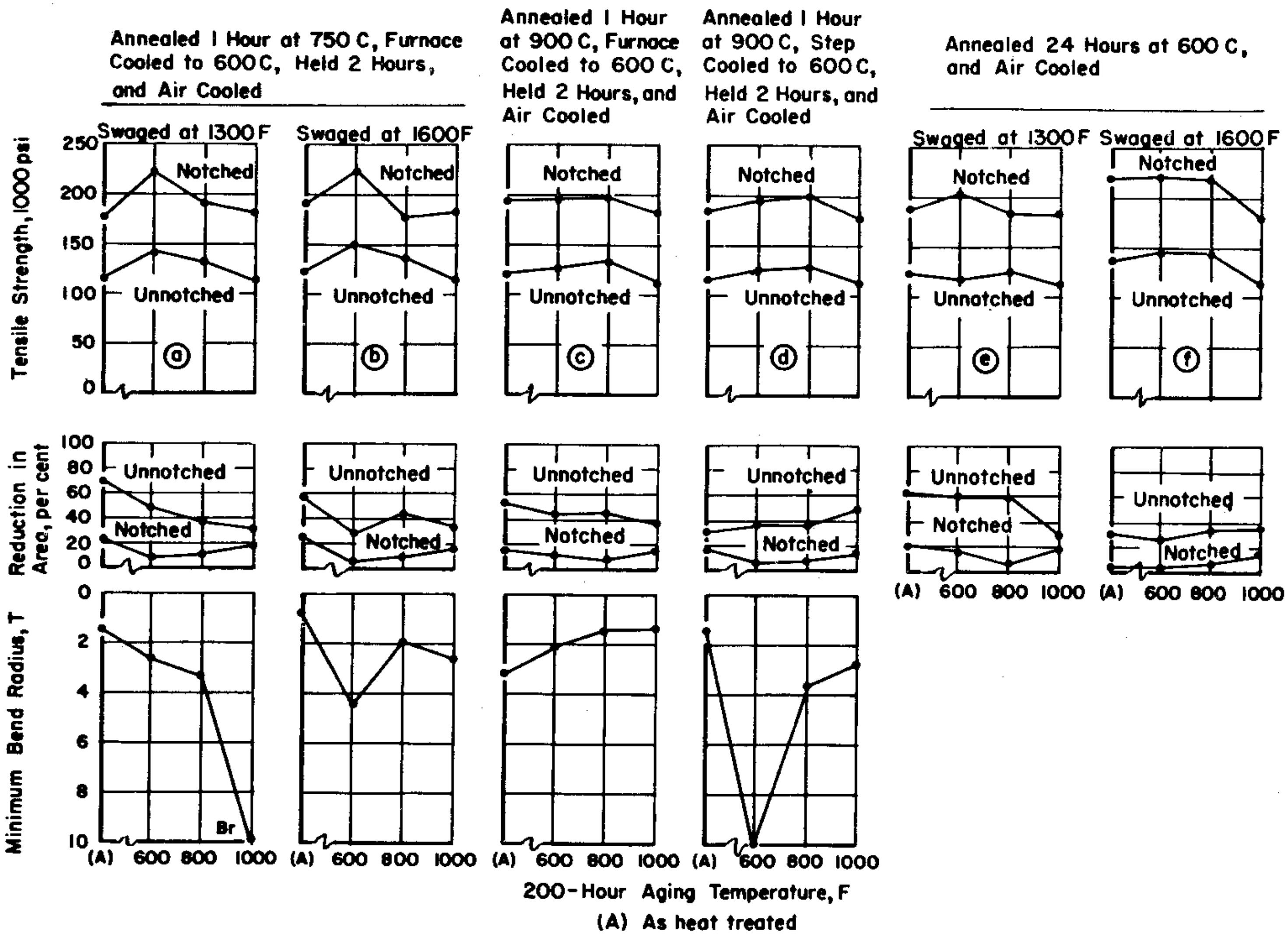

FIGURE 7. EFFECT OF FABRICATION TEMPERATURE AND STABILIZING TREATMENT ON THE MECHANICAL PROPERTIES OF A Ti-5.0Cr-5.0Mo ALLOY

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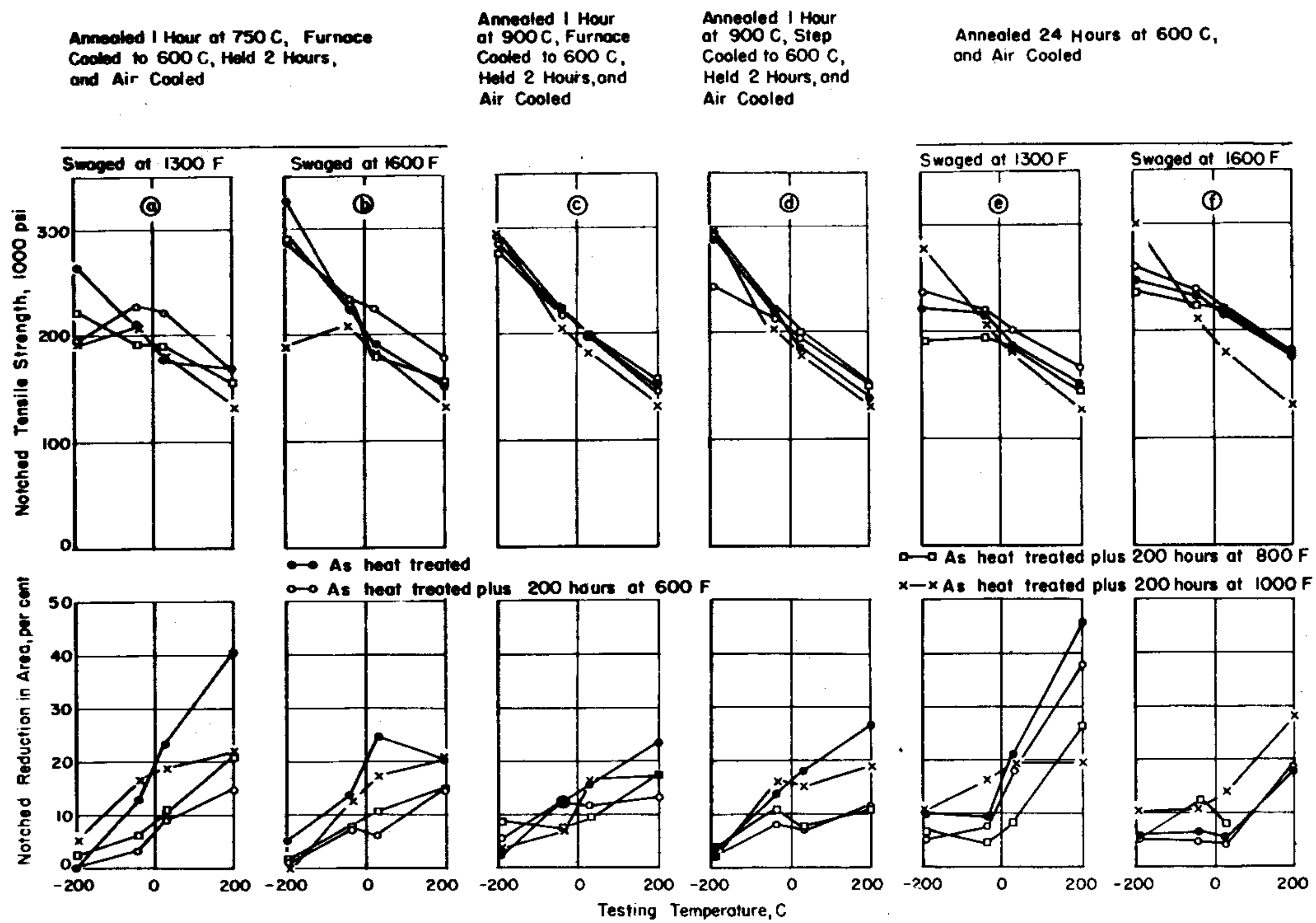

FIGURE 8. EFFECT OF TESTING TEMPERATURE ON THE NOTCHED TENSILE PROPERTIES OF A Ti-5.0 Cr-5.0Mo ALLOY

observed for specimens annealed in the alpha-beta field (Figures 7a and 7b) are not observed when the heat treatment is started in the beta field (Figures 7c and 7d). Bend ductility, except for the 600 F temperature for step-cooled specimens, is better for the specimens heat treated in the beta field. This improved stability also is shown in Figure 8 which presents notched tensile strength and ductility plotted against testing temperature. The better thermal stability, shown by the closer grouping of curves, appears in specimens initially heated into the beta field.

Effect of Exposure at 600 F Under Stress

Included in the evaluation procedures was a series of specimens aged 200 hours at 600 F under an applied stress of 25,000 psi. These tests were conducted to determine the effect, if any, of a combination of stress and temperature on thermal stability. The stress level was selected as 50 per cent of the tensile strength at 600 F, and no appreciable strain was observed as a result of this exposure. Complete test data are included in the Appendix. Figures 9 and 10 illustrate the lack of stress dependence for notched tensile properties. For both the alloys and all conditions tested, no significant effect of the applied stress during aging was observed.

Room-Temperature Stress-Rupture Tests

In certain titanium alloys, notably those containing excessive hydrogen, loss of ductility under conditions of static loading is observed. Therefore, in this program, the effects of static loading of notched specimens were studied to determine if these alloys were susceptible to strain-aging embrittlement. Each alloy was tested in the equiaxed alpha-beta condition before and after aging for 200 hours at 800 F.

The results of these tests are summarized in Figure 11. Although failure in the stress-rupture test generally takes place slightly below the notched tensile strength, there is no evidence of strain aging. The differences in strength probably are caused by a simple strain-rate effect. All the specimens tested in this program would easily pass the hydrogen acceptance test of 250 hours at 110 per cent of the unnotched tensile strength.

DISCUSSION

The research described in this report has been directed toward two closely related subjects: (1) the factors that affect thermal stability and (2) the stabilizing process. Thus, the evaluation of thermal stability for a given alloy is a measure of the efficiency of the stabilizing treatment employed.

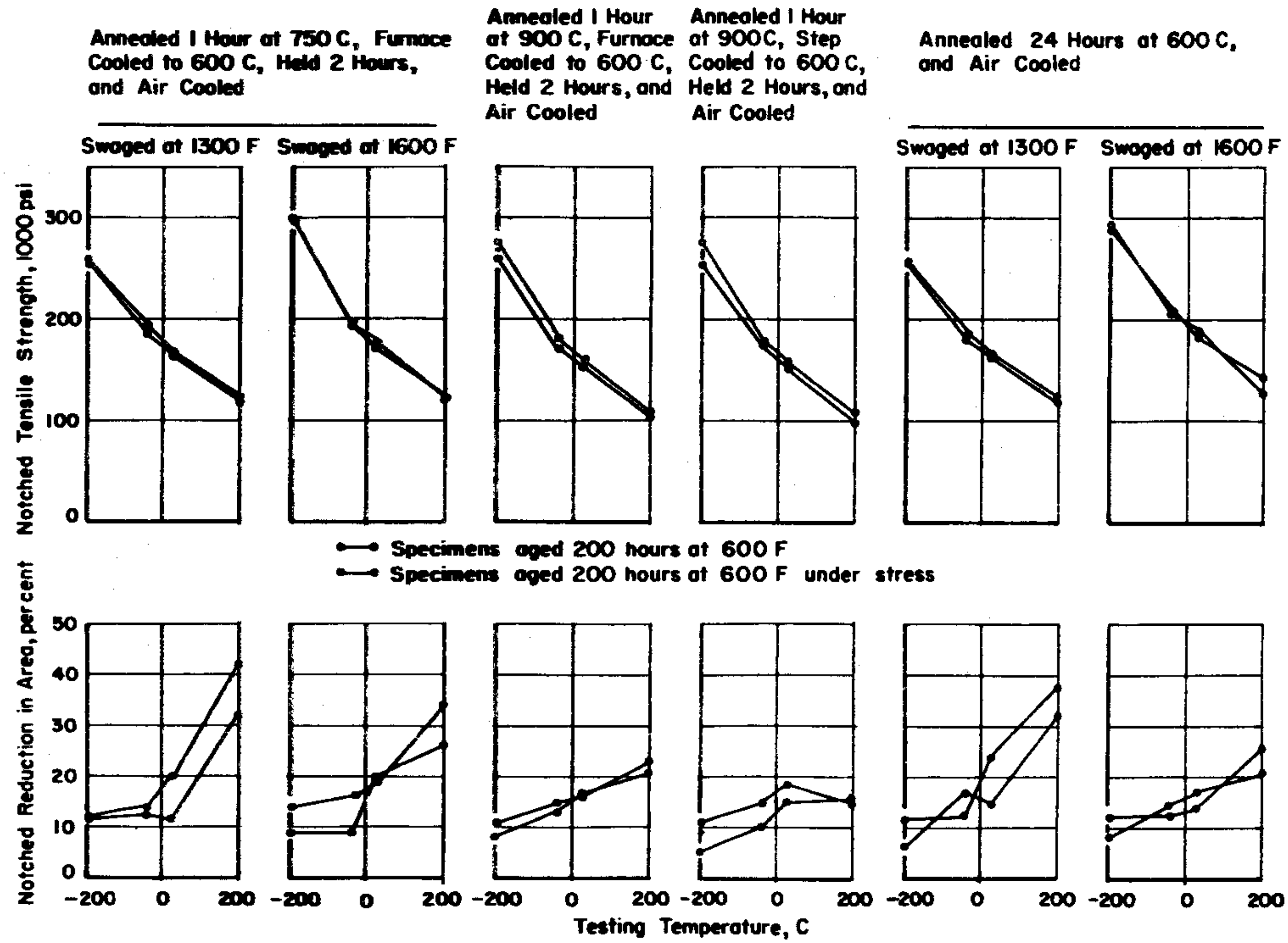

FIGURE 9. EFFECT OF TESTING TEMPERATURE ON THE NOTCHED TENSILE PROPERTIES OF A Ti-2.5 Cr-2.5 Mo ALLOY AGED AT 600F WITH AND WITHOUT APPLIED STRESS

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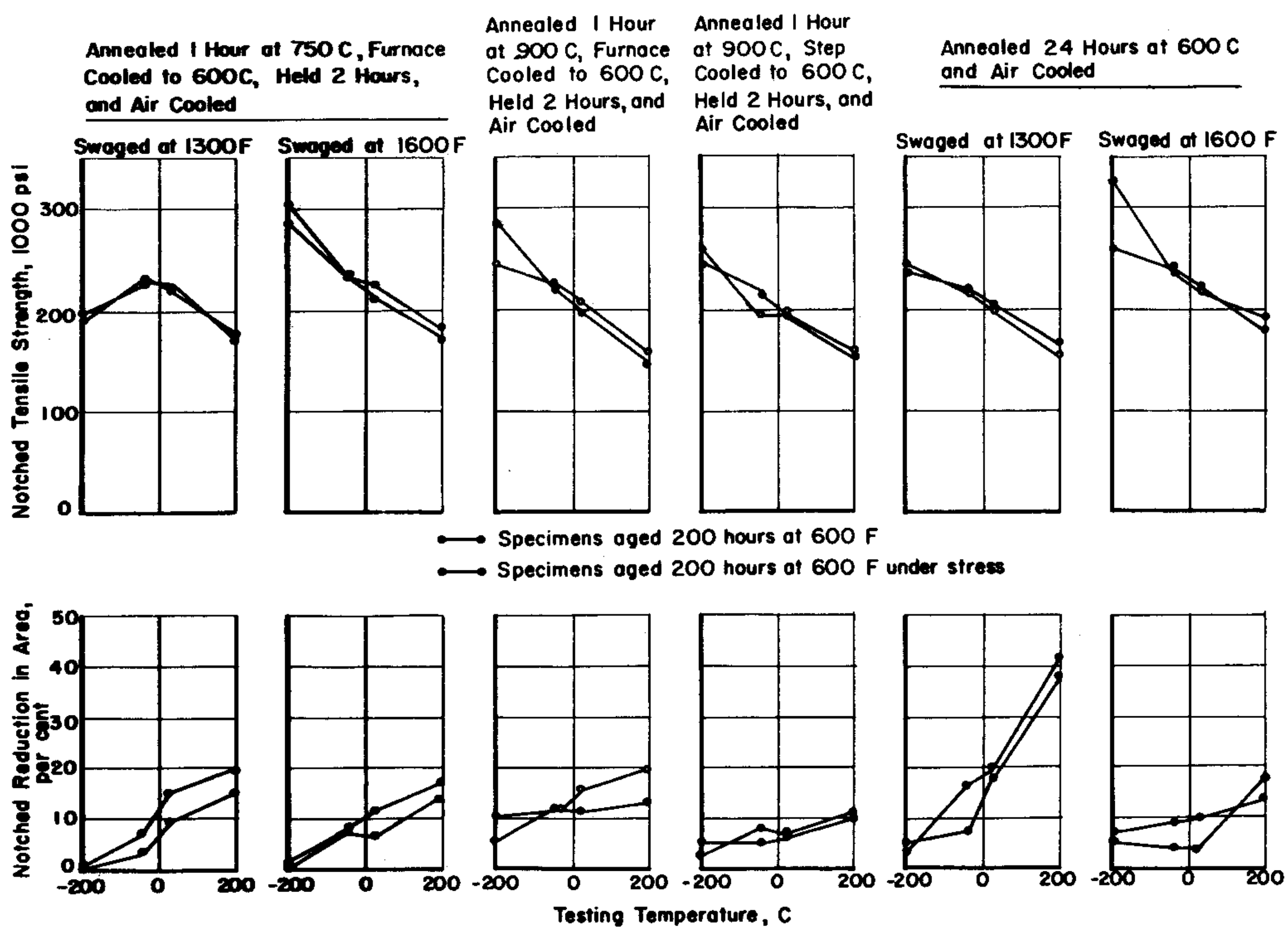

FIGURE 10. EFFECT OF TESTING TEMPERATURE ON THE NOTCHED TENSILE PROPERTIES OF A Ti-5.0 Cr-5.0 Mo ALLOY AGED AT 600F WITH AND WITHOUT APPLIED STRESS

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Specimens Swaged at 1300 F; Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled

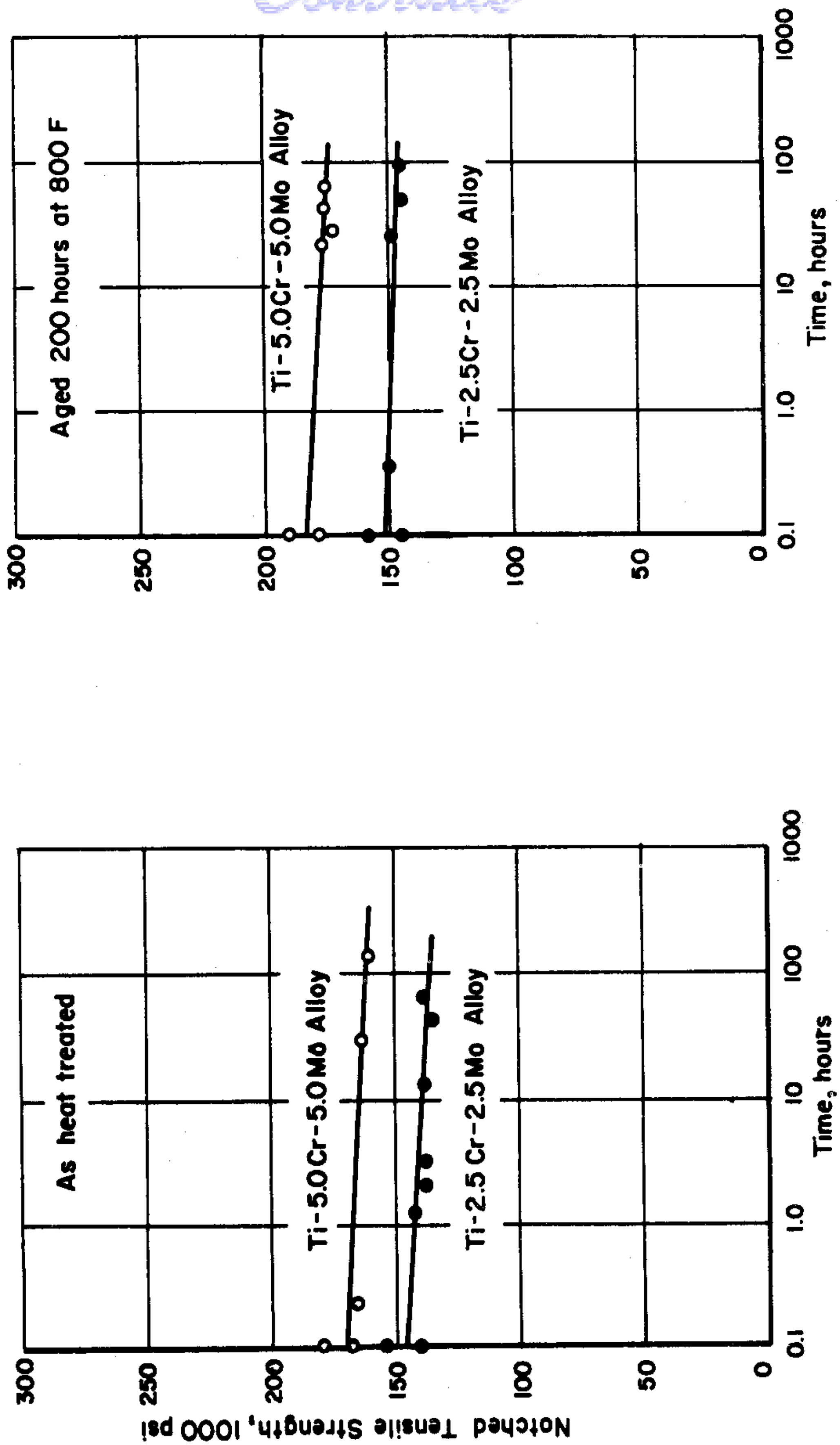

FIGURE 11. ROOM-TEMPERATURE STRESS-RUPTURE DATA FOR A Ti-2.5Cr-2.5Mo AND A Ti-5.0Cr-5.0Mo ALLOY

Thermal stability in the titanium alpha-beta alloys is governed directly by beta phase transformations. The stabilizing heat treatments generally in use are designed to approach equilibrium conditions as closely as possible (usually by alpha rejection), so that the beta phase is not transformed further under conditions of service at elevated temperature. The more important findings of this study relating to thermal stability and its attainment are summarized below:

(1) The thermal stability of an alpha-beta Ti-5Cr alloy is improved by substitution of molybdenum (beta-isomorphous) for chromium (beta-eutectoid). Examination of specimens of the Ti-5Cr alloy aged at 800 and 1000 F showed that the beta phase had transformed to the eutectoid decomposition products, with consequent loss of strength and ductility. Specimens of a Ti-2.5Cr-2.5Mo alloy under the same conditions did not contain visible eutectoid products. The improvement in stability with additions of molybdenum (a beta-isomorphous addition) probably is caused both by the lowered eutectoid temperature and the increased sluggishness of embrittling reactions.

(2) The thermal history of the material is a most important factor in the stabilizing process. In particular, the equilibration process is easier when the alloy has been fabricated at a temperature close to the equilibration temperature. For example, an alloy can be brought to alpha-beta equilibrium at 750 C more easily if the fabrication is done at 750 C than if it is fabricated at 850 C and air cooled to room temperature before equilibration.

(3) The process of developing a stable condition (stabilization) is more rapid for an acicular than for an equiaxed alpha-beta structure. Thus, although the ductility of a specimen with an equiaxed alpha-beta structure is higher in the as-heat-treated condition, this advantage may be countered by poorer thermal stability.

(4) Although it is known that interstitial alpha-stabilizing elements (C, O, N) accelerate the decomposition of the beta phase it has been found that they have little or no effect on the stability of alpha-beta alloys in the stabilized condition. It is believed that the partition of the interstitial elements to the alpha phase in a stabilized alloy probably reduces their concentration in the beta phase, so that they have little or no effect on the properties of the beta phase.

FCH:HRO:RIJ/ks/bt

TABLE A-1. EFFECT OF 200-HOUR AGING TREATMENTS ON THE TENSILE PROPERTIES OF EQUIAXED ALPHA-BETA TITANIUM ALLOYS

Specimens Were Forged at 1600 F, Swaged at 1400 F to 1/4-Inch-Diameter Rounds, Annealed 1 Hour at 750 C, Furnace Cooled to 700 C, Held 2 Hours, Furnace Cooled to 650 C, Held 2 Hours, Furnace Cooled to 600 C, Held 2 Hours and Air Cooled

Aging Treatment	Specimen	Reduction in Area, per cent	Elongation, per cent in 1/2 inch	Ultimate Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi: 0.01 Per Cent Offset	Yield Strength, psi: 0.1 Per Cent Offset	Yield Strength, psi: 0.2 Per Cent Offset
				Ti-5Cr Alloy (L-11)				
None	A1	33	23	103,000	91,000	--	92,000 Y.P.[a]	
	A2	34	22	103,000	93,000	--	95,000 Y.P.	
200 hours at 600 F	B1	21	16	120,000	84,000	94,000	99,000 Y.P.	
	B2	12	8	122,000	91,000	100,000	101,000 Y.P.	
200 hours at 800 F	C1	24	15	116,000	--	--	--	--
	C2	33	22	115,000	72,000	79,000	87,000 Y.P.	
200 hours at 1000 F	D1	11	9	101,000	60,000	67,000	74,000	74,000
	D2	9	12	102,000	61,000	67,000	76,000 Y.P.	
200 hours at 600 F under stress	E1	64	31	104,000	93,000	94,000	94,000 Y.P.	
	E2	26	16	129,000	98,000	115,000	115,000 Y.P.	
				Ti-5Mo Alloy (L-12)				
None	A1	70	32	95,000	65,000	--	85,000 Y.P.	
	A2	56	26	93,000	65,000	74,000	85,000 Y.P.	
200 hours at 600 F	B1	65	27	93,000	68,000	73,000	83,000 Y.P.	
	B2	64	28	93,000	60,000	60,000	84,000 Y.P.	
200 hours at 800 F	C1	62	20	96,000	62,000	71,000	86,000 Y.P.	
	C2	60	36	94,000	61,000	69,000	85,000 Y.P.	
200 hours at 1000 F	D1	58	40	93,000	64,000	69,000	84,000 Y.P.	
	D2	66	38	91,000	67,000	73,000	85,000 Y.P.	
200 hours at 600 F under stress	E1	65	34	94,000	61,000	69,000	88,000 Y.P.	
	E2	65	34	96,000	60,000	68,000	87,000 Y.P.	
				Ti-2.5Cr-2.5Mo Alloy (L-13)				
None	A1	67	38	104,000	76,000	90,000	98,000 Y.P.	
	A2	63	38	104,000	90,000	96,000	98,000 Y.P.	
200 hours at 600 F	B1	64	28	103,000	83,000	88,000	84,000 Y.P.	
	B2	51	20	104,000	76,000	92,000	96,000 Y.P.	
200 hours at 800 F	C1	60	36	103,000	--	--	--	--
	C2	40	34	105,000	--	--	95,000 Y.P.	
200 hours at 1000 F	D1	51	33	101,000	87,000	91,000	95,000 Y.P.	
	D2	47	40	101,000	82,000	91,000	91,000 Y.P.	

TABLE A-1. (Continued)

Aging Treatment	Specimen	Reduction in Area, per cent	Elongation, per cent in 1/2 inch	Ultimate Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi 0.01 Per Cent Offset	0.1 Per Cent Offset	0.2 Per Cent Offset
200 hours at 600 F under stress	E1	63	35	107,000	84,000	92,000	99,000 Y.P.	
	E2	68	38	104,000	88,000	94,000	100,000 Y.P.	
				Ti-5Cr-0.1 O Alloy (L-14)				
None	A1	57	38	117,000	108,000	--	108,000 Y.P.	
	A2	56	36	118,000	109,000	--	111,000 Y.P.	
200 hours at 600 F	B1	35	25	128,000	110,000	114,000	115,000 Y.P.	
	B2	12	8	134,000	113,000	119,000	121,000 Y.P.	
200 hours at 800 F	C1	6	6	125,000	81,000	91,000	104,000 Y.P.	
	C2	8	6	127,000	87,000	96,000	104,000	105,000
200 hours at 1000 F	D1	11	11	115,000	82,000	85,000	92,000 Y.P.	
	D2	10	12	116,000	73,000	81,000	92,000	92,000
200 hours at 600 F under stress	E1	9	10	135,000	118,000	118,000	119,000 Y.P.	
	E2	15	16	135,000	114,000	119,000	122,000 Y.P.	
				Ti-5Mo-0.1 O Alloy (L-15)				
None	A1	67	35	116,000	96,000	--	115,000 Y.P.	
	A2	47	26	118,000	112,000	--	112,000 Y.P.	
200 hours at 600 F	B1	62	25	117,000	98,000	107,000	113,000 Y.P.	
	B2	69	31	116,000	99,000	106,000	113,000 Y.P.	
200 hours at 800 F	C1	63	30	116,000	105,000	112,000	115,000 Y.P.	
	C2	42	26	116,000	109,000	--	114,000 Y.P	
200 hours at 1000 F	D1	61	34	114,000	98,000	104,000	111,000 Y.P.	
	D2	66	38	110,000	--	--	110,000 Y.P.	
200 hours at 600 F under stress	E1	66	33	118,000	109,000	112,000	115,000 Y.P.	
	E2	66	30	117,000	104,000	119,000	115,000 Y.P.	
				Ti-2.5Cr-2.5Mo-0.1 O Alloy (L-16)				
None	A1	67	35	117,000	107,000	--	111,000 Y.P.	
	A2	45	20	118,000	--	--	--	--
200 hours at 600 F	B1	64	30	119,000	94,000	106,000	115,000 Y.P.	
	B2	64	34	117,000	96,000	104,000	113,000 Y.P.	
200 hours at 800 F	C1	56	32	118,000	109,000	--	114,000 Y.P.	
	C2	63	36	119,000	111,000	--	114,000 Y.P.	
200 hours at 1000 F	D1	40	28	116,000	--	--	109,000 Y.P.	
	D2	39	22	116,000	--	--	109,000 Y.P.	
200 hours at 600 F under stress	E1	64	32	120,000	107,000	114,000	117,000 Y.P.	
	E2	65	31	119,000	104,000	111,000	115,000 Y.P.	

(a) Y. P. indicates sharp yield point.

TABLE A-2. EFFECT OF 200-HOUR AGING TREATMENTS ON THE TENSILE PROPERTIES OF ACICULAR ALPHA-BETA TITANIUM ALLOYS

Specimens Were Forged at 1600 F, Swaged at 1600 F to 1/4-Inch-Diameter Rounds, Annealed 1 Hour at 900 C, Furnace Cooled to 750 C, Held 1 Hour, Furnace Cooled to 700 C, Held 2 Hours, Furnace Cooled to 650 C, Held 2 Hours, Furnace Cooled to 600 C, Held 2 Hours and Air Cooled

Aging Treatment	Specimen	Reduction in Area, per cent	Elongation, per cent in 1/2 inch	Ultimate Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi: 0.01 Per Cent Offset	Yield Strength, psi: 0.1 Per Cent Offset	Yield Strength, psi: 0.2 Per Cent Offset
				Ti-5Cr Alloy (L-20)				
None	F1	48	30	101,000	73,000	77,000	84,000	85,000
	F2	48	33	103,000	80,000	82,000	86,000	88,000
200 hours at 600 F	G1	12	13	115,000	72,000	77,000	88,000	94,000
	G2	4	4	117,000	72,000	77,000	89,000	93,000
200 hours at 800 F	H1	8	7	117,000	63,000	68,000	79,000	82,000
	H2	11	10	116,000	65,000	69,000	78,000	83,000
200 hours at 1000 F	J1	9	10	95,000	50,000	55,000	65,000	68,000
	J2	--	--	--	--	--	--	--
200 hours at 600 F under stress	K1	9	2	116,000	78,000	81,000	90,000	93,000
	K2	6	7	116,000	81,000	85,000	92,000	96,000
				Ti-5Mo Alloy (L-21)				
None	F1	59	34	89,000	61,000	66,000	75,000	--
	F2	57	29	90,000	67,000	75,000	82,000	--
200 hours at 600 F	G1	43	31	90,000	62,000	66,000	74,000	76,000
	G2	47	26	92,000	63,000	69,000	76,000	79,000
200 hours at 800 F	H1	42	32	91,000	58,000	62,000	74,000	77,000
	H2	44	28	89,000	61,000	65,000	74,000	76,000
200 hours at 1000 F	J1	46	28	90,000	62,000	68,000	76,000	78,000
	J2	44	28	88,000	62,000	66,000	73,000	75,000
200 hours at 600 F under stress	K1	48	30	89,000	61,000	66,000	73,000	75,000
	K2	43	27	90,000	67,000	70,000	77,000	79,000
				Ti-2.5Cr-2.5Mo Alloy (L-22)				
None	F1	53	28	96,000	69,000	73,000	81,000	84,000
	F2	52	31	96,000	71,000	76,000	82,000	84,000
200 hours at 600 F	G1	32	18	103,000	70,000	73,000	81,000	83,000
	G2	28	28	107,000	66,000	72,000	83,000	85,000
200 hours at 800 F	H1	36	25	102,000	62,000	67,000	77,000	79,000
	H2	36	23	103,000	64,000	68,000	79,000	82,000
200 hours at 1000 F	J1	31	26	94,000	63,000	68,000	76,000	78,000
	J2	28	16	92,000	64,000	68,000	75,000	77,000

TABLE A-2. (Continued)

Aging Treatment	Specimen	Reduction in Area, per cent	Elongation, per cent in 1/2 inch	Ultimate Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi 0.01 Per Cent Offset	Yield Strength, psi 0.1 Per Cent Offset	Yield Strength, psi 0.2 Per Cent Offset
200 hours at 600 F under stress	K1	35	25	103,000	75,000	80,000	84,000	85,000
	K2	34	22	102,000	72,000	77,000	84,000	85,000
				Ti-5Cr-0.1 O Alloy (L-23)				
None	F1	48	31	114,000	91,000	96,000	101,000	102,000
	F2	48	28	116,000	101,000	104,000	--	--
200 hours at 600 F	G1	2	0	124,000	97,000	102,000	111,000	115,000
	G2	7	10	125,000	86,000	93,000	107,000	110,000
200 hours at 800 F	H1	9	7	131,000	83,000	87,000	99,000	103,000
	H2	9	18	130,000	79,000	85,000	98,000	102,000
200 hours at 1000 F	J1	6	2	107,000	68,000	74,000	83,000	86,000
	J2	8	19	106,000	71,000	76,000	85,000	88,000
200 hours at 600 F under stress	K1	5	10	127,000	100,000	104,000	113,000	115,000
	K2	2	4	127,000	103,000	106,000	112,000	115,000
				Ti-5Mo-0.1 O Alloy (L-24)				
None	F1	47	25	96,000	--	--	--	--
	F2	52	38	94,000	69,000	73,000	82,000	84,000
200 hours at 600 F	G1	38	26	96,000	67,000	71,000	79,000	82,000
	G2	46	30	97,000	72,000	75,000	82,000	85,000
200 hours at 800 F	H1	42	34	98,000	60,000	69,000	82,000	85,000
	H2	44	24	97,000	66,000	71,000	82,000	85,000
200 hours at 1000 F	J1	42	27	95,000	58,000	69,000	84,000	86,000
	J2	44	31	95,000	67,000	71,000	81,000	83,000
200 hours at 600 F under stress	K1	48	29	98,000	71,000	77,000	86,000	88,000
	K2	46	26	97,000	70,000	75,000	84,000	86,000
				Ti-2.5Cr-2.5Mo-0.1 O Alloy (L-25)				
None	F1	50	30	114,000	96,000	100,000	106,000	106,000
	F2	55	33	115,000	95,000	99,000	106,000	106,000
200 hours at 600 F	G1	27	24	121,000	97,000	101,000	107,000	109,000
	G2	37	27	118,000	95,000	105,000	108,000	109,000
200 hours at 800 F	H1	32	26	118,000	84,000	92,000	101,000	103,000
	H2	30	23	120,000	88,000	93,000	103,000	105,000
200 hours at 1000 F	J1	38	22	113,000	88,000	92,000	100,000	102,000
	J2	34	26	112,000	93,000	97,000	101,000	102,000
200 hours at 600 F under stress	K1	30	26	118,000	100,000	103,000	108,000	108,000
	K2	34	24	118,000	101,000	104,000	108,000	109,000

TABLE A-3. EFFECT OF 200-HOUR AGING TREATMENTS ON THE NOTCHED TENSILE PROPERTIES OF EQUIAXED ALPHA-BETA TITANIUM ALLOYS

Specimens Were Forged at 1600 F, Swaged at 1400 F to 1/4-Inch-Diameter Rounds, Annealed 1 Hour at 750 C, Furnace Cooled to 700 C, Held 2 Hours, Furnace Cooled to 650 C, Held 2 Hours, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled

Testing Temperature, C	Property	Not Aged	Aged 200 Hours at 600 F	Aged 200 Hours at 800 F	Aged 200 Hours at 1000 F	Aged 200 Hours at 600 F Under Stress
		Ti-5Cr Alloy (L-11)				
-196	Reduction in Area, per cent	5	3	0	0	2
	Ultimate Tensile Strength, psi	240,000	220,000	192,000	151,000	188,000
-40	Reduction in Area, per cent	12	12	14	14	17
	Ultimate Tensile Strength, psi	176,000	161,000	123,000	138,000	169,000
25	Reduction in Area, per cent	10	7	4	3	4
	Ultimate Tensile Strength, psi	150,000	155,000	127,000	119,000	163,000
200	Reduction in Area, per cent	15	10	4	5	8
	Ultimate Tensile Strength, psi	101,000	130,000	109,000	84,000	124,000
		Ti-5Mo Alloy (L-12)				
-196	Reduction in Area, per cent	9	8	5	2	8
	Ultimate Tensile Strength, psi	230,000	222,000	218,000	224,000	227,000
-40	Reduction in Area, per cent	19	12	14	14	17
	Ultimate Tensile Strength, psi	157,000	162,000	162,000	157,000	163,000
25	Reduction in Area, per cent	21	21	16	22	20
	Ultimate Tensile Strength, psi	136,000	140,000	135,000	135,000	143,000
200	Reduction in Area, per cent	73	66	67	56	63
	Ultimate Tensile Strength, psi	98,000	100,000	99,000	93,000	100,000
		Ti-2.5Cr-2.5Mo Alloy (L-13)				
-196	Reduction in Area, per cent	6	3	5	3	7
	Ultimate Tensile Strength, psi	252,000	242,000	245,000	208,000	243,000
-40	Reduction in Area, per cent	17	10	10	6	12
	Ultimate Tensile Strength, psi	180,000	186,000	178,000	168,000	182,000
25	Reduction in Area, per cent	21	15	15	5	17
	Ultimate Tensile Strength, psi	156,000	159,000	163,000	143,000	160,000
200	Reduction in Area, per cent	54	47	30	14	38
	Ultimate Tensile Strength, psi	112,000	111,000	112,000	100,000	111,000
		Ti-5Cr-0.1O Alloy (L-14)				
-196	Reduction in Area, per cent	2	1	0	0	2
	Ultimate Tensile Strength, psi	216,000	174,000	137,000	96,000	163,000
-40	Reduction in Area, per cent	3	1	2	0	1
	Ultimate Tensile Strength, psi	186,000	178,000	171,000	112,000	161,000
25	Reduction in Area, per cent	8	5	2	2	3
	Ultimate Tensile Strength, psi	175,000	180,000	160,000	124,000	175,000

TABLE A-3. (Continued)

Testing Temperature, C	Property	Not Aged	Aged 200 Hours at 600 F	Aged 200 Hours at 800 F	Aged 200 Hours at 1000 F	Aged 200 Hours at 600 F Under Stress
200	Reduction in Area, per cent	16	7	3	6	5
	Ultimate Tensile Strength, psi	116,000	132,000	123,000	93,000	122,000
	Ti-5Mo-0.1O Alloy (L-15)					
-196	Reduction in Area, per cent	0	2	1	5	0
	Ultimate Tensile Strength, psi	180,000	159,000	165,000	152,000	160,000
-40	Reduction in Area, per cent	5	7	6	3	8
	Ultimate Tensile Strength, psi	193,000	198,000	197,000	192,000	203,000
25	Reduction in Area, per cent	17	12	12	14	12
	Ultimate Tensile Strength, psi	177,000	180,000	178,000	176,000	185,000
200	Reduction in Area, per cent	65	48	43	51	52
	Ultimate Tensile Strength, psi	119,000	124,000	117,000	112,000	121,000
	Ti-2.5Cr-2.5Mo-0.1O Alloy (L-16)					
-196	Reduction in Area, per cent	3	2	0	0	3
	Ultimate Tensile Strength, psi	187,000	208,000	229,000	182,000	154,000
-40	Reduction in Area, per cent	9	7	8	3	7
	Ultimate Tensile Strength, psi	198,000	191,000	202,000	168,000	206,000
25	Reduction in Area, per cent	14	13	8	5	12
	Ultimate Tensile Strength, psi	176,000	179,000	179,000	168,000	182,000
200	Reduction in Area, per cent	48	38	25	12	48
	Ultimate Tensile Strength, psi	120,000	120,000	122,000	107,000	121,000

TABLE A-4. EFFECT OF 200-HOUR AGING TREATMENTS ON THE NOTCHED TENSILE PROPERTIES OF ACICULAR ALPHA-BETA TITANIUM ALLOYS

Specimens Were Forged at 1600 F, Swaged at 1600 F to 1/4-Inch-Diameter Rounds, Annealed 1 Hour at 900 C, Furnace Cooled to 750 C, Held 1 Hour, Furnace Cooled to 700 C, Held 2 Hours, Furnace Cooled to 650 C, Held 2 Hours, Furnace Cooled to 600 C, Held 2 Hours and Air Cooled

Testing Temperature, C	Property	Not Aged	Aged 200 Hours at 600 F	Aged 200 Hours at 800 F	Aged 200 Hours at 1000 F	Aged 200 Hours at 600 F Under Stress
		Ti-5Cr Alloy (L-20)				
-196	Reduction in Area, per cent	2	0	3	0	1
	Ultimate Tensile Strength, psi	271,000	197,000	157,000	121,000	199,000
-40	Reduction in Area, per cent	16	3	3	0	4
	Ultimate Tensile Strength, psi	191,000	158,000	158,000	128,000	147,000
25	Reduction in Area, per cent	22	2	4	2	0
	Ultimate Tensile Strength, psi	156,000	148,000	155,000	124,000	143,000
200	Reduction in Area, per cent	24	10	10	3	9
	Ultimate Tensile Strength, psi	112,000	129,000	120,000	118,000	128,000
		Ti-5Mo Alloy (L-21)				
-196	Reduction in Area, per cent	9	8	9	9	6
	Ultimate Tensile Strength, psi	271,000	268,000	265,000	260,000	267,000
-40	Reduction in Area, per cent	20	17	21	21	21
	Ultimate Tensile Strength, psi	169,000	163,000	172,000	162,000	161,000
25	Reduction in Area, per cent	23	22	27	24	23
	Ultimate Tensile Strength, psi	149,000	122,000	147,000	142,000	145,000
200	Reduction in Area, per cent	36	37	39	33	41
	Ultimate Tensile Strength, psi	94,000	94,000	95,000	90,000	95,000
		Ti-2.5Cr-2.5Mo Alloy (L-22)				
-196	Reduction in Area, per cent	8	2	4	7	3
	Ultimate Tensile Strength, psi	272,000	275,000	270,000	265,000	281,000
-40	Reduction in Area, per cent	21	8	16	16	16
	Ultimate Tensile Strength, psi	173,000	185,000	180,000	170,000	179,000
25	Reduction in Area, per cent	23	15	16	18	20
	Ultimate Tensile Strength, psi	149,000	164,000	157,000	149,000	120,000
200	Reduction in Area, per cent	28	17	21	27	24
	Ultimate Tensile Strength, psi	99,000	105,000	108,000	94,000	137,000
		Ti-5Cr-0.1O Alloy (L-23)				
-196	Reduction in Area, per cent	0	0	0	2	1
	Ultimate Tensile Strength, psi	265,000	194,000	147,000	63,000	133,000
-40	Reduction in Area, per cent	14	1	3	3	1
	Ultimate Tensile Strength, psi	205,000	148,000	167,000	129,000	122,000
25	Reduction in Area, per cent	18	3	5	7	2
	Ultimate Tensile Strength, psi	181,000	173,000	171,000	128,000	161,000

TABLE A-4. (Continued)

Testing Temperature, C	Property	Not Aged	Aged 200 Hours at 600 F	Aged 200 Hours at 800 F	Aged 200 Hours at 1000 F	Aged 200 Hours at 600 F Under Stress
200	Reduction in Area, per cent	21	11	10	3	3
	Ultimate Tensile Strength, psi	122,000	122,000	127,000	80,000	137,000
	Ti-5Mo-0.1O Alloy (L-24)					
-196	Reduction in Area, per cent	14	8	6	12	8
	Ultimate Tensile Strength, psi	273,000	272,000	274,000	271,000	284,000
-40	Reduction in Area, per cent	18	22	19	15	15
	Ultimate Tensile Strength, psi	181,000	181,000	179,000	179,000	186,000
25	Reduction in Area, per cent	22	20	22	22	23
	Ultimate Tensile Strength, psi	151,000	157,000	152,000	151,000	159,000
200	Reduction in Area, per cent	36	41	36	34	46
	Ultimate Tensile Strength, psi	94,000	95,000	94,000	95,000	96,000
	Ti-2.5Cr-2.5Mo-0.1O Alloy (L-25)					
-196	Reduction in Area, per cent	5	2	10	6	2
	Ultimate Tensile Strength, psi	275,000	248,000	232,000	261,000	268,000
-40	Reduction in Area, per cent	17	6	9	13	11
	Ultimate Tensile Strength, psi	202,000	208,000	203,000	204,000	213,000
25	Reduction in Area, per cent	18	9	13	23	13
	Ultimate Tensile Strength, psi	178,000	187,000	184,000	177,000	189,000
200	Reduction in Area, per cent	28	22	24	30	27
	Ultimate Tensile Strength, psi	115,000	120,000	120,000	110,000	121,000

TABLE A-5. ROOM-TEMPERATURE NOTCHED STRESS-RUPTURE DATA FOR EQUIAXED ALPHA-BETA TITANIUM ALLOYS

Specimens Were Loaded Initially at 60 Per Cent of the Notched Ultimate Tensile Strength, and the Stress Was Increased by 10,000 Psi at 12-Hour Intervals Until Fracture

Specimens Were Forged at 1600 F, Swaged at 1400 F to 1/4-Inch-Diameter Rounds, Annealed 1 Hour at 750 C, Furnace Cooled to 700 C, Held 2 Hours, Furnace Cooled to 650 C, Held 2 Hours, Furnace Cooled to 600 C, Held 2 Hours and Air Cooled

Aging Treatment	Reduction in Area, per cent	Ultimate Strength, psi	Total Time to Fracture, hours	Reduction in Area, per cent	Ultimate Strength, psi	Total Time to Fracture, hours
	Ti-5Cr Alloy (L-11)			Ti-5Cr-0.1 O Alloy (L-14)		
None	11	133,000	93.8	8	154,000	104.0
200 hours at 600 F	5	145,000	89.5	6	138,000	43.0
200 hours at 800 F	2	115,000	48.1	3	129,000	44.4
200 hours at 1000 F	5	112,000	48.1	2	117,000	58.8
200 hours at 600 F under stress	4	119,000	26.8	2	125,000	27.7
	Ti-5Mo Alloy (L-12)			Ti-5Mo-0.1 O Alloy (L-15)		
None	21	148,000	103.8	16	171,000	118.0
200 hours at 600 F	22	143,000	118.8	13	180,000	84.0
200 hours at 800 F	16	141,000	72.1	--	--	--
200 hours at 1000 F	--	--	--	16	165,000	76.6
200 hours at 600 F under stress	19	149,000	76.5	15	182,000	84.0
	Ti-2.5Cr-2.5Mo Alloy (L-13)			Ti-2.5Cr-2.5Mo-0.1 O Alloy (L-16)		
None	--	--	--	19	159,000	119.8
200 hours at 600 F	23	157,000	105.1	--	--	--
200 hours at 800 F	19	148,000	63.1	12	177,000	84.0
200 hours at 1000 F	7	147,000	72.1	5	152,000	65.2
200 hours at 600 F under stress	17	154,000	76.0	15	180,000	84.0

TABLE A-6. ROOM-TEMPERATURE NOTCHED STRESS-RUPTURE DATA FOR ACICULAR ALPHA-BETA TITANIUM ALLOY

Specimens Were Loaded Initially at 60 Per Cent of the Notched Ultimate Tensile Strength, and the Stress Was Increased by 10,000 Psi at 12-Hour Intervals Until Fracture

Specimens Were Forged at 1600 F, Swaged at 1600 F to 1/4-Inch-Diameter Rounds, Annealed 1 Hour at 900 C, Furnace Cooled to 750 C, Held 1 Hour, Furnace Cooled to 700 C, Held 2 Hours, Furnace Cooled to 650 C, Held 2 Hours, Furnace Cooled to 600 C, Held 2 Hours and Air Cooled

Aging Treatment	Reduction in Area, per cent	Ultimate Strength, psi	Total Time to Fracture, hours	Reduction in Area, per cent	Ultimate Strength, psi	Total Time to Fracture, hours
	Ti-5Cr Alloy (L-20)			Ti-5Cr-0.1 O Alloy (L-23)		
None	18	155,000	72.3	20	173,000	72.3
200 hours at 600 F	13	120,000	45	0	144,000	48.8
200 hours at 800 F	--	--	--	2	113,000	15.3
200 hours at 1000 F	1	104,000	36.5	0	118,000	48.2
200 hours at 600 F under stress	2	108,000	26.5	4	115,000	25
	Ti-5Mo Alloy (L-21)			Ti-5Mo-0.1 O Alloy (L-24)		
None	26	150,000	72.3	24	141,000	60.3
200 hours at 600 F	18	143,000	83.5	21	145,000	65.8
200 hours at 800 F	16	152,000	72	--	--	--
200 hours at 1000 F	19	127,000	48.8	24	140,000	60.2
200 hours at 600 F under stress	12	155,000	84	--	--	--
	Ti-2.5Cr-2.5Mo Alloy (L-22)			Ti-2.5Cr-2.5Mo-0.1 O Alloy (L-25)		
None	24	150,000	72.3	21	189,000	96.1
200 hours at 600 F	7	138,000	48.8	19	182,000	84
200 hours at 800 F	16	152,000	72.0	16	179,000	84
200 hours at 1000 F	20	150,000	72.1	20	164,000	76.7
200 hours at 600 F under stress	18	146,000	85.5	--	--	--

TABLE A-7. EFFECT OF 200-HOUR AGING TREATMENTS ON THE BEND DUCTILITY AND HARDNESS OF A Ti-2.5Cr-2.5Mo ALLOY

	As Heat Treated		Aged 200 Hours at 600 F		Aged 200 Hours at 800 F		Aged 200 Hours at 1000 F	
Rolling Temperature, F	MBR, T	VHN	MBR, T	VHN	MBR, T	VHN	MBR, T	VHN
Annealed 1 Hour at 750 C; Furnace Cooled to 700 C, Held 2 Hours; Furnace Cooled to 650 C, Held 2 Hours; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	1.5, 4.4	271	1.5, 4.4	242	6.6, 6.8	237	8.3, 2.8	216
1600	1.2, 1.1	239	1.4, 0.4	260	1.1, 0.6	249	1.6, 1.0	249
Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	1.0, 1.2	283	2.5, 1.7	247	5.0, 1.6	245	5.0, 5.3	232
1600	0.4, 0.4	257	2.1, 1.5	245	1.5, 1.5	243	1.7, 1.7	239
Annealed 2 Hours at 700 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	0.8, 1.2	251	1.5, 3.2	237	5.0, 5.0	238	5.2, 2.5	236
1600	0.3, 0.3	262	1.4, 1.4	253	1.3, 0.3	253	2.4, 2.6	262
Annealed 16 Hours at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	1.7, 1.7	246	--	--	1.3, 0.9	234	--	--
1600	1.2, 1.2	257	--	--	0, 0	280	--	--
Annealed 1 Hour at 750 C, Furnace Cooled to 550 C, Held 2 Hours, and Air Cooled								
1400	2.6, 6.6	246	4.9, 3.4	241	6.4, 16.1	270	9.4, 5.2	227
1600	1.1, 0.7	260	1.1, 1.1	248	2.3, 2.2	250	1.7, 1.6	257

TABLE A-7. (Continued)

Rolling Temperature, F	As Heat Treated MBR, T	As Heat Treated VHN	Aged 200 Hours at 600 F MBR, T	Aged 200 Hours at 600 F VHN	Aged 200 Hours at 800 F MBR, T	Aged 200 Hours at 800 F VHN	Aged 200 Hours at 1000 F MBR, T	Aged 200 Hours at 1000 F VHN
Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 16 Hours, and Air Cooled								
1400	1.3	260	1.5, 1.2	228	2.5, 1.7	243	1.6	260
1600	1.4, 1.1	271	1.2, 1.2	245	1.1, 1.1	251	1.6	251
Annealed 1 Hour at 900 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	0.8, 0.8	260	0.8, 1.2	288	0.9, 0.7	261	0.5, 0.5	274
1600	0.8, 0.7	283	1.5, 1.5	303	0.8, 1.1	260	1.5, 1.4	270
Annealed 1 Hour at 900 C; Furnace Cooled to 750 C, Held 1 Hour; Furnace Cooled to 700 C, Held 2 Hours; Furnace Cooled to 650 C, Held 2 Hours; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	0.4, 0.7	262	0.4, 0.4	256	0, 0	259	0.5, 0.4	289
1600	0.4, 0.8	289	1.1, 1.1	273	1.1, 1.1	277	1.0, 1.1	258
Annealed 1 Hour at 900 C and Air Cooled; Reheated to 600 C, Held 2 Hours, and Air Cooled								
1400	0.4, 0.5	303	1.8, 2.1	321	1.2, 0.9	265	1.2, 1.3	273
1600	2.2, 4.8	321	4.8, 4.4	329	1.1, 1.4	298	1.5, 1.4	279
Annealed 1 Hour at 900 C and Air Cooled; Reheated to 750 C, Held 1 Hour; Furnace Cooled to 700 C, Held 2 Hours; Furnace Cooled to 650 C, Held 2 Hours; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	1.0, 0.9	265	0.8, 1.4	271	1.3, 1.2	254	1.3, 1.3	267
1600	1.5, 1.5	274	1.5, 1.7	266	1.5, 1.5	275	1.8, 1.5	258

TABLE A-7. (Continued)

Rolling Temperature, F	As Heat Treated MBR, T	As Heat Treated VHN	Aged 200 Hours at 600 F MBR, T	Aged 200 Hours at 600 F VHN	Aged 200 Hours at 800 F MBR, T	Aged 200 Hours at 800 F VHN	Aged 200 Hours At 1000 F MBR, T	Aged 200 Hours At 1000 F VHN
Annealed 16 Hours at 900 C; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	0.7, 0.5	277	0.8, 2.0	--	0.9, 0.8	264	1.2, 1.2	285
1600	0, 0	306	1.1, 1.2	277	1.5, 0.4	257	1.5, 1.5	278
Annealed 1 Hour at 1000 C; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	0.4, 0.4	276	--	--	0.4, 0.4	254	0, 0	265
1600	0.4, 0.7	270	--	--	0.4, 0.4	287	1.5, 1.6	268
Annealed 24 Hours at 650 C and Air Cooled								
1400	1.7, 1.7	--	--	--	--	--	--	--
1600	1.3, 1.2	--	--	--	--	--	--	--
Tested Without Further Heat Treatment After Rolling								
1400	5.2, 6.0	--	--	--	--	--	--	--
1600	Brittle	--	--	--	--	--	--	--

TABLE A-8. EFFECT OF 200-HOUR AGING TREATMENTS ON THE BEND DUCTILITY AND HARDNESS OF A Ti-5.0Cr-5.0Mo ALLOY

Rolling Temperature, F	As Heat Treated		Aged 200 Hours at 600 F		Aged 200 Hours at 800 F		Aged 200 Hours at 1000 F	
	MBR, T	VHN	MBR, T	VHN	MBR, T	VHN	MBR, T	VHN
Annealed 1 Hour at 750 C; Furnace Cooled to 700 C, Held 2 Hours; Furnace Cooled to 650 C, Held 2 Hours; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	2.6, 4.0	303	3.8, 4.2	312	6.2, 5.8	324	>24, 15	313
1600	3.0, 3.1	310	2.8, 2.8	321	2.2, 2.2	335	5.2, 4.4	329
Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	1.4, 1.4	306	4.0, 1.3	313	4.3, 2.2	338	16, 17	299
1600	0.7, 0.7	321	4.3, 4.4	328	2.2, 1.5	344	2.3, 2.9	341
Annealed 2 Hours at 700 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	0.4, 0.4	317	2.1, 2.0	316	3.9, 4.2	319	17, >24	313
1600	0.7, 0.7	321	3.1, 3.0	332	1.1, 1.1	340	4.9, 4.9	349
Annealed 16 Hours at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	1.1, 1.1	325	--	--	2.3, 1.9	--	--	--
1600	2.2, 2.3	303	--	--	1.9, 2.3	--	--	--
Annealed 1 Hour at 750 C, Furnace Cooled to 550 C, Held 2 Hours and Air Cooled								
1400	0.9, 0.6	329	3.8, 1.4	322	5.4, 5.4	331	21, >24	321
1600	5.8, 2.2	325	2.8, 3.0	336	4.3, 4.6	341	1.2, 1.3	321

TABLE A-8. (Continued)

Rolling Temperature, F	As Heat Treated MBR, T	As Heat Treated VHN	Aged 200 Hours at 600 F MBR, T	Aged 200 Hours at 600 F VHN	Aged 200 Hours at 800 F MBR, T	Aged 200 Hours at 800 F VHN	Aged 200 Hours at 1000 F MBR, T	Aged 200 Hours at 1000 F VHN
Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 16 Hours, and Air Cooled								
1400	4.0, 4.1	306	0.7, 0.7	313	4.0, 5.4	319	>24	295
1600	4.4, 4.6	321	0.7, 0.7	319	2.4, 1.1	343	4.0	331
Annealed 1 Hour at 900 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	4.3, 2.0	329	2.0, 2.1	359	1.4, 1.4	344	1.3, 1.3	316
1600	3.2, 1.5	325	10.0, 2.3	348	>24, 1.5	323	9.6, 1.5	341
Annealed 1 Hour at 900 C; Furnace Cooled to 750 C, Held 1 Hour; Furnace Cooled to 700 C, Held 2 Hours; Furnace Cooled to 650 C, Held 2 Hours; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	1.0, 1.5	325	10.9, 11.6	376	1.4, 5.8	347	4.2, 1.1	309
1600	9.8, 4.4	336	9.2, 6.2	353	9.8, >24	355	20.4, 1.5	313
Annealed 1 Hour at 900 C and Air Cooled; Reheated to 600 C, Held 2 Hours, and Air Cooled								
1400	Brittle	429	Brittle	510	2.0, 2.1	355	5.5, 5.3	363
1600	Brittle	473	Brittle	577	4.7, 4.7	353	>24, 6.2	348
Annealed 1 Hour at 900 C and Air Cooled; Reheated to 750 C, Held 1 Hour; Furnace Cooled to 700 C, Held 2 Hours; Furnace Cooled to 650 C, Held 2 Hours; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	3.9, 8.6	325	1.1, 2.2	325	1.4, 1.4	321	8.0, 4.0	317
1600	1.5, 0.8	321	3.0, 3.2	385	2.3, 2.3	329	12.8, 1.5	322

TABLE A-8. (Continued)

Rolling Temperature, F	As Heat Treated MBR, T	As Heat Treated VHN	Aged 200 Hours at 600 F MBR, T	Aged 200 Hours at 600 F VHN	Aged 200 Hours at 800 F MBR, T	Aged 200 Hours at 800 F VHN	Aged 200 Hours at 1000 F MBR, T	Aged 200 Hours at 1000 F VHN
Annealed 16 Hours at 900 C; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	4.9	345	4.6, 4.4	341	1.7, 1.7	327	1.1, 1.1	344
1600	Brittle	329	Brittle	368	1.4, 2.3	323	4.6, 1.5	331
Annealed 1 Hour at 1000 C; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled								
1400	2.2, 2.2	322	--	--	3.3, 1.3	342	1.5, 1.3	341
1600	9.4	305	--	--	19.2, 4.3	323	2.3, 2.2	335
Annealed 24 Hours at 650 C and Air Cooled								
1400	1.4, 1.5	--	--	--	--	--	--	--
1600	1.5, 1.5	--	--	--	--	--	--	--
Tested Without Further Heat Treatment After Rolling								
1400	12.2, 9.4	--	--	--	--	--	--	--
1600	>24, 7.4	--	--	--	--	--	--	--

TABLE A-9. EFFECT OF 200-HOUR AGING TREATMENTS ON THE TENSILE PROPERTIES OF A Ti-2.5Cr-2.5Mo ALLOY FOR VARIOUS STABILIZING TREATMENTS

Aging Treatment	Specimen	Swaging Temper-ature, F	Reduction in Area, per cent	Elongation, per cent in 1/2 inch	Ultimate Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi: 0.01 Per Cent Offset	Yield Strength, psi: 0.1 Per Cent Offset	Yield Strength, psi: 0.2 Per Cent Offset
			Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled						
None	AA1	1300	64	34	98,000	--	--	--	--
	AA2	1300	66	34	100,000	84,000	90,000	95,000 Y.P.[a]	
200 hours at 600 F	AB1	1300	58	27	106,000	--	--	--	--
	AB2	1300	61	29	107,000	87,000	90,000	97,000 Y.P.	
200 hours at 800 F	AC1	1300	36	27	101,000	--	--	--	--
	AC2	1300	55	33	100,000	87,000	91,000	93,000 Y.P.	
200 hours at 1000 F	AD1	1300	40	26	94,000	64,000	70,000	76,000	77,000
	AD2	1300	39	31	94,000	66,000	70,000	77,000	78,000
200 hours at 600 F under stress	AE1	1300	59	31	109,000	99,000	100,000	101,000 Y.P.	
	AE2	1300	50	30	104,000	93,000	96,000	97,000 Y.P.	
			Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled						
None	BA1	1600	63	30	110,000	81,000	86,000	96,000	99,000
	BA2	1600	44	25	107,000	--	--	--	--
200 hours at 600 F	BB1	1600	54	26	115,000	88,000	92,000	--	--
	BB2	1600	49	20	113,000	70,000	77,000	91,000	97,000
200 hours at 800 F	BC1	1600	43	21	109,000	76,000	80,000	94,000	--
	BC2	1600	56	26	105,000	66,000	71,000	82,000	87,000
200 hours at 1000 F	BD1	1600	43	32	96,000	69,000	74,000	80,000	82,000
	BD2	1600	42	27	95,000	68,000	72,000	80,000	81,000
200 hours at 600 F under stress	BE1	1600	51	26	111,000	86,000	89,000	96,000	98,000
	BE2	1600	58	28	114,000	88,000	91,000	100,000	102,000
			Annealed 1 Hour at 900 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled						
None	EA1	1300	72	29	116,000	--	--	--	--
	EA2	1600	70	28	117,000	98,000	102,000	109,000 Y.P.	
200 hours at 600 F	EB1	1300	44	18	142,000	--	--	--	--
	EB2	1600	53	21	145,000	103,000	107,000	124,000	127,000
200 hours at 800 F	EC1	1300	30	19	129,000	102,000	107,000	112,000	113,000
	EC2	1600	55	24	135,000	85,000	92,000	113,000	115,000
200 hours at 1000 F	ED1	1300	35	23	114,000	83,000	87,000	99,000	101,000
	ED2	1600	28	24	115,000	88,000	91,000	99,000	101,000

TABLE A-9. (Continued)

Aging Treatment	Specimen	Swaging Temper-ature, F	Reduction in Area, per cent	Elongation, per cent in 1/2 inch	Ultimate Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi 0.01 Per Cent Offset	0.1 Per Cent Offset	0.2 Per Cent Offset
200 hours at 600 F under stress	EE1	1300	53	20	140,000	106,000	113,000	123,000	124,000
	EE2	1600	54	27	138,000	105,000	112,000	122,000	122,000
Annealed 1 Hour at 900 C; Furnace Cooled to 750 C, Held 1 Hour; Furnace Cooled to 700 C, Held 2 Hours; Furnace Cooled to 650 C, Held 2 Hours; Furnace Cooled to 600 C, Held 2 Hours and Air Cooled									
None	GA1	1300	51	33	94,000	64,000	69,000	76,000	78,000
	GA2	1600	40	25	96,000	72,000	75,000	81,000	--
200 hours at 600 F	GB1	1300	50	31	94,000	61,000	68,000	77,000	79,000
	GB2	1600	40	29	98,000	73,000	81,000	92,000	93,000
200 hours at 800 F	GC1	1300	39	27	98,000	61,000	66,000	74,000	76,000
	GC2	1600	41	25	100,000	64,000	68,000	77,000	79,000
200 hours at 1000 F	GD1	1300	51	33	90,000	64,000	68,000	73,000	74,000
	GD2	1600	51	33	94,000	65,000	71,000	79,000	81,000
200 hours at 600 F under stress	GE1	1300	42	27	102,000	80,000	81,000	82,000	83,000
	GE2	1600	35	22	97,000	74,000	78,000	85,000	86,000
Annealed 24 Hours at 600 C and Air Cooled									
None	JA1	1300	68	34	105,000	83,000	89,000	96,000 Y.P.	
	JA2	1300	63	32	105,000	81,000	85,000	97,000 Y.P.	
200 hours at 600 F	JB1	1300	63	40	107,000	73,000	80,000	100,000 Y.P.	
	JB2	1300	65	25	111,000	92,000	97,000	--	--
200 hours at 800 F	JC1	1300	31	20	107,000	84,000	90,000	98,000 Y.P.	
	JC2	1300	50	29	108,000	81,000	91,000	99,000 Y.P.	
200 hours at 1000 F	JD1	1300	41	32	95,000	64,000	69,000	77,000	78,000
	JD2	1300	46	27	93,000	64,000	69,000	77,000	78,000
200 hours at 600 F under stress	JE1	1300	60	28	108,000	93,000	96,000	99,000	99,000
	JE2	1300	57	37	106,000	90,000	95,000	102,000 Y.P.	
Annealed 24 Hours at 600 C and Air Cooled									
None	KA1	1600	45	19	124,000	87,000	97,000	111,000	116,000
	KA2	1600	36	18	120,000	85,000	91,000	103,000	107,000
200 hours at 600 F	KB1	1600	53	25	113,000	82,000	87,000	99,000	102,000
	KB2	1600	44	23	123,000	84,000	94,000	107,000	112,000
200 hours at 800 F	KC1	1600	48	28	112,000	75,000	80,000	96,000	101,000
	KC2	1600	53	28	115,000	83,000	89,000	101,000	103,000
200 hours at 1000 F	KD1	1600	46	26	96,000	71,000	74,000	81,000	82,000
	KD2	1600	43	27	96,000	67,000	72,000	80,000	81,000
200 hours at 600 F under stress	KE1	1600	53	26	115,000	80,000	84,000	96,000	101,000
	KE2	1600	52	27	113,000	91,000	94,000	99,000	101,000

(a) Y. P. indicates sharp yield point.

TABLE A-10. EFFECT OF 200-HOUR AGING TREATMENTS ON THE TENSILE PROPERTIES OF A Ti-5.0Cr-5.0Mo ALLOY FOR VARIOUS STABILIZING TREATMENTS

Aging Treatment	Specimen	Swaging Temper-ature, F	Reduction in Area, per cent	Elongation, per cent in 1/2 inch	Ultimate Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi 0.01 Per Cent Offset	Yield Strength, psi 0.1 Per Cent Offset	Yield Strength, psi 0.2 Per Cent Offset
			Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled						
None	CA1	1300	72	29	116,000	--	--	--	--
	CA2	1300	70	28	117,000	98,000	102,000	109,000 Y.P.(a)	
200 hours at 600 F	CB1	1300	44	18	142,000	--	--	--	--
	CB2	1300	53	21	145,000	103,000	107,000	124,000	127,000
200 hours at 800 F	CC1	1300	30	19	129,000	102,000	107,000	112,000	113,000
	CC2	1300	55	24	135,000	85,000	92,000	113,000	115,000
200 hours at 1000 F	CD1	1300	35	23	114,000	83,000	87,000	99,000	101,000
	CD2	1300	28	24	115,000	88,000	91,000	99,000	101,000
200 hours at 600 F under stress	CE1	1300	53	20	140,000	106,000	113,000	123,000	124,000
	CE2	1300	54	27	138,000	105,000	112,000	122,000	122,000
			Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled						
None	DA1	1600	64	27	123,000	95,000	103,000	114,000	115,000
	DA2	1600	53	25	126,000	109,000	112,000	119,000	119,000
200 hours at 600 F	DB1	1600	21	20	151,000	123,000	129,000	142,000	145,000
	DB2	1600	34	22	150,000	--	--	--	--
200 hours at 800 F	DC1	1600	48	23	135,000	95,000	99,000	114,000	118,000
	DC2	1600	43	12	140,000	101,000	106,000	120,000	125,000
200 hours at 1000 F	DD1	1600	32	26	116,000	87,000	93,000	100,000	102,000
	DD2	1600	37	24	116,000	84,000	89,000	100,000	103,000
200 hours at 600 F under stress	DE1	1600	44	22	139,000	110,000	116,000	129,000	131,000
	DE2	1600	44	23	137,000	109,000	113,000	126,000	129,000
			Annealed 1 Hour at 900 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled						
None	FA1	1300	54	27	123,000	86,000	96,000	113,000	115,000
	FA2	1600	55	25	124,000	90,000	94,000	110,000	113,000
200 hours at 600 F	FB1	1300	45	33	127,000	90,000	96,000	111,000	117,000
	FB2	1600	46	27	127,000	--	--	--	--
200 hours at 800 F	FC1	1300	35	20	134,000	86,000	90,000	103,000	109,000
	FC2	1600	58	22	136,000	84,000	89,000	104,000	110,000
200 hours at 1000 F	FD1	1300	35	26	113,000	82,000	88,000	100,000	103,000
	FD2	1600	40	26	114,000	83,000	91,000	103,000	105,000
200 hours at 600 F under stress	FE1	1300	38	20	132,000	85,000	93,000	111,000	117,000
	FE2	1600	31	20	134,000	101,000	105,000	118,000	122,000

TABLE A-10. (Continued)

Aging Treatment	Specimen	Swaging Temperature, F	Reduction in Area, per cent	Elongation, per cent in 1/2 inch	Ultimate Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi 0.01 Per Cent Offset	Yield Strength, psi 0.1 Per Cent Offset	Yield Strength, psi 0.2 Per Cent Offset
			Annealed 1 Hour at 900 C; Furnace Cooled to 750 C, Held 1 Hour; Furnace Cooled to 700 C, Held 2 Hours; Furnace Cooled to 650 C, Held 2 Hours; Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled						
None	HA1	1300	50	27	117,000	88,000	92,000	104,000	106,000
	HA2	1600	52	25	117,000	--	--	--	--
200 hours at 600 F	HB1	1300	33	18	127,000	81,000	86,000	100,000	105,000
	HB2	1600	42	22	127,000	84,000	89,000	103,000	108,000
200 hours at 800 F	HC1	1300	42	20	131,000	87,000	93,000	109,000	117,000
	HC2	1600	37	19	132,000	83,000	91,000	107,000	113,000
200 hours at 1000 F	HD1	1300	51	25	113,000	77,000	85,000	94,000	98,000
	HD2	1600	51	26	114,000	83,000	89,000	98,000	101,000
200 hours at 600 F under stress	HE1	1300	27	31	136,000	88,000	95,000	108,000	113,000
	HE2	1600	23	13	139,000	95,000	101,000	104,000	109,000
			Annealed 24 Hours at 600 C and Air Cooled						
None	LA1	1300	68	24	126,000	--	--	--	--
	LA2	1300	62	26	125,000	111,000	117,000	125,000 Y.P.	
200 hours at 600 F	LB1	1300	64	24	132,000	109,000	119,000	--	--
	LB2	1300	55	26	111,000	92,000	97,000	--	--
200 hours at 800 F	LC1	1300	61	28	134,000	--	--	--	--
	LC2	1300	62	27	127,000	--	--	126,000 Y.P.	
200 hours at 1000 F	LD1	1300	33	22	114,000	88,000	90,000	99,000	101,000
	LD2	1300	28	32	114,000	91,000	95,000	101,000	102,000
200 hours at 600 F under stress	LE1	1300	65	28	127,000	--	--	--	--
	LE2	1300	51	27	129,000	118,000	123,000	129,000 Y.P.	
			Annealed 24 Hours at 600 C and Air Cooled						
None	MA1	1600	28	7	138,000	120,000	124,000	132,000	133,000
	MA2	1600	36	17	140,000	116,000	122,000	134,000	135,000
200 hours at 600 F	MB1	1600	15	11	144,000	--	--	--	--
	MB2	1600	36	18	153,000	119,000	130,000	140,000	141,000
200 hours at 800 F	MC1	1600	40	17	146,000	108,000	115,000	134,000	138,000
	MC2	1600	31	11	144,000	119,000	127,000	143,000	143,000
200 hours at 1000 F	MD1	1600	36	23	115,000	89,000	94,000	101,000	103,000
	MD2	1600	40	25	117,000	86,000	90,000	101,000	104,000
200 hours at 600 F under stress	ME1	1600	49	21	141,000	123,000	127,000	138,000	139,000
	ME2	1600	40	22	141,000	119,000	123,000	135,000	138,000

(a) Y.P. indicates sharp yield point.

TABLE A-11. EFFECT OF 200-HOUR AGING TREATMENTS ON THE

Specimen	Aging Treatment	Swaging Temperature, F	Specimens Tested at -196 C: Reduction in Area, per cent	Ultimate Strength, psi
			Annealed 1 Hour at 750 C, Furnace Cooled	
AA	None	1300	12	252,000
AB	200 hours at 600 F	1300	12	261,000
AC	200 hours at 800 F	1300	10	228,000
AD	200 hours at 1000 F	1300	18	264,000
AE	200 hours at 600 F under stress	1300	11	259,000
			Annealed 1 Hour at 750 C, Furnace Cooled	
BA	None	1600	9	295,000
BB	200 hours at 600 F	1600	9	301,000
BC	200 hours at 800 F	1600	13	275,000
BD	200 hours at 1000 F	1600	16	219,000
BE	200 hours at 600 F under stress	1600	14	298,000
			Annealed 1 Hour at 900 C, Furnace Cooled	
EA	None	1600	8	276,000
EB	200 hours at 600 F	1600	8	261,000
EC	200 hours at 800 F	1600	11	262,000
ED	200 hours at 1000 F	1600	8	260,000
EE	200 hours at 600 F under stress	1600	11	278,000
			Annealed 1 Hour at 900 C; Furnace Cooled to 700 C, Furnace Cooled to 650 C, Held 2 Hours; Furnace	
GA	None	1600	5	272,000
GB	200 hours at 600 F	1600	11	255,000
GC	200 hours at 800 F	1600	10	254,000
GD	200 hours at 1000 F	1600	7	266,000
GE	200 hours at 600 F under stress	1600	5	277,000
			Annealed 24 Hours at	
JA	None	1300	9	258,000
JB	200 hours at 600 F	1300	6	259,000
JC	200 hours at 800 F	1300	8	229,000
JD	200 hours at 1000 F	1300	9	268,000
JE	200 hours at 600 F under stress	1300	12	257,000

NOTCHED TENSILE PROPERTIES OF A Ti-2.5Cr-2.5Mo ALLOY

Specimens Tested at -40 C		Specimens Tested at 25 C		Specimens Tested at 200 C	
Reduction in Area, per cent	Ultimate Strength, psi	Reduction in Area, per cent	Ultimate Strength, psi	Reduction in Area, per cent	Ultimate Strength, psi
to 600 C, Held 2 Hours and Air Cooled					
17	176,000	16	154,000	47	111,000
13	193,000	12	168,000	32	124,000
7	174,000	11	159,000	25	117,000
16	177,000	21	159,000	24	100,000
14	186,000	20	168,000	42	119,000
to 600 C, Held 2 Hours and Air Cooled					
14	208,000	20	170,000	37	123,000
9	195,000	20	179,000	26	122,000
11	189,000	21	167,000	26	120,000
13	183,000	19	162,000	25	101,000
16	198,000	19	172,000	34	124,000
to 600 C, Held 2 Hours and Air Cooled					
12	176,000	19	155,000	28	--
13	173,000	17	155,000	21	105,000
13	174,000	12	152,000	18	104,000
12	180,000	20	150,000	22	97,000
15	183,000	16	163,000	23	107,000
Held 1 Hour; Furnace Cooled to 700 C, Held 2 Hours; Cooled to 600 C, Held 2 Hours, and Air Cooled					
15	178,000	20	143,000	23	98,000
15	175,000	19	151,000	15	99,000
11	176,000	12	159,000	17	100,000
15	175,000	20	145,000	21	97,000
10	178,000	15	158,000	16	109,000
600 C and Air Cooled					
13	189,000	20	159,000	39	120,000
17	187,000	15	166,000	33	126,000
9	176,000	10	160,000	16	114,000
0	174,000	18	149,000	22	98,000
13	182,000	24	164,000	38	118,000

TABLE A-11.

Specimen	Aging Treatment	Swaging Temperature, F	Specimens Tested at -196 C: Reduction in Area, per cent	Specimens Tested at -196 C: Ultimate Strength, psi
				Annealed 24 Hours at
KA	None	1600	10	296, 000
KB	200 hours at 600 F	1600	8	289, 000
KC	200 hours at 800 F	1600	12	282, 000
KD	200 hours at 1000 F	1600	13	259, 000
KE	200 hours at 600 F under stress	1600	13	295, 000

(Continued)

Specimens Tested at -40 C		Specimens Tested at 25 C		Specimens Tested at 200 C	
Reduction in Area, per cent	Ultimate Strength, psi	Reduction in Area, per cent	Ultimate Strength, psi	Reduction in Area, per cent	Ultimate Strength, psi
600 C and Air Cooled					
15	208,000	14	182,000	24	144,000
15	212,000	17	183,000	21	144,000
7	189,000	13	185,000	21	140,000
18	179,000	21	161,000	22	103,000
13	208,000	14	190,000	26	126,000

TABLE A-12. EFFECT OF 200-HOUR AGING TREATMENTS ON THE

Specimen	Aging Treatment	Swaging Temperature, F	Specimens Tested at -196 C: Reduction in Area, per cent	Ultimate Strength, psi
			Annealed 1 Hour at 750 C, Furnace Cooled	
CA	None	1300	0	266,000
CB	200 hours at 600 F	1300	0	195,000
CC	200 hours at 800 F	1300	3	225,000
CD	200 hours at 1000 F	1300	6	193,000
CE	200 hours at 600 F under stress	1300	0	>188,000[(a)]
			Annealed 1 Hour at 750 C, Furnace Cooled	
DA	None	1600	5	327,000
DB	200 hours at 600 F	1600	1	287,000
DC	200 hours at 800 F	1600	2	289,000
DD	200 hours at 1000 F	1600	0	191,000
DE	200 hours at 600 F under stress	1600	0	>302,000[(a)]
			Annealed 1 Hour at 900 C, Furnace Cooled	
FA	None	1600	3	295,000
FB	200 hours at 600 F	1600	6	286,000
FC	200 hours at 800 F	1600	9	277,000
FD	200 hours at 1000 F	1600	4	297,000
FE	200 hours at 600 F under stress	1600	10	246,000
			Annealed 1 Hour at 900 C; Furnace Cooled to 750 C, Furnace Cooled to 650 C, Held 2 Hours, Furnace	
HA	None	1600	3	291,000
HB	200 hours at 600 F	1600	3	245,000
HC	200 hours at 800 F	1600	4	294,000
HD	200 hours at 1000 F	1600	2	296,000
HE	200 hours at 600 F under stress	1600	6	260,000
			Annealed 24 Hours at	
LA	None	1300	11	222,000
LB	200 hours at 600 F	1300	5	238,000
LC	200 hours at 800 F	1300	6	191,000
LD	200 hours at 1000 F	1300	10	279,000
LE	200 hours at 600 F under stress	1300	4	247,000

NOTCHED TENSILE PROPERTIES OF A Ti-5.0Cr-5.0Mo ALLOY

Specimens Tested at -40 C		Specimens Tested at 25 C		Specimens Tested at 200 C	
Reduction in Area, per cent	Ultimate Strength, psi	Reduction in Area, per cent	Ultimate Strength, psi	Reduction in Area, per cent	Ultimate Strength, psi
to 600 C, Held 2 Hours and Air Cooled					
13	210,000	24	179,000	41	171,000
4	228,000	9	223,000	15	171,000
6	194,000	11	191,000	21	156,000
17	207,000	19	183,000	22	134,000
7	233,000	15	219,000	20	173,000
to 600 C, Held 2 Hours and Air Cooled					
14	226,000	25	192,000	20	152,000
8	235,000	7	226,000	14	180,000
8	227,000	11	178,000	15	153,000
13	210,000	18	185,000	21	132,000
9	235,000	12	211,000	17	173,000
to 600 C, Held 2 Hours and Air Cooled					
12	224,000	16	197,000	24	153,000
12	218,000	12	197,000	13	148,000
8	224,000	10	199,000	18	158,000
7	207,000	17	184,000	17	135,000
12	226,000	16	209,000	20	161,000
Held 1 Hour; Furnace Cooled to 700 C, Held 2 Hours Cooled to 600 C, Held 2 Hours, and Air Cooled					
14	220,000	18	186,000	27	139,000
8	216,000	7	196,000	12	154,000
11	223,000	8	200,000	11	152,000
16	205,000	15	179,000	19	132,000
5	194,000	6	197,000	11	161,000
600 C and Air Cooled					
10	217,000	21	187,000	46	150,000
8	222,000	18	205,000	38	169,000
5	197,000	9	185,000	27	147,000
17	209,000	19	184,000	20	129,000
17	223,000	20	201,000	42	156,000

TABLE A-12.

Specimen	Aging Treatment	Swaging Temperature, F	Specimens Tested at -196 C: Reduction in Area, per cent	Ultimate Strength, psi
				Annealed 24 Hours at
MA	None	1600	6	248,000
MB	200 hours at 600 F	1600	6	261,000
MC	200 hours at 800 F	1600	6	237,000
MD	200 hours at 1000 F	1600	10	301,000
ME	200 hours at 600 F under stress	1600	8	327,000

(a) Specimen failed in threaded section.

(Continued)

Specimens Tested at -40 C		Specimens Tested at 25 C		Specimens Tested at 200 C	
Reduction in Area, per cent	Ultimate Strength, psi	Reduction in Area, per cent	Ultimate Strength, psi	Reduction in Area, per cent	Ultimate Strength, psi
600 C and Air Cooled					
7	235,000	5	220,000	18	182,000
5	241,000	4	222,000	19	180,000
12	226,000	9 8	218,000 219,000	--	--
12	213,000	14	181,000	28	131,000
9	239,000	10	220,000	15	192,000

TABLE A-13. ROOM-TEMPERATURE NOTCHED STRESS-RUPTURE DATA FOR A Ti-2.5Cr-2.5Mo ALLOY IN TWO CONDITIONS

Specimens Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled

		As Heat Treated			Aged 200 Hours at 800 F		
Specimen	Swaging Temperature, F	Reduction in Area, per cent	Ultimate Strength, psi	Time to Fracture, hours	Reduction in Area, per cent	Ultimate Strength, psi	Time to Fracture, hours
8	1300	20	139,000	12.3	16	145,000	55.0
9	1300	23	142,000	1.1	14	146,000	94.7
10	1300	20	136,000	44.9	15	150,000	27.0
11	1300	23	139,000	70.2	13	151,000	0.4
12	1300	17	142,000	<0.1	9	146,000	0.1
13	1300	24	139,000	3.5	--	--	--
14	1300	24	139,000	2.5	--	--	--
15	1300	--	136,000	--	--	--	--

TABLE A-14. ROOM-TEMPERATURE NOTCHED STRESS-RUPTURE DATA FOR A Ti-5.0Cr-5.0Mo ALLOY IN TWO CONDITIONS

Specimens Annealed 1 Hour at 750 C, Furnace Cooled to 600 C, Held 2 Hours, and Air Cooled

		As Heat Treated			Aged 200 Hours at 800 F		
Specimen	Swaging Temperature, F	Reduction in Area, per cent	Ultimate Strength, psi	Time to Fracture, hours	Reduction in Area, per cent	Ultimate Strength, psi	Time to Fracture, hours
8	1300	16	161,000	170.0	6	172,000	30.9
9	1300	19	165,000	32.5	10	176,000	44.8
10	1300	20	168,000	<0.1	11	180,000	<0.1
11	1300	20	166,000	0.2	10	176,000	69.5
12	1300	--	--	--	11	178,000	24.0
13	1300	--	--	--	10	178,000	23.4
14	1300	--	--	--	--	--	--