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ASD TECHNICAL REPORT 62-7-675
January 1962

TITANIUM DIRECTIONALITY PROGRAM

A. E. Leach

Crucible Steel Company of America
Midland Research Laboratory
Contract: AF33(600)-37938
ASD Project: 7-675

Final Technical Engineering Report
7 January 1959 - 15 September 1961

This manufacturing process development determined techniques for strip processing to minimize high directional mechanical properties in three DOD titanium alloys. Full-scale strip processing production operations starting with 4000 pound Ti-6Al-4V, Ti-4Al-3Mo-1V and Ti-2½Al-16V ingots have shown that the Ti-2½Al-16V alloy is almost ideally suited to strip processing, developing negligible directionality and having excellent rolling and processing characteristics. The production of Ti-2½Al-16V sheet by strip rolling instead of hand sheet processing will result in greater economies in production of better gage, flatness, and surface finish control. While much information was developed on strip processing the Ti-6Al-4V and Ti-4Al-3Mo-1V alloys, final directionality in these two alloys was still higher than in hand sheet product.

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Manufacturing Technology Laboratory

Aeronautical Systems Division
United States Air Force
Wright-Patterson Air Force Base, Ohio

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Manufacturing Technology Laboratory

Aeronautical Systems Division
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ABSTRACT-SUMMARY
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The approach taken to investigate directionality control in titanium alloy strip was to determine the effect of empirical processing schedules on directionality in the laboratory, then to test these laboratory results by full-scale production operations, the results of which are summarized above. The investigation of empirical processing schedules was necessary because insufficient information was available in the literature to base investigations on the development of crystallographic textures and their effects on directionality. The literature contains comprehensive data on cold rolled and annealed textures and deformation mechanisms of unalloyed hexagonal-close-packed alpha titanium, but very little information on textures and deformation mechanisms of alloyed titanium. Experience has shown that, in general, strip processed beta titanium alloys are least directional, alpha titanium alloys are most directional, and combined alpha-beta titanium alloys are intermediate with respect to directionality.

Laboratory investigations of twenty combinations of strip processing variables indicated that a decrease in Ti-6Al-4V strip directionality could be achieved by increasing final cold reduction to the practical limit of ductility. However, this finding was not supported by full-scale Ti-6Al-4V strip rolling. Directionality of the Ti-2½Al-16V and Ti-4Al-3Mo-1V alloys does not respond to processing variations to the same degree as Ti-6Al-4V.

Rolling speed, roll diameter, and strip tension appears to have no effect on strip directionality. Aged Ti-6Al-4V properties are unaffected by tensile prestrain such as may be encountered during forming operations.

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FOREWORD

This Final Technical Engineering Report covers all work performed from January 1959 to September 1961, under contract AF33(600)-37938, Crucible Steel Company of America, Midland Research Laboratory. The manuscript was released by the author on 3 January 1962 for publication as an ASD Technical Report.

This contract with Midland Research Laboratory of the Crucible Steel Company of America, Midland, Pennsylvania was initiated under ASD Manufacturing Methods Project 7-675, "Titanium Directionality Program." It was accomplished under the technical direction of Hugh L. Black of the Basic Industry Branch of the Manufacturing Technology Laboratory, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

Midland Research Laboratory personnel are A. E. Leach, Project Engineer, Dr. H. J. Clark, Manager, Midland Research Laboratory, R. F. Malone, Supervisor, Mill Process Research Section. The entire project was under the guidance of Dr. P. F. Darby, Supervisor of the Mechanical Metallurgy Section.

The methods used to demonstrate a process or technique on a laboratory scale are inadequate for use in production operations. The objective of the Air Force Manufacturing Methods Program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components. This program encompasses the following technical areas:

Rolled Sheets, Forgings, Extrusions, Castings, Fiber and Powder Metallurgy.
Component Fabrication, Joining, Forming, Materials Removal.
Fuels, Lubricants, Ceramics, Graphites, Non-metallic Structural Materials.
Solid State Devices, Passive Devices, Thermionic Devices.

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated.

* *

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER

JACK R. MARSH
Assistant Chief
Manufacturing Technology Laboratory
Directorate of Materials and Processes

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INTRODUCTION

It has been established that continuously hot and cold rolled titanium alloys exhibit pronounced directionality of properties. The purpose of this project is to reduce the differential between longitudinal and transverse properties to an acceptable minimum for rolled titanium alloy sheet and strip.

Objectives

1. To relate the directionality of sheet or strip as rolled with the capability to form final aircraft components with satisfactory characteristics.

2. To obtain data on the extent of uniform deformation and preferred orientation in the DOD sheet alloys exposed to various hot rolling cycles and may include cold rolling cycles.

3. To correlate the extent of the preferred orientation resulting from these rolling operations with mechanical tests.

4. To establish the minimum differential in directionality that is economical and design-wise acceptable to the airframe and missile industry.

5. To establish the optimum rolling cycles for the DOD Sheet Rolling Alloys which would result in the minimum directionality.

Since continuous rolling is a high volume method of production these objectives are particularly appropriate for the DOD alloys, Ti-6Al-4V, Ti-4Al-3Mo-1V and Ti-2½Al-16V. The sequence used in this investigation is Phase I literature survey, Phase II rolling processes selected and tried on laboratory equipment, Phase III production of full sized strip.

PHASE I

Literature Search

DISCUSSION

It is generally agreed that the principal causes of directionality in strip product are phase or inclusion pattern and preferred crystallographic orientation.

In ordinary ferrous and non-ferrous strip product, inclusion shape and distribution can be a large contributing factor to directionality.[1*] This is not the case in titanium-base alloys which are vacuum-arc melted in an inert atmosphere. These alloys are free of compounds and particles of the inclusion type. Phase pattern (principally elongated alpha or beta grains) can contribute to directionality in titanium alloy strip but this is controllable in strip processing to a certain extent through cold rolling and annealing cycles and is therefore believed to be a minor factor. This leaves preferred crystallographic orientations as a major contributor to titanium alloy strip directionality. This discussion will be confined to data on titanium alloy orientations and general information applicable thereto, and the reader is referred to existing works on the subject of preferred orientations for additional information. Probably one of the best of these is Barrett[1], which contains a complete bibliography and discusses hot and cold rolling textures, recrystallization textures, their effects on directionality, and such effects of processing on orientations as are known.

Very little data exist on deformation mechanisms or textures of highly alloyed hexagonal-close-packed or body-centered-cubic titanium alloys such as are being processed under this contract. However, substantial work[3,4,6,7,16,18] has been done to determine deformation mechanisms of unalloyed HCP alpha titanium, which has been summarized[2] as follows:

Temperature, °F	Slip Systems	Twinning Systems	References
-320	$\{10\bar{1}0\}$ $\langle 11\bar{2}0\rangle$	$\{11\bar{2}4\}$, $\{11\bar{2}2\}$, $\{11\bar{2}1\}$, $\{10\bar{1}2\}$, $\{11\bar{2}3\}$	6
75	$\{10\bar{1}0\}$ $\langle 11\bar{2}0\rangle$, $\{10\bar{1}1\}$ $\langle 11\bar{2}0\rangle$, $\{0001\}$ $\langle 11\bar{2}0\rangle$	$\{10\bar{1}2\}$, $\{11\bar{2}1\}$, $\{11\bar{2}2\}$	3, 16, 18
930	$\{10\bar{1}0\}$ $\langle 11\bar{2}0\rangle$, $\{10\bar{1}1\}$ $\langle 11\bar{2}0\rangle$, $\{0001\}$ $\langle 11\bar{2}0\rangle$	$\{10\bar{1}2\}$	6
1470	$\{10\bar{1}0\}$ $\langle 11\bar{2}0\rangle$, $\{10\bar{1}1\}$ $\langle 11\bar{2}0\rangle$	$\{10\bar{1}2\}$	6
1500	$\{10\bar{1}0\}$ $\langle 11\bar{2}0\rangle$, $\{10\bar{1}1\}$ $\langle 11\bar{2}0\rangle$	$\{11\bar{2}1\}$, $\{11\bar{2}2\}$	7

* Numbers indicate references in selected bibliography.

These mechanisms may be considerably different in alloyed HCP titanium. Increasing interstitial content[3] strongly affects the critical resolved shear stress for slip and the ratios between the various slip systems and similar effects may be expected from increasing substitutional alloy content.

Available information on critical resolved shear stress for slip in unalloyed HCP titanium has been summarized[2] as:

Investigator	Critical Resolved Shear Stress, kg/mm^2 (a)					
	$\{10\bar{1}0\}$	$\langle 11\bar{2}0\rangle$	$\{10\bar{1}1\}$	$\langle 11\bar{2}0\rangle$	$\{0001\}$	$\langle 11\bar{2}0\rangle$
Churchman[3]						
(a) 0.1 $O_2 + N_2$	9.19 (13,060)		9.90 (14,060)		10.90 (15,480)	
(b) 0.01 $O_2 + N_2$	1.4 (1,990)		-		6.3 (8,950)	
Rosi, et al.[5]	4.9-6.8 (6,960-9,660)		-		-	
Anderson, et al.[16]	5 (7,110)		-		10.9-13.5 (15,480-19,170)	

(a) Parenthetical values show pounds per square inch

At room temperature slip occurs on $\{10\bar{1}0\}$ $\langle 11\bar{2}0\rangle$, $\{10\bar{1}1\}\langle 11\bar{2}0\rangle$, and (0001) $\langle 11\bar{2}0\rangle$ in slightly decreasing order of preference but a decrease in interstitial content markedly favors slip on $\{10\bar{1}0\}$ $\langle 11\bar{2}0\rangle$.

Barrett[1] gives "ideal" rolling textures for HCP metals (with axial ratios near that for the close packing of spheres, c/a = 1.633) as (0001) $[10\bar{1}0]$ and for BCC metals as (100) [011]. He also points out that the ideal HCP rolling texture is commonly modified by twinning. Several investigators [11, 12, 14, 15] have determined that the rolling texture of HCP titanium differs from the ideal in that (0001) poles are rotated about 30° toward the transverse direction around an axis located in the rolling direction. This departure from the ideal is believed [2,19] caused by $\{11\bar{2}2\}$ twinning, which would tend to alter all (0001) planes within 30° of the rolling plane to a position about 90° from the rolling plane. During deformation this would be a continuous process, of course, which can be pictured [2,19] as (0001) planes being rotated by slip from a position perpendicular to the transverse direction to 30° from the rolling plane and then being rotated back to their original position by twinning.

Rolling textures of Ti-7.1 Zr, Ti-3.6 Ta, Ti-3.6 Cb and Ti-3.8 Al HCP alpha alloys have been determined [17]. The Ti-3.8 Al alloy developed almost none of the basal plane tilt described above for pure titanium and was very close to the ideal texture for HCP metals. The other alloys had rolling textures similar to that of pure titanium.

Hot rolling of alpha titanium produces a texture similar to that caused by cold rolling. Material [2,12] rolled at 1050F and 1450F had (0001) $[10\bar{1}0]$ textures with considerable spread in both the transverse and rolling directions.

The behavior of titanium rolling textures during recrystallization (or "annealing", for a more appropriate, general term) is very complex, and is complicated further by the allotropic transformation from HCP to BCC. Several investigations[10,11,12,14] on the effect of annealing treatments on the unalloyed HCP titanium texture have been summarized[2] and indicate that -

1) Low temperature annealing (less than 1000F) produce only a sharpening of the rotated (0001) $[10\bar{1}0]$ rolling texture.

2) Increasing the annealing temperature up to 1500F increases the predominance of a new (0001) $[11\bar{2}0]$ rotated texture over the old one. Some investigators also report a rotated (0001) $[10\bar{1}0]$ texture with the $[10\bar{1}0]$ direction 14 - 20° from the rolling direction for anneals in this temperature range.

3) Heating to just above the beta transus temperature (1650F-1920F) produced a rotated (0001) $[11\bar{2}0]$ texture which could be explained if the (0001) alpha plane tended to coincide with $\{110\}$ beta planes during transformation.

4) Heating high into the beta field (2190F) produced a new complex texture which was believed caused by the development of a (001) [100] cube texture in the beta phase by secondary recrystallization and subsequent transformation to alpha phase with the (0001) alpha plane forming parallel to prior $\{110\}$ beta planes.

No discussion of preferred orientation in the beta phase of alpha-beta or beta titanium alloys was encountered in the literature. A review of Crucible Steel Company of America data on tensile properties of alpha-beta sheet alloys, such as 6Al-4V, 4Al-3Mo-1V, 16V-2½Al (the DOD alloys), and 8Mn reveals that the magnitude of the directionality problem decreases with increasing proportions of beta phase in the annealed microstructure. Therefore, though the contribution of beta phase preferred orientation to mechanical property directionality is not clearly established, it is not felt to be of any significant importance. Based on this assumption, the directionality problem in the three alloys being investigated under this contract in order of decreasing magnitude will probably be 6Al-4V, 4Al-3Mo-1V and 16V-2½Al.

The foregoing discussion illustrates the difficulty of applying fundamental texture studies to the problem of minimizing directionality in titanium alloy strip. The alloys investigated under this contract have both HCP alpha and BCC beta phases co-existing in their structures. Furthermore, both of these phases are high in alloy content and chemical composition of the individual phases can be varied by heat treatment. These factors, plus recrystallization characteristics of the individual phases, mode of phase transformation (precipitation plus growth or growth of existing phase particles), cold rolling variables, and heat treatments can all affect texture behavior. Therefore, our approach to the titanium alloy strip directionality problem will be to investigate the effects of a variety of empirical processing schedules on mechanical

properties determined at several angles to the rolling direction. This is traditionally the method used to minimize directionality in strip products, since there are few well defined laws governing crystal behavior under various combinations of deformation and annealing. In developing these empirical processing schedules we have relied largely upon Crucible's extensive experience in the strip processing of titanium alloys.

Phase pattern may also contribute to mechanical property directionality. While never actively investigated in sheet material, Crucible Steel Company of America has long recognized the directional effects of elongated alpha in two-phase alloy billet material; therefore, the possibility of the existence of a dispersion of preferentially elongated alpha grains in a transformation or beta matrix in strip product should not be overlooked. It is impossible to distinguish between the contributions of crystallographic orientation and phase pattern to directionality by mechanical testing. Although metallographic examination need not necessarily confirm existence of a phase pattern, this technique was employed in an attempt to minimize the possibility of phase pattern occurrence.

Strip processing can conveniently be divided into three sections--hot rolling, cold rolling and thermal treatments (other than simple heating for hot rolling)--each involving a number of independent variables which influence preferred orientation. The three sections listed above will be discussed individually with respect to past Crucible experience.

Hot Rolling

Temperature, heating schedule, reduction schedule and rolling speed are the four primary independent variables in the hot rolling section of strip processing. Of these, attention has been focused on temperature. Directionality at the 1/8" thick (hot-band) stage has been minimized by rolling to gage entirely above the beta transus, i.e., at a temperature sufficiently high that only the body-centered-cubic beta phase exists during rolling. This effect is shown in Tables I and II, which give the hot rolled tensile properties of the two-phase alloys 4Al-3Mo-1V and 16V-2½Al respectively, after laboratory rolling to 1/8" at various temperatures. This condition, while closely approximated, has not been readily achieved in production rolling of alpha-beta alloys. The maximum rolling temperature is limited by oxide skin formation, gas absorption and excessive grain growth. Excessive grain growth in combination with heavy oxide skin formation results in severe surface tearing and cracking during rolling, making conditioning extremely difficult and expensive. Under these conditions, subsequent operations do not result in satisfactory product. Minimum rolling temperature is influenced primarily by roll pressure requirements.

It has been demonstrated by mill experience that the heating schedule should be such that heating time should not exceed the time required for material to attain a uniform temperature throughout, since gas absorption, oxide skin formation and grain growth proceed rapidly, particularly at temperatures above the beta transus. Since heating schedule is largely a matter of accurate temperature measurement and process control, it requires no investigation.

We did not find any discussion in the literature of the influence of heavy versus light hot reductions per pass on preferred orientation nor do we know of any unreported investigations. It is expected, however, that the effect will be similar to that encountered in the cold rolling of alpha titanium and zirconium--heavy reductions will produce a more highly oriented structure than will light reductions. Maximum and minimum reductions on production facilities are determined by mill capabilities and minimum finishing temperature considerations. Since rolling speed and reduction schedules are both strain rate variables, and since speed cannot be controlled as readily as reduction schedules, only the latter variable was investigated for the hot rolling portion of this work.

Cold Rolling

During cold rolling there are more processing variables available to influence directionality. Of greatest importance are starting condition, total reduction or strain, mill tension and the strain rate variables, roll speed and roll size. Starting condition refers to grain size and the relative proportions of alpha and beta phase in the microstructure. Rolling a metastable beta obtained by solution treatment anneals offers a possibility for reducing preferred orientation and resultant mechanical property directionality. However, the effectiveness of solution treatments is limited by cold rollability and quality considerations.

Greater total reductions generally result in a higher degree of preferred orientation. A minimum reduction of approximately 20% is required, however, to restore mechanical properties which are destroyed by some of the randomization thermal treatments which are to be investigated. Here again is exhibited the great inderdependence of thermal treatment and cold rolling variables.

Strain rate sensitivity of titanium is well known and was investigated by Crucible Steel Company of America under AMC contract, AF 33(038)-21912. However, the effects of the strain rate variables, roll speed and size, on directionality are not reported in the literature. Nor have mill tension effects been reported. These are examined under Phase II of this contract.

Thermal Treatments

The greatest emphasis has been placed on development of thermal cycles to reduce directionality. Independent variables investigated were time, temperature and cooling rate.

Short time betatizing anneals, i.e. annealing above the beta transus, followed by air cooling to retain a large portion of metastable beta phase, and long time alpha-beta final anneals have produced satisfactory directionality results in 6Al-4V alloy strip. However, the low directionality has usually been accompanied by low strength. Tables III and IV give mechanical property results of C120AV at each processing stage. The influence of a solution treatment is shown in Table III: directionality is reduced considerably.

Overaging of solution treated strip (i.e., material containing a large portion of metastable beta in the microstructure) in combination with a variety of prior and subsequent thermal treatments and cold rolling schedules offers some possibility for minimizing preferred orientation in titanium alloy strip.

Considerable work is required in the promising area of themal treatments.

CONCLUSIONS

Comprehensive studies of deformation mechanisms and textures of cold rolled and annealed unalloyed hexagonal-close-packed alpha titanium have been made and are reported in the literature. Little information is available, however, on the effects of alloying on hexagonal-close-packed alpha textures or body-centered-cubic beta textures. Moreover, the effects of textures on directionality are known only in a general way.

Hexagonal-close-packed metals such as zinc and cadmium do not deform as titanium does because they have an abnormally high c/a ratio. Others such as beryllium, zirconium, hafnium and osmium have been explored less than titanium. Magnesium and its alloys have been studied extensively but directionality is severe and is minimized largely by cross rolling. Accordingly the literature provides little that is directly applicable to this program.

On the other hand body-centered-cubic metals have been studied in detail and their crystallographic and directional characteristics are consistent. Since the alloys being investigated under this contract are two phase, additional complications arise during heat treatment because of the transitions from one phase to the other and resulting changes in orientation.

The prior art indicates that the rolling texture of alpha or hexagonal-close-packed titanium is $[10\bar{1}0]$. The basal plane (0001) rotates out of the rolling plane by various amounts depending on the alloy content, but concentrates at 30° for unalloyed titanium. Combinations of slip and twinning have been shown to account for this phenomena depending on specific assumptions about the ratios of the critical resolved shear stress. Certain annealed and recrystallized textures are explainable as arising from the basal plane transforming to the (110) plane of the beta phase. These suggest that heat treatment during processing is of major importance in directionality.

Therefore, the literature search conducted under this contract indicates that titanium alloy strip directionality control can best be investigated by determining the effects of a variety of empirical processing schedules.

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PHASE II

Laboratory Investigations of Processing Variables

DESCRIPTION OF PHASE II PROGRAM

Phase II is an intermediate step in which the results of the Phase I literature search and Crucible experience in strip processing were combined in laboratory investigations of processing variables. These were designed to lead to improved production processing sequences, to be tried out on production-size slabs in Phase III.

Of the three alloys being investigated, most of the Phase II laboratory work was carried out on the Ti-6Al-4V alloy in order to refine the strip processing attempted under Navy Contract NOas 56-995c. The processing and metallurgical characteristics of Ti-4Al-3Mo-1V and Ti-2½Al-16V sheet were still being explored under the latter contract at the time the directionality program reported here was begun. The Navy contract was directed to hand sheet processing, but also called for exploration of basic Ti-4Al-3Mo-1V and Ti-2½Al-16V strip processing characteristics. The laboratory processing of Ti-6Al-4V for minimizing directionality was synchronized with the exploratory work on the other two alloys on the Navy contract. Subsequent refinements of the strip processing of Ti-4Al-3Mo-1V and Ti-2½Al-16V were accomplished under the directionality contract.

Hot rolling of 4" thick forged slabs to 0.125" thick coiled hot band is the first rolling operation in making strip product. The effects of three rolling temperatures and two reduction schedules on Ti-6Al-4V directionality were investigated at the intermediate 0.75" thick sheet bar stage as well as at the final 0.125" thick hot band gage.

Strip product is processed from 0.125" thick to final gage by a series of cold reductions and intermediate anneals. Twenty candidate cold roll/anneal cycles, involving the evaluation of long time anneals well below the beta transus, short time anneals very near or above the beta transus, and cold reductions of 20 to 50%, were investigated for effects on annealed mechanical property directionality. The two cycles which produced the least directionality and which appeared to be most practical for existing production equipment were selected for a more comprehensive directionality evaluation in the annealed, solution treated, and solution treated and aged conditions. Room and elevated temperature tensile and compression tests and room temperature bend tests were used for this evaluation.

The effects of roll diameter, rolling speed, and strip tension on directionality were also determined under Phase II.

The effect of cold work in the solution treated condition on Ti-6Al-4V aging response (prestrain effect) was investigated for both processes screened from the twenty candidates. In the early stages of our program under Navy contract NOas 56-995c, it was found that such cold work caused the Ti-4Al-3Mo-1V and Ti-2½Al-16V alloys to age to lower strengths than if no cold work were performed. Intensive investigations at that time, which eliminated Ti-4Al-3Mo-1V and minimized Ti-2½Al-16V prestrain effects, showed that prestrain effect was affected by processing history. The purpose of investigating Ti-6Al-4V prestrain effect under this contract was to determine if it occurred in this alloy and, if so, how it was affected by processing history.

Laboratory investigations of Ti-4Al-3Mo-1V and Ti-2½Al-16V strip processing were then carried out. Methods developed to minimize Ti-6Al-4V directionality were applied to these other alloys to determine if they had an equally beneficial effect..

HOT ROLLING 0.75" THICK SHEET BAR

This part of the program involved hot rolling 7" wide by 3" thick by 4" long slab sections to 0.75" thick sheet bar using starting temperatures of 1900, 2050, and 2200F and reductions per pass of 13 and 21% (a total of six temperature-reduction schedules). All material for the six tests was rolled to 1.50" thick at 1900, 2050 and 2200F before starting the program.

Table V contains the detailed temperature-reduction schedules followed in processing the six hot rolling tests from 1.50" to 0.75" thick. The starting temperatures shown were selected so as to result in six finishing temperatures spaced over the temperature range of 1550F to 1930F at the 0.125" thick hot band stage and thus, with a minimum number of experiments, investigate finishing temperatures from substantially below to above the beta transus. Reduction schedules were chosen on the basis of production mill capabilities and related temperature requirements. A temperature drop of 5F per pass for hot rolling to 0.75" thick sheet bar was assumed.

Annealed tensile properties in three directions of 0.75" thick Ti-6Al-4V sheet bar hot rolled by the six schedules are listed in Table VI. The low ultimate and yield strength directionalities were anticipated since all rolling to 0.75" thick was conducted above the beta transus. Because of the overall low strength directionality, any of these schedules seems satisfactory for sheet bar rolling.

HOT ROLLING 0.125" THICK HOT BAND

Hot rolling from 0.750" thick sheet bar to 0.125" thick hot band was accomplished by the temperature reduction schedules outlined in Table VII. Here, temperature drops of 150F between the 2-high slab mill and the 4-high hot strip mill and 15F per pass in the 4-high mill were assumed. Reductions per pass of 15 and 23% were investigated.

Table VIII contains the annealed tensile properties in three directions of 0.125" thick Ti-6Al-4V hot band rolled in accordance with the six temperature-reduction schedules described in Table VII. As expected, material finished at the higher temperatures exhibited the lowest directionality, due probably to more body-centered-cubic beta phase in the microstructure.

Figures 1 and 2 are plots of ultimate and yield strength directionality versus finish hot rolling temperature at constant reduction per pass for 0.125" thick Ti-6Al-4V hot band. The relationships shown are believed to be valid even though the data are limited.

Longitudinal microstructures of Ti-6Al-4V finish hot rolled to 0.125" above the beta transus or in the all beta field at 1930 and 1850F are shown in Figures 3 and 4. Figures 5 and 6 represent material hot rolled 23 and 15% per pass and finished at 1780 and 1700F, respectively. Note that Figure 5 is a very coarse transformation structure while Figure 6 is a fine worked alpha-beta structure. At still lower finishing temperatures (1630 and 1550F)

where the effect of reduction per pass ceases to be of importance, as shown by Figures 1 and 2, microstructures are both fine alpha-beta.

Two hot rolling processes were selected from the six combinations of temperature-reduction: Test 32, the best with respect to directionality, and Test 11, the most practical production practice. Additional material was hot rolled by each of the two procedures described and tensile tested in three directions in the annealed, solution treated, and solution treated and aged conditions. These test results appear in Table IX. Annealed tensile directionalities are somewhat higher than those obtained in the initial testing. Ultimate and yield strength directionality of hot rolled 0.125" thick Ti-6Al-4V finished below the beta transus decreases, while directionality of material finished above the beta transus shows a marked increase, upon solution treatment. Directionality in both cases shows a marked decrease upon aging.

COLD ROLLING TO FINAL GAGE

Cold rolling and intermediate annealing process variables selected for investigation were:

1. Anneals of long duration well below the beta transus.
2. Short time anneals similar to production anneals well below the transus.
3. Short time anneals very near or above the beta transus.
4. Cold reductions of 20% to 50% between anneals.

Lengthy annealing has the reputation of enhancing bend properties, low temperature "strand line" anneals* fit present equipment best, and high temperature strand line anneals were presumed to minimize directionality. Cold reductions of 20% to 30% and 50% were selected as typical of average and maximum production performance.

Ti-6Al-4V hot band 0.125" thick hot rolled by the two selected schedules was processed to 0.040" thick strip by ten combinations of annealing and cold reduction for a total of 20 hot roll-cold roll-anneal processes. Each of the processes is described in Table X. Duplicate annealed tensile tests were taken in five directions from material processed to 0.040" thick. These results appear in Table XI with a summary of ultimate and yield strength directionality in Table XII.

Selection of optimum processing sequences for further evaluation was based on the data of Table XII and practical considerations concerning production equipment available for processing. Table XII indicates that hot rolling temperatures are unimportant, so attention was concentrated on processes 1A through 1K. These processes are most practical on present equipment because of the lower hot rolling temperature (finish-rolled below the beta transus). They will also produce less oxidation, and hence better hot rolled surfaces with less conditioning loss than processes 3A through 3K.

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*This refers to passing the strip continuously thru the annealing furnaces, pickling baths, dryers, etc. and rewinding into a coil.

Of processes 1A through 1K, 1B, 1F, and 1K are the best with regard to directionality. Processes 1B and 1K were selected for further evaluation because process 1F requires an initial short time anneal above the beta transus (10 minutes at 1800F). While known to have a beneficial effect on directionality, such anneals usually result in severe edge cracking during cold rolling. Therefore, the possibility of high scrap loss makes process 1F a third-choice candidate for production processing.

The work reported and discussed above concluded a broad survey of mill processing effects on directionality, using annealed room temperature tensile tests for screening. Available processing sequences were narrowed to two candidates and the next phase of laboratory work under this contract was to select the better of these. This was done by means of a comprehensive evaluation of directionalities, using x-ray diffraction studies, room and elevated temperature tension and compression tests, and room temperature bend tests in five testing directions and three conditions--annealed, solution treated and solution treated and aged.

Preliminary pole figures of both alpha and beta phases of process 1B and process 1K material are shown in Figures 7 through 10. Textures of both processes were similar and can be idealized as alpha [01$\bar{1}$0] and beta (100) [011]. A set of unexplained clear areas (representing almost zero pole density) were found near the center circle of the pole figure for the alpha phase of process 1B, which cannot be readily explained by assigning a rolling plane. This would require further study for explanation. Though not the result of an exhaustive investigation, these textures are reasonably consistent with studies made on textures of unalloyed titanium (discussed under Phase I). The Ti-6Al-4V material examined was annealed after cold rolling, but it appears that the alpha phase developed a rolling texture similar to unalloyed titanium (except that the basal plane was rotated more toward the transverse direction) and retained this texture through the annealing cycle. The Ti-6Al-4V beta phase developed a rolling texture typical of body-centered-cubic metals and retained this texture through annealing.

Results of the comprehensive testing of 0.040" thick Ti-6Al-4V sheet produced in the laboratory by processes 1B and 1K are presented in Tables XIII through XVII and are plotted in Figures 11 through 20. Table XVIII is a summary of these data which facilitates a comparison of test results on both processes.

Process 1K results in less tension and compression strength directionality and ductility directionality than process 1B in the great majority of comparable tests (Table XVIII), regardless of test temperature or material condition. The few exceptions may be attributed to normal spread in test results.

Table XVIII also shows that there is no significant difference between the two processes with regard to strength levels under equivalent test conditions. However, a comparison of ductility results again shows an advantage for process 1K--tensile specimens from process 1K material consistently have higher percent elongations. Differences between bend results are not considered significant, except that Process 1B results vary over a wider range with test direction, as shown in the directionality summary (Table XVIII).

The data plotted in Figures 11 through 20 show the same Ti-6Al-4V strip directionality pattern discovered by earlier investigations under this contract. Minimum tension and compression strength values occur at 45 degrees from the direction of rolling and ductility is at a maximum in this test direction. This pattern persists regardless of processing method, heat treated condition, or testing temperature. Minimum bend radius is also at a minimum in the 45 degree test direction. This would be expected since bend performance usually improves with percent elongation.

The effect of rolling speed and roll diameter on Ti-6Al-4V directionality is shown in Table XIX. These data are plotted in Figures 21 and 22 and can be summarized as follows:

Rolling Conditions		Directionality* (ksi)					
Diameter	Speed	UTS		YS		El	
(")	('/min.)	1B	1K	1B	1K	1B	1K
4	60	6.5	5.9	9.0	9.5	2.5	4.0
$2\frac{1}{2}$	60	12.0	7.5	12.0	7.7	4.5	3.5
$2\frac{1}{2}$	140	14.0	15.0	7.0	14.0	3.5	4.5

*Directionality is expressed as the difference between maximum and minimum values.

The effect these variables have on directionality is so small that it can be ignored, for practical purposes. As rate of deformation increases (i.e. smaller roll diameter or faster rolling speed) ultimate tensile strength directionality increases but does not reach a high level. An increasing rate of deformation introduces no significant variation in yield strength or ductility directionality.

The effect of strip tension on Ti-6Al-4V directionality is summarized below. Individual test results are shown in Table XX and are plotted in Figure 23.

Strip Tension (% of YS)		Directionality (ksi)		
Forward	Back	UTS	YS	El
30	30	34.4	24.7	5.5
10	10	32.5	22.2	7.0
30	10	36.3	29.3	9.0
10	30	34.1	24.8	12.5

The four combinations of strip tension investigated cover conditions which would be encountered in production rolling. In spite of large changes in strip tension, directionality remains almost constant, showing that strip tension has a negligible effect on directionality. The directionality of the strip material available for this experiment is rather high but we believe these conclusions are valid.

Ti-6Al-4V PRESTRAIN EFFECT

Test data (Figures 24 through 33 and Tables XXI and XXII) show that neither process 1B nor process 1K produces Ti-6Al-4V strip having a prestrain effect, within the limitations of the investigation. Tensile prestraining was carried out at room temperature, 400F, 700F and 1000F in five test directions. Specimens were tested in both tension and compression in the as-prestrained condition as well as after prestraining and aging. Tensile prestrains employed were varied over a range but did not, of course, exceed the limit of uniform elongation, or the point where specimens would start to neck and non-uniform strain begin.

Since this investigation indicates that parts formed of both 1B and 1K Ti-6Al-4V strip will age to strengths equivalent to unformed material, prestrain effect can be eliminated as a basis for selection of the optimum processing schedule. Nevertheless, several interesting observations and conclusions can be made from a study of these data, which are listed below. For the reader's convenience in verifying these conclusions, reference is made to specific figures in the column at the left.

Figures	Conclusion
Compare Figures 24 thru 27 for 1B to 29 thru 32 for 1K	1. Processing affects heat treat response. While neither process shows a prestrain effect, 1K material ages to a somewhat lower strength-higher ductility property combination than does 1B material for the aging cycle used--4 hours at 1000F. This emphasizes the importance of process control--to obtain uniform heat treating response, processing must be uniform from one coil to another.
Compare Figures 25 thru 27 for 1B to 30 thru 32 for 1K.	2. Process 1K material is probably more suitable for hot forming at temperatures of 400F to 1000F than process 1B material. One of the difficulties encountered in hot forming Ti-6Al-4V sheet metal parts by the airframe industry has been extreme brittleness at forming temperatures of 700F and above. The combination of high temperature and plastic working accelerates aging response so that ductility is lost, for all practical purposes. This is shown in Figures 25 through 27 for 1B strip. At temperatures of 400F, 700F and 1000F prestrain results in little-to-no yield/ultimate spread and room temperature test specimens were so brittle that no percent elongation measurement could be made, in most cases. On the other hand, 1K material retains a large proportion of its ductility under equivalent prestrain conditions (Figures 30 through 32), indicating that it could

be successfully hot formed to more severe contours than 1B material. Aging 4 hours at 1000F after prestrain restores a substantial portion of lost ductility for material produced by both processes.

Figures 24 thru 27 for 1B and 29 thru 32 for 1K

3. While there is no prestrain effect with regard to aged strength levels, there appears to be a slight loss in ductility for material which has been prestrained and aged compared to material aged without prior prestrain. This ducitlity prestrain effect is more pronounced in 1B material than in 1K material.

1B and 1K material tensile prestrained at room temperature and then tested in compression without aging shows the conventional Bauschinger effect--compression yield strength drops with increasing prestrain. However, aging 4 hours at 1000F after tensile prestraining counteracts the Bauschinger effect and specimens so aged show no variation in compression yield strength with percent prestrain. Compression yield strengths are uniformly high for all aged specimens (see Tables XXI and XXII and Figures 28 and 33).

The data from compression testing of material prestrained at elevated temperatures were not plotted in figures but are merely listed in Tables XXI and XXII. This material is overaged but, nevertheless, the resulting properties show that overaged compression yield strengths are not affected by tensile prestraining at temperatures up to 1000F.

Aside from prestrain considerations, Figures 28 and 33 show that aging Ti-6Al-4V strip 4 hours at 1000F does not increase compression strength as it does tension strength. Compression yield strength is as high, or possibly somewhat higher, before aging than tension yield strength is after aging and is not noticeably affected by the aging cycle. In fact, these data indicate that the only benefit to Ti-6Al-4V compression strength from aging is to remove any Bauschinger effect which may have been introduced by forming.

Test procedure for the Ti-6Al-4V prestrain program was as follows:

All specimens were strained in a Baldwin Tate-Emery tensile testing machine. Strain values shown on the data sheets represent plastic strain and were measured after the removal of load and elastic recovery.

Specimens strained at elevated temperatures were resistance heated (i.e. specimen was resistance element in an electrical circuit). Edges were machined parallel before straining and a thermocouple was attached to the specimen to indicate temperature. Temperature was controlled by means of a rheostat and was within ± 10F of the target temperature throughout the time the specimen was being strained.

Specimens strained at elevated temperatures required a cycle of approximately 2.5 minutes for heating and testing. In order to eliminate the effect of time at elevated temperatures on final test results, specimens for 0% prestrain at 400F, 700F and 1000F were exposed to the same heating cycle.

SELECTION OF THE OPTIMUM Ti-6Al-4V STRIP PROCESSING CYCLE

On the basis of the data comparing processes 1B and 1K discussed previously, process 1K is the outstanding candidate for Ti-6Al-4V strip processing. It promises to provide strip having low property directionality and excellent heat treating response and is one of the most practical and economical processes considered under this contract. Briefly, process 1K involves hot rolling from forged-slab to 0.125" thick hot band from 1900F, using about 23% reduction per pass. Finish rolling temperature is 1630F. The hot band is then stress relieved, cold rolled 30%, stress relieved again, cold rolled another 30% and given a complete anneal. After a final cold reduction of 50%, the strip is given another complete anneal (See Table VI).

EVALUATION OF Ti-4Al-3Mo-1V AND Ti-2½Al-16V STRIP PROCESSING

The major features of strip processing cycles for Ti-4Al-3Mo-1V and Ti-2½Al-16V established by the Crucible Steel Company of America under Navy contract NOas 56-995c are:

Ti-4Al-3Mo-1V	Ti-2½Al-16V
1. Double consumable melt 25" diameter ingots.	1. Double consumable melt 25" diameter ingots.
2. Forge 25" diameter ingots to 4" thick slabs at 1700-1950F.	2. Forge 25" diameter ingots to 4" thick slabs at 1700-1800F.
3. Hot roll 4" thick slabs to 0.125" thick coiled hot band from 1800F.	3. Hot roll 4" thick slabs to 0.125" thick coiled hot band from 1650F.
4. Anneal at 1600F.	4. Anneal at 1400F.
5. Cold reductions.	5. Cold reductions.
6. Intermediate anneals.	6. Intermediate anneals.

Our limited mill experience with these cycles to date has shown that the Ti-4Al-3Mo-1V alloy develops a fairly high strip directionality and that the Ti-2½Al-16V alloy develops low directionality. High final cold reductions (50%), found to be beneficial to Ti-6Al-4V directionality, were incorporated into these cycles and their effects on Ti-2½Al-16V and Ti-4Al-3Mo-1V directionality were investigated in the laboratory. It was found that cold reductions of the order investigated did not have a significant effect on the already-low directionality of the Ti-2½Al-16V alloy. Test results in the solution treated and solution treated and aged conditions for Ti-4Al-3Mo-1V strip which had received a final 50% cold reduction are shown in Table XXIII. These data are plotted in Figure 34 and are summarized as follows:

Condition	Directionality (ksi) UTS	YS	EL	Property Ranges[1] UTS	YS	EL
Solution Treated 1655F, 20', WQ	10.7	16.8	5.0	136.4-147.1	94.2-111.0 115 max[2]	13-18 10.5 min[2]
Solution Treated + Aged 12 Hours at 925F	16.5	28.2	1.5	189.1-205.6 185 min[2]	159.0-187.2 155 min[2]	5.0-6.5 5.5 min[2]

1 - Five test directions; two specimens per direction for each range.
2 - Common specification value for Ti-4Al-3Mo-1V sheet.

Although a final high cold reduction of 50% is not as effective in minimizing directionality in Ti-4Al-3Mo-1V strip as in Ti-6Al-4V strip, it does produce material having excellent mechanical properties with regard to current specification values. We therefore processed the Phase III Ti-4Al-3Mo-1V material according to the schedule tested in the laboratory.

CONCLUSIONS

Laboratory investigations of twenty combinations of strip processing variables show that a major decrease in Ti-6Al-4V strip directionality may be achieved by increasing final cold reduction to the practical limit of ductility.

Rolling speed, roll diameter and strip tension appear to have no measurable effect on directionality. Other variables such as slab hot rolling temperatures and intermediate annealing treatments have some effect but are offset by other property and processing considerations. Aged properties of Ti-6Al-4V appear to be unaffected by tensile prestrain such as may be encountered during forming operations.

Ti-2½Al-16V and Ti-4Al-3Mo-1V do not respond to the same degree to processing variations as Ti-6Al-4V. Ti-2½Al-16V alloy strip is basically non-directional. A modest improvement in Ti-4Al-3Mo-1V strip directionality is achieved by increasing final cold reduction to the practical limit of ductility.

PHASE III

Production Application

MILL PROCESSING

Four thousand pound ingots of the Ti-6Al-4V, Ti-4Al-3Mo-1V and Ti-2½Al-16V alloys were processed under Phase III in Crucible Steel Company of America's modern strip mill. The purpose of this full-scale production operation was to verify that the minimum-directionality strip processing cycles developed under Phase II could be applied to production operations.

Production operations for all Phase III ingots are shown in the flow sheets of Tables XXIV, XXV and XXVI. These operations are discussed in more detail in the paragraphs that follow.

The 25" diameter 4000-pound ingots were double consumable-arc vacuum melted. They were then forged to 42" x 4" x L slabs by upsetting to 42" diameter and swaging to final thickness. Forging temperatures were:

	Ti-6Al-4V	Ti-4Al-3Mo-1V	Ti-2½Al-16V
Upsetting and rough forging	2050F	1950F	1800F
Final forging	1700F	1700F	1700F

The heats were conditioned by grinding at intermediate and final forging stages. The 42" x 4" x L forged slabs were hot rolled to 42" x 0.125" to 0.150" x L coiled hot bands on our hot strip mill. Slab temperatures were 1875F for Ti-6Al-4V and 1800F for the other two alloys. This hot strip mill consisted principally of slab heating furnaces, a scale breaker, a two-high reversing mill (with edging rolls) to reduce forged slabs to approximately 0.800" thick sheet bar, shears to square sheet bar ends, a four-high reversing mill to reduce sheet bar to approximately 0.140" thick hot band, and a hot band coiler. Hot coilers are contained in furnaces on both sides of the four-high reversing mill to retard heat loss during the final hot band rolling. The strip is alternately coiled and uncoiled in these hot coilers as it is reduced in thickness by rolling in the four-high reversing mill. These pieces of equipment are joined by run-out tables and their operations are synchronized so that normally within about three to five minutes after a heated slab is removed from the furnace it has been reduced to a 0.125" thick coiled hot band. Test samples can be obtained at two stages--sheet bar, as the ends are squared by shearing, and hot band, after the final hot reduction. Hot rolling of contract slabs to coiled hot band was accomplished in a routine manner by the equipment described above.

Following hot band rolling, Ti-4Al-3Mo-1V, Ti-6Al-4V and Ti-2½Al-16V coils were stress relieved at 1250F, slow cooled, and descaled by wheelabrating and pickling in a continuous strip line. They were then annealed as follows:

Ti-6Al-4V	-	1550F, slow cooled 5F/minute maximum
Ti-4Al-3Mo-1V	-	1650F, slow cooled 5F/minute maximum
Ti-2½Al-16V	-	1400F, slow cooled 5F/minute maximum

After annealing, the coils were side-trimmed to remove edge defects. From this point, processing consisted basically of cold reductions and intermediate anneals until final gage was reached. A variety of equipment was available and

was used for this processing. A three-stand four-high continuous cold rolling mill was used for initial cold reductions. This followed Crucible's standard mill practice, in which this high-speed mill is used to break down hot bands to gages not lower than 0.075". After initial breakdown, contract coils were cold rolled in either a 54" wide reversing Sendzimir mill (2" diameter work rolls) or a 44" wide four-high reversing mill (8" or 10" diameter work rolls). Selection of mill for finish rolling depended on a number of factors--coil width (the Sendzimir mill will not roll narrow coils), gage to be rolled (the Sendzimir mill will roll to thinner gages), type of alloy, etc. Standard strip mill equipment was used for other operations. Annealing was done in either strip anneal-descale-pickle lines or in batch furnaces. Side trimmers were used to condition edges after each cold roll and surface conditioning was done in strip inspection and conditioning lines.

Operations sequence was guided principally by the results of Phase II laboratory investigations, as mentioned previously, because the purpose of production processing was to verify that methods developed in the laboratory for minimizing titanium alloy strip directionality could be applied on a production basis. Practical considerations during Phase III mill operations required that certain minor modifications in strip processing cycles be made but it was not necessary to depart from the principal features of the cycles developed by Phase II investigations. Phase II showed that Ti-6Al-4V strip directionality could best be minimized by a heavy final cold reduction (preferably 50%). The goal of 50% final cold reduction was not achieved in production operations; during the final cold rolling operation the Ti-6Al-4V strip was reduced 33% when edge cracking became severe and cold rolling had to be stopped. This constitutes an improvement, however, for Ti-6Al-4V strip is not normally cold rolled more than 20-25% between intermediate anneals. Intermediate anneals at 1550F were employed in the laboratory work. These were not satisfactory in production operations, for after an anneal at this temperature the material was not in its most rollable condition. Annealing at 1650F was found to be more satisfactory and this annealing temperature was used for all but the initial and final anneals.

From the standpoint of processability, excellent results were achieved with the Ti-4Al-3Mo-1V alloy. Minimum material loss was encountered during production operations and our final cold reduction of 40% approached the aimed-for 50%.

The Ti-2½Al-16V alloy is superior to both of the other two alloys with regard to strip processability. Excellent cold reductions were obtained (the last two were 40% and 55%) and other operations were performed without difficulty. Subsequent discussion in this report will also show that Ti-2½Al-16V strip develops almost negligible directionality.

QUALITY TESTS

Quality tests on contract heats are discussed here, in a separate section, because they are not directly related to the directionality testing which constituted the great majority of tests performed under this phase of the contract. Samples of material were taken from the top and bottom of each ingot during rough forging for in-process chemistry analyses and mechanical property tests. These pieces were reforged to 7/8" RCS (Ti-6Al-4V - 1750F,

Ti-4Al-3Mo-1V - 1700F, Ti-16V-2½Al - 1700F) before testing. All metallic alloying elements and interstitial elements were under good control and well within target composition ranges, as shown in Table XXVII. Table XXVIII shows that mechanical properties are excellent. Strengths are consistent within each ingot and ductility values are uniformly high.

Table XXIX reports metallic and interstitial analytical results on samples which were taken at the 0.8" thick sheet bar stage to double-check earlier analyses. These analyses confirm that all elements are under excellent control and are within target ranges, with the exception of a single result on molybdenum from one end of one Ti-4Al-3Mo-1V ingot. This analysis is only 0.1% above the target range and is still within analytical error. Previous analyses on this same heat (see Table XXVII) showed that molybdenum was under excellent control.

These tests showed us early in Phase III that contract material for production try-outs was of excellent quality.

DIRECTIONALITY TESTS

Phase III production strip was tested for directionality by the same technique used in earlier phases of this program. Room temperature tensile properties were determined in the longitudinal and transverse directions and either one or three intermediate directions. Directionality is then expressed as the difference between maximum and minimum yield strengths for the directions tested. Yield strength is the property most sensitive to directionality variation. Material was tested in those conditions of greatest commercial interest, i.e. annealed, solution treated, and solution treated and aged. Since Ti-6Al-4V is used primarily in the annealed condition, it was tested in this condition at all stages and in the solution treated and solution treated plus aged conditions only at final gage. Phase III strip was tested at all intermediate gages and, in addition, directionality at final gage was investigated by compression and tensile tests at room and elevated temperatures. Textures of alpha and beta phases of each alloy were also determined at final gage. The results of these tests are discussed below for each alloy.

Ti-6Al-4V

Room temperature mechanical property tests and directionality of Phase III Ti-6Al-4V strip are shown in Tables XXX through XXXV and are plotted in Figures 35 through 40. These may be summarized as follows:

Processing Stage	Condition	Directionality KSI	Direction of Max Strength	Direction of Min Strength	Phase II Predicted Directionality (ksi)
0.8" thick (sheet bar)	Ann	7.1	L	45°	2.1
0.150" thick (hot band)	Ann	16.2	T	L	15.7, 19.4
0.131" thick (1st CR)	Ann	19.0	T	45°	-
0.097" thick (2nd CR)	Ann	21.0	T	45°	-
0.077" thick (3rd CR)	Ann	18.4	T	45°	-
0.051" thick (4th CR)	Ann	36.3	T	45°	8.9, 7.1
	ST	32.6	T	45°	10.4
	STA	28.2	T	45°	8.7

Mill processed Ti-6Al-4V strip directionality was close to that predicted by Phase II laboratory work at sheet bar and hot band stages and did not change significantly at intermediate cold rolled stages. However, the final mill cold reduction did not have the expected effect of reducing directionality but, instead, increased it. The cause of this unexpected increase in directionality has not been explained.

Throughout this contract, Ti-6Al-4V strip has had a consistent directionality pattern of minimum strength in the 45° direction and maximum strength in the transverse direction, particularly after cold rolling operations have begun.

Aside from directionality considerations, Ti-6Al-4V strip mechanical properties (Tables XXX through XXXV) are quite satisfactory and typical of this alloy. Ductilities are uniformly high and strengths are consistent at all stages tested. No ductility gage effect is evident for the material tested (0.051" thick and greater).

Compression test results at room temperature and 800F are shown in Table XXXVI and elevated temperature tensile test results are shown in Table XXXVII. These data are plotted in Figures 41 through 44. Directionality is somewhat greater in compression than in tension, but is unaffected by elevated temperatures:

	Temperature	Condition	Directionality (ksi)
Compression	RT	Ann	51.2
		ST	49.6
		STA	61.7
	800F	Ann	49.7
		STA	50.1
Tension	RT	Ann	36.3
		ST	32.6
		STA	28.2
	400F	Ann	35.8
		STA	24.1
	600F	Ann	34.2
		STA	37.1
	800F	Ann	34.4
		STA	38.4

Figures 45 and 46 show pole figures for alpha and beta phases of 0.051" thick Ti-6Al-4V strip in the annealed condition. The alpha phase has a $(\bar{2}110)$ $[01\bar{1}0]$ texture with slight deviations about the rolling direction. This departs from the "ideal" texture for hexagonal metals ((0001) $[10\bar{1}0]$) and suggests that (0001) slip has been interfered with and that $(10\bar{1}0)$ $[\bar{1}210]$ is now dominant, although this situation has not been examined in detail. The beta phase has a (100) [011] texture with some deviation about the rolling direction. This is basically in good agreement with typical textures for cubic metals. Both of these pole figures are also in reasonably good agreement with those of laboratory-processed material, shown in Figures 7 through 10.

Ti-4Al-3Mo-1V

Room temperature mechanical property data tests and directionality of Phase III Ti-4Al-3Mo-1V strip are shown in Tables XXXVIII through XLIII and are plotted in Figures 47 through 52. A summary of these data shows:

		Directionality		
Processing Stage	Condition	KSI	Direction of Max Strength	Direction of Min Strength
0.8" thick (sheet bar)	Ann	3.7	L	45°
	ST	10.0	T	45°
	STA	9.3	T	45°
0.140" thick (hot band)	Ann	24.8	T	L
	ST	21.6	T	45°
	STA	26.6	T	L

Processing Stage	Condition	KSI	Directionality: Direction of Max Strength	Directionality: Direction of Min Strength
0.110" thick (1st CR)	Ann	24.3	T	L
	ST	16.7	T	45°
	STA	17.5	T	L
0.078" thick (2nd CR)	Ann	27.1	T	L
	ST	18.7	T	45°
	STA	14.4	T	L
0.057" thick (3rd CR)	Ann	30.9	T	L
	ST	27.6	T	45°
	STA	20.3	T	45°
0.034" thick (4th CR)	Ann	32.6	T	L
	ST	24.5	T	L
	STA	22.3	T	45°

Mill processed Ti-4Al-3Mo-1V strip directionality was lowest at the hot rolled 0.8" thick sheet bar stage. This is probably the result of hot rolling high in the alpha-beta field, with little of the hexagonal alpha phase present in the structure. Directionality was fairly high at the 0.140" thick hot band stage and changed little during subsequent cold reductions. Once cold reductions were started, directionality was consistently higher in the annealed condition than in either the solution treated or solution treated plus aged conditions.

Ti-4Al-3Mo-1V strip also has a tendency to develop minimum strength in the 45° direction, particularly in the solution treated condition, though this tendency is not as strong as in the Ti-6Al-4V alloy.

A comparison with typical hand sheet properties indicates that the Ti-4Al-3Mo-1V strip being processed under this contract has excellent mechanical properties. The hand sheet properties used for comparison consisted of a large quantity of data on material produced by the Crucible Steel Company of America under Bureau of Naval Weapons Contract NOas 56-995c* which had been statistically analyzed. The data show:

	Avg UTS** (ksi)		Avg YS** (ksi)		Avg EL**	
	L	T	L	T	L	T
0.057" thick Ti-4Al-3Mo-1V strip	208.2	216.9	171.9	191.4	3.5	8.0
0.063" thick Ti-4Al-3Mo-1V hand sheet	210	205	184	178	5.2	6.3
0.034" thick Ti-4Al-3Mo-1V strip	208.1	212.9	186.2	197.9	4.5	3.8
0.040" thick Ti-4Al-3Mo-1V hand sheet	206	202	175	170	4.6	5.6

* See Procedures for Producing Improved Titanium Alloy Sheet, Final Technical Report, Bureau of Naval Weapons Contract NOas 56-995c, Crucible Steel Company of America, dated 12-30-60.

** Solution treated and aged condition.

This comparison cannot be considered statistically valid for insufficient data are available on strip product. However, it indicates that Ti-4Al-3Mo-1V strip will heat treat to strength-ductility combinations equivalent to hand sheet but that, in spite of improvements in directionality control made under this contract, strip material is still somewhat more directional.

Compression test results at room temperature and 800F are given in Table XLIV and elevated temperature tensile test results are given in Table XLV. These data are plotted in Figures 53 through 56. Compression directionality is higher than tension directionality in the annealed and solution treated conditions but is about the same in the solution treated and aged condition. Tension directionality is unaffected by elevated temperatures but compression directionality is reduced:

	Temperature	Condition	Directionality (ksi)
Compression	RT	Ann	53.4
		ST	49.8
		STA	29.4
	800F	Ann	33.4
		STA	11.9
Tension	RT	Ann	32.6
		ST	24.5
		STA	22.3
	400F	Ann	27.4
		STA	27.8
	600F	Ann	25.7
		STA	32.3
	800F	Ann	25.6
		STA	31.3

Figures 57 and 58 show pole figures for alpha and beta phases of 0.034" thick Ti-4Al-3Mo-1V strip in the annealed condition. The alpha phase has a $(\bar{2}110)$ $[01\bar{1}0]$ texture with slight deviations about the rolling direction, identical to the alpha phase texture of Ti-6Al-4V strip. As in the case of Ti-6Al-4V strip, this texture departs from the "ideal" for hexagonal metals. This departure is probably caused by deformation mechanisms in addition to (0001) slip. The Ti-4Al-3Mo-1V beta phase has a (100) [011] texture but an anomalous pole distribution was observed in the central region of the figure.

Ti-2½Al-16V

Room temperature mechanical property tests and directionality of Phase III Ti-2½Al-16V strip are shown in Tables XLVI through LI and are plotted in Figures 59 through 64. The following is a summary of these data:

Processing Stage	Condition	KSI	Directionality: Direction of Max Strength	Directionality: Direction of Min Strength
0.8" thick (sheet bar)	Ann	7.7	T	L
	ST	9.3	T	L
	STA	7.9	T	45°
0.136" thick (hot band)	Ann	11.5	T	L
	ST	0.9	T	45°
	STA	8.0	T, 45°	L
0.100" thick (1st CR)	Ann	3.7	T	45°
	ST	9.6	L	T
	STA	7.2	T	L
0.080" thick (2nd CR)	Ann	3.2	T	L
	ST	8.3	T	L
	STA	7.6	T	L
0.045" thick (3rd CR)	Ann	7.1	T	67½°
	ST	2.4	45°	T
	STA	4.4	22½°	67½°
0.021" thick (4th CR)	Ann	9.9	T	L
	ST	6.2	T	45°
	STA	7.3	67½°	45°

Ti-2½Al-16V strip directionality is negligible. The data indicate that at no thickness would directionality cause problems in either fabrication or heat treating to minimum strength and ductility values.

As was the case for the Ti-4Al-3Mo-1V alloy, a comparison with typical hand sheet properties indicates that Ti-2½Al-16V strip has exceptionally good mechanical properties. This comparison* follows:

	Avg UTS** (ksi)		Avg YS** (ksi)		Avg EL**	
	L	T	L	T	L	T
0.100" thick Ti-2½Al-16V strip	172.2	179.5	157.8	165.0	7.3	7.0
0.096" thick Ti-2½Al-16V hand sheet	175	183	163	172	5.6	5.6
0.045" thick Ti-2½Al-16V strip	161.8	163.7	149.1	151.7	8.0	7.8
0.040" thick Ti-2½Al-16V hand sheet	169	176	157	165	5.0	5.0
0.021" thick Ti-2½Al-16V strip	162.5	169.4	149.3	153.7	6.5	-
0.025" thick Ti-2½Al-16V hand sheet	179	183	162	167	3.6	4.5

* See Procedures for Producing Improved Titanium Alloy Sheet, Final Technical Report, Bureau of Naval Weapons Contract NOas 56-995c, Crucible Steel Co. of America, dated 12-30-60, for data and statistical analysis of Ti-2½Al-16V hand sheet properties.

** Solution treated and aged condition.

More test results on strip product would be required to make this comparison statistically valid, but it indicates that the directionality of Ti-2½Al-16V strip will probably be lower than that of hand sheet. Strip also has substantially higher ductility than hand sheet. This higher ductility is due in part to the lower heat treated strength of the strip but strip processing per se is believed to have contributed also, by greater structural refinement through cold work. Further testing has indicated that another heat treatment will produc substantially higher aged strengths at some ductility sacrifice so that a range of properties is available.

Compression test results at room temperature and 800F are shown in Table LII and elevated temperature tensile test results are shown in Table LIII. These data are plotted in Figures 65 thru 68. Elevated temperatures have no significant effect on directionality, as determined by either compression or tensile testing:

	Temperature	Condition	Directionality (ksi)
Compression	RT	Ann	8.4
		ST	10.2
		STA	10.9
	800F	Ann	13.6
		STA	15.4
Tension	RT	Ann	9.9
		ST	6.2
		STA	7.3
	400F	Ann	11.7
		STA	11.6
	600F	Ann	11.2
		STA	5.2
	800F	Ann	9.0
			9.0

Figures 69 and 70 show pole figures for alpha and beta phases of 0.040" thick Ti-2½Al-16V strip in the annealed condition. The alpha phase has a (0001) [01$\bar{1}$0] texture, which is substantially different from the alpha phase textures of Ti-6Al-4V and Ti-4Al-3Mo-1V strip (Figures 45 and 57). Ti-2½Al-16V alpha phase deformation appears to be principally by (0001) slip, which results in a texture in very close agreement with the "ideal" for hexagonal metals. The Ti-2½Al-16V beta phase has a (100) [011] texture, similar to the beta phase textures of Ti-6Al-4V and Ti-4Al-3Mo-1V strip and typical of cubic metals.

CRACK PROPAGATION RESISTANCE

Crack propagation tests were made on the three titanium alloys processed under this contract to examine their notch sensitivity and to determine if notch

sensitivity is affected by test direction. Specimens were tested in the most common commercial conditions, i.e. Ti-6Al-4V in the annealed condition and Ti-4Al-3Mo-1V and Ti-2½Al-16V in the solution treated and solution treated plus aged conditions.

The specimen used for these tests was similar to the one developed by Srawley and Beacham at the Naval Research Laboratory*. It consists of a center-notched tensile specimen which is subjected to axial tension fatigue loading to induce a transverse crack which constitutes an ultra-sharp notch. The ratio of total crack length to specimen width is in the range of .35 to .45. The net fracture stress or notched tensile strength in a subsequent tensile test is fairly independent of this ratio in this range. Approximately 15 minutes of cycling in a tension-tension fatigue machine initiated and propagated the crack to the desired length. The transverse fatigue crack was placed in solution treated plus aged specimens before the aging treatment.

In this test the ratio of net fracture stress to ultimate tensile strength is usually the basis for judging materials. Ratios of less than about .6 are taken as an indication of notch sensitivity, or the inability to resist propagation of cracks in the presence of ultra-sharp notches. Ratios above about .6 indicate good resistance to crack propagation. Therefore, it is believed that high-strength materials with NFS/UTS ratios above .6 will behave reliably in highly stressed structures.

Test results are given in Table LIV. The highest NFS/UTS ratios obtained (.980-1.057) were for annealed Ti-6Al-4V strip. This was not unexpected, because of its relatively low strength.

The Ti-4Al-3Mo-1V and Ti-2½Al-16V alloys are readily heat treated to high strengths commercially and were therefore tested in these high strength conditions. Aged Ti-2½Al-16V strip appears to be superior to aged Ti-4Al-3Mo-1V strip in its resistance to crack propagation. At yield strengths of 150,000 to 156,000 psi, NFS/UTS ratios of .760 to .833 were obtained for Ti-2½Al-16V strip while NFS/UTS ratios of .416 to .604 were obtained for Ti-4Al-3Mo-1V strip at yield strengths of 164,000 to 185,000 psi. The data show that the Ti-2½Al-16V aging treatment does not result in a loss of crack propagation resistance, as might be expected of the less-ductile higher-strength material.

Ti-4Al-3Mo-1V strip has excellent crack propagation resistance (NFS/UTS ratios of .825 to .956) in the solution treated condition but loses this resistance when aged to high strengths.

The crack propagation test described here has not been widely used in evaluating high-strength titanium alloy sheet, but the limited test results available indicate that Ti-2½Al-16V strip heat treated to 150,000 psi yield strength has exceptionally good crack propagation resistance.

In all cases, crack propagation resistance was not significantly affected by test direction.

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*J. E. Srawley and C. D. Beacham, Crack Propagation Tests of High-Strength Sheet Steels Using Small Specimens, NRL Report 5127, Naval Research Laboratory, Washington, D.C., April 9, 1958.

CONCLUSIONS

The program conducted under this contract shows that the Ti-2½Al-16V alloy meets all the requirements for strip processing. Ti-2½Al-16V strip develops almost negligible directionality, is easily handled in strip mill equipment, and in-process material yield is high. Also, comparison to data on Ti-2½Al-16V hand sheet indicates that strip product has a better strength-ductility combination.

While this program developed a substantial body of knowledge concerning the strip processing of the Ti-6Al-4V and Ti-4Al-3Mo-1V alloys, directionality is higher than that of hand sheet. This effect is greater below about 0.060" thick material. Also, final directionality of Ti-6Al-4V strip processed under Phase III of this contract was higher than predicted by Phase II laboratory investigations.

Crack propagation resistance of Ti-2½Al-16V strip heat treated to high strengths is excellent.

TABLE I

Mechanical Properties of 0.125" Thick Laboratory-Rolled Ti-4Al-3Mo-1V Alloy Hot Band

Slab Temperature At Start Of Rolling	Condition	Axis of Specimen With Respect To Rolling Direction		Room Temperature Tensile Properties (1) Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	% Elongation in 0.6"	% Reduction in Area	Break (2)	(3) Yield Strength Directionality
2000F	As hot rolled & air cooled	0°	(L)	151.4	128.9	15.0	26.4	4	± 24.6
		45°		146.2	134.4	13.3	52.4	3	
		90°	(T)	163.7	153.5	13.3	50.9	3	
1775F	As hot rolled & air cooled	0°	(L)	148.5	127.0	13.3	25.1	3	± 36.6
		45°		148.1	132.6	12.5	35.4	3	
		90°	(T)	172.7	163.6	13.3	46.2	4	
1675F	As hot rolled & air cooled	0°	(L)	155.0	131.0	13.3	28.3	3	± 37.5
		45°		151.5	136.4	14.2	41.5	3	
		90°	(T)	179.1	168.5	10.0	47.8	3	
2000F	Solution Treated 1625F, W.Q.	0°	(L)	145.5	88.0	23.3	56.4	2	± 8.9
		90°	(T)	154.8	96.9	23.3	57.0	2	
	Solution Treated 1625F, W.Q. & Aged 925F 12 Hours	0°	(L)	200.0	163.9	8.3	17.6	2	± 19.6
		90°	(T)	206.3	183.5	11.7	32.3	3	
1775F	Solution Treated 1625F, W.Q.	0°	(L)	146.3	94.2	23.3	49.7	3	± 5.8
		90°	(T)	156.0	100.0	20.0	46.8	3	

TABLE I
(Continued)

Slab Temperature At Start Of Rolling	Condition	Axis of Specimen With Respect To Rolling Direction		Room Temperature Tensile Properties (1): Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	% Elongation in 0.6"	% Reduction in Area	Break (2)	(3) Yield Strength Directionality
1775F	Solution Treated 1625F, W.Q. & Aged 925F, 12 hours	0°	(L)	200.3	169.4	6.7	13.4	2	+ 15.8
		90°	(T)	208.9	184.2	10.0	28.5	3	
1675F	Solution Treated 1625F, W.Q.	0°	(L)	146.1	92.4	25.0	47.6	3	+ 11.8
		90°	(T)	153.2	104.2	23.3	55.8	2	
	Solution Treated 1625F, W.Q. & Aged 925F, 12 hours	0°	(L)	201.9	163.9	8.3	12.4	2	+ 20.3
		90°	(T)	204.7	184.2	10.0	32.3	2	

(1) Sub-size flat specimens used (0.6" gage length). Individual test values shown.

(2) Indicates location of break in tensile specimen. Number 1 is a center break, midway between gage marks. Numbers 2, 3 and 4 are progressively nearer a gage mark. GM is a break on a gage mark. OGM is a break outside a gage mark.

(3) + indicates higher transverse properties.

Reference 24

TABLE II

Mechanical Properties of 0.125" Thick Laboratory-Rolled Ti-16V-2½Al Alloy Hot Band

Slab Temperature At Start Of Rolling	Condition	Axis of Specimen With Respect To Rolling Direction		Room Temperature Tensile Properties (1) Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	% Elongation in 0.6"	% Reduction in Area	Break (2)	(3) Yield Strength Directionality
1650F	As hot rolled & air cooled	0°	(L)	127.2	119.3	12.5	29.8	3	+ 11.9
		45°		127.3	119.6	13.3	32.5	2	
		90°	(T)	143.1	131.2	7.5	16.2	2	
1450F	As hot rolled & air cooled	0°	(L)	133.5	126.5	11.7	30.5	2	+ 23.1
		45°		133.4	128.7	10.0	31.8	3	
		90°	(T)	158.3	149.6	4.1	12.7	4	
1350F	As hot rolled & air cooled	0°	(L)	129.4	122.7	11.7	33.1	2	+ 25.6
		45°		134.6	128.6	13.3	38.7	3	
		90°	(T)	158.2	148.3	5.0	14.4	4	
1650F	Solution treated 1380F, W.Q.	0°	(L)	110.5	44.6	23.3	42.2	2	+ 13.9
		90°	(T)	108.8	58.5	21.7	44.7	3	
	Solution treated 1380F, W.Q. & Aged 960F, 4 hours	0°	(L)	180.6	166.9	6.7	15.4	3	+ 7.1
		90°	(T)	188.2	174.0	8.3	23.6	3	
1450F	Solution treated 1380F, W.Q.	0°	(L)	109.4	50.6	26.7	40.9	2	+ 11.6
		90°	(T)	109.7	62.2	25.0	47.2	3	

TABLE II
(Continued)

Slab Temperature At Start Of Rolling	Condition	Axis of Specimen With Respect To Rolling Direction		Room Temperature Tensile Properties(1) Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	% Elongation in 0.6"	% Reduction in Area	Break (2)	(3) Yield Strength Directionality
1450F	Solution Treated 1380F, W.Q. & Aged 960F, 4 hours	0°	(L)	178.0	167.2	8.3	13.1	2	≠ 6.1
		90°	(T)	186.8	173.3	8.3	18.7	4	
1350F	Solution Treated 1380F, W.Q.	0°	(L)	112.0	50.2	23.3	36.4	2	≠ 9.5
		90°	(T)	108.8	59.7	21.7	42.4	3	
	Solution Treated 1380F, W.Q. & Aged 960F, 4 hours	0°	(L)	175.9	165.7	10.0	22.8	2	≠ 7.4
		90°	(T)	186.4	173.1	6.7	27.8	4	

(1) Sub-size flat specimens used (0.6" gage length). Individual test values shown.

(2) Indicates location of break in tensile specimen. Number 1 is a center break, midway between gage marks. Numbers 2, 3 and 4 are progressively nearer a gage mark. GM is a break on a gage mark. OGM is a break outside a gage mark.

(3) ≠ indicates higher transverse properties.

Reference 24

TABLE III

Mechanical Properties of 6Al-4V Coil Heat H-0414B

Stage*	Longitudinal			Transverse			Yield Strength Directionality**
	Ultimate Tensile Strength ksi	Yield Strength ksi	Elongation %	Ultimate Tensile Strength ksi	Yield Strength ksi	Elongation %	
HR - ANN - .750"	133.8	123.7	13.1	139.8	132.6	12.8	↑ 8.9
HR - SR - .125"	133.2	113.2	9.6	150.3	143.9	7.8	↑ 30.7
HR - ANN - .125"	128.4	115.4	7.3	156.0	152.1	8.4	↑ 36.7
CR - ANN - .055"	130.9	116.2	10.6	150.1	144.7	6.1	↑ 28.5
CR - ANN - .037"	138.0	118.2	12.1	154.7	143.1	9.0	↑ 24.9
CR - ANN - .029"	137.1	116.1	9.3	154.1	143.8	6.7	↑ 27.7
CR - ST - .027"	155.3	141.8	11.7	154.2	143.2	8.8	↑ 1.4

* HR - Hot Rolled
CR - Cold Rolled
ANN - Annealed
SR - Stress Relieved
ST - Solution Treated
** ↑ indicates higher transverse properties

Reference 25

TABLE IV

Mechanical Properties of 6Al-4V Coil Heat H-0414T

Stage*	Longitudinal			Transverse			Yield Strength Directionality**
	Ultimate Tensile Strength ksi	Yield Strength ksi	Elongation %	Ultimate Tensile Strength ksi	Yield Strength ksi	Elongation %	
HR - ANN - .750"	142.1	130.8	13.4	139.9	127.3	10.0	- 3.5
HR - SR - .125"	137.9	118.1	12.5	147.6	139.1	12.4	+ 21.0
HR - ANN - .125"	132.4	120.6	13.9	141.7	135.8	13.7	+ 15.2
CR - ANN - .087"	133.9	111.2	12.5	150.0	138.1	13.7	+ 26.9
CR - ANN - .055"	136.8	114.4	14.6	143.1	132.1	13.4	+ 17.7
CR - ANN - .040"	135.1	115.3	14.9	136.0	126.0	14.9	+ 10.7

* HR - Hot Rolled
CR - Cold Rolled
ANN - Annealed
SR - Stress Relieved
**+ indicates higher transverse properties

Reference 25

TABLE V

Hot Rolling 1.50" Thick Ti-6Al-4V Slab to 0.75" Thick Sheet Bar

	Thickness			Furnace Temperatures		
Pass	Before	After	Reduction %	Test 11	Test 21	Test 31
1	1.50"	1.19"	20.6	1880F	2030F	2180F
2	1.19"	0.95"	20.2	1875F	2025F	2175F
3	0.95"	0.75"	21.0	1870F	2020F	2170F
				Test 12	Test 22	Test 32
1	1.50"	1.30"	13.3	1870F	2020F	2170F
2	1.30"	1.13"	13.1	1865F	2015F	2165F
3	1.13"	0.99"	12.4	1860F	2010F	2160F
4	0.99"	0.86"	13.1	1855F	2005F	2155F
5	0.86"	0.75"	12.8	1850F	2000F	2150F

TABLE VI

Annealed Tensile Properties of 0.75" Thick Ti-6Al-4V Sheet Bar[1]

Test[2] Number	Direction[3]	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 4D	Reduction in Area %	Directionality Ultimate psix10^{-3}	Directionality 0.2% Yield psix10^{-3}
11	0°	138.0	124.3	13.0	30.5		
	45°	138.4	125.3	13.0	30.8		
	90°	139.3	126.4	12.0	31.2		
						1.3	2.1
12	0°	136.4	122.5	12.0	28.1		
	45°	136.8	123.4	14.0	30.6		
	90°	137.7	125.1	13.0	30.9		
						1.3	2.6
21	0°	139.3	124.8	14.0	29.4		
	45°	137.4	123.6	14.0	33.1		
	90°	139.2	125.7	14.0	27.8		
						1.9	2.1
22	0°	137.5	123.0	13.0	31.4		
	45°	138.0	123.2	13.0	35.4		
	90°	138.0	125.5	12.0	29.0		
						0.5	2.5
31	0°	137.0	122.5	15.0	35.2		
	45°	138.2	123.1	14.0	32.7		
	90°	139.8	124.9	12.0	31.9		
						2.8	2.4
32	0°	137.5	121.7	12.0	32.8		
	45°	137.1	121.2	12.0	26.1		
	90°	139.6	123.4	10.0	24.8		
						2.5	2.2

1 - Annealed 2 hours at 1550°F, slow cooled 5°F/minute to 1050°F - $\frac{1}{4}$" diameter tensile specimens.
2 - Hot rolling procedure described in Table V.
3 - Angle from rolling direction.

TABLE VII

Hot Rolling 0.750" Thick Ti-6Al-4V Sheet Bar to 0.125" Thick Hot Band

	Thickness			Furnace Temperatures		
Pass	Before	After	Reduction %	Test 11	Test 21	Test 31
1	0.750"	0.580"	22.6	1720F	1870F	2020F
2	0.580"	0.450"	22.4	1705F	1855F	2005F
3	0.450"	0.350"	22.2	1690F	1840F	1990F
4	0.350"	0.270"	22.8	1675F	1825F	1975F
5	0.270"	0.210"	22.2	1660F	1810F	1960F
6	0.210"	0.160"	23.8	1645F	1795F	1945F
7	0.160"	0.125"	21.9	1630F	1780F	1930F
				Test 12	Test 22	Test 32
1	0.750"	0.640"	13.3	1700F	1850F	2000F
2	0.640"	0.540"	15.6	1685F	1835F	1985F
3	0.540"	0.460"	14.8	1670F	1820F	1970F
4	0.460"	0.390"	15.2	1655F	1805F	1955F
5	0.390"	0.330"	15.4	1640F	1790F	1940F
6	0.330"	0.280"	15.1	1625F	1775F	1925F
7	0.280"	0.240"	14.3	1610F	1760F	1910F
8	0.240"	0.200"	16.6	1595F	1745F	1895F
9	0.200"	0.170"	15.0	1580F	1730F	1880F
10	0.170"	0.145"	14.7	1565F	1715F	1865F
11	0.145"	0.125"	13.8	1550F	1700F	1850F

TABLE VIII

Annealed Tensile Properties of 0.125" Thick Ti-6Al-4V Hot Band[1]

Test[2] Number	Direction[3]	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 4D	Reduction in Area %	Directionality Ultimate psix10^{-3}	Directionality 0.2% Yield psix10^{-3}
11	0°	144.2	130.8	10.0	25.0		
	45°	133.8	128.3	11.0	45.8		
	90°	151.4	144.0	10.5	33.6		
						17.6	15.7
12	0°	143.0	129.9	10.0	25.5		
	45°	131.9	127.0	12.0	25.5		
	90°	151.9	144.4	10.5	35.4		
						20.0	17.4
21	0°	147.2	128.8	9.0	27.9		
	45°	147.0	136.4	11.0	28.6		
	90°	150.1	139.2	9.0	32.3		
						4.1	10.4
22	0°	139.5	131.4	9.0	28.8		
	45°	138.8	130.9	12.0	41.7		
	90°	150.1	141.5	11.0	34.4		
						11.9	10.6
31	0°	146.5	134.7	8.5	25.3		
	45°	147.4	132.0	9.5	26.4		
	90°	150.7	137.3	9.0	30.8		
						4.2	5.3
32	0°	149.1	138.5	8.0	24.0		
	45°	147.8	135.0	7.5	15.1		
	90°	147.0	137.6	7.5	12.7		
						2.1	3.5

1 - Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F - standard flat tensile specimens.
2 - Hot rolling procedure described in Table VII.
3 - Angle from rolling direction.

TABLE IX

Heat Treated Tensile Properties of 0.125" Thick Ti-6Al-4V Hot Band[1]

Test[2] Number	Condition	Direction[3]	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %	Directionality[4] Ultimate Strength psix10^{-3}	Directionality[4] 0.2% Yield Strength psix10^{-3}
11	Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F.	0°	135.5	124.1	12.5	34.5		
			135.7	124.9	15.0	30.3		
			135.6	124.5				
		45°	126.9	125.1	17.0	47.4		
			127.8	124.9	16.5	46.8		
			127.4	125.0				
		90°	148.4	143.9	14.0	41.4		
			149.3	143.9	14.5	38.7		
			148.9	143.9			21.5	19.4
32		0°	143.1	129.4	13.5	25.0		
			144.8	130.7	12.0	25.1		
			144.0	130.1				
		45°	144.5	132.4	9.0	21.3		
			144.9	131.9	11.5	17.3		
			144.7	132.2				
		90°	144.7	137.6	13.0	29.8		
			142.6	134.8	11.5	28.9		
			143.7	136.2			1.0	6.1
11	Annealed as above solution treated 15 minutes at 1700F, water quenched.	0°	156.1	134.7	13.0	38.7		
			160.2	138.9	10.0	41.6		
			158.2	136.8				

TABLE IX
(Continued)

Test Number[2]	Condition	Direction[3]	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %	Directionality[4] Ultimate Strength psix10^{-3}	Directionality[4] 0.2% Yield Strength psix10^{-3}
11	Annealed as above solution treated 15 minutes at 1700F, water quenched	45°	149.6	132.1	14.5	49.2		
			154.7	135.3	14.0	55.5		
			152.2	133.7				
		90°	167.0	148.5	11.5	42.4		
			170.1	152.3	10.0	40.3		
			168.6	150.4				
32		0°	157.2	123.3	10.0	25.7	16.4	16.7
			157.8	125.4	9.0	21.6		
			157.5	124.4				
		45°	165.9	139.8	7.5	18.5		
			163.9	137.9	6.5	14.9		
			164.9	138.9				
		90°	164.6	144.0	9.5	30.1		
			156.5	134.1	11.5	27.3		
			160.6	139.1			7.4	14.7
11	Annealed and solution treated as above, aged 4 hours at 1000F, air cooled.	0°	169.7	158.7	9.0	37.8		
			170.0	158.3	8.5	38.3		
			169.9	158.5				
		45°	161.9	152.7	13.0	46.8		
			166.4	156.2	10.0	43.2		
			164.2	154.5				

TABLE IX
(Continued)

Test[2] Number	Condition	Direction[3]	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %	Directionality[4] Ultimate Strength psix10^{-3}	Directionality[4] 0.2% Yield Strength psix10^{-3}
11	Annealed and solution treated as above, aged 4 hours at 1000°F, air cooled.	90°	173.4 179.5 176.5	165.2 170.5 167.9	8.5 8.0	37.8 37.4	12.3	13.4
32		0°	174.9 174.2 174.6	160.1 158.9 159.5	4.0 5.0	16.9 13.6		
		45°	176.8 178.8 177.8	162.0 165.6 163.8	4.5	13.2		
		90°	176.8 171.9 174.4	164.7 159.0 161.9	8.5 10.0	31.1 28.4	3.4	4.3

1 - Standard flat tensile specimens.
2 - Hot rolling procedure described in Tables V and VII.
3 - Angle from rolling direction.
4 - Maximum difference of average strengths.

TABLE X

Experimental Cold Rolling and Annealing Cycles

Process 1A :

1. #11 material annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 30% (.144" to .101").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 30% (.099" to .069").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 31% (.065" to .045").
7. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 1B :

1. #11 material annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 29% (.142" to .101").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 30% (.094" to .066").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 30% (.064" to .045").
7. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 1C :

1. #11 material annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 24.8% (.122" to .092").
3. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
4. Cold rolled 28.8% (.090" to .064").
5. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Cold rolled 30.6% (.062" to .043").
7. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 1D :

1. #11 material annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 20.4% (.122" to .097").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 20.2% (.094" to .075").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 20.6% (.073" to .058").
7. Stress relieved 10 minutes at 1450F, air cooled.
8. Cold rolled 19.7% (.056" to .045").
9. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

TABLE X
(Continued)

Process 1E :

1. #11 material solution treated 10 minutes at 1800F, air cooled, followed by annealing 2 hours at 1550F, slow cooling 5F/minute to 1050F, air cooling.
2. Cold rolled 21.3% (.122" to .096").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 20.6% (.095" to .076").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 20.6% (.073" to .058").
7. Stress relieved 10 minutes at 1450F, air cooled.
8. Cold rolled 19.7% (.056" to .045").
9. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 1F :

1. #11 material solution treated 10 minutes at 1800F, air cooled, followed by annealing 5 hours at 1550F, slow cooling 5F/minute to 1050F, air cooling.
2. Cold rolled 21% (.144" to .114").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 20% (.107" to .086").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 17.9% (.084" to .069").
7. Stress relieved 10 minutes at 1450F, air cooled.
8. Cold rolled 20.9% (.062" to .049").
9. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 1G :

1. #11 material solution treated 10 minutes at 1800F, air cooled. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 30%.
3. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
4. Cold rolled 30%.
5. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Solution treated 10 minutes at 1800F, air cooled.
7. Cold rolled 30%.
8. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

TABLE X
(Continued)

Process 1H :

1. #11 material annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 24.6% (.122" to .092").
3. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
4. Cold rolled 30.4% (.092" to .064").
5. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Cold rolled 29.5% (.061" to .043").
7. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 1J :

1. #11 material solution treated 10 minutes at 1800F, air cooled. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 30%.
3. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
4. Cold rolled 30%.
5. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Cold rolled 30%.
7. Solution treated 10 minutes at 1800F, air cooled.
8. Cold rolled 30%.
9. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 1K :

1. #11 material stress relieved 10 minutes at 1450F, air cooled.
2. Cold rolled 30%.
3. Stress relieved 10 minutes at 1550F, air cooled.
4. Cold rolled 30%.
5. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Cold rolled 50%.
7. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 3A :

1. #32 material annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 27.5% (.134" to .097").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 30% (.094" to .066").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 30% (.063" to .044").
7. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

TABLE X
(Continued)

Process 3B :
1. #32 material annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 29% (.132" to .093").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 27% (.091" to .066").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 31% (.064" to .044").
7. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 3C :
1. #32 material annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 20% (.110" to .088").
3. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
4. Cold rolled 29.6% (.086" to .060").
5. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Cold rolled 30.5% (.059" to .041").
7. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 3D :
1. #32 material annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 19.1% (.110" to .089").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 20.6% (.087" to .069").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 19.4% (.067" to .054").
7. Stress relieved 10 minutes at 1450F, air cooled.
8. Cold rolled 19.3% (.052" to .042").
9. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 3E :
1. #32 material solution treated 10 minutes at 1800F, air cooled, followed by annealing 2 hours at 1550F, slow cooling 5F/minute to 1050F, air cooling.
2. Cold rolled 19.1% (.110" to .089").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 19.8% (.086" to .069").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 19.4% (.067" to .054").
7. Stress relieved 10 minutes at 1450F, air cooled.
8. Cold rolled 19.3% (.052" to .042").
9. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

TABLE X
(Continued)

Process 3F :
1. #32 material solution treated 10 minutes at 1800F, air cooled, followed by annealing 5 hours at 1550F, slow cooling 5F/minute to 1050F, air cooling.
2. Cold rolled 20.0% (.110" to .088").
3. Stress relieved 10 minutes at 1450F, air cooled.
4. Cold rolled 21.2% (.085" to .067").
5. Stress relieved 10 minutes at 1450F, air cooled.
6. Cold rolled 19.7% (.066" to .053").
7. Stress relieved 10 minutes at 1450F, air cooled.
8. Cold rolled 19.6% (.051" to .041").
9. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 3G :
1. #32 material solution treated 10 minutes at 1800F, air cooled. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 30%.
3. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
4. Cold rolled 30%.
5. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Solution treated 10 minutes at 1800F, air cooled.
7. Cold rolled 30%.
8. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 3H :
1. #32 material annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 21.8% (.110" to .086").
3. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
4. Cold rolled 31.0% (.087" to .060").
5. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Cold rolled 31.0% (.058" to .040").
7. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

TABLE X
(Continued)

Process 3J :

1. #32 material solution treated 10 minutes at 1800F, air cooled. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
2. Cold rolled 30%.
3. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
4. Cold rolled 30%.
5. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Cold rolled 30%.
7. Solution treated 10 minutes at 1800F, air cooled.
8. Cold rolled 30%.
9. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

Process 3K :

1. #32 material stress relieved 10 minutes at 1450F, air cooled.
2. Cold rolled 30%.
3. Stress relieved 10 minutes at 1550F, air cooled.
4. Cold rolled 30%.
5. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.
6. Cold rolled 50%.
7. Annealed 5 hours at 1550F, slow cooled 5F/minute to 1050F, air cooled.

TABLE XI

Cold Rolled-Annealed Tensile Properties[1] of 0.040" Thick Ti-6Al-4V Strip

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1A								
Hot rolled 21% per pass from 1.500" to 0.750" thk and 23% per pass from .750" to .125" thick finishing below the beta transus.	2 hours @ 1550F slow cool 5F/minute to 1050F.	10 minutes @ 1450F air cool.	30%	0	144.0 144.9 144.5	130.0 127.8 128.9	14.5 15.0	35.3 32.1
				22½	137.2 136.7 137.0	128.2 126.9 127.6	15.0 18.5	34.0 35.3
				45	126.7 126.2 126.5	122.7 122.8 122.8	18.0 18.0	35.2 37.1
				67½	135.3 134.7 135.0	133.6 133.3 133.5	17.0 16.0	41.9 35.8
				90	144.8 143.6 144.2	138.8 137.0 137.9	15.0 15.5	40.5 36.7

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1B								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.75" to 0.125" thk finishing below the beta transus.	5 hours @ 1550F slow cool 5F/minute to 1050F.	10 minutes @ 1450F air cool.	30%	0	133.8 135.7 134.8	124.5 126.3 125.4	18.0 17.5	37.7 38.7
				22½	130.0 130.4 130.2	123.4 123.6 123.5	18.5 17.5	41.3 44.8
				45	125.2 125.2 125.2	118.6 121.5 120.1	16.5 18.5	46.1 47.0
				67½	129.1 129.4 129.3	124.5 125.0 124.8	18.5 19.0	51.5 49.8
				90	132.9 133.3 133.1	126.8 128.5 127.7	17.5 16.0	48.2 45.6

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1C								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.750" to 0.125 thk finishing below the beta transus.	2 hours @ 1550F slow cool 5F/minute to 1050F.	2 hours @ 1550F slow cool 5F/minute to 1050F.	30%	0	142.9	124.9	14.5	37.6
					143.1	124.6	15.5	38.6
					143.0	124.8		
				22½	135.5	125.7	14.5	35.2
					135.7	125.9	13.5	34.3
					135.6	125.8		
				45	126.2	121.2	17.5	41.4
					124.3	119.6	16.5	41.0
					125.3	120.4		
				67½	132.9	127.6	17.0	47.6
					133.6	128.0	16.5	42.5
					133.3	127.8		
				90	144.7	132.8	15.0	40.9
					144.2	134.0	12.5	39.4
					144.5	133.4		

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1D								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.750" to 0.125" thk finishing below the beta transus.	5 hours @ 1550F slow cool 5F/minute to 1050F.	10 minutes @ 1450F air cool.	20%	0	140.5 141.4 141.0	125.1 125.6 125.4	13.5 14.0	38.1 35.2
				22½	134.9 134.9 134.9	126.4 126.4 126.4	13.5 13.5	36.7 37.2
				45	126.0 126.2 126.1	120.8 122.7 121.8	16.5 15.0	41.4 41.9
				67½	135.0 135.2 135.1	131.6 131.4 131.5	17.0 15.0	45.5 43.3
				90	144.4 146.7 145.6	136.2 138.5 137.4	16.0 15.5	38.6 38.1

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1E								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.750" to 0.125" thk finishing below the beta transus.	Solution treated 10 minutes @ 1800F air cooled. 2 hours @ 1550F slow cool 5F/ minute to 1050F.	10 minutes @ 1450F air cooled.	20%	0	144.8 145.1 145.0	130.2 130.2 130.2	14.0 13.5	37.0 37.4
				22½	139.4 138.9 139.2	130.7 129.9 130.3	14.0 15.5	35.6 36.6
				45	131.8 131.4 131.6	129.0 127.1 128.1	15.5 13.5	40.5 41.1
				67½	137.3 137.5 137.4	134.2 133.8 134.0	13.0 12.0	38.5 39.5
				90	147.3 147.8 147.6	138.7 139.8 139.3	14.0 16.0	42.0 41.5

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1F								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.750" to 0.125 thk finishing below the beta transus.	Solution treated 10 minutes @ 1800F air cooled. 5 hours @ 1550F slow cool 5F/ minute to 1050F.	10 minutes @ 1450F air cooled.	20%	0	143.0 142.6 142.8	130.0 127.1 128.6	13.5 13.5	37.9 34.6
				22½	136.1 135.1 135.6	127.0 124.3 125.7	17.0 14.0	38.8 36.7
				45	131.4 130.7 131.1	124.2 125.1 124.7	16.5 16.0	38.1 40.3
				67½	135.0 135.7 135.4	129.9 132.9 131.4	15.0 15.0	39.2 44.1
				90	142.1 139.9 141.0	134.3 130.9 132.6	15.5 14.0	39.3 38.7

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1G								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.75" to 0.125" thk, finishing below the beta transus.	Solution treated 10 minutes @ 1800F air cooled. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cooled.	1. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cool. 2. Same and solution treated 10 minutes @ 1800F, air cool.	30%	0	144.4 145.3 144.9	131.4 132.9 132.2	14.0 13.5	41.3 33.4
				22½	137.4 140.9 139.2	129.3 131.5 130.4	15.5 15.0	48.1 40.6
				45	134.6 131.7 133.2	127.2 124.4 125.8	14.0 14.5	48.1 46.3
				67½	142.1 141.1 141.6	135.2 134.2 134.7	13.5 12.5	45.1 43.8
				90	150.0 150.9 150.5	142.6 139.9 141.3	11.5 13.0	31.9 38.9

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1H								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.750" to 0.125" thk finishing below the beta transus.	5 hours @ 1550F slow cool to 1050F.	5 hours @ 1550F slow cool to 1050F.	30%	0	140.5 140.1 140.3	124.6 124.6 124.6	15.5 15.5	36.6 37.2
				22½	133.3 134.5 133.9	125.2 125.5 125.4	16.5 17.0	38.6 38.1
				45	124.9 124.9 124.9	120.1 120.7 120.4	18.5 19.5	44.4 43.9
				67½	131.2 131.7 131.5	127.9 128.7 128.3	19.0 18.0	49.3 50.2
				90	140.5 140.2 140.4	133.9 133.3 133.6	16.0 16.5	40.5 42.4

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1J								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.75" to 0.125" thk, finishing below the beta transus.	Solution treated 10 minutes @ 1800F air cooled, 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cooled.	1. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cool. 2. Same. 3. Solution treated 10 minutes @ 1800F, air cool.	30%	0	144.1 142.7 143.4	131.4 129.2 130.3	11.0 13.5	36.0 40.1
				22½	139.4 138.2 138.8	130.6 129.4 130.0	16.0 14.5	35.2 33.3
				45	132.2 131.9 132.1	126.9 127.4 127.2	15.5 16.0	36.9 38.8
				67½	141.7 141.4 141.6	135.3 137.2 136.3	15.5 13.0	42.6 35.2
				90	150.0 148.5 149.3	142.4 137.9 140.2	12.0 14.0	37.0 38.3

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1K[2]								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.75" thk finishing below the beta transus.	Stress relieved 10 minutes @ 1450F, air cooled. 5 hours @ 1550F, slow cool 5F/ minute to 1050F, air cooled.	1. Stress relieved 10 minutes @ 1550F, air cool. 2. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cool.	1. 30% 2. 30% 3. 50%	0	137.6 138.1 137.9	119.7 120.5 120.1	18.3 18.3	-
				22½	134.9 133.0 134.0	121.4 120.4 120.9	18.3 20.0	-
				45	125.9 128.6 127.3	118.2 118.5 118.4	20.0 20.0	-
				67½	129.7 130.9 130.3	126.9 126.6 126.8	21.7 20.0	-
				90	137.1 136.3 136.7	130.7 127.5 128.8	16.7 18.3	-

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 1K[2]								
Hot rolled 21% per pass from 1.50" to 0.75" thk and 23% per pass from 0.75" thk finishing below the beta transus.	Final anneal 2 hours @ 1550F, slow cool 5F/minute to 1050F, air cool.	1. Stress relieved 10 minutes @ 1550F, air cool. 2. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cool.	1. 30% 2. 30% 3. 50%	0	141.6 140.3 141.0	126.3 121.8 124.1	18.3 16.7	-
				22½	135.5 136.6 136.1	120.3 124.4 122.4	16.7 16.7	-
				45	126.1 127.0 126.6	119.0 121.7 120.4	18.3 18.3	-
				67½	132.3 129.2 130.8	127.9 124.0 126.0	16.7 16.7	-
				90	136.3 137.9 137.1	128.9 129.6 129.3	16.7 16.7	-

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3A								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk.	2 hours @ 1550F slow cool to 1050F.	10 minutes @ 1450F air cool.	30%	0	142.8	129.8	14.5	42.8
					141.8	129.0	15.0	42.7
					142.3	129.4		
				22½	136.5	128.3	14.0	46.0
					137.9	129.6	16.0	36.2
					137.2	129.0		
				45	129.2	122.6	16.5	47.3
					129.5	125.7	17.5	46.4
					129.4	124.2		
				67½	135.2	129.2	14.5	44.8
					135.7	132.3	13.5	49.0
					135.5	130.8		
				90	138.3	133.6	14.5	45.4
					139.1	133.9	15.5	42.3
					138.7	133.8		

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3B								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk.	5 hours @ 1550F slow cool 5F/minute to 1050F.	10 minutes @ 1450F air cool.	30%	0	139.2 138.4 138.8	127.7 128.0 127.9	- -	44.6 43.9
				22½	132.2 131.5 131.9	120.8 124.0 122.4	16.0 15.5	41.5 40.4
				45	127.3 128.2 127.8	121.1 123.5 122.3	17.5 17.0	47.8 49.3
				67½	130.0 130.5 130.3	126.6 125.3 126.0	19.0 18.0	45.2 46.2
				90	134.8 134.5 134.7	131.0 127.7 129.4	16.0 17.0	47.3 43.3

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3C								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk.	2 hours @ 1550F slow cool 5F/minute to 1050F.	2 hours @ 1550F slow cool 5F/minute to 1050F.	30%	0	141.5 142.2 141.9	128.2 130.8 129.5	16.0 16.0	-
				22½	138.5 139.4 139.0	129.8 129.2 129.5	16.0 16.0	-
				45	128.7 128.2 128.5	125.7 123.7 124.7	19.5 17.0	-
				67½	132.7 133.3 133.0	128.4 130.2 129.3	16.0 16.5	-
				90	142.1 140.4 141.3	136.2 135.8 136.0	10.0 -	-

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3D								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk.	5 hours @ 1550F slow cool 5F/minute 50 1050F.	10 minutes @ 1450F air cool.	20%	0	142.2 142.3 142.3	129.4 130.2 129.8	15.0 16.0	33.3 33.8
				22½	134.5 136.0 135.3	127.2 129.7 128.5	14.5 15.5	37.0 38.0
				45	129.6 131.6 130.6	121.6 126.4 124.0	16.0 16.5	40.4 38.9
				67½	138.5 137.2 137.9	134.8 133.2 134.0	13.0 15.0	42.1 38.5
				90	145.1 143.7 144.4	138.3 136.4 137.4	13.0 14.5	25.6 29.4

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3E								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk.	Solution treated 10 minutes @ 1800F air cooled. 2 hours @ 1550F slow cool 5F/ minute to 1050F.	10 minutes @ 1450F air cooled.	20%	0	140.3 141.3 140.8	124.8 126.0 125.4	9.5 13.0	19.5 25.4
				22½	135.3 136.1 135.7	127.6 128.7 128.2	12.0 14.0	32.1 29.4
				45	127.5 127.7 127.6	123.3 122.6 123.0	14.0 15.5	33.2 37.1
				67½	134.3 134.3 134.3	130.1 130.4 130.3	12.5 13.0	37.5 35.5
				90	147.9 149.0 148.5	140.2 141.5 140.9	11.0 11.5	25.6 26.0

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3F								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk.	Solution treated 10 minutes @ 1800F air cooled. 5 hours @ 1550F slow cooled 5F/minute to 1050F.	10 minutes @ 1450F air cooled.	20%	0	140.0 139.1 139.6	125.8 125.7 125.8	14.0 13.0	30.0 31.3
				22½	134.0 134.8 134.4	127.1 126.1 126.6	15.0	33.5
				45	127.0 127.5 127.3	123.3 122.9 123.1	15.5 17.0	39.4 40.9
				67½	137.6 136.4 137.0	132.4 131.8 132.1	13.5 13.0	33.3 34.8
				90	145.0 144.6 144.8	137.2 137.4 137.3	12.0 12.5	29.0 28.2

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3G								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk finishing above the beta transus.	Solution treated 10 minutes @ 1800F, air cooled. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cooled.	1. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cool. 2. Same and solution treated 10 minutes @ 1800F, air cool.	30%	0	142.8 143.2 143.0	129.9 128.6 129.3	12.0 11.0	24.6 34.3
				22½	137.4 137.5 137.5	128.5 128.4 128.5	11.5 14.0	28.7 30.2
				45	133.1 132.5 132.8	127.8 123.6 125.7	16.0 13.0	49.4 48.3
				67½	141.4 138.9 139.7	135.4 131.8 133.8	12.5 12.5	25.7 35.4
				90	150.3 146.3 148.3	140.5 135.7 138.1	9.5 12.5	20.6 30.3

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3H								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk.	5 hours @ 1550F slow cool 5F/minute to 1050F.	5 hours @ 1550F slow cool 5F/minute to 1050F.	30%	0	139.8	122.4	16.0	33.1
					138.1	125.0	15.5	32.6
					139.0	123.7		
				22½	135.2	126.2	13.5	34.4
					133.7	124.8	14.0	33.7
					134.5	125.5		
				45	125.6	120.9	19.0	43.1
					126.2	122.4	15.0	37.8
					125.9	121.7		
				67½	133.2	128.2	16.5	39.4
					131.5	127.1	15.0	41.5
					132.4	127.7		
				90	139.0	124.4	14.5	35.9
					139.1	125.5	14.5	36.9
					139.1	125.0		

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3J								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk finishing above the beta transus.	Solution treated 10 minutes @ 1800F air cool. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cool.	1. 5 hours @ 1550F slow cool 5F/minute to 1050F, air cool. 2. Same 3. Solution treated 10 minutes @ 1800F, air cool.	30%	0	144.7 142.8 143.8	132.0 129.7 130.9	8.5 7.0	18.9 18.0
				22½	140.4 139.1 139.8	129.3 130.4 129.9	17.0 16.0	32.3 33.1
				45	132.2 132.4 132.3	125.7 125.9 125.8	17.5 17.5	37.3 40.6
				67½	141.8 142.1 142.0	135.3 136.0 135.7	14.0 15.0	33.5 36.5
				90	149.7 150.0 149.9	139.6 140.3 140.0	15.0 14.0	35.3 28.8

TABLE XI
(Continued)

Processing Details					Tensile Properties			
Hot Rolling Procedure	Initial & Final Anneals	Intermediate Anneals	Cold Reduction	Direction Degrees From Long	Ultimate Strength psix10^{-3}	0.2% Yield Strength psix10^{-3}	Elongation % in 2"	Reduction in Area %
Process 3K								
Hot rolled 13% per pass from 1.50" to 0.75" thk and 15% per pass from 0.75" to 0.125" thk, finishing above the beta transus.	Stress relieved 10 minutes @ 1450F, air cool. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cool.	1. Stress relieved 10 minutes @ 1550F, air cool. 2. 5 hours @ 1550F, slow cool 5F/minute to 1050F, air cool.	1. 30% 2. 30% 3. 50%	0	131.0 130.2 130.6	122.2 122.0 122.1	19.0 18.0	43.9 44.1
				22½	128.8 129.4 129.1	124.2 123.7 124.0	17.5 18.0	40.5 40.6
				45	125.1 125.4 125.3	123.0 121.5 122.3	19.0 20.0	41.7 42.2
				67½	126.6 125.7 126.2	123.1 122.2 122.7	18.5 19.0	45.7 45.7
				90	129.7 130.6 130.2	126.5 127.1 126.8	17.0 18.5	43.4 44.5

1. Test data obtained on standard flat tensile specimens with 2" gage length, except as noted.
2. Test data obtained on sub-standard flat tensile specimens with 0.6" gage length.

TABLE XII

Process-Directionality Relationship for 0.040" Thick Ti-6Al-4V Annealed Strip

Process[1]	Thermal Treatment[2]			Cold Reductions	Directionality[3] (ksi)	
	Initial	Intermediate	Final		Ultimate Strength	Yield Strength
1A	2 hrs @ 1550F	10 min @ 1450F	2 hrs @ 1550F	(3) 30%	18.0	15.1
1B	5 hrs @ 1550F	10 min @ 1450F	5 hrs @ 1550F	(3) 30%	9.6	7.6
1D	5 hrs @ 1550F	10 min @ 1450F	5 hrs @ 1550F	(4) 20%	19.5	15.6
1C	2 hrs @ 1550F	2 hrs @ 1550F	2 hrs @ 1550F	(3) 30%	19.2	12.0
1H	5 hrs @ 1550F	5 hrs @ 1550F	5 hrs @ 1550F	(3) 30%	15.5	13.2
1E	10 min @ 1800F 2 hrs @ 1550F	10 min @ 1450F	2 hrs @ 1550F	(4) 20%	16.0	11.2
1F	10 min @ 1800F 2 hrs @ 1550F	10 min @ 1450F	5 hrs @ 1550F	(4) 20%	11.7	7.9
1G	10 min @ 1800F	1. 5 hrs @ 1550F 2. 5 hrs @ 1550F 3. 10 min @ 1800F	5 hrs @ 1550F	(3) 30%	17.3	15.5
1J	10 min @ 1800F 5 hrs @ 1550F	1. 5 hrs @ 1550F 2. 5 hrs @ 1550F 3. 10 min @ 1800F	5 hrs @ 1550F	(4) 30%	17.2	13.0
1K	10 min @ 1450F	1. 10 min @ 1550F 2. 5 hrs @ 1550F	5 hrs @ 1550F	1. 30% 2. 30% 3. 50%	10.6	10.4

TABLE XII
(Continued)

Process[1]	Thermal Treatment[2]			Cold Reductions	Directionality[3] (ksi)	
	Initial	Intermediate	Final		Ultimate Strength	Yield Strength
1K	10 min @ 1405F	1. 10 min @ 1550F 2. 5 hrs @ 1550F	2 hrs @ 1550F	1. 30% 2. 30% 3. 50%	14.4	8.9
3A	2 hrs @ 1550F	10 min @ 1450F	2 hrs @ 1550F	(3) 30%	12.9	9.6
3B	3 hrs @ 1550F	10 min @ 1450F	5 hrs @ 1550F	(3) 30%	11.0	7.2
3D	5 hrs @ 1550F	10 min @ 1450F	5 hrs @ 1550F	(4) 20%	13.8	13.4
3C	2 hrs @ 1550F	2 hrs @ 1550F	2 hrs @ 1550F	(3) 30%	13.4	11.3
3H	5 hrs @ 1550F	5 hrs @ 1550F	5 hrs @ 1550F	(3) 30%	13.2	6.0
3E	10 min @ 1800F 2 hrs @ 1550F	10 min @ 1450F	2 hrs @ 1550F	(4) 20%	20.9	17.9
3F	10 min @ 1800F 5 hrs @ 1550F	10 min @ 1450F	5 hrs @ 1550F	(4) 20%	17.1	14.2
3G	10 min @ 1800F 5 hrs @ 1550F	1. 5 hrs @ 1550F 2. 5 hrs @ 1550F 3. 10 min @ 1800F	5 hrs @ 1550F	(3) 30%	15.5	12.4
3J	10 min @ 1800F 5 hrs @ 1550F	1. 5 hrs @ 1550F 2. 5 hrs @ 1550F 3. 10 min @ 1800F	5 hrs @ 1550F	(4) 30%	17.6	14.2
3K	10 min @ 1450F	1. 10 min @ 1550F 2. 5 hrs @ 1550F	5 hrs @ 1550F	1. 30% 2. 30% 3. 50%	5.3	4.5

TABLE XII
(Continued)

1. Processes 1A through 1K hot rolled 23% per pass from 0.750" to 0.125" thick below transus.
   Processes 3A through 3K hot rolled 15% per pass from 0.750" to 0.125" thick above transus.

2. All 2 and 5 hour treatments at 1550F were anneals slow cooled 5F/minute to 1050F and then air cooled.
   Ten minute treatments at 1450F, 1550F and 1800F were air cooled.

3. Difference between maximum and minimum test values determined in five testing directions.

TABLE XIII

Tensile Test and Bend Test Results on Process 1B and Process 1K
.040" Thick Ti-6Al-4V Sheet at Room Temperature

		Process 1B				Process 1K			
Condition	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"	Minimum Bend (xT)	Ultimate Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"	Minimum Bend (xT)
Annealed	0	139.3	125.3	13.0	3.2	139.0	122.5	12.5	2.8
(1550F,	22.5	135.2	126.9	12.0	2.5	132.4	122.7	13.0	2.8
slow cool	45	122.9	119.2	15.0	2.5	125.3	123.1	14.0	2.8
to 1050F)	67.5	136.5	134.1	12.5	2.5	129.8	127.9	13.5	2.8
	90	146.4	138.2	8.5	2.8	133.9	129.6	14.5	3.0
Solution	0	162.9	132.9	12.5	3.1	160.6	131.1	11.0	2.9
Treated	22.5	153.7	124.3	9.5	2.9	154.8	129.4	12.0	3.1
(1700F,	45	150.2	128.2	14.0	2.4	149.5	120.7	14.0	2.7
20', WQ)	67.5	151.6	129.4	12.0	2.8	149.8	129.4	12.0	2.7
	90	162.9	137.9	13.0	2.9	152.1	129.3	9.5	3.0
Solution	0	181.3	165.4	7.0	-	175.6	157.9	7.5	-
Treated &	22.5	174.6	162.3	7.5	-	165.4	153.9	7.5	-
Aged (ST	45	171.0	161.7	8.0	-	163.6	152.5	10.5	-
plus 1000F,	67.5	179.3	169.0	5.5	-	174.4	161.2	8.0	-
4 hours)	90	178.0	170.2	6.5	-	174.6	159.8	8.0	-

TABLE XIV

Tensile Test Results on Process 1B and Process 1K
.040" Thick Ti-6Al-4V Sheet at 400F

Condition	Test Direction (° From Long.)	Process 1B Ultimate Tensile Strength ksi	Process 1B Yield Strength ksi	Process 1B Elongation % in 2"	Process 1K Ultimate Tensile Strength ksi	Process 1K Yield Strength ksi	Process 1K Elongation % in 2"
Annealed (1550F, slow cool to 1050F)	0	108.6	87.8	11.0	109.7	88.9	17.0
	22.5	103.1	88.4	16.0	102.8	88.3	19.0
	45	90.7	79.2	21.0	92.6	84.7	19.5
	67.5	105.2	96.8	13.0	98.0	88.1	17.0
	90	106.6	96.0	10.0	104.7	91.9	17.0
Solution Treated (1700F, 20', WQ)	0	-	-	-	133.7	99.9	11.0
	22.5	-	-	-	129.7	93.1	14.0
	45	-	-	-	117.7	85.9	16.5
	67.5	-	-	-	125.0	91.7	15.5
	90	-	-	-	136.3	104.9	9.0
Solution Treated & Aged (ST plus 1000F, 4 hours)	0	145.8	120.6	6.5	144.0	116.7	8.5
	22.5	139.9	118.7	7.5	135.4	109.3	11.5
	45	125.2	113.9	-	132.4	108.1	12.0
	67.5	135.8	115.5	7.5	142.1	118.7	9.5
	90	146.3	121.1	7.0	145.8	121.6	10.0

TABLE XV

Tensile Test Results on Process 1B and Process 1K .040" Thick Ti-6Al-4V Sheet at 600F

		Process 1B			Process 1K		
Condition	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"	Ultimate Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"
Annealed (1550F, slow cool to 1050F)	0	102.0	76.0	10.0	106.1	77.1	14.0
	22.5	93.8	74.5	14.0	94.5	73.6	15.5
	45	81.7	67.1	18.0	84.1	69.3	18.5
	67.5	90.2	79.4	10.0	89.0	75.0	15.5
	90	99.2	84.2	10.0	94.1	77.6	15.0
Solution Treated (1700F, 20', WQ)	0	-	-	-	125.0	93.0	8.0
	22.5	-	-	-	125.7	90.0	12.0
	45	-	-	-	112.6	78.5	12.5
	67.5	-	-	-	117.9	86.5	10.0
	90	-	-	-	128.1	94.4	7.5
Solution Treated & Aged (ST plus 1000F, 4 hours)	0	137.4	106.0	6.5	131.1	99.9	9.5
	22.5	126.4	97.9	7.0	125.1	96.2	-
	45	125.6	98.6	7.5	121.9	95.0	10.0
	67.5	125.1	99.3	7.0	128.4	99.6	9.0
	90	138.6	112.3	5.5	134.3	104.9	8.0

TABLE XVI

Tensile Test Results on Process 1B and Process 1K
.040" Thick Ti-6Al-4V Sheet at 800F

Condition	Test Direction (° From Long.)	Process 1B Ultimate Tensile Strength ksi	Process 1B Yield Strength ksi	Process 1B Elongation % in 2"	Process 1K Ultimate Tensile Strength ksi	Process 1K Yield Strength ksi	Process 1K Elongation % in 2"
Annealed (1550F, slow cool to 1050F)	0	99.0	70.4	11.5	93.6	71.0	15.0
	22.5	88.1	68.4	15.5	91.5	68.6	17.5
	45	79.3	62.7	17.0	81.4	64.3	22.5
	67.5	87.4	75.1	11.5	86.4	73.1	16.5
	90	92.7	78.0	10.5	87.1	71.1	15.0
Solution Treated (1700F, 20', WQ)	0	-	-	-	127.3	93.4	7.5
	22.5	-	-	-	120.9	83.8	13.0
	45	-	-	-	115.8	78.6	14.5
	67.5	-	-	-	123.4	87.0	13.0
	90	-	-	-	130.1	90.1	7.0
Solution Treated & Aged (ST plus 1000F, 4 hours)	0	128.9	97.7	7.0	124.9	93.7	9.0
	22.5	118.7	89.7	9.5	118.4	89.7	10.0
	45	118.4	90.7	9.0	115.5	85.7	9.0
	67.5	117.6	91.0	8.5	122.0	93.0	8.0
	90	133.5	104.8	6.5	125.3	97.4	4.0

TABLE XVII

Compression Test Results on Process 1B and Process 1K
.040" Thick Ti-6Al-4V Sheet at Room Temperature, 600F and 800F

Condition	Test Direction (° From Long.)	Compression Yield Strength (ksi)					
		Room Temperature		600F		800F	
		1B	1K	1B	1K	1B	1K
Annealed (1550F, slow cool to 1050F)	0	125.3	134.8	79.6	80.9	70.5	74.9
	22.5	126.5	137.3	75.2	78.2	71.6	71.4
	45	128.1	128.3	69.2	75.4	67.8	66.0
	67.5	148.1	136.9	90.1	78.6	80.3	72.9
	90	155.6	155.1	102.1	80.1	93.0	76.4
Solution Treated and Aged (1700F, 20', WQ plus 1000F, 4 hours)	0	182.4	172.3	101.9	114.2	97.7	95.8
	22.5	172.3	164.8	122.4	98.3	99.1	94.7
	45	166.2	166.1	95.0	98.9	-	90.7
	67.5	189.1	177.3	-	106.6	102.4	92.4
	90	-	174.4	94.5	110.2	87.2	105.5

TABLE XVIII

Comprehensive Test Program Data on .040" Thick C120AV Sheet Rolled by Processes 1B and 1K

Condition	Type of Test	Test Temp	Directionality: UTS 1B	UTS 1K	YS 1B	YS 1K	EL 1B	EL 1K	Bend 1B	Bend 1K	Test result ranges (5 test directions): UTS (ksi) 1B	UTS (ksi) 1K	YS (ksi) 1B	YS (ksi) 1K	EL (% in 2") 1B	EL (% in 2") 1K	Bend(XT) 1B	Bend(XT) 1K
Annealed	Tension	RT	23.5	13.7	19.0	7.1	6.5	2.0			122.9-146.4	125.3-139.0	119.2-138.2	122.5-129.6	8.5-15.0	12.5-14.5		
		400F	17.9	17.1	17.6	7.2	11.0	2.5			90.7-108.6	92.6-109.7	79.2- 96.8	84.7- 91.9	10.0-21.0	17.0-19.5		
		600F	20.3	22.0	17.1	8.3	8.0	4.5			81.7-102.0	84.1-106.1	67.1- 84.2	69.3- 77.6	10.0-18.0	14.0-18.5		
		800F	19.7	12.2	12.2	8.8	6.5	7.5			79.3- 99.0	81.4- 93.6	62.7- 78.0	64.3- 73.1	10.5-17.0	15.0-22.5		
	Compression	RT	-	-	30.3	26.8	-	-			-	-	125.3-155.6	128.3-155.1	-	-		
		600F	-	-	32.9	5.5	-	-			-	-	69.2-102.1	75.4- 80.9	-	-		
		800F	-	-	25.2	10.4	-	-			-	-	67.8- 93.0	66.0- 76.4	-	-		
	Bend	RT							.7	.2							2.5-3.2	2.8-3.0
Solution Treated 1700F, 20', WQ	Tension	RT	12.7	11.1	13.6	10.4	4.5	4.5			150.2-162.9	149.5-160.6	124.3-137.9	120.7-131.1	9.5-14.0	9.5-14.0		
		400F	-	18.6	-	19.0	-	7.5			-	117.7-136.3	-	85.9-104.9	-	9.0-16.5		
		600F	-	15.5	-	15.9	-	5.0			-	112.6-128.1	-	78.5- 94.4	-	7.5-12.5		
		800F	-	14.3	-	14.8	-	7.5			-	115.8-130.1	-	78.6- 93.4	-	7.0-14.5		
	Bend	RT							.7	.4							2.4-3.1	2.7-3.1
Solution Treated plus 1000F, 4 hr, age	Tension	RT	10.3	12.0	8.5	8.7	2.5	3.0			171.0-181.3	163.6-175.6	161.7-170.2	152.5-161.2	5.5- 8.0	7.5-10.5		
		400F	21.1	13.4	7.2	13.5	-	3.5			125.2-146.3	132.4-145.8	113.9-121.1	108.1-121.6	6.5- -	8.5-12.0		
		600F	13.5	12.4	14.4	9.9	2.0	2.0			125.1-138.6	121.9-134.3	97.9-112.3	95.0-104.9	5.5- 7.5	8.0-10.0		
		800F	15.9	9.8	15.1	11.7	3.0	2.0			117.6-133.5	115.5-125.3	89.7-104.8	85.7- 97.4	6.5- 9.5	8.0-10.0		
	Compression	RT	-	-	22.9	12.5	-	-			-	-	166.2-189.1	164.8-177.3	-	-		
		600F	-	-	27.9	15.9	-	-			-	-	94.5-122.4	98.3-114.2	-	-		
		800F	-	-	15.2	14.8	-	-			-	-	87.2-102.4	90.7-105.5				

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TABLE XIX

Effect of Rolling Speed and Roll Diameter on Ti-6Al-4V Strip Directionality Processes 1B and 1K[1]

Condition - Annealed 1550°F, 5 Hours, Slow Cooled to 1050°F

Roll Diameter	Rolling Speed	Process	Test Direction (° from Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"
4"	60'/min	1B	0	136.1	127.3	12.5
				137.5	127.8	12.5
			22½	135.3	130.8	12.0
				134.3	128.6	13.5
			45	131.7	130.3	14.5
				132.2	129.4	13.5
			67½	131.8	131.4	14.5
				131.3	129.9	14.0
			90	133.3	131.2	13.0
				137.1	136.0	12.5
		1K	0	119.5	119.5	(2)
				133.8	123.9	13.0
			22½	131.6	125.3	12.0
				132.5	128.4	15.0
			45	131.1	129.7	13.5
				130.6	127.4	13.5
			67½	129.3	127.9	16.5
				130.2	122.6	13.5
			90	135.2	132.0	14.0
				134.0	131.5	13.0

TABLE XIX
(Continued)

Roll Diameter	Rolling Speed	Process	Test Direction (° from Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"
2½"	60'/min	1B	0	138.8	127.8	12.0
				141.6	130.5	13.0
			22½	132.8	125.8	12.0
				133.9	128.0	16.5
			45	129.4	124.8	11.5
				130.4	127.2	12.0
			67½	132.5	129.5	12.0
				134.5	132.2	15.0
			90	138.3	136.2	12.5
				138.5	135.3	13.5
		1K	0	133.6	124.9	14.0
				134.3	124.2	12.5
			22½	130.7	127.2	13.5
				131.8	126.3	16.0
			45	127.0	125.2	12.5
				128.6	127.2	14.5
			67½	130.7	129.6	16.0
				130.7	127.9	16.0
			90	134.0	130.8	13.0
				133.2	131.8	14.0

TABLE XIX
(Continued)

Roll Diameter	Rolling Speed	Process	Test Direction (° from Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"
2½"	140'/min	1B	0	140.8	129.3	11.5
				136.6	125.4	11.5
			22½	135.6	129.7	12.0
				135.9	129.0	12.5
			45	127.9	125.0	10.5
				127.0	125.9	10.5
			67½	131.8	131.4	12.0
				130.6	129.9	12.0
			90	135.7	132.0	14.0
				134.1	131.4	12.5
		1K	0	135.2	127.0	13.5
				139.5	129.3	12.0
			22½	133.9	126.3	12.0
				137.2	128.8	11.5
			45	124.8	121.1	14.0
				128.1	125.0	13.0
			67½	135.0	129.2	15.0
				131.7	126.3	14.0
			90	137.5	132.7	13.5
				138.3	134.2	13.0

TABLE XIX
(Continued)

1 - Process 1B - Hot rolled to hot band below the beta transus, finished with 30% cold reductions and intermediate anneals.

Process 1K - Hot rolled to hot band below the beta transus, finished with a series of 30% cold reductions and a final 50% cold reduction and intermediate anneals.

2 - Outside gage mark break.

TABLE XX

Effect of Strip Tension on Ti-6Al-4V Strip Directionality

Condition - Annealed 1550°F, 5 Hours, Slow Cooled to 1050°F

Strip Tension (% of Yield Strength) Forward	Strip Tension (% of Yield Strength) Back	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"
30	30	0	143.6	128.0	12.5
			141.5	128.1	13.5
		22½	137.7	132.3	15.0
			137.0	131.2	14.5
		45	125.6	122.8	16.0
			125.6	120.0	17.0
		67½	143.8	137.3	15.5
			144.4	137.1	13.5
		90	160.0	144.7	12.0
			160.0	144.7	11.5
10	10	0	145.2	131.8	11.0
			144.6	130.6	8.0
		22½	138.0	131.1	9.0
			138.0	130.3	11.0
		45	127.5	126.0	18.0
			126.9	124.6	17.0
		67½	144.4	141.3	14.5
			142.5	134.2	15.0
		90	158.9	144.2	12.5
			159.4	146.8	12.0

TABLE XX
(Continued)

Strip Tension (% of Yield Strength) Forward	Back	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"
30	10	0	142.7	127.3	9.0
			143.0	127.6	9.0
		22½	137.0	130.7	12.0
			137.0	129.6	13.0
		45	126.1	120.9	10.0
			124.8	120.7	18.5
		67½	142.4	136.2	13.0
			142.4	134.7	15.0
		90	159.2	141.6	13.5
			161.1	150.0	13.5
10	30	0	146.1	132.5	12.5
			144.8	131.9	10.5
		22½	138.1	130.3	13.5
			137.4	130.7	15.5
		45	127.7	126.1	14.5
			126.5	123.7	18.0
		67½	140.6	134.7	12.5
			140.8	134.8	13.5
		90	160.6	144.9	8.5
			155.4	148.5	5.5

TABLE XXI

Process 1B - Effect of Prestrain on Room Temperature Mechanical Properties of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched

Aging Treatment - 4 hours at 1000F except for values marked (†), which were aged 19.5 hours at 1000F.

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
RT	As-strained	0	0	182.9	155.0	7.5	185.9
				185.6	157.1	6.0	174.6
			22½	179.9	155.2	7.0	143.4
				176.8	153.3	9.0	146.5
			45	175.6	144.8	8.0	164.2
				177.8	154.2	7.5	-
			67½	187.5	158.8	6.0	153.0
				186.1	155.0	7.0	162.3
			90	185.3	178.0	5.5	192.6
				187.8	168.9	4.5	195.5
		0.5	45	-	-	-	168.7
		1.0	90	-	-	-	143.7
		1.5	0	-	-	-	127.8
		2.0	67½	-	-	-	132.7
		2.5	0	200.0	195.1	3.0	-
			90	196.9	194.6	2.0	-
		3.0	0	193.4	183.8	4.5	-
			22½	-	-	-	102.1

TABLE XXI
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
RT	As-strained	3.0	45	192.9	187.8	4.0	-
				187.3	183.7	5.0	-
			67½	197.9	189.9	4.5	-
		4.0	0	-	-	-	76.1
			22½	192.0	186.9	4.0	-
				191.8	187.5	5.0	-
			67½	198.7	192.6	3.0	-
		5.0	0	198.4	190.9	2.5	-
				200.0	198.7	2.5	-
	Aged After Prestrain	0	0	193.4	177.3	4.5	185.3
				196.2	182.2	5.0	185.7
			22½	189.7	175.3	6.0	127.8
				186.0	171.9	5.0	129.8
			45	187.5	173.6	6.0	179.4
				188.2	172.6	6.0	175.7
			67½	192.3	178.4	6.0	157.5
				194.2	180.3	9.0	152.4
			90	195.5	181.0	5.0	192.4
				193.3	176.1	2.5	194.9
		1.0	90	-	-	-	191.9
		2.0	0	-	-	-	179.1
		3.0	0	199.7	186.5	3.5	-
				199.0	185.8	4.0	-

TABLE XXI
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
RT	Aged After Prestrain	3.0	22½	-	-	-	183.6
			67½	194.6	184.5	5.5	196.9
				198.9	186.6	4.5	-
		3.5	0	-	-	-	185.5
			22½	189.5	177.4	5.5	-
			45	192.6	187.1	4.0	-
		4.0	22½	188.0	175.8	5.5	-
			45	-	-	-	184.2
		4.5	45	193.2	187.4	4.0	-
		5.0	0	196.0	183.7	3.5	-
				197.6	187.1	3.0	-
400F	As-strained	0	0	178.4	154.7	7.5	180.4
				184.3	161.0	6.0	-
		2.5	0	187.5	187.5	*	-
		3.0	0	195.5	195.5	*	78.4
		3.5	0	-	-	-	80.2
				-	-	-	83.5
		5.0	0	206.9	206.2	1.5	-
				199.7	198.7	2.0	-

TABLE XXI
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
400F	As-strained	7.0	0	-	-	-	81.3
	Aged After Prestrain	0	0	195.8	179.9	5.5	186.2
				191.8	179.1	6.0	-
		3.0	0	191.0	178.9	6.0	183.2
				-	-	-	187.1
		4.5	0	200.0	188.9	3.5	-
		5.0	0	196.6	188.3	4.0	180.0/
				191.4	179.8	2.5	167.1/
700F	As-strained	0	0	192.5	172.7	*	176.3
				189.8	166.3	4.0	-
			22½	188.5	165.0	7.0	181.4
				192.2	167.2	*	-
			45	189.2	169.9	3.0	181.7
				188.0	167.0	*	-
			67½	192.3	168.3	5.0	196.6
				194.5	171.7	5.0	-
			90	193.4	182.8	*	205.5
				199.1	176.6	*	-
		2.0	67½	-	-	-	111.3
			90	195.2	193.7	*	-
		2.5	90	200.5	200.2	*	-

TABLE XXI
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
700F	As-strained	3.0	0	195.3	195.3	*	97.1
				204.0	204.0	*	114.1
			22½	191.7	191.7	*	-
				192.5	191.3	*	-
			67½	202.5	202.5	*	-
				199.0	199.0	*	-
		3.5	0	202.2	201.2	*	-
			22½	-	-	-	111.9
				-	-	-	105.6
			45	-	-	-	98.7
				-	-	-	100.6
			90	-	-	-	103.9
				-	-	-	100.5
		4.0	0	208.1	207.8	*	100.5
				-	-	-	99.4
		4.5	45	200.0	200.0	1.5	-
		5.0	45	192.3	192.3	0.5	-
	Aged After Prestrain	0	0	198.8	183.8	5.0	184.6
				193.8	180.2	6.0	-
			22½	190.0	173.9	7.0	184.7
				188.8	173.4	5.0	-
			45	189.8	175.9	5.0	199.2
				190.6	176.2	5.0	-

TABLE XXI
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
700F	Aged After Prestrain	0	67½	194.7	179.5	6.5	191.1
				195.8	180.9	5.0	-
			90	200.5	185.6	5.0	202.0
				201.5	184.4	*	-
		2.5	22½	193.2	180.6	5.0	-
			67½	-	-	-	186.7/
		3.0	0	192.9	183.4	4.0	180.4/
				-	-	-	178.3/
			45	191.3	187.3	2.5	-
				191.9	184.2	5.5	-
			67½	195.7	186.3	4.0	-
				192.0	181.7	5.0	-
		3.5	0	186.0	182.2	2.0	-
			22½	187.8	182.3	1.5	177.8/
			45	-	-	-	194.1/
				-	-	-	183.2/
			90	184.9	177.4	1.5	-
		4.0	0	188.4	185.5	1.5	188.8/
				-	-	-	190.1/
		5.0	0	194.5	185.6	2.5	-
1000F	As-strained	0	0	187.6	175.1	*	188.7
				186.0	174.7	*	-
		2.0	0	-	-	-	176.0

TABLE XXI
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
1000F	As-strained	3.0	0	205.9	197.5	4.0	167.2
				206.9	199.5	2.0	168.9
				-	-	-	177.5
		4.0	0	205.1	198.6	2.0	-
		5.0	0	203.2	196.3	2.5	-
	Aged After Prestrain	0	0	196.7	181.0	5.5	191.9
				192.4	179.7	6.5	-
		3.0	0	195.0	185.0	5.0	182.8*
				-	-	-	183.9*
		3.5	0	187.6	181.0	3.5	-
		4.5	0	188.7	179.2	4.5	-
		5.0	0	191.1	181.9	3.5	199.4*

*Broke outside gage mark.

TABLE XXII

Process 1K - Effect of Prestrain on Room Temperature Mechanical Properties of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched

Aging Treatment - 4 Hours at 1000F except for values marked (/), which were aged 19.5 hours at 1000F.

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
RT	As-strained	0	0	176.4	155.1	8.5	165.6
				171.6	149.5	7.5	169.3
			22½	165.8	146.9	8.0	158.0
				168.5	144.2	7.5	163.2
			45	170.7	149.6	9.5	166.8
				168.0	148.1	10.0	-
			67½	177.0	158.6	6.5	178.3
				165.0	149.4	8.0	184.5
			90	173.3	152.4	6.0	190.3
				170.1	149.0	8.0	186.8
		1.5	0	-	-	-	107.2
		2.0	67½	-	-	-	107.9
		2.5	45	-	-	-	71.9
			90	193.5	192.9	1.0	-
		3.0	0	181.6	179.2	5.0	-
				188.3	186.7	4.0	-
		3.5	22½	-	-	-	62.8
			90	-	-	-	134.2

TABLE XXII
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
RT	As-strained	4.0	0	-	-	-	64.2
			90	201.8	200.4	2.5	-
		4.5	0	195.3	185.8	2.5	-
			22½	182.8	178.1	4.5	-
			67½	185.4	182.7	1.0	-
		5.0	22½	179.8	172.4	4.0	-
				177.9	175.7	4.5	-
				183.8	183.5	4.0	-
	Aged After Prestrain	0	0	181.1	166.3	8.0	166.9
				172.8	163.0	8.0	172.8
			22½	172.3	159.0	7.0	170.7
				178.0	164.0	8.0	174.2
			45	173.1	162.6	8.0	163.3
				173.4	162.7	7.5	162.8
			67½	181.9	167.8	7.0	175.8
				179.1	164.5	6.5	180.1
			90	180.1	168.3	5.0	207.5
				178.1	163.2	6.5	207.1
		2.0	0	-	-	-	174.4
			22½	-	-	-	169.3
			45	-	-	-	173.8
		3.0	0	188.7	177.2	5.0	165.8
			67½	-	-	-	177.1
			90	185.7	184.3	2.0	-

TABLE XXII
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
RT	Aged After Prestrain	3.5	0	186.4	175.2	4.5	-
			90	185.7	176.6	4.0	180.7
		5.0	0	183.6	171.1	4.0	-
				187.0	177.9	3.0	-
			22½	181.8	174.3	5.0	-
			45	178.1	172.6	6.0	-
				176.7	170.9	5.0	-
			67½	184.8	176.0	4.0	-
				185.6	177.3	4.0	-
400F	As-strained	0	0	177.3	154.1	6.0	172.7
				169.0	146.0	9.5	-
		3.0	0	187.2	184.7	3.0	68.3
				186.9	182.5	*	75.9
		5.0	0	184.9	184.9	*	72.5
				192.7	189.3	4.5	79.3
	Aged After Prestrain	0	0	164.7	150.3	8.5	171.4
				181.0	165.5	8.0	-
		3.0	0	172.4	159.6	7.5	171.1
				174.7	162.1	7.0	172.6
		5.0	0	187.3	178.5	4.0	168.5/
				--	--	--	189.2/
700F	As-strained	0	0	166.2	144.8	7.0	175.5
				188.3	165.7	5.5	-

TABLE XXII
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
700F	As-strained	0	22½	179.6	159.5	5.0	175.5
				170.6	150.3	7.0	-
			45	178.6	160.6	5.5	173.7
				179.1	154.5	6.0	-
			67½	182.3	164.8	5.0	182.5
				180.7	163.8	4.0	-
			90	183.0	164.9	6.0	179.4
				185.8	168.3	6.0	-
		3.0	0	195.6	194.8	2.0	88.3
				181.9	181.9	*	92.4
				183.3	182.1	*	-
				192.6	192.6	*	-
			22½	181.9	180.4	3.0	-
			45	178.8	178.8	2.5	-
			90	190.9	190.0	3.0	92.0
				192.0	187.2	1.5	-
		3.5	67½	193.0	193.0	*	111.5
				197.5	197.5	2.0	-
		4.0	0	-	-	-	88.9
			22½	-	-	-	112.2
		5.0	22½	-	-	-	98.8
			45	-	-	-	90.3
				-	-	-	96.9
			67½	-	-	-	97.3

TABLE XXII
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
700F	Aged After Prestrain	0	0	173.8	159.9	6.0	162.6
				182.2	166.5	6.5	-
			22½	180.6	168.8	8.0	177.0
			45	172.3	161.7	7.5	169.0
			67½	183.1	171.4	8.5	179.4
				181.9	168.4	7.5	-
			90	183.4	171.9	8.0	182.8
				185.4	174.8	9.0	-
		2.0	90	-	-	-	176.8/
		3.0	0	177.3	165.4	8.5	155.8/
				181.0	172.7	5.5	182.4/
				175.7	164.8	4.0	-
				187.9	177.2	4.0	-
			22½	180.2	170.4	7.0	-
				179.0	169.2	6.0	-
			45	175.0	166.0	8.0	-
				181.9	172.6	5.5	-
			67½	184.0	175.0	5.0	-
				180.9	170.5	6.5	-
		4.0	0	-	-	-	173.0/
			67½	-	-	-	181.3/
		5.0	22½	-	-	-	173.7/
				-	-	-	164.1/
			45	-	-	-	171.3/
			67½	-	-	-	187.3/

TABLE XXII
(Continued)

Prestrain Temperature	Condition	% Prestrain	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"	Compressive Yield Strength ksi
1000F	As-strained	0	0	156.0 172.5	146.6 156.9	8.5 4.0	179.0 -
		3.0	0	188.9 178.2 -	179.7 171.9 -	4.5 5.5 -	155.9 160.1 160.6
		4.0	0	-	-	-	151.1
		5.0	0	193.1 182.3	185.6 174.5	3.5 4.5	- -
	Aged After Prestrain	0	0	178.8 179.5	165.2 166.5	7.0 6.0	177.8 -
		3.0	0	179.0 184.0	169.0 172.2	6.0 6.0	166.9* 164.5*
		5.0	0	180.2 181.3	170.8 174.4	5.0 5.0	184.0* 173.3*

*Broke outside gage mark.

TABLE XXIII

Mechanical Properties of .040" Ti-4Al-3Mo-1V Strip Finish Rolled With a 50% Cold Reduction (Heat R6749)

Condition	Test Direction (° From Long.)	Ultimate Tensile Strength ksi	0.2% Offset Yield Strength ksi	Elongation % in 2"
Solution Treated 1655F, 20', WQ	0	146.3	98.0	15.0
		145.9	94.2	15.0
	22½	140.8	104.8	16.0
		141.1	104.1	17.0
	45	138.0	98.1	18.0
		136.4	100.5	17.0
	67½	139.2	106.4	14.5
		142.0	108.7	13.0
	90	147.1	111.0	*
		145.7	107.0	15.0
Solution Treated and Aged 12 Hours at 925F	0	200.5	184.9	5.5
		199.9	184.6	5.5
	22½	197.9	187.2	5.5
		195.5	169.6	5.5
	45	189.1	161.2	6.0
		189.5	159.0	5.5
	67½	197.0	172.8	5.5
		196.8	174.2	5.5
	90	205.6	179.1	5.0
		205.0	183.3	6.5

*Broke outside gage mark.

TABLE XXIV

Production Processing Steps on 4000 Pound Ti-6Al-4V Ingots

1. Double consumable-arc vacuum melt to 25" diameter.

2. Forge to 42" x 4" x L slabs by upsetting and swaging. Forging temperature for upsetting and rough swaging - 2050F. Final forging temperature - 1700F.

3. Hot roll to 42" x 0.150" x L coiled hot band in Crucible's hot strip mill from 1875F.

4. Stress relieve at 1250F.

5. Descale and pickle in a continuous strip line.

6. Anneal at 1550F, slow cool 5F/minute maximum.

7. Condition.

8. Cold roll to 0.131" thick in a three-stand four-high continuous cold rolling mill.

9. Anneal.

10. Condition.

11. Cold roll to 0.097" thick in a three-stand four-high continuous cold rolling mill.

12. Anneal.

13. Condition.

14. Cold roll to 0.077" thick in a three-stand four-high continuous cold rolling mill.

15. Anneal.

16. Condition.

17. Cold roll to 0.051" thick in a 44" wide four-high reversing mill.

18. Final anneal.

19. Pickle.

TABLE XXV

Production Processing Steps on 4000 Pound Ti-4Al-3Mo-1V Ingots

1. Double consumable-arc vacuum melt to 25" diameter.
2. Forge to 42" x 4" x L slabs by upsetting and swaging. Forging temperature for upsetting and rough swaging - 1950F. Final forging temperature - 1700F.
3. Hot roll to 42" x 0.140" x L coiled hot band in Crucible's hot strip mill from 1800F.
4. Stress relieve at 1250F.
5. Descale and pickle in a continuous strip line.
6. Anneal at 1650F, slow cool 5F/minute maximum.
7. Condition.
8. Cold roll to 0.110" thick in a three-stand four-high continuous cold rolling mill.
9. Anneal.
10. Condition.
11. Cold roll to 0.078" thick in a three-stand four-high continuous cold rolling mill.
12. Anneal.
13. Condition.
14. Cold roll to 0.057" thick in a 44" wide four-high reversing mill.
15. Anneal.
16. Condition.
17. Cold roll to 0.034" thick in a 44" wide four-high reversing mill.
18. Final anneal.
19. Pickle.

TABLE XXVI

Production Processing Steps on 4000 Pound Ti-2½Al-16V Ingots

1. Double consumable-arc vacuum melt to 25" diameter.
2. Forge to 42" x 4" x L slabs by upsetting and swaging. Forging temperature for upsetting and rough swaging - 1800F. Final forging temperature - 1700F.
3. Hot roll to 42" x .136" x L coiled hot band in Crucible's hot strip mill from 1800F.
4. Stress relieve at 1250F.
5. Descale and pickle in a continuous strip line.
6. Anneal at 1400F, slow cool 5F/minute maximum.
7. Condition.
8. Cold roll to 0.100" thick in a three-stand four-high continuous cold rolling mill.
9. Anneal.
10. Condition.
11. Cold roll to 0.080" thick in a three-stand four-high continuous cold rolling mill.
12. Anneal.
13. Condition.
14. Cold roll to 0.045" thick in a 54" wide reversing Sendzimir mill (2" diameter work rolls).
15. Anneal.
16. Condition.
17. Cold roll to 0.021" thick in a 54" wide reversing Sendzimir mill (2" diameter work rolls).
18. Final anneal.
19. Pickle.

TABLE XXVII

Analytical Results on Samples Taken From Phase III 4000 Pound Ingots During Forging

Alloy	Ingot No.	Location	Al(%)	V(%)	Mo(%)	Fe(%)	C(%)	N(%)
Ti-6Al-4V	Target Composition		5.5-6.5	3.5-4.5	-	.30 max	.10 max	.050 max
	R-8840	Top	6.1	4.1	-	.24	.04	.018
			6.1	4.1				
		Bottom	6.2	4.0	-	.23	.03	.018
			6.2	4.0				
	R-8918	Top	6.1	4.0	-	.19	.03	.017
			6.0	4.0				
		Bottom	6.0	3.9	-	.16	.04	.020
			6.0	3.9				
Ti-4Al-3Mo-1V	Target Composition		3.75-4.75	0.5-1.5	2.5-3.5	.35 max	.10 max	.050 max
	R-8853	Top	4.4	0.9	3.0	.15	.02	.016
			4.6	0.9	3.0			
		Bottom	4.6	1.0	3.0	.17	.02	.017
			4.6	1.0	3.0			
	R-8865	Top	4.4	1.00	2.9	.27	.03	.023
			4.4	1.02	2.9			
		Bottom	4.5	.98	2.9	.27	.06	.030
			4.5	1.02	2.9			
Ti-16V-2½Al	Target Composition		2.25-3.25	14.0-17.0	-	.60 max	.10 max	.05 max
	R-8848	Top	2.5	15.6	-	.27	.03	.037
			2.5	15.6				
		Bottom	2.6	15.4	-	.25	.02	.035
			2.5	15.4				
	R-8856	Top	2.5	15.7	-	.28	.04	.030
			2.5	15.8				
		Bottom	2.5	15.6	-	.28	.04	.031
			2.5	15.6				

TABLE XXVIII

Mechanical Properties of Test Material[1] From Phase III 4000 Pound Ingots

Alloy	Condition	Ingot No.	Ingot Location	Room Temperature Mechanical Properties[2] Ultimate Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area %
Ti-6Al-4V	Annealed 2 Hrs 1300F, Slow Cool	R-8840	Top	157.3	147.0	18.0	42.7
			Bottom	147.2	143.2	18.0	49.5
		R-8918	Top	145.7	133.1	13.0	29.6
			Bottom	155.9	149.3	18.0	38.7
Ti-4Al-3Mo-1V	Annealed ½ Hr 1500F, Slow Cool	R-8853	Top	135.3	128.8	17.0	45.9
			Bottom	141.3	130.9	18.0	42.7
		R-8865	Top	133.6	131.1	18.0	58.0
			Bottom	131.8	128.2	18.0	55.6
Ti-16V-2½Al	Annealed ½ Hr 1300F, Slow Cool	R-8848	Top	131.6	117.8	19.0	55.9
			Bottom	140.1	123.8	17.0	55.9
		R-8856	Top	126.4	114.1	18.0	53.4
			Bottom	133.5	119.2	18.0	56.5

1 - Taken during ingot forging. Reforged to 7/8" RCS before final anneal and testing.

2 - Standard ¼" diameter x 1" gage length specimens.

TABLE XXIX

Analytical Results on Samples Taken From Phase III Ingots at the Sheet Bar Stage

Alloy	Ingot No.	Sheet Bar Test Location	Aluminum (%)	Vanadium (%)	Molybdenum (%)	Iron (%)	Carbon (%)	Nitrogen (%)
Ti-6Al-4V	Target Composition		5.5-6.5	3.5-4.5	-	.30 max	.10 max	.050 max
	R-8918	Head	6.1	3.8	-	.15	.01	.024
		Tail	5.9	4.1	-	.27	.02	.017
	R-8840	Head	5.9	4.1	-	.20	.02	.017
		Tail	6.0	4.0	-	.17	.02	.022
Ti-4Al-3Mo-1V	Target Composition		3.75-4.75	0.5-1.5	2.5-3.5	.35 max	.10 max	.050 max
	R-8853	Head	4.4	1.1	3.0	.23	.03	.021
		Tail	4.4	1.1	2.8	.20	.02	.023
	R-8865	Head	4.5	1.1	3.1	.27	.01	.020
		Tail	4.6	1.1	3.6	.20	.05	.030
Ti-2½Al-16V	Target Composition		2.25-3.25	14.0-17.0	-	.60 max	.10 max	.050 max
	R-8848	Head	2.4	16.2	-	.31	.02	.018
		Tail	2.6	15.1	-	.18	.01	.034
	R-8856	Head	2.4	16.1	-	.28	.01	.022
		Tail	2.5	15.7	-	.23	.01	.032

TABLE XXX

Mechanical Properties and Directionality of Samples Taken From Phase III Ti-6Al-4V Ingots at the 0.800" Thick Sheet Bar Stage
(Annealed 1550F, 2 Hours, Furnace Cooled at 5F/Minute Maximum)

			Room Temperature Mechanical Properties[1]				Directionality[2]		
Heat	Test Location	Test Direction	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area(%)	ksi	Direction of Max Strength	Direction of Min Strength
R8918	Head	L	143.7	131.9	12.0	31.2	7.9	L	45°
		L	143.6	130.7	13.0	29.5			
		Average	143.7	131.3	12.5	30.4			
		45°	136.5	123.6	14.0	36.0			
		45°	135.5	123.1	13.0	33.5			
		Average	136.0	123.4	13.5	34.8			
		T	142.2	127.9	10.0	26.1			
		T	139.1	123.7	12.0	37.0			
		Average	140.7	123.8	11.0	31.6			
	Tail	L	141.6	126.8	13.0	31.1	6.1	L	45°
		L	140.9	125.7	13.0	32.7			
		Average	141.3	126.3	13.0	31.9			
		45°	132.4	120.1	13.0	39.7			
		45°	131.9	120.2	13.0	40.9			
		Average	132.2	120.2	13.0	40.3			
		T	139.1	126.1	9.0	17.7			
		T	138.6	120.6	9.0	17.7			
		Average	138.9	123.4	9.0	17.7			
R8840	Head	L	140.0	124.3	13.0	29.5	10.6	T	45°
		L	142.1	126.8	11.0	23.2			
		Average	141.1	125.6	12.0	26.4			

TABLE XXX
(Continued)

Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[1] Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
R8840	Head	45°	133.9	125.3	14.0	41.5			
		45°	134.5	125.7	14.0	42.3			
		Average	134.2	125.5	14.0	41.9			
		T	141.2	136.0	13.0	29.0			
		T	140.6	136.1	12.0	23.7			
		Average	140.9	136.1	12.5	26.4			
	Tail	L	141.5	128.1	13.0	31.4	3.8	T	45°
		L	143.1	129.7	13.0	32.8			
		Average	142.3	128.9	13.0	32.1			
		45°	136.5	124.8	14.0	37.3			
		45°	137.0	125.9	12.0	36.4			
		Average	136.8	125.4	13.0	36.9			
		T	142.6	129.1	10.0	26.7			
		T	142.0	129.2	12.0	32.5			
		Average	142.3	129.2	11.0	29.7			

1 - Standard $\frac{1}{4}$" diameter x 1" gage length specimens.

2 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XXXI

Mechanical Properties and Directionality of Phase III Ti-6Al-4V (Heat R8840) at the 0.150" Thick Hot Band Stage
(Annealed 1550F, 2 Hours, Furnace Cooled at 5F/Minute Maximum)

	Room Temperature Mechanical Properties[1]				Directionality[2]		
Test Direction	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area(%)	ksi	Direction of Max Strength	Direction of Min Strength
L	135.0	126.0	15.0	29.0	16.2	T	L
L	134.0	125.0	14.0	27.8			
Average	134.5	125.5	14.5	28.4			
45°	133.6	130.5	16.0	42.6			
45°	133.8	130.2	16.0	44.9			
Average	133.7	130.4	16.0	43.8			
T	146.4	141.9	15.5	36.2			
T	146.9	141.4	15.0	32.6			
Average	146.7	141.7	15.3	34.4			

1 - Standard 0.500" wide x 2" gage length flat tensile specimens.

2 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XXXII

Mechanical Properties and Directionality of Ti-6Al-4V (Heat R8918) After Its First Cold Reduction to 0.131" Thick (Annealed 1550F, 2 Hours, Furnace Cooled at 5F/Minute Maximum)

	Room Temperature Mechanical Properties[1]				Directionality[2]		
Test Direction	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area(%)	ksi	Direction of Max Strength	Direction of Min Strength
L	139.1	119.9	14.5	21.7	19.0	T	45°
L	140.3	125.3	12.5	19.8			
Average	139.7	122.6	13.5	20.8			
45°	127.0	124.1	18.0	40.4			
45°	125.8	119.6	16.0	34.9			
Average	126.4	121.9	17.0	37.7			
T	149.7	140.6	11.5	13.5			
T	151.3	141.1	10.5	12.6			
Average	150.5	140.9	11.0	13.1			

1 - Standard 0.500" wide x 2" gage length flat tensile specimens.

2 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XXXIII

Mechanical Properties and Directionality of Ti-6Al-4V (Heat R8918) After Its Second Cold Reduction to 0.097" Thick
(Annealed 1550F, 2 Hours, Furnace Cooled at 5F/Minute Maximum)

	Room Temperature Mechanical Properties[1]				Directionality[2]		
Test Direction	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area(%)	ksi	Direction of Max Strength	Direction of Min Strength
L	139.7	121.3	15.5	30.9	21.0	T	45°
L	137.3	120.7	12.5	27.3			
Average	138.5	121.0	14.0	29.1			
45°	123.7	120.5	18.5	48.5			
45°	123.2	115.0	19.0	49.7			
Average	123.5	117.8	18.8	49.1			
T	151.7	139.7	12.5	30.9			
T	152.0	137.9	14.0	34.9			
Average	151.9	138.8	13.3	32.9			

1 - Standard 0.500" wide x 2" gage length flat tensile specimens.

2 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XXXIV

Mechanical Properties and Directionality of Ti-6Al-4V (Heat R8918) After Its Third Cold Reduction to 0.077" Thick (Annealed 1550F, 2 Hours, Furnace Cooled at 5F/Minute Maximum)

Test Direction	Room Temperature Mechanical Properties[1]				Directionality[2]		
	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	ksi	Direction of Max Strength	Direction of Min Strength
L	136.1	118.2	13.5	31.2	18.4	T	45°
L	135.1	118.2	12.0	26.8			
Average	135.6	118.2	12.8	29.0			
45°	120.6	116.7	18.5	43.6			
45°	120.8	118.4	18.5	45.6			
Average	120.7	117.6	18.5	44.6			
T	148.3	136.1	13.5	29.3			
T	148.9	135.9	13.5	31.0			
Average	148.6	136.0	13.5	30.2			

1 - Standard 0.500" wide x 2" gage length flat tensile specimens.

2 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XXXV

Mechanical Properties and Directionality of Ti-6Al-4V (Heat R8918) After Its Fourth Cold Reduction to 0.051" Thick

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	L	133.0	118.1	9.5	32.2	36.3	T	45°
	L	131.2	117.1	10.0	35.9			
	Average	132.1	117.6	9.8	34.1			
	22½°	128.5	121.6	13.0	42.6			
	22½°	127.1	119.7	14.0	34.2			
	Average	127.8	120.7	13.5	38.4			
	45°	120.5	115.3	16.0	53.0			
	45°	120.5	117.1	17.0	55.6			
	Average	120.5	116.2	16.5	54.3			
	67½°	137.3	132.9	(4)	48.0			
	67½°	137.8	132.6	10.5	53.8			
	Average	137.6	132.8	10.5	50.9			
	T	159.6	148.1	(4)	27.1			
	T	172.1	156.9	13.5	26.2			
	Average	165.9	152.5	13.5	26.7			
Solution Treated	L	156.1	-	13.5	33.8	32.6	T	45°
	L	158.5	120.6	14.0	34.9			
	Average	157.3	120.6	13.8	34.4			
	22½°	150.4	115.6	15.0	26.3			
	22½°	150.9	115.9	14.5	35.5			
	Average	150.7	115.8	14.8	30.9			

TABLE XXXV
(Continued)

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated	45°	144.4	108.7	16.5	58.6			
	45°	142.6	103.6	19.0	56.8			
	Average	143.5	106.2	17.8	57.7			
	67½°	154.2	117.5	14.0	51.3			
	67½°	153.8	122.8	14.0	55.1			
	Average	154.0	120.2	14.0	53.2			
	T	173.3	142.7	(4)	24.0			
	T	168.9	134.8	11.5	22.3			
	Average	171.1	138.8	11.5	23.2			
Solution Treated and Aged	L	172.3	153.2	6.0	24.2	28.2	T	45°
	L	177.0	160.6	5.5	24.9			
	Average	174.7	157.1	5.8	24.6			
	22½°	173.0	162.2	8.0	28.1			
	22½°	172.1	162.1	8.0	29.4			
	Average	172.6	162.2	8.0	28.8			
	45°	159.9	146.7	10.5	53.3			
	45°	161.1	147.6	11.0	51.1			
	Average	160.5	147.2	10.8	52.2			
	67½°	176.4	160.6	5.5	19.6			
	67½°	176.5	161.5	8.5	50.4			
	Average	176.5	161.1	7.0	35.0			
	T	190.1	175.5	7.5	32.9			
	T	188.8	175.2	5.0	18.2			
	Average	189.5	175.4	6.3	25.6			

TABLE XXXV
(Continued)

1 - Annealed - 1550F, 5 hours, furnace cooled at 5F/minute maximum.
Solution treated - 1700F, 20 minutes, WQ.
Solution treated and aged - Solution treated as above and aged 4 hours at 1000F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of five directions tested.

4 - Outside gage mark break.

TABLE XXXVI

Compression Test Results and Compression Directionality of Ti-6Al-4V (Heat R8918) After its Fourth Cold Reduction to 0.051" Thick

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Annealed	70F	L	140.4	51.2	T	$22\frac{1}{2}^{\circ}$
		L	142.7			
		Average	141.6			
		$22\frac{1}{2}^{\circ}$	128.1			
		$22\frac{1}{2}^{\circ}$	136.7			
		Average	132.4			
		45°	133.0			
		45°	138.5			
		Average	135.8			
		$67\frac{1}{2}^{\circ}$	170.5			
		$67\frac{1}{2}^{\circ}$	176.7			
		Average	173.6			
		T	183.5			
		T	183.7			
		Average	183.6			
	800F	L	60.4	49.7	T	45°
		L	66.4			
		Average	63.4			
		$22\frac{1}{2}^{\circ}$	72.0			
		$22\frac{1}{2}^{\circ}$	70.3			
		Average	71.2			

TABLE XXXVI
(Continued)

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Annealed	800F	45°	61.4			
		45°	64.4			
		Average	62.9			
		67½°	79.3			
		67½°	83.1			
		Average	81.2			
		T	111.3			
		T	113.8			
		Average	112.6			
Solution Treated	70F	L	149.6	49.6	T	45°
		L	146.4			
		Average	148.0			
		22½°	143.6			
		22½°	152.2			
		Average	147.9			
		45°	143.8			
		45°	134.7			
		Average	139.3			
		67½°	168.6			
		67½°	169.6			
		Average	169.1			
		T	187.0			
		T	190.7			
		Average	188.9			

TABLE XXXVI
(Continued)

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	70F	L	164.6	61.7	T	L
		L	165.9			
		Average	165.3			
		$22\frac{1}{2}^{\circ}$	171.4			
		$22\frac{1}{2}^{\circ}$	164.3			
		Average	169.9			
		45°	169.2			
		45°	167.5			
		Average	168.4			
		$67\frac{1}{2}^{\circ}$	201.0			
		$67\frac{1}{2}^{\circ}$	205.9			
		Average	203.5			
		T	234.1			
		T	219.9			
		Average	227.0			
	800F	L	114.0	50.1	T	45°
		L	98.7			
		Average	106.4			
		$22\frac{1}{2}^{\circ}$	89.1			
		$22\frac{1}{2}^{\circ}$	86.5			
		Average	87.8			
		45°	81.8			
		45°	84.0			
		Average	82.9			

TABLE XXXVI
(Continued)

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	800F	$67\frac{1}{2}^{\circ}$	102.5			
		$67\frac{1}{2}^{\circ}$	102.3			
		Average	102.4			
		T	130.9			
		T	135.0			
		Average	133.0			

1 - Annealed - 1550F, 5 hours, furnace cooled at 5F/minute maximum.
Solution Treated - 1700F, 20 minutes, water quenched.
Solution Treated and Aged - Solution treated as above and aged 4 hours at 1000F.

2 - Differences between highest average yield strength and lowest average yield strength of five directions tested.

TABLE XXXVII

Elevated Temperature Tensile Test Results and Directionality of Ti-6Al-4V (Heat R8918) After Its Fourth Cold Reduction to 0.051" Thick

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	400F	L	101.0	82.6	14.0	32.3	35.8	T	45°
		L	99.5	81.1	13.5	31.1			
		Average	100.3	81.9	13.8	31.7			
		22½°	96.1	81.5	17.0	46.1			
		22½°	97.8	83.8	13.0	39.2			
		Average	97.0	82.7	15.0	42.7			
		45°	86.5	74.0	24.0	56.3			
		45°	86.1	73.5	19.5	55.7			
		Average	86.3	73.8	21.8	56.0			
		67½°	96.6	87.2	12.5	54.6			
		67½°	97.9	89.8	9.0	53.4			
		Average	97.3	88.5	10.8	54.0			
		T	124.9	108.6	7.5	41.5			
		T	127.1	110.5	7.5	38.4			
		Average	126.0	109.6	7.5	40.0			
	600F	L	93.2	73.0	21.5	27.1	34.2	T	45°
		L	92.2	70.9	21.5	32.1			
		Average	92.7	72.0	21.5	29.6			
		22½°	86.8	70.5	15.0	48.1			
		22½°	86.8	70.7	12.5	51.8			
		Average	86.8	70.6	13.8	50.0			

TABLE XXXVII
(Continued)

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	600F	45°	79.4	63.0	21.0	51.3			
		45°	77.2	62.6	20.5	58.5			
		Average	78.3	62.8	20.8	54.9			
		67½°	86.8	77.8	10.0	59.1			
		67½°	85.1	76.5	10.0	53.6			
		Average	86.0	77.2	10.0	56.4			
		T	111.4	97.6	5.5	46.6			
		T	110.9	96.3	5.5	38.0			
		Average	111.2	97.0	5.5	42.3			
	800F	L	86.6	69.0	13.0	35.6	34.4	T	45°
		L	85.9	67.2	12.5	31.3			
		Average	86.3	68.1	12.8	33.5			
		22½°	80.1	65.3	15.0	54.1			
		22½°	81.1	65.7	16.0	46.4			
		Average	80.6	65.5	15.5	50.3			
		45°	71.5	63.7	19.0	48.9			
		45°	71.4	57.5	21.5	58.2			
		Average	71.5	60.6	20.3	53.6			
		67½°	74.5	68.2	9.0	56.1			
		67½°	74.2	67.4	10.0	64.1			
		Average	74.4	67.8	9.5	60.1			
		T	103.1	94.0	5.0	42.2			
		T	103.6	96.0	3.0	38.5			
		Average	103.4	95.0	4.0	40.4			

TABLE XXXVII
(Continued)

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	400F	L	155.5	131.3	(4)	29.7	24.1	T	45°
		L	153.1	131.0	6.0	28.9			
		Average	154.3	131.2	6.0	29.3			
		22½°	147.4	122.8	7.5	41.1			
		22½°	145.8	121.2	8.0	42.7			
		Average	146.6	122.0	7.8	41.9			
		45°	137.8	115.8	8.0	49.5			
		45°	137.9	115.8	9.0	47.5			
		Average	137.9	115.8	8.5	48.5			
		67½°	152.0	131.4	6.5	43.9			
		67½°	154.3	132.2	6.0	38.8			
		Average	153.2	131.8	6.3	41.4			
		T	161.7	137.0	7.0	41.7			
		T	161.3	142.7	6.0	37.1			
		Average	161.5	139.9	6.5	39.4			
	600F	L	137.2	112.5	6.0	30.6	37.1	T	45°
		L	140.3	113.1	5.5	30.5			
		Average	138.8	112.8	5.8	30.6			
		22½°	137.7	109.1	8.0	47.0			
		22½°	138.0	110.5	(4)	42.9			
		Average	137.9	109.8	8.0	45.0			
		45°	122.4	94.6	9.0	56.6			
		45°	125.0	96.1	9.5	52.0			
		Average	123.7	95.4	9.3	54.3			

TABLE XXXVII
(Continued)

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	600F	67½°	140.0	115.4	5.5	54.7			
		67½°	139.9	115.8	6.0	52.9			
		Average	140.0	115.6	5.8	53.8			
		T	158.2	133.7	6.0	47.8			
		T	157.0	131.3	6.0	45.4			
		Average	157.6	132.5	6.0	46.6			
	800F	L	126.2	100.0	6.0	35.6	38.4	T	45°
		L	126.6	99.8	(4)	37.5			
		Average	126.4	99.9	6.0	36.6			
		22½°	123.7	98.3	6.0	47.9			
		22½°	126.1	99.0	7.5	40.6			
		Average	124.9	98.7	6.8	44.3			
		45°	112.8	85.1	7.5	53.1			
		45°	117.3	90.0	8.5	53.1			
		Average	115.1	87.6	8.0	53.1			
		67½°	129.2	100.9	5.5	53.3			
		67½°	127.8	100.1	5.0	50.8			
		Average	128.5	100.5	5.3	52.1			
		T	145.8	128.0	(4)	35.4			
		T	146.2	124.0	4.0	40.8			
		Average	146.0	126.0	4.0	38.1			

TABLE XXXVII
(Continued)

1 - Annealed - 1550F, 5 hours, furnace cooled at 5F/minute maximum.
Solution Treated and Aged - Solution treated 1700F, 20 minutes, water quenched and aged 4 hours at 1000F.

2 - Standard 0.400" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of five directions tested.

4 - Outside gage mark break.

TABLE XXXVIII

Mechanical Properties and Directionality of Samples Taken From Phase III Ti-4Al-3Mo-1V Ingots at the 0.800" Thick Sheet Bar Stage

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	R8853	Head	L	130.1	116.9	15.0	40.9	4.6	L	T
			L	132.0	117.0	16.0	37.3			
			Average	131.1	117.0	15.5	39.1			
			45°	124.2	113.7	15.0	47.2			
			45°	122.2	113.2	16.0	48.5			
			Average	123.2	113.5	15.5	47.9			
			T	127.7	111.8	12.0	24.6			
			T	127.9	113.0	12.0	28.1			
			Average	127.8	112.4	12.0	26.4			
		Tail	L	132.6	117.3	15.0	36.8	2.6	T	L
			L	134.5	119.2	15.0	34.3			
			Average	133.6	118.3	15.0	35.6			
			45°	128.1	119.0	16.0	28.3			
			45°	127.5	118.4	16.0	54.6			
			Average	127.8	118.7	16.0	41.5			
			T	132.2	119.3	12.0	16.2			
			T	135.1	122.5	11.0	19.1			
			Average	133.7	120.9	11.5	17.5			
	R8865	Head	L	131.8	116.5	15.0	37.4	5.3	L	T
			L	131.0	116.4	15.0	39.8			
			Average	131.4	116.5	15.0	38.6			

TABLE XXXVIII
(Continued)

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2] Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3] ksi	Direction of Max Strength	Direction of Min Strength
Annealed	R8865	Head	45°	121.8	111.2	16.0	47.8			
			45°	122.4	111.5	16.0	45.4			
			Average	122.1	111.4	16.0	46.6			
			T	128.7	110.9	10.0	14.8			
			T	130.0	111.5	12.0	16.2			
			Average	129.4	111.2	11.0	15.5			
		Tail	L	140.5	124.5	15.0	33.1	6.7	L	45°
			L	140.9	126.9	15.0	31.4			
			Average	140.7	125.7	15.0	32.3			
			45°	132.4	119.1	18.0	43.4			
			45°	131.4	118.9	14.0	42.2			
			Average	131.9	119.0	16.0	42.8			
			T	136.8	118.8	9.0	16.2			
			T	136.7	119.4	10.0	16.9			
			Average	136.8	119.1	9.5	16.6			
Solution Treated	R8853	Head	L	161.7	134.1	13.0	19.9	5.0	T	45°
			L	160.9	136.0	13.0	26.3			
			Average	161.3	135.1	13.0	23.1			
			45°	161.7	133.4	11.0	30.8			
			45°	159.2	128.0	13.0	29.3			
			Average	160.5	130.7	12.0	30.1			
			T	169.4	135.3	6.0	12.5			
			T	171.1	136.1	6.0	12.4			
			Average	170.3	135.7	6.0	12.5			

TABLE XXXVIII
(Continued)

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated	R8853	Tail	L	156.3	124.5	12.0	27.5	16.3	T	L
			L	160.8	135.3	11.0	22.1			
			Average	158.6	129.9	11.5	24.8			
			45°	156.6	131.5	13.0	37.4			
			45°	157.7	131.5	14.0	40.6			
			Average	157.2	131.5	13.5	39.0			
			T	172.7	149.3	4.0	7.9			
			T	176.0	143.1	4.0	2.5			
			Average	174.4	146.2	4.0	5.2			
	R8865	Head	L	163.2	134.7	10.0	26.1	9.0	T	45°
			L	161.9	131.0	12.0	24.6			
			Average	162.6	132.9	11.0	25.4			
			45°	159.7	128.1	11.0	36.1			
			45°	157.8	123.9	10.0	28.1			
			Average	158.8	126.0	10.5	32.1			
			T	176.6	135.0	4.0	8.2			
			T	176.7	134.9	3.0	7.9			
			Average	176.7	135.0	3.5	8.1			
		Tail	L	161.2	129.3	12.0	10.9	9.9	T	45°
			L	162.9	132.1	13.0	14.1			
			Average	162.1	130.7	12.5	12.5			
			45°	158.9	127.9	10.0	20.1			
			45°	158.4	124.5	11.0	23.2			
			Average	158.7	126.2	10.5	21.7			

TABLE XXXVIII
(Continued)

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated	R8865	Tail	T	170.8	132.7	5.0	7.0			
			T	170.2	139.5	4.0	5.7			
			Average	170.5	136.1	4.5	6.4			
Solution Treated and Aged	R8853	Head	L	182.3	153.8	6.0	15.8	7.9	45°	L
			L	180.1	145.5	4.0	19.0			
			Average	181.2	149.7	5.0	17.4			
			45°	185.1	164.8	5.0	12.0			
			45°	177.9	150.4	5.0	14.3			
			Average	181.5	157.6	5.0	13.2			
			T	191.4	154.7	4.0	5.7			
			T	190.9	157.0	5.0	7.9			
			Average	191.2	155.9	4.5	6.8			
		Tail	L	196.1	160.7	5.0	12.5	3.5	T	L
			L	188.9	162.3	5.0	7.0			
			Average	192.5	161.5	5.0	9.8			
			45°	194.6	167.9	3.0	14.8			
			45°	184.3	160.3	6.0	22.6			
			Average	189.5	164.1	4.5	8.7			
			T	201.9	163.1	2.0	6.3			
			T	200.6	166.8	2.0	7.9			
			Average	201.3	165.0	2.0	7.1			
	R8865	Head	L	191.4	158.9	5.0	16.0	10.7	T	45°
			L	190.4	158.2	4.0	16.8			
			Average	190.9	158.6	4.5	16.4			

TABLE XXXVIII
(Continued)

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	R8865	Head	45°	179.3	147.6	5.0	13.1			
			45°	182.3	150.5	6.0	15.4			
			Average	180.8	149.1	5.5	14.3			
			T	188.9	154.8	2.0	8.7			
			T	179.6	164.8	2.0	8.7			
			Average	193.6	159.8	2.0	8.7			
		Tail	L	198.2	174.2	5.0	7.1	15.2	L	45°
			L	196.6	166.6	4.0	5.5			
			Average	197.4	170.4	4.5	6.3			
			45°	186.3	151.7	5.0	9.4			
			45°	191.9	158.6	4.0	7.5			
			Average	189.1	155.2	4.5	8.5			
			T	186.4	152.1	2.0	4.8			
			T	191.0	161.8	2.0	2.5			
			Average	188.7	157.0	2.0	3.7			

1 - Annealed - 1500F, 30 minutes, furnace cooled at 5F/minute maximum.
Solution Treated - 1650F, 20 minutes, WQ. All specimens machined to ½" diameter rounds before solution treating.
Solution Treated and Aged - Solution treated as above and aged 12 hours at 900F.

2 - Standard ¼" diameter x 1" gage length specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XXXIX

Mechanical Properties and Directionality of Phase III Ti-4Al-3Mo-1V (Heat R8865) at the 0.140" Thick Hot Band Stage

		Room Temperature Mechanical Properties[2]				Directionality[3]		
Condition[1]	Test Direction	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area(%)	ksi	Direction of Max Strength	Direction of Min Strength
Annealed	L	124.7	113.9	14.0	35.1	24.8	T	L
	L	123.6	113.5	16.0	34.7			
	Average	124.2	113.7	15.0	34.9			
	45°	123.5	120.2	15.5	49.8			
	45°	124.7	122.2	16.0	49.4			
	Average	124.1	121.2	15.8	49.6			
	T	140.9	139.6	14.0	38.3			
	T	141.6	137.4	14.0	41.7			
	Average	141.3	138.5	14.0	40.0			
Solution Treated	L	152.8	127.1	(4)	27.4	21.6	T	45°
	L	150.9	118.6	13.0	25.1			
	Average	151.9	122.9	13.0	26.3			
	45°	142.9	109.7	18.0	38.6			
	45°	140.1	110.7	18.5	41.6			
	Average	141.5	110.2	18.3	40.1			
	T	159.3	131.1	14.0	36.8			
	T	158.4	132.4	14.5	33.5			
	Average	158.9	131.8	14.3	35.2			
Solution Treated and Aged	L	190.4	161.7	5.0	16.8	26.6	T	L
	L	187.0	156.0	6.0	12.6			
	Average	188.7	158.9	5.5	14.7			

TABLE XXXIX
(Continued)

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2] Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area(%)	Directionality[3] ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	45°	180.8	158.6	7.5	31.1			
	45°	194.8	171.7	(4)	30.5			
	Average	187.8	165.2	7.5	30.8			
	T	205.5	187.0	7.5	24.2			
	T	200.0	184.0	8.5	27.5			
	Average	202.8	185.5	8.0	25.9			

1 - Annealed - 1500F, 30 minutes, furnace cooled at 5F/minute maximum.
Solution Treated - 1650F, 20 minutes, WQ.
Solution Treated and Aged - Solution treated as above and aged 12 hours at 900F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

4 - Outside gage mark break.

TABLE XL

Mechanical Properties and Directionality of Ti-4Al-3Mo-1V (Heat R8865) After Its First Cold Reduction to 0.110" Thick

Condition[1]	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	Head	L	120.5	105.0	12.0	27.9	23.1	T	L
		L	120.1	105.4	12.0	30.0			
		Average	120.3	105.2	12.0	29.0			
		45°	117.4	115.5	13.5	49.5			
		45°	116.3	113.1	15.0	50.0			
		Average	116.9	114.3	14.3	49.8			
		T	138.8	127.3	15.5	43.2			
		T	138.9	129.3	15.5	43.2			
		Average	138.9	128.3	15.5	43.2			
	Tail	L	124.4	107.1	12.0	25.2	25.6	T	L
		L	123.6	105.5	14.0	32.2			
		Average	124.0	106.3	13.0	28.7			
		45°	120.4	117.5	11.5	47.2			
		45°	120.8	117.0	12.0	46.6			
		Average	120.6	117.3	11.8	46.9			
		T	143.6	131.8	15.0	38.7			
		T	142.9	131.9	13.5	25.0			
		Average	143.3	131.9	14.3	31.9			
Solution Treated	Head	L	134.4	89.7	15.5	37.0	15.3	T	45°
		L	134.2	89.8	15.5	29.2			
		Average	134.3	89.8	15.5	33.1			

TABLE XL
(Continued)

Condition[1]	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated	Head	45°	131.2	85.0	19.0	51.3			
		45°	132.9	86.7	20.0	52.7			
		Average	132.1	85.9	19.5	52.0			
		T	146.5	98.6	12.5	15.1			
		T	144.5	103.8	7.5	13.8			
		Average	145.5	101.2	10.0	14.5			
	Tail	L	141.6	95.0	17.0	31.0	18.2	T	45°
		L	142.4	97.3	17.0	44.0			
		Average	142.0	96.2	17.0	37.5			
		45°	136.2	90.5	20.0	51.9			
		45°	137.9	91.1	20.0	51.6			
		Average	137.1	90.8	20.0	51.8			
		T	143.9	111.0	(4)	(4)			
		T	152.6	106.9	16.5	36.3			
		Average	148.3	109.0	16.5	36.3			
Solution Treated and Aged	Head	L	199.7	155.4	6.0	11.9	13.6	T	L
		L	190.2	149.3	5.5	9.4			
		Average	195.0	152.4	5.8	10.7			
		45°	183.8	153.3	9.0	30.6			
		45°	189.2	162.8	(4)	(4)			
		Average	186.5	158.1	9.0	30.6			
		T	200.2	165.8	9.0	16.1			
		T	201.0	166.2	9.0	15.3			
		Average	200.6	166.0	9.0	15.7			

TABLE XI
(Continued)

Condition[1]	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	Tail	L	193.4	149.8	6.0	5.7	21.4	T	L
		L	193.7	150.8	6.0	1.6			
		Average	193.6	150.3	6.0	3.7			
		45°	188.1	155.8	7.0	23.7			
		45°	191.2	161.0	9.0	19.8			
		Average	189.7	158.4	8.0	21.8			
		T	201.6	172.0	10.5	15.0			
		T	203.6	171.4	11.0	22.0			
		Average	202.6	171.7	10.8	18.5			

1 - Annealed - 1500F, 30 minutes, furnace cooled at 5F/minute maximum.
Solution Treated - 1650F, 20 minutes, WQ.
Solution Treated and Aged - Solution treated as above and aged 12 hours at 925F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

4 - Outside gage mark break.

TABLE XLI

Mechanical Properties and Directionality of Ti-4Al-3Mo-1V (Heat R8865) After Its Second Cold Reduction to 0.078" Thick

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	L	128.1	110.2	9.0	19.9	27.1	T	L
	L	127.5	111.1	8.0	22.0			
	Average	127.8	110.7	8.5	21.0			
	45°	123.9	122.7	18.0	37.4			
	45°	123.3	119.9	14.5	35.9			
	Average	123.6	121.3	16.3	36.7			
	T	147.1	137.2	11.5	27.3			
	T	148.1	138.4	12.0	30.7			
	Average	147.6	137.8	11.8	29.0			
Solution Treated	L	135.9	86.8	18.0	37.2	18.7	T	45°
	L	136.4	88.8	18.0	45.8			
	Average	136.2	87.8	18.0	41.5			
	45°	133.5	84.8	19.0	64.0			
	45°	132.6	83.7	19.0	67.5			
	Average	133.1	84.3	19.0	65.8			
	T	143.9	97.9	15.0	38.3			
	T	155.2	108.0	15.5	39.3			
	Average	149.6	103.0	15.3	38.8			
Solution Treated and Aged	L	187.2	151.8	6.5	12.8	14.4	T	L
	L	188.3	153.2	6.0	11.8			
	Average	187.8	152.5	6.3	12.3			

TABLE XLI
(Continued)

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]				Directionality[3]		
		Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	45°	182.0	156.1	9.5	39.1			
	45°	182.4	156.5	9.0	38.1			
	Average	182.2	156.3	9.3	38.6			
	T	195.0	166.6	9.0	28.9			
	T	195.6	167.2	10.0	27.5			
	Average	195.3	166.9	9.5	28.2			

1 - Annealed - 1500F, 30 minutes, furnace cooled at 5F/minute maximum.
Solution Treated - 1650F, 20 minutes, WQ.
Solution Treated and Aged - Solution treated as above and aged 12 hours at 925F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XLII

Mechanical Properties and Directionality of Ti-4Al-3Mo-1V (Heat R8865) After Its Third Cold Reduction to 0.057" Thick

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	L	130.2	116.9	11.5	30.8	30.9	T	L
	L	130.8	114.7	13.5	33.5			
	Average	130.5	115.8	12.5	32.2			
	45°	129.3	124.8	10.5	50.8			
	45°	132.1	128.0	11.5	56.3			
	Average	130.7	126.4	11.0	53.6			
	T	155.7	147.0	13.5	45.3			
	T	155.5	146.4	13.0	42.5			
	Average	155.6	146.7	13.3	43.9			
Solution Treated	L	149.6	105.8	14.0	27.8	27.6	T	45°
	L	149.4	103.3	14.5	43.1			
	Average	149.5	104.6	14.3	35.5			
	45°	142.9	90.4	17.5	56.8			
	45°	144.0	91.0	16.0	57.5			
	Average	143.5	90.7	16.8	57.2			
	T	159.4	114.7	14.0	30.9			
	T	160.0	121.8	13.5	28.8			
	Average	159.7	118.3	13.8	29.9			
Solution Treated and Aged	L	208.4	174.4	3.5	9.4	20.3	T	45°
	L	207.9	169.4	3.5	7.8			
	Average	208.2	171.9	3.5	8.6			

TABLE XLII
(Continued)

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	45°	201.0	172.8	6.0	18.5			
	45°	198.3	169.4	4.5	16.9			
	Average	199.7	171.1	5.3	17.7			
	T	216.3	191.2	9.0	22.7			
	T	217.4	191.5	7.0	18.0			
	Average	216.9	191.4	8.0	20.4			

1 - Annealed - 1500F, 30 minutes, furnace cooled at 5F/minute maximum.
Solution Treated - 1650F, 20 minutes, WQ.
Solution Treated and Aged - Solution treated as above and aged 12 hours at 925F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XLIII

Mechanical Properties and Directionality of Ti-4Al-3Mo-1V (Heat R8865) After Its Fourth Cold Reduction to 0.034" Thick

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]				Directionality[3]		
		Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area(%)	ksi	Direction of Max Strength	Direction of Min Strength
Annealed	L	128.0	109.3	13.5	41.4	32.6	T	L
	L	128.0	108.1	11.5	32.2			
	Average	128.0	108.7	12.5	36.8			
	$22\frac{1}{2}^{\circ}$	122.3	111.3	13.5	55.5			
	$22\frac{1}{2}^{\circ}$	122.1	111.9	14.0	40.9			
	Average	122.2	111.6	13.8	48.2			
	45°	122.4	121.2	13.5	59.9			
	45°	121.4	119.4	12.5	61.8			
	Average	121.9	120.3	13.0	60.9			
	$67\frac{1}{2}^{\circ}$	136.7	135.8	9.0	62.6			
	$67\frac{1}{2}^{\circ}$	136.6	136.6	7.0	61.7			
	Average	136.7	136.2	8.0	62.2			
	T	144.8	140.2	11.5	32.4			
	T	145.2	142.3	10.5	33.4			
	Average	145.0	141.3	11.0	32.9			
Solution Treated	L	147.0	100.1	16.5	31.8	24.5	T	L
	L	145.8	106.1	13.5	35.9			
	Average	146.4	102.6	15.0	33.9			
	$22\frac{1}{2}^{\circ}$	145.8	113.6	(4)	35.9			
	$22\frac{1}{2}^{\circ}$	145.6	121.1	16.0	39.9			
	Average	145.7	117.4	16.0	37.9			

TABLE XLIII
(Continued)

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated	45°	142.7	99.7	17.5	38.7			
	45°	144.5	110.8	16.5	43.4			
	Average	143.6	105.3	17.0	41.1			
	67½°	150.7	115.0	14.5	35.3			
	67½°	149.3	112.2	14.0	40.4			
	Average	150.0	113.6	14.3	37.9			
	T	152.6	127.4	(4)	32.9			
	T	156.8	126.8	11.5	36.5			
	Average	154.7	127.1	11.5	34.7			
Solution Treated and Aged	L	207.8	186.2	4.5	17.5	22.3	T	45°
	L	208.3	186.1	4.5	19.3			
	Average	208.1	186.2	4.5	18.4			
	22½°	199.0	179.4	6.5	22.2			
	22½°	205.2	185.9	5.0	24.8			
	Average	202.1	182.7	5.8	23.5			
	45°	197.6	177.7	7.0	26.0			
	45°	193.7	173.4	3.0	17.9			
	Average	195.7	175.6	5.0	22.0			
	67½°	210.1	195.4	(4)	21.7			
	67½°	204.9	189.4	(4)	28.6			
	Average	207.5	192.4	-	25.2			
	T	213.7	199.4	3.5	24.9			
	T	212.0	196.3	4.0	21.2			
	Average	212.9	197.9	3.8	23.1			

TABLE XLIII
(Continued)

1 - Annealed - 1500F, 30 minutes, furnace cooled 5F/minute maximum.
Solution Treated - 1650F, 20 minutes, WQ.
Solution Treated and Aged - Solution treated as above and aged 12 hours at 925F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of five directions tested.

4 - Outside gage mark break.

TABLE XLIV

Compression Test Results and Compression Directionality of Ti-4Al-3Mo-1V (Heat R8865) After Its Fourth Cold Reduction to 0.034" Thick

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Annealed	70F	L	132.9	53.4	T	L
		L	129.7			
		Average	131.3			
		22½°	143.5			
		22½°	143.2			
		Average	143.4			
		45°	170.3			
		45°	143.9			
		Average	157.1			
		67½°	182.8			
		67½°	166.1			
		Average	174.5			
		T	194.4			
		T	174.9			
		Average	184.7			
	800F	L	75.2	33.4	T	45°
		22½°	81.0			
		22½°	69.7			
		Average	75.4			
		45°	69.9			
		45°	70.7			
		Average	70.3			

TABLE XLIV
(Continued)

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Annealed	800F	67½°	80.7			
		67½°	88.2			
		Average	84.5			
		T	114.4			
		T	92.9			
		Average	103.7			
Solution Treated	70F	L	168.5	49.8	T	45°
		L	163.5			
		Average	166.0			
		22½°	158.4			
		22½°	159.3			
		Average	158.9			
		45°	143.2			
		45°	140.2			
		Average	141.7			
		67½°	173.8			
		67½°	162.9			
		Average	168.4			
		T	190.2			
		T	192.7			
		Average	191.5			
Solution Treated and Aged	70F	L	209.2	29.4	67½°	L
		L	212.9			
		Average	211.1			

TABLE XLIV
(Continued)

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	76F	22½°	209.8			
		22½°	215.1			
		Average	212.5			
		45°	205.2			
		45°	220.1			
		Average	212.7			
		67½°	240.8			
		67½°	240.2			
		Average	240.5			
		T	226.0			
		T	250.7			
		Average	238.4			
	800F	L	111.3	11.9	T	45°
		22½°	110.1			
		22½°	104.5			
		Average	107.3			
		45°	110.1			
		45°	99.1			
		Average	104.6			
		T	116.6			
		T	116.3			
		Average	116.5			

TABLE XLIV
(Continued)

1 - Annealed - 1500F, 30 minutes, furnace cooled 5F/minute maximum.
Solution Treated - 1650F, 20 minutes, oil quenched. Oil quenching was necessary (instead of water quenching) to retain satisfactory specimen flatness.
Solution Treated and Aged - Solution treated as above and aged 12 hours at 925F.

2 - Difference between highest average yield strength and lowest average yield strength of five directions tested.

TABLE XLV

Elevated Temperature Tensile Test Results and Directionality of Ti-4Al-3Mo-1V (Heat R8865) After Its Fourth Cold Reduction to 0.034" Thick

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	400F	L	98.3	82.1	11.0	40.5	27.4	T	45°
		L	99.2	80.8	10.5	40.0			
		Average	98.8	81.5	10.8	40.3			
		22½°	96.1	86.8	13.5	49.1			
		22½°	95.8	85.4	11.5	53.3			
		Average	96.0	86.1	12.5	51.2			
		45°	82.3	76.6	12.0	43.5			
		45°	88.7	82.4	14.0	54.0			
		Average	85.5	79.5	13.0	48.8			
		67½°	98.8	94.3	7.5	48.3			
		67½°	96.3	92.3	7.0	45.8			
		Average	97.6	93.3	7.3	47.1			
		T	113.3	106.8	5.0	35.0			
		T	112.9	106.9	(4)	38.3			
		Average	113.1	106.9	5.0	36.7			
	600F	L	90.0	72.9	9.0	51.7	25.7	T	45°
		L	89.3	71.9	8.5	51.6			
		Average	89.7	72.4	8.8	51.7			
		22½°	83.3	72.3	11.0	54.2			
		22½°	80.7	69.1	10.5	53.3			
		Average	82.0	70.7	10.8	53.8			

TABLE XLV
(Continued)

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	600F	45°	77.0	68.3	11.5	58.9			
		45°	76.3	69.4	10.0	47.5			
		Average	76.7	68.9	11.8	53.2			
		67½°	86.1	81.1	7.5	54.9			
		67½°	86.7	82.1	7.0	56.7			
		Average	86.4	81.6	7.3	55.8			
		T	98.8	92.4	(4)	54.1			
		T	103.8	96.8	4.0	55.0			
		Average	101.3	94.6	4.0	54.6			
	800F	L	83.1	68.5	6.5	39.8	25.6	T	45°
		L	84.5	69.6	7.5	38.8			
		Average	83.8	69.1	7.0	39.3			
		22½°	77.9	66.9	10.0	37.2			
		22½°	78.8	68.7	(4)	37.0			
		Average	78.4	67.8	10.0	37.1			
		45°	71.7	64.3	(4)	51.2			
		45°	72.5	65.3	8.5	49.6			
		Average	72.1	64.8	8.5	50.4			
		67½°	82.9	76.7	6.0	42.1			
		67½°	82.5	76.3	6.0	53.3			
		Average	82.7	76.5	6.0	47.7			
		T	97.6	91.2	3.5	23.6			
		T	95.6	89.5	3.0	30.3			
		Average	96.6	90.4	3.3	27.0			

TABLE XLV
(Continued)

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	400F	L	164.7	150.3	5.5	22.7	27.8	67½"	45°
		L	167.4	134.9	2.5	23.4			
		Average	166.1	142.6	4.0	23.1			
		22½°	156.8	119.0	4.5	34.2			
		22½°	161.1	127.6	(4)	10.3			
		Average	159.0	123.3	4.5	22.3			
		45°	152.6	117.1	3.5	16.2			
		45°	155.0	119.2	6.0	29.4			
		Average	153.8	118.2	4.8	22.8			
		67½°	169.6	153.5	4.0	23.5			
		67½°	163.1	138.4	(4)	16.2			
		Average	166.4	146.0	4.0	19.9			
		T	177.0	143.4	4.0	19.5			
		T	171.7	137.8	5.5	24.6			
		Average	174.4	140.6	4.8	22.1			
	600F	L	158.1	124.6	3.0	21.2	32.3	T	45°
		L	155.0	119.1	4.0	31.9			
		Average	156.6	121.9	3.5	26.6			
		22½°	149.1	112.0	5.0	17.7			
		22½°	149.1	116.4	(4)	28.2			
		Average	149.1	114.2	5.0	23.0			
		45°	141.2	103.6	6.0	29.4			
		45°	143.6	109.6	4.0	18.2			
		Average	142.4	106.6	5.0	23.8			

TABLE XLV
(Continued)

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	600F	67½°	155.9	118.5	4.0	18.6			
		67½°	155.9	125.3	5.0	26.9			
		Average	155.9	121.9	4.5	22.8			
		T	157.2	140.3	(4)	(4)			
		T	148.2	137.4	(4)	(4)			
		Average	152.7	138.9	-	-			
	800F	L	141.8	108.3	(4)	20.2	31.3	T	45°
		L	138.6	106.5	(4)	(4)			
		Average	140.2	107.4	-	20.2			
		22½°	136.6	99.3	6.0	27.8			
		22½°	139.7	101.7	6.5	26.9			
		Average	138.2	100.5	6.3	27.4			
		45°	131.4	92.3	6.0	35.3			
		45°	119.8	85.1	8.5	31.1			
		Average	125.6	88.7	7.3	33.2			
		67½°	142.9	103.2	5.0	36.1			
		67½°	142.4	107.9	4.0	21.0			
		Average	142.7	105.6	4.5	28.6			
		T	155.4	124.0	2.5	32.7			
		T	149.1	116.0	3.0	32.2			
		Average	152.3	120.0	2.8	32.5			

TABLE XLV
(Continued)

1 - Annealed - 1500F, 30 minutes, furnace cooled 5F/minute maximum.
Solution Treated and Aged - Solution treated 1650F, 20 minutes, water quenched and aged 12 hours at 925F.

2 - Standard 0.400" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of five directions tested.

4 - Outside gage mark break.

TABLE XLVI

Mechanical Properties and Directionality of Samples Taken From Phase III Ti-2½Al-16V Ingots at the 0.800" Thick Sheet Bar Stage

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2] Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3] ksi	Direction of Max Strength	Direction of Min Strength
Annealed	R8848	Head	L	123.2	108.7	15.0	48.3	9.8	T	L
			L	123.7	108.3	15.0	40.1			
			Average	123.5	108.5	15.0	44.2			
			45°	118.6	108.6	18.0	47.8			
			T	132.4	118.3	14.0	41.1			
			T	132.8	-	13.0	36.6			
			Average	132.6	118.3	13.5	38.9			
		Tail	L	138.3	122.6	13.0	34.8	7.9	T	L
			L	141.3	125.2	14.0	32.8			
			Average	139.8	123.9	13.5	33.8			
			45°	132.8	123.8	16.0	42.4			
			45°	133.5	124.3	17.0	41.4			
			Average	133.2	124.1	16.5	41.9			
			T	146.1	131.6	12.0	28.1			
			T	147.7	132.0	11.0	23.0			
			Average	146.9	131.8	11.5	25.6			
	R8856	Head	L	128.1	115.8	13.0	29.0	7.3	T	L
			L	124.8	110.3	13.0	36.0			
			Average	126.5	113.1	13.0	32.5			
			45°	123.8	112.6	16.0	47.7			
			45°	124.9	115.4	16.0	49.1			
			Average	124.4	114.0	16.0	48.4			

TABLE XLVI
(Continued)

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	R8856	Head	T	133.1	118.6	12.0	33.5			
			T	135.4	122.1	12.0	29.5			
			Average	134.3	120.4	12.0	31.5			
		Tail	L	136.7	121.1	14.0	37.9	5.8	T	L
			L	138.0	121.6	13.0	28.1			
			Average	137.4	121.4	13.5	33.0			
			45°	133.9	123.1	16.0	51.1			
			45°	133.9	121.1	17.0	52.5			
			Average	133.9	122.1	16.5	51.8			
			T	143.1	128.2	11.0	29.6			
			T	141.9	126.2	10.0	24.0			
			Average	142.5	127.2	10.5	26.8			
Solution Treated	R8848	Head	L	88.8	39.3	34.0	50.9	9.0	T	L
			L	88.5	38.3	36.0	50.7			
			Average	88.7	38.8	35.0	50.8			
			45°	90.9	43.7	31.0	47.9			
			45°	90.5	44.0	32.0	48.7			
			Average	90.7	43.9	31.5	48.3			
			T	91.6	47.2	37.0	45.8			
			T	92.7	48.4	40.0	46.4			
			Average	92.2	47.8	38.5	46.1			
		Tail	L	110.6	48.5	6.0	11.0	7.6	T	45°
			L	109.2	53.3	6.0	10.6			
			Average	109.9	50.9	6.0	10.8			

TABLE XLVI
(Continued)

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2] Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3] ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated	R8848	Tail	45°	125.7	49.5	6.0	9.4			
			45°	118.7	50.6	6.0	7.1			
			Average	122.2	50.1	6.0	8.3			
			T	112.4	61.9	4.0	11.6			
			T	109.0	53.5	4.0	6.3			
			Average	110.7	57.7	4.0	9.0			
	R8856	Head	L	89.0	28.8	30.0	47.7	7.8	45°	L
			L	88.8	26.6	32.0	47.9			
			Average	88.9	27.7	31.0	47.8			
			45°	92.7	42.4	19.0	48.3			
			45°	92.9	28.5	22.0	43.4			
			Average	92.8	35.5	20.5	45.9			
			T	92.2	33.8	34.0	46.2			
			T	91.9	35.4	36.0	37.9			
			Average	92.1	34.6	35.0	42.1			
		Tail	L	102.9	43.7	8.0	16.1	15.3	T	45°
			L	104.5	43.2	8.0	12.9			
			Average	103.7	43.5	8.0	14.5			
			45°	112.0	41.0	10.0	17.5			
			45°	113.6	43.8	9.0	16.4			
			Average	112.8	42.4	9.5	17.0			
			T	98.2	39.5	14.0	19.0			
			T	104.4	75.9	6.0	18.2			
			Average	101.3	57.7	10.0	18.6			

TABLE XLVI
(Continued)

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	R8848	Head	L	172.2	156.4	5.0	13.1	8.0	T	L
			L	171.0	155.2	4.0	13.5			
			Average	171.6	155.8	4.5	13.3			
			45°	164.6	154.3	7.0	16.2			
			45°	168.5	158.1	7.0	25.5			
			Average	166.6	156.2	7.0	20.9			
			T	176.2	160.9	4.0	10.2			
			T	181.3	166.6	4.0	10.2			
			Average	178.8	163.8	4.0	10.2			
		Tail	L	177.8	163.8	5.0	10.9	9.0	T	45°
			L	175.7	160.8	6.0	17.5			
			Average	176.8	162.3	5.5	14.2			
			45°	170.2	159.3	6.0	19.0			
			45°	171.3	160.4	8.0	23.8			
			Average	170.8	159.9	7.0	21.4			
			T	181.3	169.1	2.0	5.7			
			T	182.8	168.7	5.0	10.9			
			Average	182.1	168.9	3.5	8.3			
	R8856	Head	L	172.1	158.3	4.0	11.2	11.0	T	45°
			L	175.5	159.6	5.0	12.8			
			Average	173.8	159.0	4.5	12.0			
			45°	166.8	157.0	5.0	14.8			
			45°	167.7	156.8	6.0	21.0			
			Average	167.3	156.9	5.5	17.9			

TABLE XLVI
(Continued)

Condition[1]	Heat	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 1")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	R8856	Head	T	180.4	164.7	3.0	10.0			
			T	183.3	171.1	2.0	7.9			
			Average	181.9	167.9	2.5	9.0			
		Tail	L	182.3	165.8	5.0	10.9	6.1	T	L
			L	179.8	164.5	5.0	12.3			
			Average	181.1	165.2	5.0	11.6			
			45°	178.0	168.1	5.0	10.1			
			45°	176.0	166.3	8.0	21.8			
			Average	177.0	167.2	7.5	16.0			
			T	186.6	173.1	3.0	9.7			
			T	185.9	169.4	2.0	9.3			
			Average	186.3	171.3	2.5	9.5			

1 - Annealed - 1250F, 30 minutes, furnace cooled at 5F/minute maximum.
Solution Treated - 1380F, 20 minutes, WQ. All specimens machined to ½" diameter rounds before solution treating.
Solution Treated and Aged - Solution treated as above and aged 4 hours at 960F.

2 - Standard ¼" diameter x 1" gage length specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XLVII

Mechanical Properties and Directionality of Phase III Ti-2½Al-16V (Heat R8848) at the 0.136" Thick Hot Band Stage

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	L	111.7	103.0	14.0	37.9	11.5	T	L
	L	112.3	103.6	13.0	41.0			
	Average	112.0	103.3	13.5	39.5			
	45°	112.2	104.9	15.0	44.5			
	45°	112.8	106.2	14.0	45.1			
	Average	112.5	105.6	14.5	44.8			
	T	125.0	114.8	10.0	27.5			
	T	125.2	114.7	13.0	29.8			
	Average	125.1	114.8	11.5	28.7			
Solution Treated	L	95.9	39.2	27.0	46.2	0.9	T	45°
	L	94.6	39.8	21.5	40.3			
	Average	95.3	39.5	24.3	43.3			
	45°	97.0	38.9	29.5	44.1			
	45°	94.2	38.5	35.0	43.6			
	Average	95.6	38.7	32.3	43.9			
	T	95.2	38.7	35.5	44.3			
	T	95.6	40.4	33.5	43.4			
	Average	95.4	39.6	34.5	43.9			
Solution Treated and Aged	L	160.4	141.9	8.5	27.0	8.0	T, 45°	L
	L	164.2	148.6	8.0	29.3			
	Average	162.3	145.3	8.3	28.2			

TABLE XLVII
(Continued)

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2] Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3] ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	45°	160.8	153.4	(4)	31.8			
	45°	164.5	153.1	6.0	25.7			
	Average	162.7	153.3	6.0	28.8			
	T	162.9	154.5	6.5	27.5			
	T	162.1	152.0	6.5	30.5			
		162.5	153.3	6.5	29.0			

1 - Annealed - 1250°F, 30 minutes, furnace cooled at 5°F/minute maximum.
Solution Treated - 1380°F, 20 minutes, WQ.
Solution Treated and Aged - Solution treated as above and aged 4 hours at 960°F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

4 - Outside gage mark break.

TABLE XLVIII

Mechanical Properties and Directionality of Ti-2½Al-16V (Heat R8848) After Its First Cold Reduction to 0.100" Thick

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	L	115.9	103.4	16.0	53.9	3.7	T	45°
	L	115.6	102.0	15.0	49.7			
	Average	115.8	102.7	15.5	51.8			
	45°	116.3	98.7	13.5	43.0			
	45°	116.2	103.9	14.5	47.0			
	Average	116.3	101.3	14.0	45.0			
	T	117.7	105.6	15.0	40.2			
	T	116.7	104.3	16.0	41.2			
	Average	117.2	105.0	15.5	40.7			
Solution Treated	L	102.6	42.3	18.5	38.0	9.6	L	T
	L	102.8	46.4	20.0	35.3			
	Average	102.7	44.4	19.3	36.7			
	45°	102.6	43.6	29.5	36.9			
	T	78.1	33.2	26.0	50.4			
	T	80.6	36.3	30.0	52.2			
	Average	79.4	34.8	28.0	51.3			
Solution Treated and Aged	L	172.3	158.6	7.5	22.4	7.2	T	L
	L	172.0	157.0	7.0	21.6			
	Average	172.2	157.8	7.3	22.0			
	45°	175.1	162.5	6.5	18.8			
	45°	176.0	163.4	6.5	22.2			
	Average	175.6	163.0	6.5	20.5			
	T	179.5	165.0	7.0	20.2			

TABLE XXVIII
(Continued)

1 - Annealed - 1250F, 30 minutes, furnace cooled at 5F/minute maximum.
Solution Treated - 1380F, 20 minutes, water quench.
Solution Treated and Aged - Solution treated as above and aged 4 hours at 960F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

TABLE XLIX

Mechanical Properties and Directionality of Ti-2½Al-16V (Heat R8848) After Its Second Cold Reduction to 0.080" Thick

Condition[1]	Test Location	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area(%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	Tail	L	113.5	98.6	15.0	43.6	3.2	T	L
		L	114.2	100.5	16.0	48.4			
		Average	113.9	99.6	15.5	46.0			
		45°	115.0	100.8	15.5	45.3			
		45°	115.1	102.3	12.5	47.9			
		Average	115.1	101.6	14.0	46.6			
		T	115.5	102.7	15.5	39.8			
		T	116.2	102.8	13.5	46.4			
		Average	115.9	102.8	14.5	43.1			
Solution Treated	Head	L	119.1	48.8	17.5	30.4	8.5	T	L
		L	117.8	48.2	18.0	33.7			
		Average	118.5	48.5	17.8	32.1			
		45°	119.1	48.0	17.5	30.5			
		45°	119.0	50.1	16.0	33.6			
		Average	119.1	49.1	16.8	32.1			
		T	113.7	58.2	18.0	34.2			
		T	113.3	55.8	19.0	34.6			
		Average	113.5	57.0	18.5	34.4			
	Tail	L	113.8	47.9	16.5	36.5	8.1	45°	T
		L	113.6	47.7	18.5	38.6			
		Average	113.7	47.8	17.5	37.6			

TABLE XLIX
(Continued)

Condition[1]	Test Location	Test Direction	Room Temperature Mechanical Properties[2] Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3] ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated	Tail	45°	108.4	49.9	18.0	38.4			
		45°	109.0	51.2	22.5	34.0			
		Average	108.7	50.6	20.3	36.2			
		T	105.2	41.8	23.5	40.0			
		T	104.8	43.2	22.5	37.8			
		Average	105.0	42.5	23.0	38.9			
Solution Treated and Aged	Head	L	171.0	158.5	8.5	20.6	12.7	T	L
		L	174.6	160.8	7.0	21.6			
		Average	172.8	159.7	7.8	21.1			
		45°	170.7	161.5	9.0	30.2			
		45°	172.9	162.8	8.0	28.8			
		Average	171.8	162.2	8.5	29.5			
		T	182.5	171.3	8.0	18.8			
		T	182.7	173.5	6.0	21.9			
		Average	182.6	172.4	7.0	20.4			
	Tail	L	170.0	161.6	8.5	23.4	2.5	45°	T
		L	168.6	158.1	8.5	24.6			
		Average	169.3	159.9	8.5	24.0			
		45°	174.5	158.7	7.5	21.0			
		45°	172.2	162.4	7.0	18.4			
		Average	173.4	160.6	7.3	19.7			
		T	167.4	159.0	(4)	(4)			
		T	167.6	157.2	7.0	17.0			
		Average	167.5	158.1	7.0	17.0			

TABLE XLIX
(Continued)

1 - Annealed - 1250F, 30 minutes, furnace cooled at 5F/minute maximum.
Solution Treated - 1380F, 20 minutes, water quench.
Solution Treated and Aged - Solution treated as above and aged 4 hours at 960F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

4 - Outside gage mark break.

TABLE I

Mechanical Properties and Directionality of Ti-2½Al-16V (Heat R8848) After Its Third Cold Reduction to 0.045" Thick

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	L	120.5	108.9	14.0	47.8	7.1	T	67½°
	L	119.0	104.2	14.0	51.7			
	Average	119.8	106.6	14.0	49.8			
	22½°	114.2	102.4	12.0	51.2			
	22½°	119.8	109.5	13.5	55.2			
	Average	117.0	106.0	12.8	53.2			
	45°	113.3	103.1	15.0	59.0			
	45°	113.3	103.5	12.0	50.7			
	Average	113.3	103.3	13.5	54.9			
	67½°	117.2	102.0	14.5	49.8			
	67½°	116.3	102.4	13.0	50.5			
	Average	116.8	102.2	13.8	50.2			
	T	123.8	110.6	13.5	35.4			
	T	123.0	109.9	11.5	23.0			
	Average	123.4	109.3	12.5	29.2			
Solution Treated	L	116.4	50.6	18.0	37.4	2.4	45°	T
	L	117.1	49.2	20.0	32.9			
	Average	116.8	49.9	19.0	35.2			
	22½°	109.1	49.6	23.0	38.8			
	22½°	108.4	47.6	23.0	39.3			
	Average	108.8	48.6	23.0	39.1			

TABLE L
(Continued)

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated	45°	112.4	50.7	16.5	36.4			
	45°	112.5	50.8	20.0	38.4			
	Average	112.5	50.8	18.3	37.4			
	67½°	115.7	49.0	15.5	31.5			
	67½°	115.3	50.9	(4)	(4)			
	Average	115.5	50.0	15.5	31.5			
	T	109.5	47.8	21.0	35.7			
	T	109.8	49.0	21.5	41.6			
	Average	109.7	48.4	21.3	38.7			
Solution Treated and Aged	L	160.1	146.7	9.5	34.0	4.4	22½°	67½°
	L	163.4	151.5	6.5	40.8			
	Average	161.8	149.1	8.0	37.4			
	22½°	165.8	152.9	8.0	38.8			
	22½°	163.8	153.0	8.0	31.2			
	Average	164.8	153.0	8.0	35.0			
	45°	162.3	150.3	8.5	40.3			
	45°	163.7	151.9	9.5	46.9			
	Average	163.0	151.1	9.0	43.6			
	67½°	161.0	147.5	8.5	37.2			
	67½°	162.1	149.7	8.5	36.6			
	Average	161.6	148.6	8.5	36.9			
	T	163.6	151.0	9.0	33.7			
	T	163.8	152.4	6.5	21.6			
	Average	163.7	151.7	7.8	27.7			

TABLE L
(Continued)

1 - Annealed - 1250°F, 30 minutes, furnace cooled at 5°F/minute maximum.
Solution Treated - 1380°F, 20 minutes, water quench.
Solution Treated and Aged - Solution treated as above and aged 4 hours at 960°F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

4 - Outside gage mark break.

TABLE LI

Mechanical Properties and Directionality of Ti-2½Al-16V (Heat R8848) After Its Fourth Cold Reduction to 0.021" Thick

		Room Temperature Mechanical Properties[2]				Directionality[3]		
Condition[1]	Test Direction	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area(%)	ksi	Direction of Max Strength	Direction of Min Strength
Annealed	L	120.2	101.4	12.5	30.7	9.9	T	L
	L	116.7	97.3	8.0	37.8			
	Average	118.5	99.4	10.3	34.3			
	22½°	117.0	101.2	12.5	46.7			
	22½°	118.0	102.0	11.5	41.1			
	Average	117.5	101.6	12.0	43.9			
	45°	113.2	99.8	11.5	42.2			
	45°	113.5	101.8	9.0	34.1			
	Average	113.4	100.8	10.3	38.2			
	67½°	116.8	103.7	9.0	42.2			
	67½°	118.7	106.3	(4)	(4)			
	Average	117.8	105.0	9.0	42.2			
	T	124.7	109.5	7.0	25.3			
	T	124.3	109.1	(4)	(4)			
	Average	124.5	109.3	7.0	25.3			
Solution Treated	L	109.7	53.9	19.0	36.4	6.2	T	45°
	L	111.5	53.5	17.5	42.5			
	Average	110.6	53.7	18.3	39.5			
	22½°	113.0	51.8	17.0	39.1			
	22½°	113.3	51.6	16.0	40.0			
	Average	113.2	51.7	16.5	39.6			

TABLE LI
(Continued)

Condition[1]	Test Direction	Room Temperature Mechanical Properties[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated	45°	113.4	51.6	19.0	29.9			
	45°	113.9	51.6	16.5	34.1			
	Average	113.7	51.6	17.8	32.0			
	67½°	110.9	53.6	20.5	31.1			
	67½°	109.3	53.6	14.0	35.6			
	Average	110.1	53.6	17.3	33.4			
	T	110.0	59.8	(4)	33.3			
	T	109.3	55.8	25.0	32.2			
	Average	109.7	57.8	25.0	32.8			
Solution Treated and Aged	L	162.5	149.3	6.5	26.6	7.3	67½°	45°
	22½°	160.2	147.5	(4)	(4)			
	22½°	162.5	151.2	4.5	26.6			
	Average	161.4	149.4	4.5	26.6			
	45°	156.7	144.6	5.5	38.9			
	45°	162.5	150.3	5.5	29.6			
	Average	159.6	147.5	5.5	34.3			
	67½°	166.5	157.8	4.0	25.8			
	67½°	164.9	151.8	5.5	26.8			
	Average	165.7	154.8	4.8	26.3			
	T	172.5	-	(4)	(4)			
	T	166.3	153.7	(4)	(4)			
	Average	169.4	153.7	-	-			

TABLE LI
(Continued)

1 - Annealed - 1250F, 30 minutes, furnace cooled at 5F/minute maximum.
Solution Treated - 1380F, 20 minutes, water quench.
Solution Treated and Aged - Solution treated as above and aged 4 hours at 960F.

2 - Standard 0.500" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of three directions tested.

4 - Outside gage mark break.

TABLE LII

Compression Test Results and Compression Directionality of Ti-2½Al-16V (Heat R8848) After Its Third Cold Reduction to 0.045" Thick

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Annealed	70°F	L	122.3	8.4	T	22½°
		L	116.9			
		Average	119.6			
		22½°	115.2			
		22½°	114.1			
		Average	114.7			
		45°	121.2			
		45°	120.4			
		Average	120.8			
		67½°	119.9			
		67½°	123.9			
		Average	121.9			
		T	127.8			
		T	118.3			
		Average	123.1			
	800°F	L	63.9	13.6	45°	L
		L	69.6			
		Average	66.8			
		22½°	77.3			
		22½°	78.0			
		Average	77.7			
		45°	79.8			
		45°	81.0			
		Average	80.4			

TABLE LII
(Continued)

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Annealed	800F	67½°	73.1			
		67½°	77.8			
		Average	75.5			
		T	81.9			
		T	76.3			
		Average	79.1			
Solution Treated	70F	L	65.1	10.2	45°	T
		L	67.0			
		Average	66.1			
		22½°	73.3			
		22½°	75.3			
		Average	74.3			
		45°	75.0			
		45°	76.8			
		Average	75.9			
		67½°	75.6			
		67½°	68.8			
		Average	72.2			
		T	66.4			
		T	64.9			
		Average	65.7			
Solution Treated and Aged	70F	L	161.0	10.9	67½°	T
		L	159.3			
		Average	160.2			

TABLE LII
(Continued)

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	70F	22½°	166.7			
		22½°	168.6			
		Average	167.7			
		45°	166.3			
		45°	168.5			
		Average	167.4			
		67½°	169.8			
		67½°	169.4			
		Average	169.6			
		T	158.7			
	800F	L	112.0	15.4	22½°	L
		L	73.9			
		Average	93.0			
		22½°	108.9			
		22½°	107.8			
		Average	108.4			
		45°	112.2			
		45°	99.0			
		Average	105.6			
		67½°	120.1			
		67½°	83.5			
		Average	101.8			

TABLE LII
(Continued)

Condition[1]	Test Temperature	Test Direction	Compression YS ksi	Directionality[2] ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	800F	T	106.3			
		T	95.1			
		Average	100.7			

1 - Annealed - 1250F, 30 minutes, furnace cool at 5F/minute maximum.
Solution Treated - 1380F, 20 minutes, WQ.
Solution Treated and Aged - Solution treated as above and aged 4 hours at 960F.

2 - Difference between highest average yield strength and lowest average yield strength of five directions tested.

TABLE LIII

Elevated Temperature Tensile Test Results and Directionality of Ti-2½Al-16V (Heat R8848) After Its Fourth Cold Reduction to 0.021" Thick

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	400F	L	102.9	86.4	10.0	32.9	11.7	T	45°
		L	100.0	82.2	11.0	32.9			
		Average	101.5	84.3	10.5	32.9			
		22½°	97.9	83.2	11.5	29.4			
		22½°	93.6	78.6	11.5	41.4			
		Average	95.8	80.9	11.5	35.4			
		45°	85.1	75.3	10.0	38.6			
		45°	89.3	78.0	12.0	41.2			
		Average	87.2	76.7	11.0	39.9			
		67½°	89.4	78.2	7.5	37.1			
		67½°	96.4	85.9	9.5	31.4			
		Average	92.9	82.1	8.5	34.3			
		T	99.3	87.9	6.5	37.5			
		T	99.3	88.9	6.5	34.7			
		Average	99.3	88.4	6.5	36.1			
	600F	L	98.6	80.5	(4)	(4)	11.2	T	45°
		L	93.6	72.8	8.5	34.2			
		Average	96.1	76.7	8.5	34.2			
		22½°	90.4	72.3	9.5	38.2			
		22½°	86.8	67.0	9.0	39.5			
		Average	88.6	69.7	9.3	38.9			

TABLE LIII
(Continued)

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Annealed	600F	45°	84.5	70.7	10.0	39.2			
		45°	81.6	68.0	11.5	40.8			
		Average	83.1	69.4	10.8	40.0			
		67½°	93.0	79.3	4.0	32.4			
		67½°	86.5	71.9	7.5	35.1			
		Average	89.8	75.6	5.3	33.8			
		T	98.5	81.7	5.0	33.3			
		T	95.5	79.4	5.5	31.1			
		Average	97.0	80.6	5.3	32.2			
	800F	L	90.3	62.8	21.0	46.1	9.0	T	45°
		L	83.2	57.8	21.0	53.8			
		Average	86.8	60.3	21.0	50.0			
		22½°	84.5	60.5	22.0	63.2			
		22½°	82.8	58.6	29.5	65.0			
		Average	83.7	59.6	25.8	64.1			
		45°	73.1	57.5	16.5	60.0			
		45°	69.1	53.0	21.5	63.2			
		Average	71.1	55.3	19.0	61.6			
		67½°	78.8	62.2	10.5	48.8			
		67½°	75.8	59.6	15.5	59.5			
		Average	77.3	60.9	13.0	54.2			
		T	83.1	65.5	18.0	55.0			
		T	81.4	63.0	11.0	39.5			
		Average	82.3	64.3	14.5	47.3			

TABLE LIII
(Continued)

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	400F	L	140.6	123.8	4.5	20.0	11.6	T	45°
		L	133.6	116.1	4.0	25.9			
		Average	137.1	120.0	4.3	23.0			
		22½°	140.0	122.5	5.5	28.6			
		22½°	143.3	125.7	6.0	37.9			
		Average	141.7	124.1	5.8	33.3			
		45°	132.0	113.7	5.0	22.2			
		45°	133.7	117.2	6.0	30.8			
		Average	132.9	115.5	5.5	26.5			
		67½°	142.2	125.1	4.5	25.9			
		67½°	139.0	123.4	4.0	27.6			
		Average	140.6	124.3	4.3	26.8			
		T	140.0	128.0	(4)	(4)			
		T	142.5	126.2	(4)	(4)			
		Average	141.3	127.1	-	-			
	600F	L	127.1	107.5	4.0	25.9	5.2	T	L
		L	131.2	111.2	5.5	15.5			
		Average	129.2	109.4	4.8	20.7			
		22½°	128.5	108.0	4.0	16.7			
		22½°	132.2	112.1	4.5	25.9			
		Average	130.4	110.1	4.3	21.3			
		45°	130.5	109.6	5.0	31.3			
		45°	130.4	111.3	4.0	17.9			
		Average	130.5	110.5	4.5	24.6			

TABLE LIII
(Continued)

Condition[1]	Test Temperature	Test Direction	Tensile Test Results[2]: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	Directionality[3]: ksi	Direction of Max Strength	Direction of Min Strength
Solution Treated and Aged	600F	67½°	131.2	111.6	4.0	15.0			
		67½°	129.5	112.4	3.5	17.2			
		Average	130.4	112.0	3.8	16.1			
		T	133.4	112.4	4.5	21.4			
		T	131.9	116.7	(4)	(4)			
		Average	132.7	114.6	4.5	21.4			
	800F	L	111.3	86.1	6.5	35.5	9.0	L, 22½°	45°
		L	120.0	96.9	6.0	38.7			
		Average	115.7	91.5	6.3	37.1			
		22½°	111.0	85.0	11.0	56.5			
		22½°	116.5	97.9	(4)	(4)			
		Average	113.8	91.5	11.0	56.5			
		45°	110.3	82.6	9.0	48.5			
		45°	108.4	82.3	9.5	50.0			
		Average	109.4	82.5	9.3	49.3			
		67½°	115.8	89.5	8.0	35.0			
		67½°	115.3	90.2	8.0	40.3			
		Average	115.6	89.9	8.0	37.7			
		T	116.7	88.3	(4)	(4)			
		T	116.6	94.4	7.5	43.5			
		Average	116.7	91.4	7.5	43.5			

TABLE LIII
(Continued)

1 - Annealed - 1250F, 30 minutes, furnace cool 5F/minute maximum.
Solution Treated and Aged - Solution treated 1380F, 20 minutes, WQ and age 4 hours at 960F.

2 - Standard 0.400" wide x 2" gage length flat tensile specimens.

3 - Difference between highest average yield strength and lowest average yield strength of five directions tested.

4 - Outside gage mark break.

TABLE LIV

Crack Propagation Tests on Mill Processed Ti-6Al-4V, Ti-4Al-3Mo-1V and Ti-2½Al-16V Strip

Alloy	Condition	Test Direction	Net Fracture Stress (ksi)	Standard Tensile Tests[1] of Comparison Specimens: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	NFS/UTS
Ti-6Al-4V	Annealed[2]	L	128.5	131.8	116.0	11.5	28.9	
		L	128.1	129.1	114.5	11.5	29.6	
		Average	128.3	130.5	115.3	11.5	29.3	.984
		45°	126.2	120.0	117.1	17.5	58.0	
		45°	126.4	119.2	115.3	17.5	59.2	
		Average	126.3	119.6	116.2	17.5	58.6	1.057
		T	150.2	154.6	140.9	13.5	33.9	
		T	152.3	154.6	141.1	13.0	31.2	
		Average	151.3	154.6	141.0	13.3	32.6	.980
Ti-4Al-3Mo-1V	Solution Treated[3]	L	118.7	145.6	95.3	14.0	32.4	
		L	119.4	143.1	93.7	15.0	34.6	
		Average	119.1	144.4	94.5	14.5	33.5	.825
		45°	133.7	136.1	90.7	16.5	35.5	
		45°	124.5	134.0	84.0	16.0	34.6	
		Average	129.1	135.1	87.4	16.3	35.1	.956
		T	123.0	149.0	106.1	11.0	30.7	
		T	130.8	150.0	107.9	(7)	39.9	
		Average	126.9	149.5	107.0	11.0	35.3	.848
	Solution Treated and Aged[4]	L	89.7	196.2	161.1	5.0	21.4	
		L	90.3	198.0	166.9	4.0	20.7	
		Average	90.0	197.1	164.0	4.5	21.1	.457

TABLE LIV
(Continued)

Alloy	Condition	Test Direction	Net Fracture Stress (ksi)	Standard Tensile Tests[1] of Comparison Specimens: Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Reduction in Area (%)	NFS/UTS
Ti-4Al-3Mo-1V	Solution Treated and Aged[4]	45°	116.4	190.0	166.0	6.5	26.0	
		45°	112.2	188.5	165.4	5.5	28.7	
		Average	114.3	189.3	165.7	6.0	27.4	.604
		T	90.3	204.1	182.2	6.5	26.4	
		T	81.2	207.9	187.2	6.5	24.8	
		Average	85.8	206.0	184.7	6.5	25.6	.416
Ti-2½Al-16V	Solution Treated[5]	L	80.8	112.2	47.1	15.5	37.1	
		L	80.1	109.5	46.2	16.0	38.0	
		Average	80.5	110.9	46.7	15.8	37.6	.726
		45°	78.4	104.4	53.3	25.5	38.9	
		45°	78.4	105.2	52.8	33.0	39.9	
		Average	78.4	104.8	53.1	29.3	39.4	.748
		T	76.4	107.2	50.1	(7)	41.0	
		T	77.2	106.7	50.4	18.5	43.8	
		Average	76.8	107.0	50.3	18.5	42.4	.718
	Solution Treated and Aged[6]	L	134.0	158.9	149.0	11.0	53.4	
		L	132.9	161.9	151.9	7.5	48.5	
		Average	133.5	160.4	150.5	9.3	51.0	.833
		45°	132.4	167.5	157.6	9.0	20.7	
		45°	133.4	165.9	155.4	7.5	42.8	
		Average	132.9	166.7	156.5	8.3	31.8	.798
		T	118.6	164.8	153.8	10.0	40.8	
		T	131.7	164.5	153.1	8.5	35.7	
		Average	125.2	164.7	153.5	9.3	38.3	.760

TABLE LIV
(Continued)

1 - Standard 0.500" wide x 2" gage length flat tensile specimens.

2 - Annealed 1550F, 5 hours, furnace cooled 5F/minute maximum.

3 - Solution treated 1650F, 20 minutes, water quenched.

4 - Solution treated 1650F, 20 minutes, water quenched and aged 12 hours at 925F.

5 - Solution treated 1380F, 20 minutes, water quenched.

6 - Solution treated 1380F, 20 minutes, water quenched and aged 4 hours at 960F.

7 - Outside gage mark break.

Figure 1

Effect of finishing temperature and reduction per pass on ultimate strength directionality of Ti-6Al-4V hot rolled from 0.750" thick sheet bar to 0.125" thick hot band.

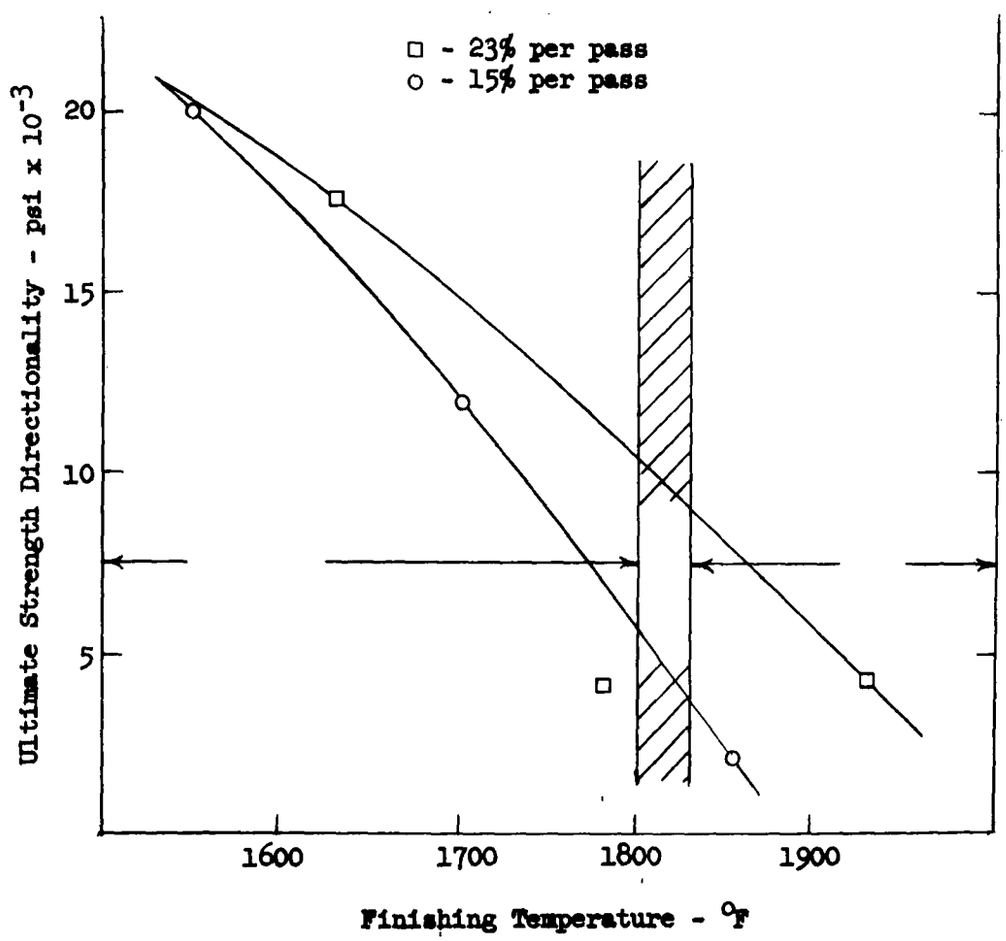


Figure 2

Effect of finishing temperature and reduction per pass on 0.2% yield strength directionality of Ti-6Al-4V hot rolled from 0.750" thick sheet bar to 0.125" thick hot band.

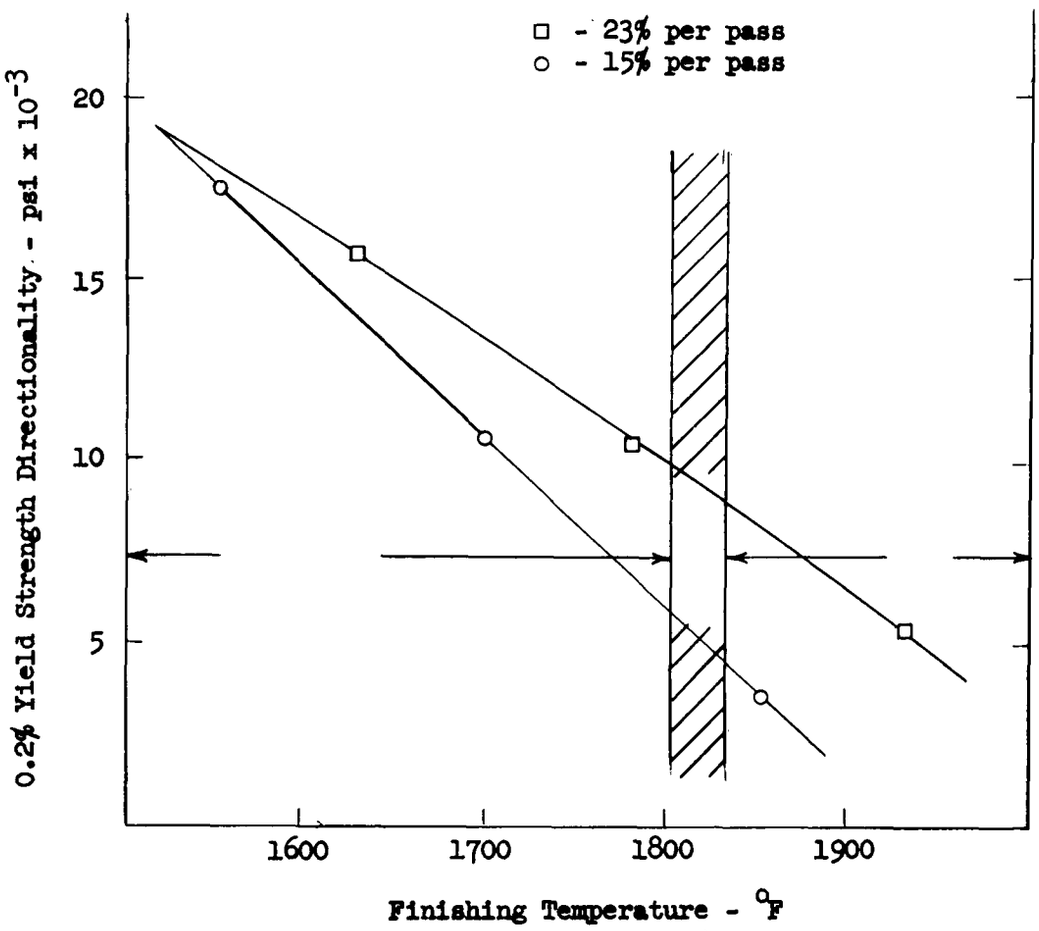


Figure 3

Grade	:	Ti-6Al-4V
Magnification	:	150X
Etchant	:	2% N - 1% HF
Condition	:	Hot rolled 23% per pass above beta transus. Annealed 2 hours at 1550F, slow cool 5F/minute to 1050F.
Description	:	Widmanstatten or transformation structure.

506-3657

Figure 4

Grade	:	Ti-6Al-4V
Magnification	:	150X
Etchant	:	2% N - 1% HF
Condition	:	Hot rolled 15% per pass above the beta transus. Annealed 2 hours at 1550F, slow cool 5F/minute to 1050F.
Description	:	Widmanstatten or transformation structure.

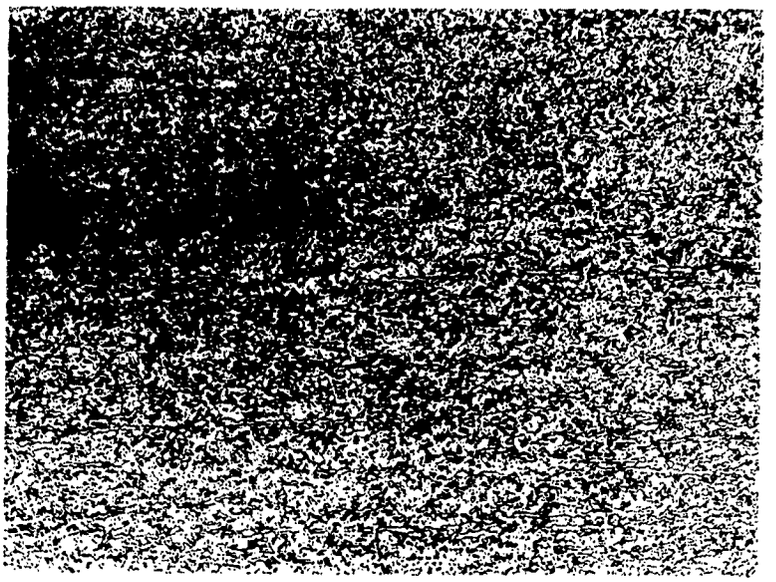
506-3658

Figure 5

Grade	:	Ti-6Al-4V
Magnification	:	150X
Etchant	:	2% N - 1% HF
Condition	:	Hot rolled 23% per pass through and then below the beta transus. Annealed 2 hours at 1550F slow cooled 5F/minute to 1050F.
Description	:	Worked transformation structure

506-3659

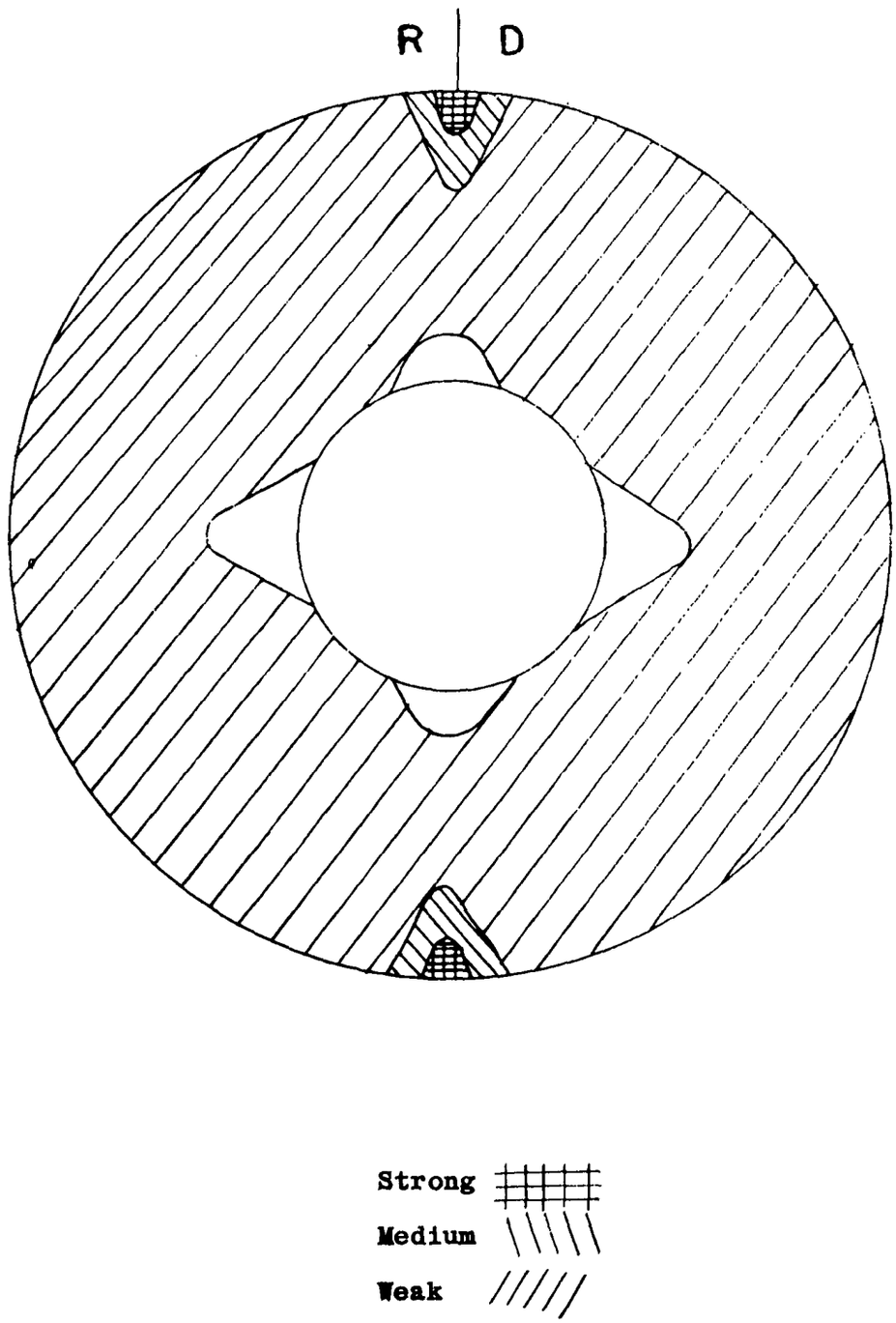
Figure 6



Grade	:	Ti-6Al-4V
Magnification	:	150X
Etchant	:	2% N - 1% HF
Condition	:	Hot rolled 15% per pass through and below the beta transus. Annealed 2 hours at 1550F, slow cooled 5F/minute to 1050F.
Description	:	Uniform alpha-beta structure.

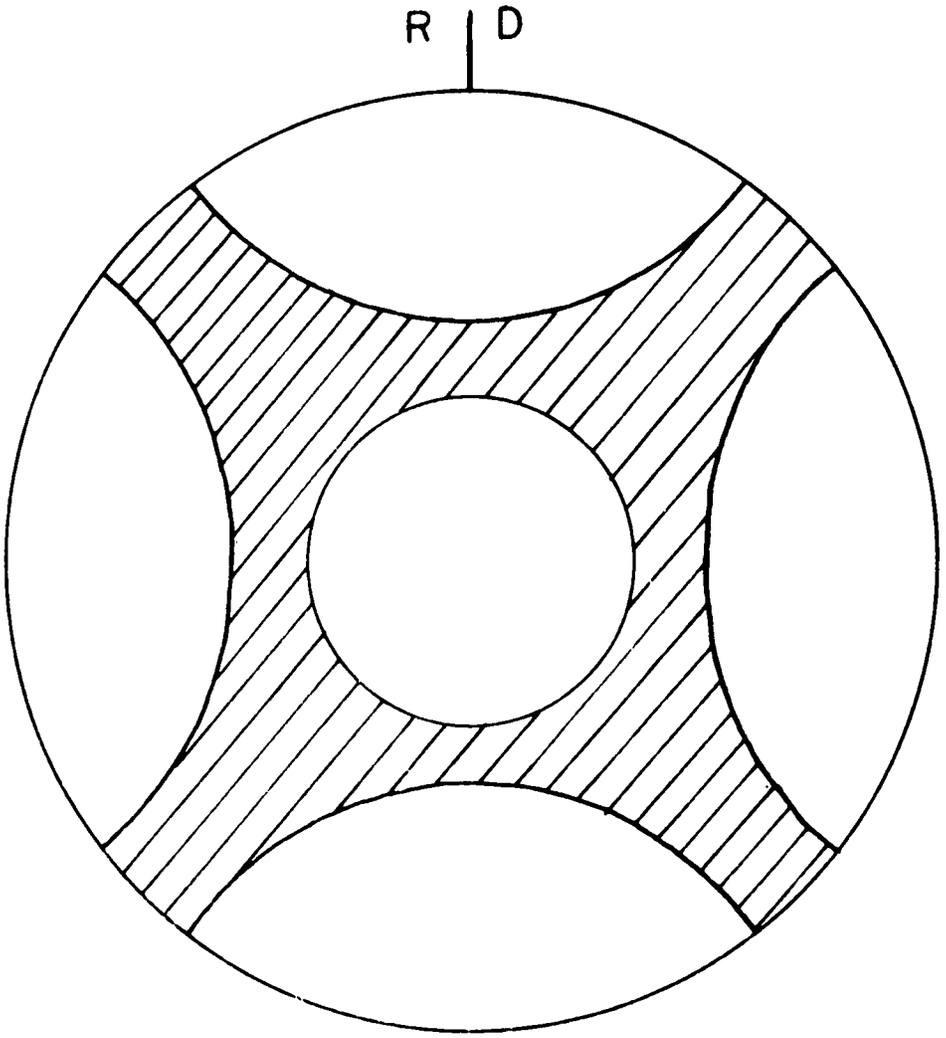
506-3660

Figure 7 Process 1B - Pole Figure for Ti-6Al-4V Alpha Phase
$(01\bar{1}0)$ plane



506-3776

Figure 8 Process 1B - Pole Figure for Ti-6Al-4V Beta Phase (100) plane



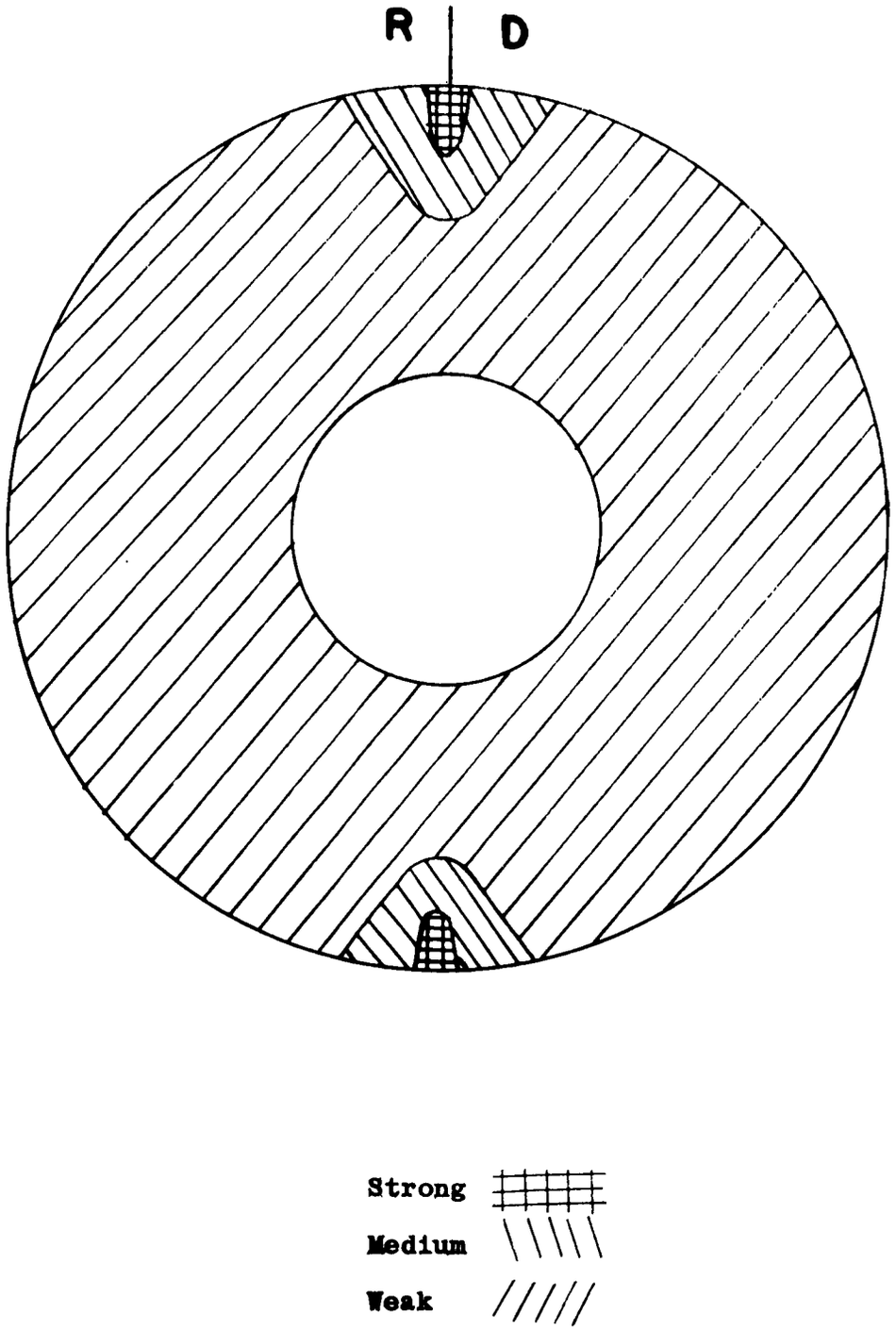
Strong

Medium

Weak

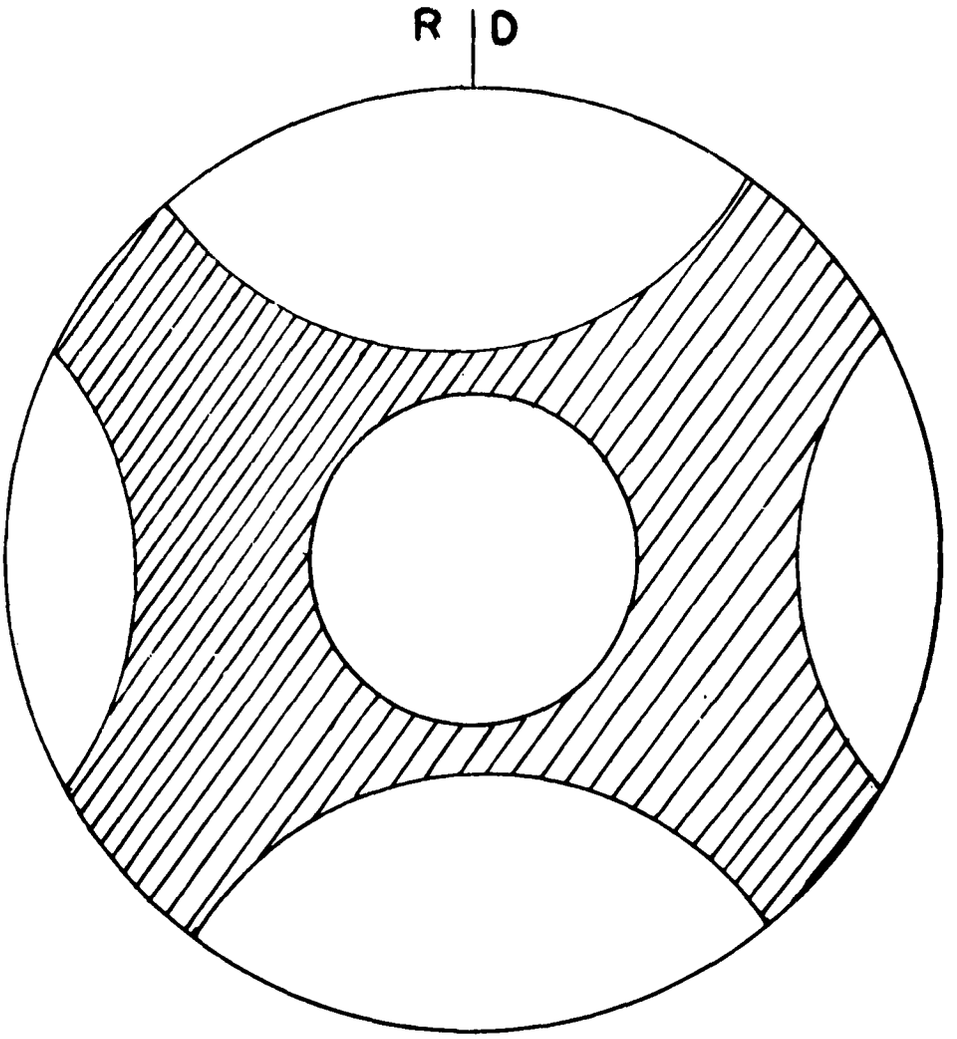
506-3777

Figure 9 Process 1K - Pole Figure for Ti-6Al-4V Alpha Phase ($01\bar{1}0$) Plane



506-3778

Figure 10 Process 1K - Pole Figure for Ti-6Al-4V Beta Phase (100) plane



Strong

Medium

Weak

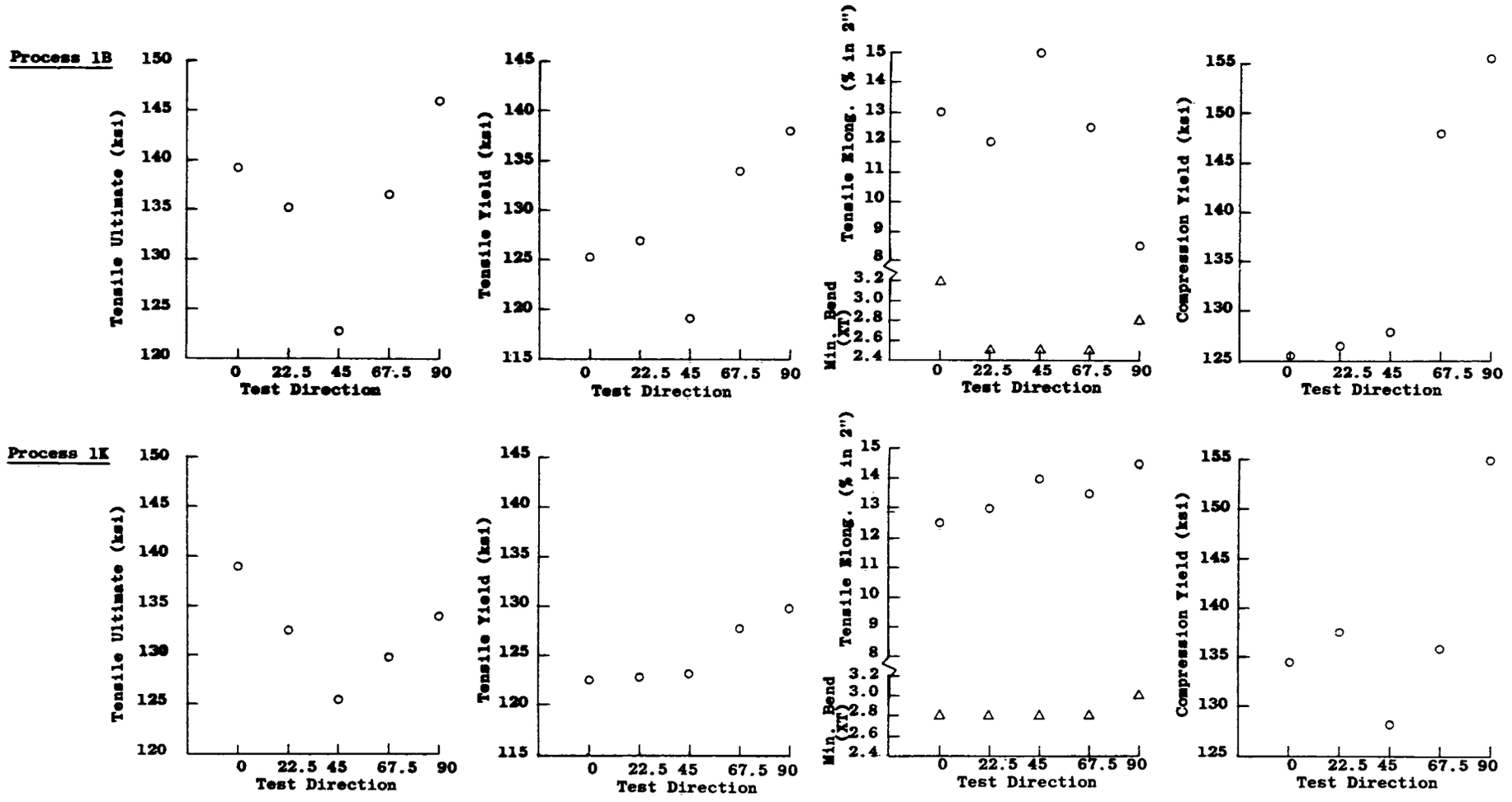
506-3779

Figure 11 Test Results on Annealed .040" Thick Ti-6Al-4V Sheet At Room Temperature - Processes 1B and 1K

Tests - Tension
Compression
Bend

Anneal - 5 hours at 1550F, slow cool to 1050F, air cool to room temperature.

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal



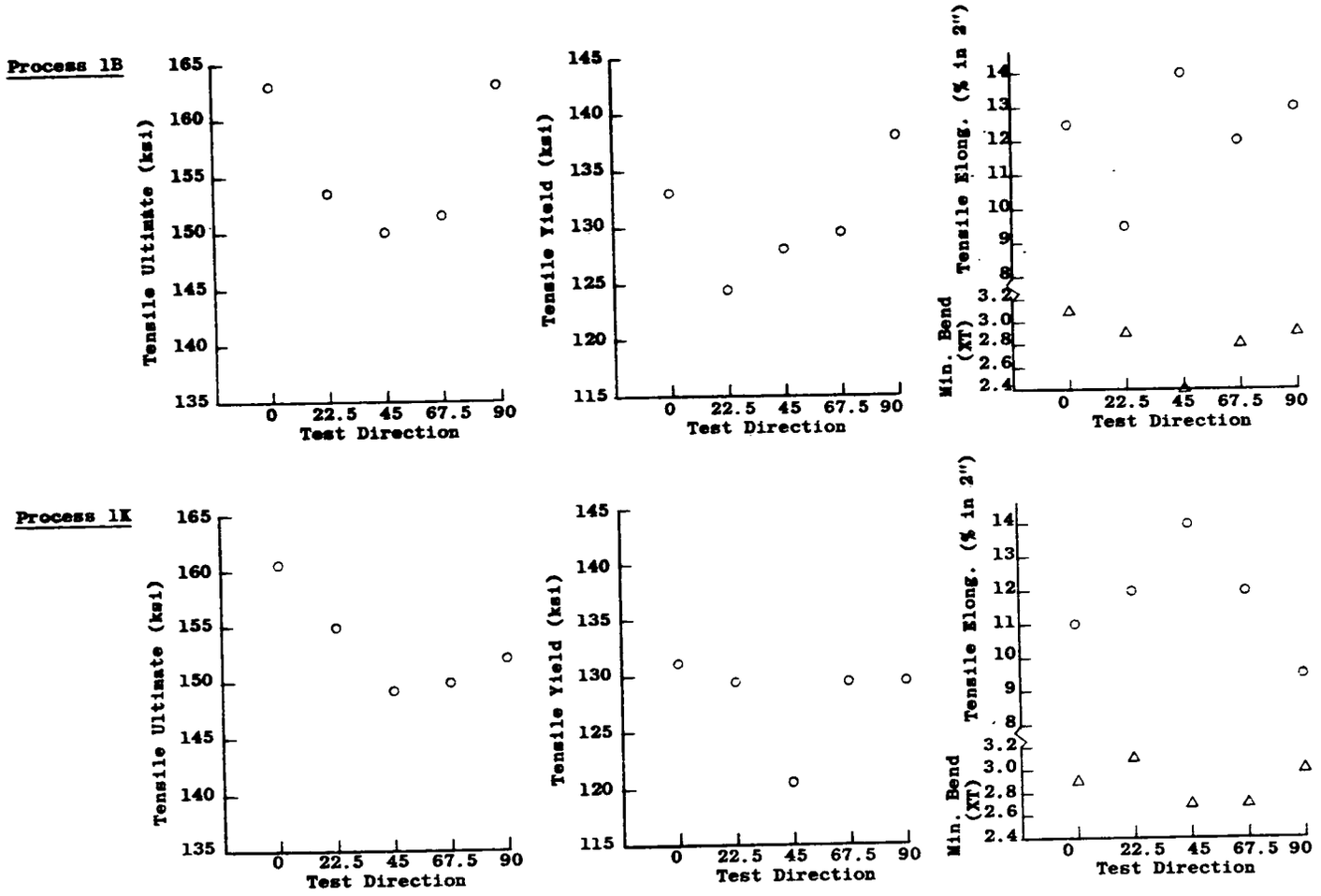
506-3766

Figure 12 Test Results on Solution Treated .040" Thick Ti-6Al-4V Sheet at Room Temperature - Processes 1B and 1K

Tests - Tension
Bend

Solution Treatment - 1700F, 20', WQ

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal



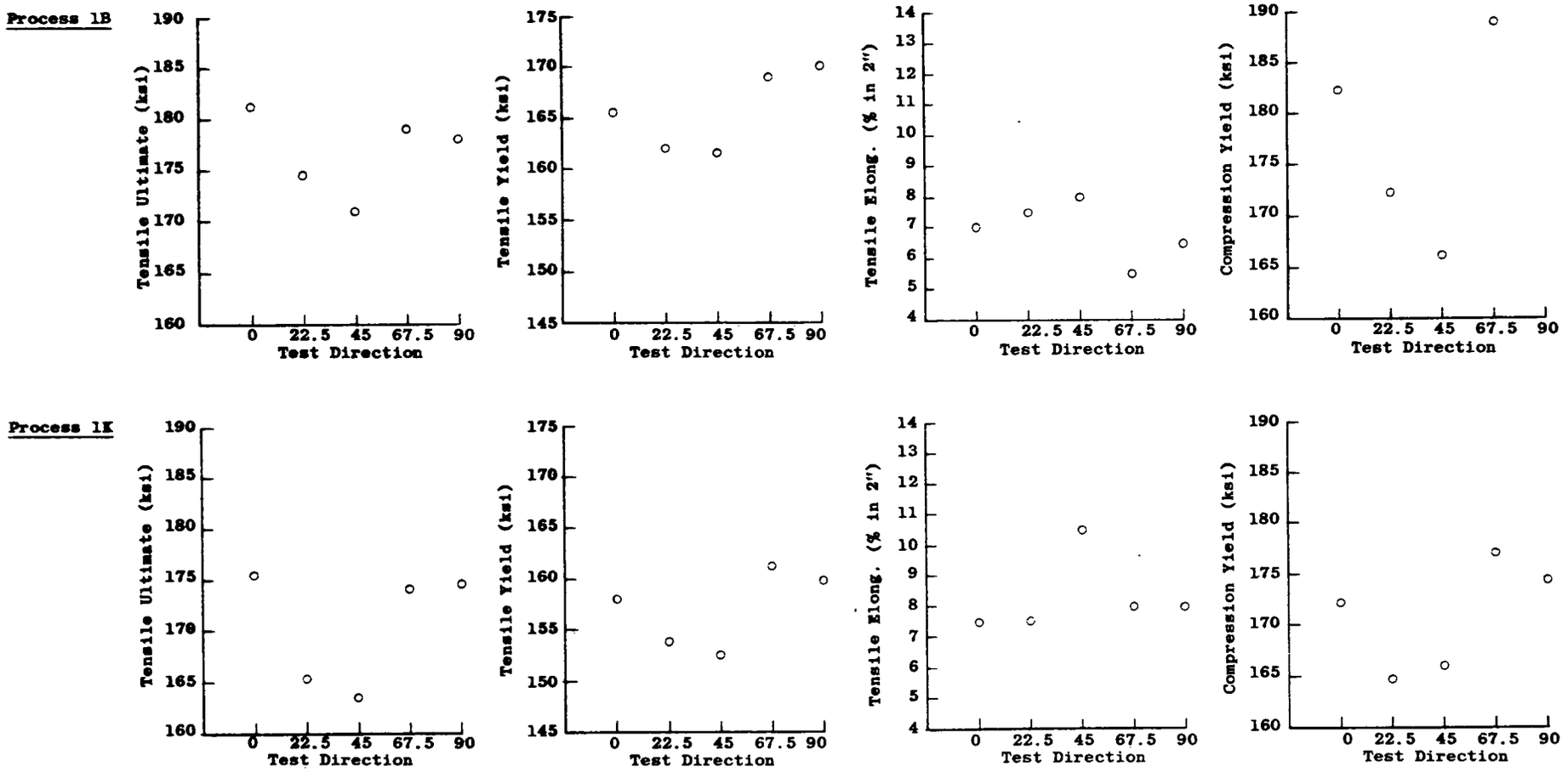
506-3767

Figure 13 Test Results on Solution Treated and Aged .040" Thick Ti-6Al-4V Sheet at Room Temperature - Processes 1B and 1K

Tests - Tension
Compression

Solution Treatment - 1700F, 20', WQ
Age - 1000F, 4 hours

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal



506-3768

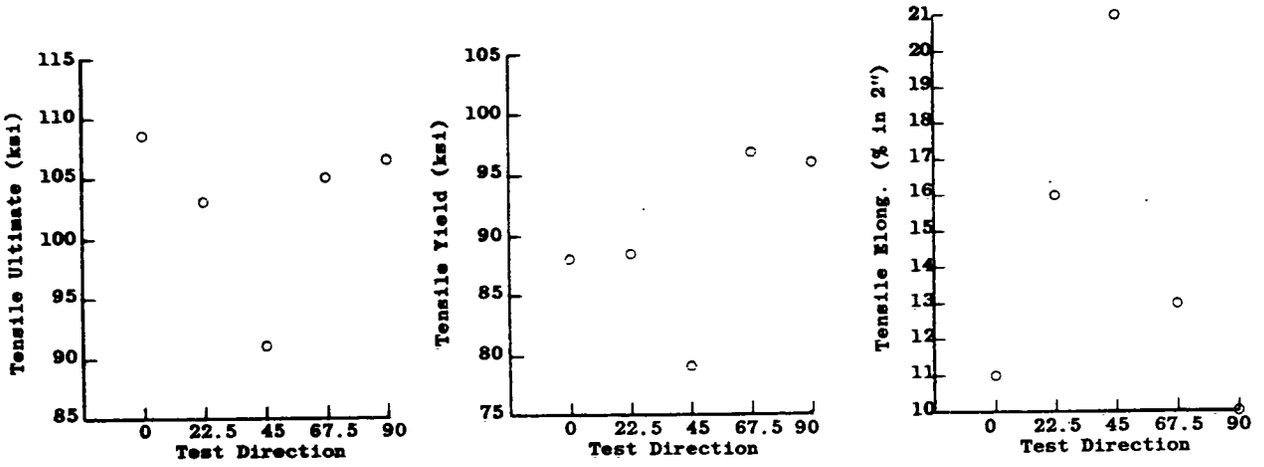
Figure 14 Test Results on Annealed .040" Thick Ti-6Al-4V Sheet at 400F - Processes 1B and 1K

Tests - Tension

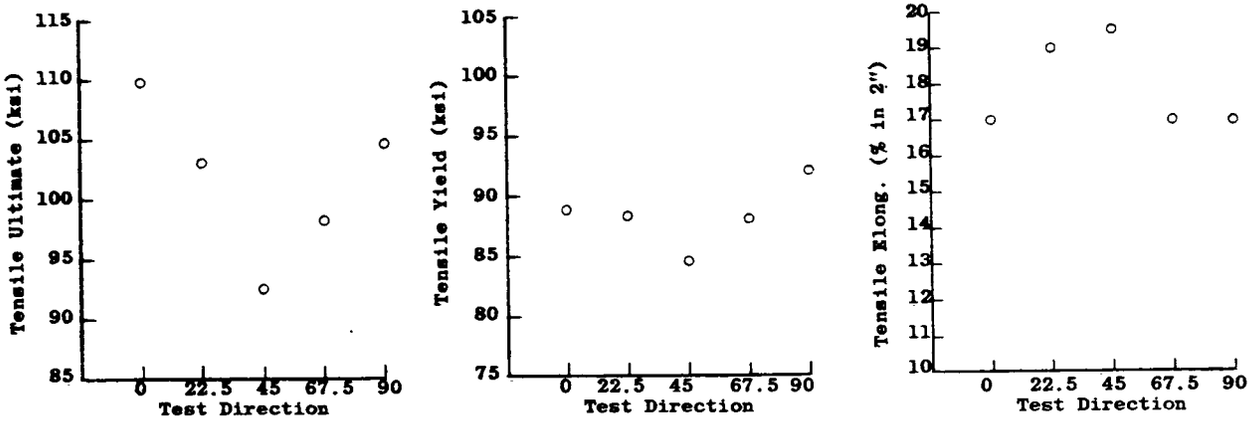
Anneal - 5 hours at 1550F, slow cool to 1050F, air cool to room temperature.

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal

Process 1B



Process 1K



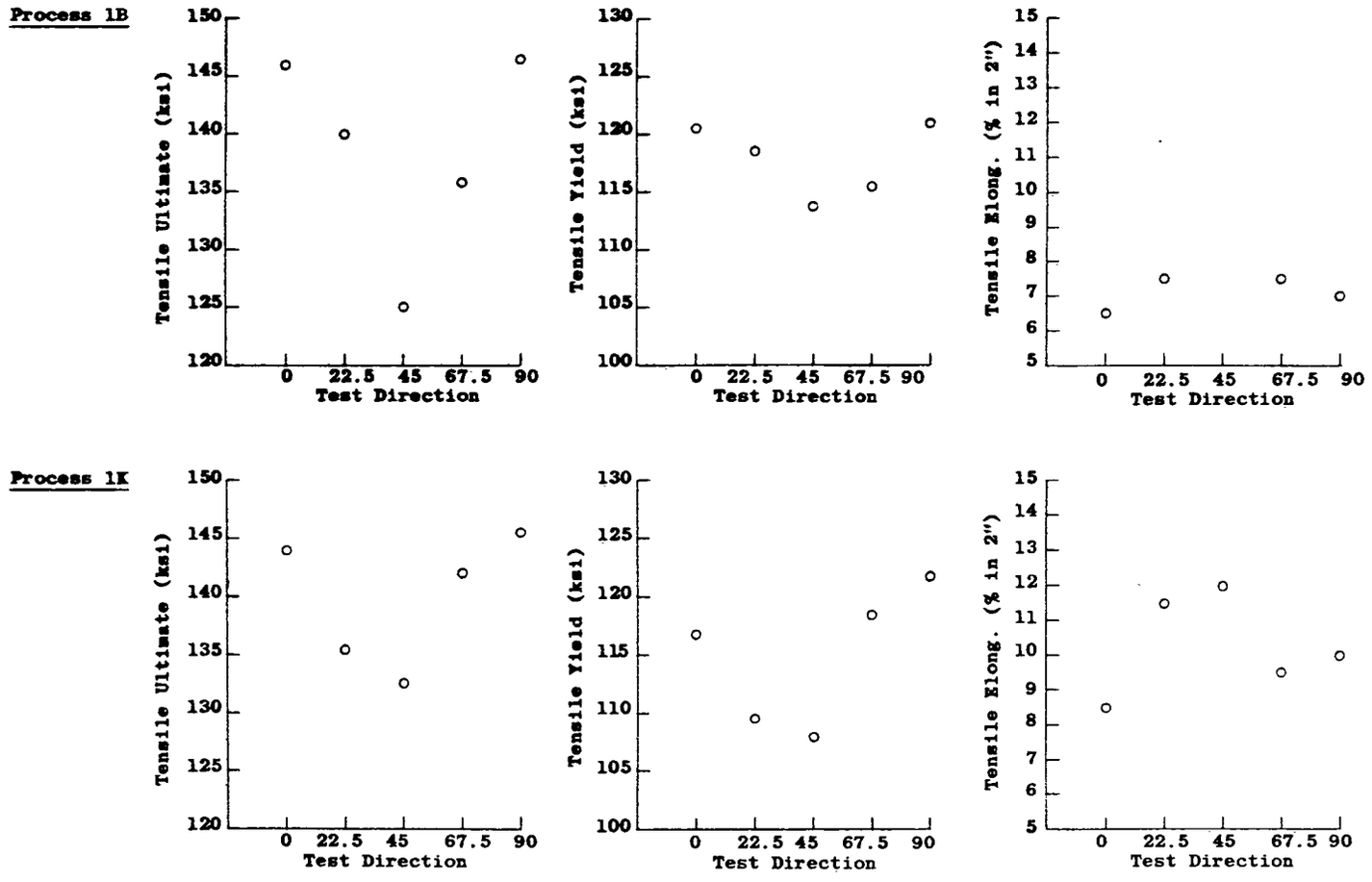
506-3769

Figure 35 Test Results on Solution Treated and Aged .040" Thick Ti-6Al-4V Sheet at 400F - Processes 1B and 1K

Tests - Tension

Solution Treatment - 1700F, 20', WQ
Age - 1000F, 4 hours

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal



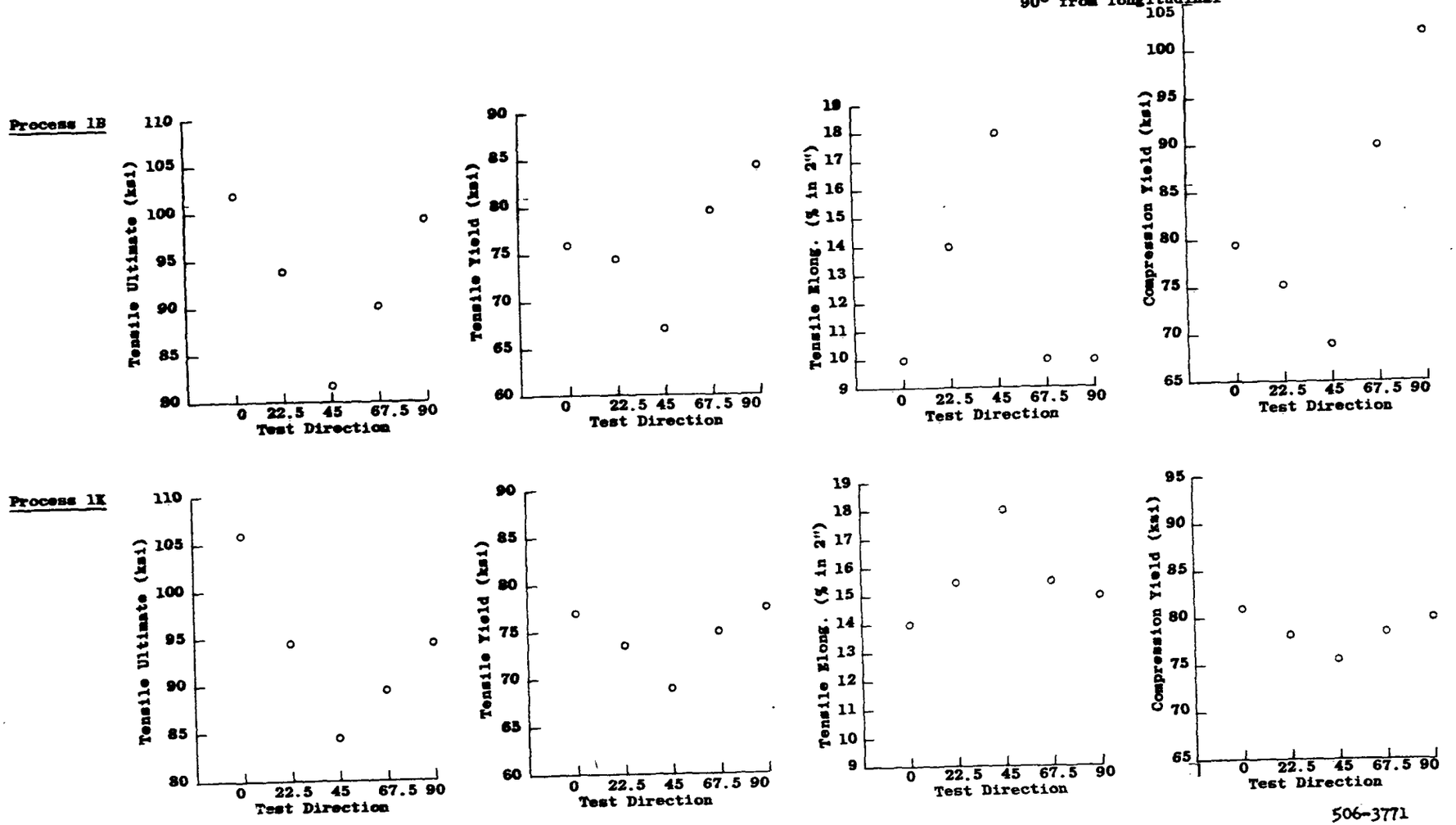
506-3770

Figure 36 Test Results on Annealed .040" Thick Ti-6Al-4V Sheet at 600F - Processes 1B and 1K

Tests - Tension
Compression

Anneal - 5 hours at 1550F, slow cool to 1050F, air cool to room temperature.

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal



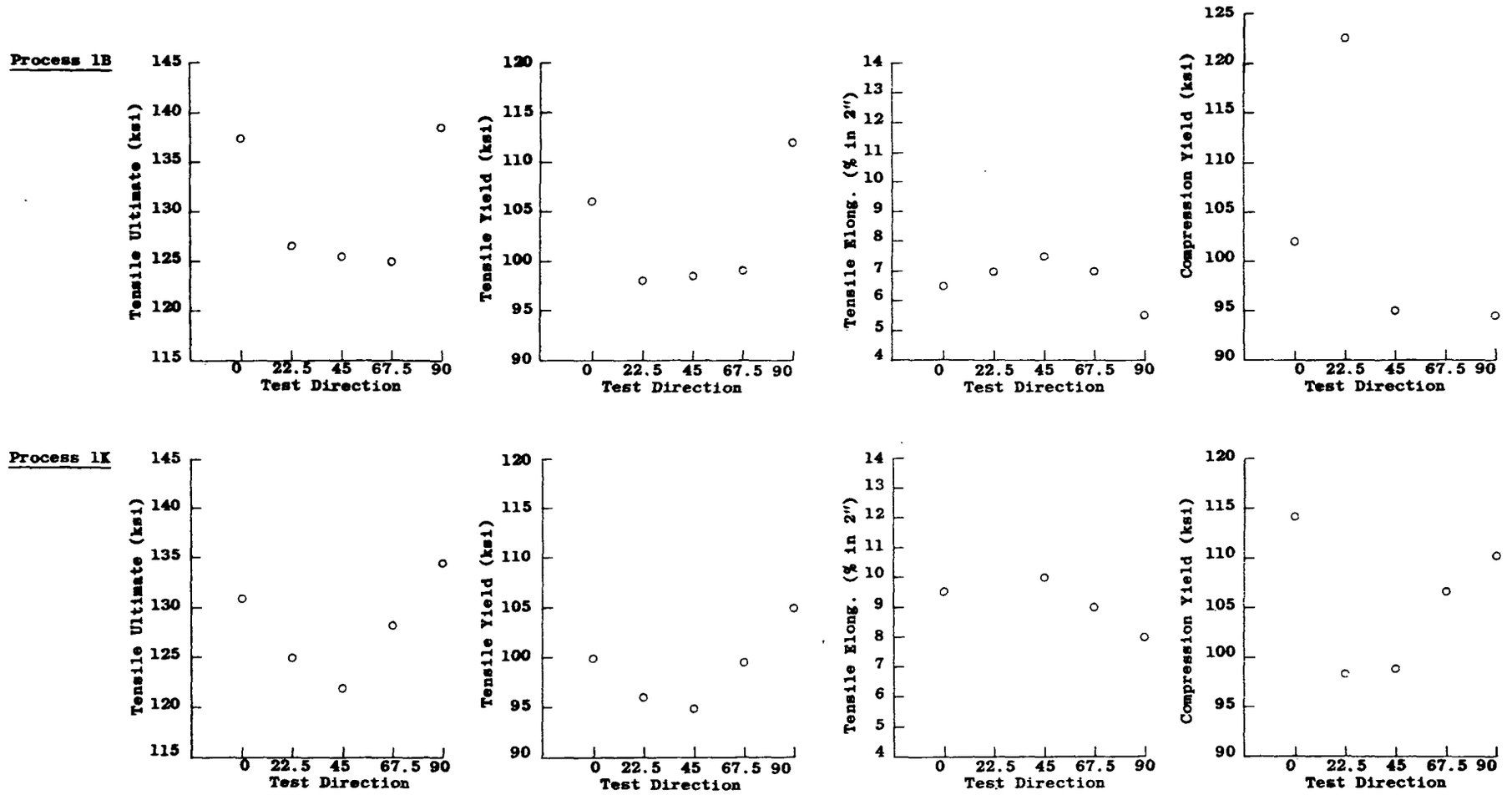
506-3771

Figure 17 Test Results on Solution Treated and Aged .040" Thick Ti-6Al-4V Sheet at 600F - Processes 1B and 1K

Tests - Tension
Compression

Solution Treatment - 1700F, 20', WQ
Age - 1000F, 4 hours

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal



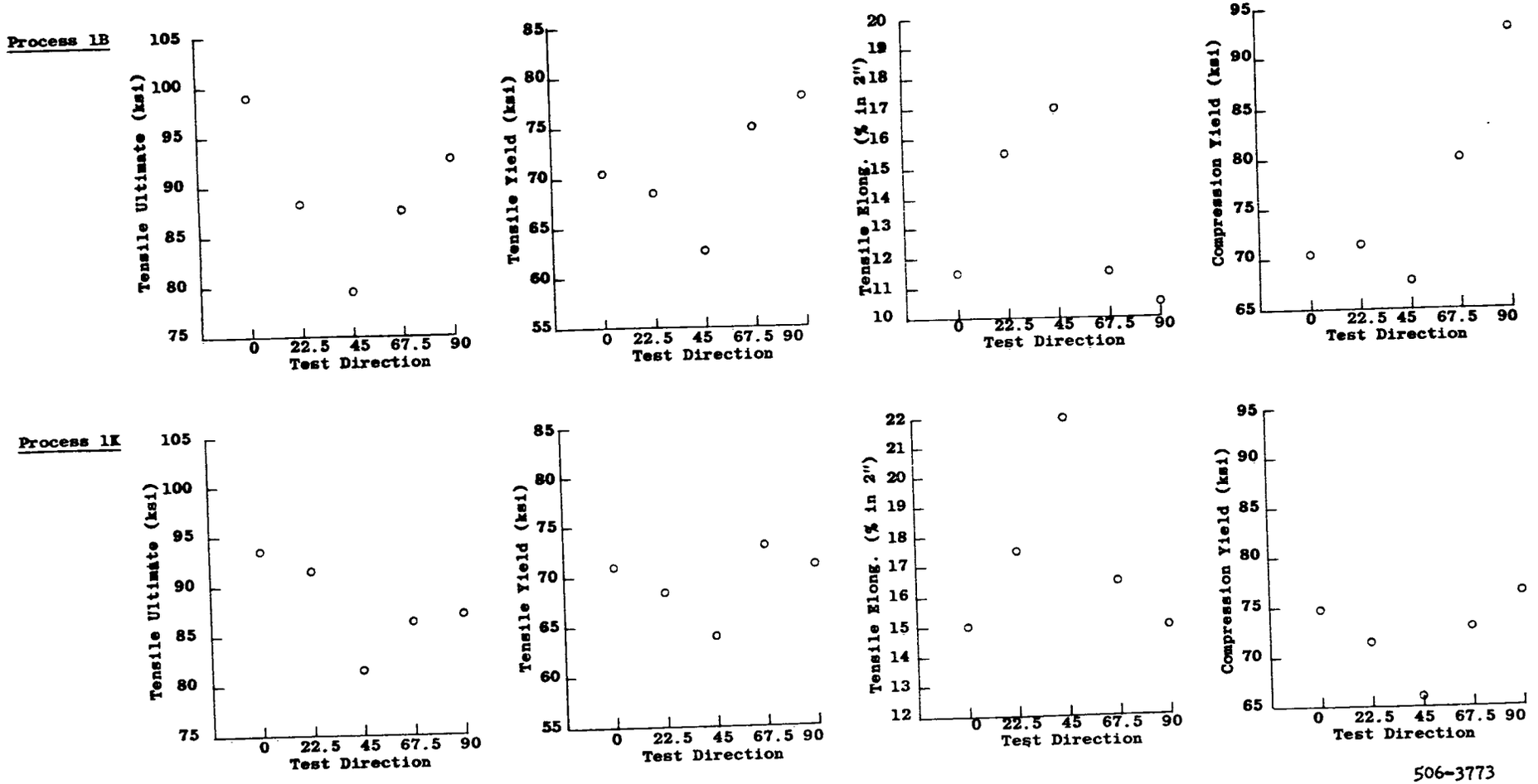
506-3772

Figure 38 Test Results on Annealed .040" Thick Ti-6Al-4V Sheet at 800F - Processes 1B and 1K

Tests - Tension
Compression

Anneal - 5 hours at 1550F, slow cool to 1050F, air cool to room temperature.

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal



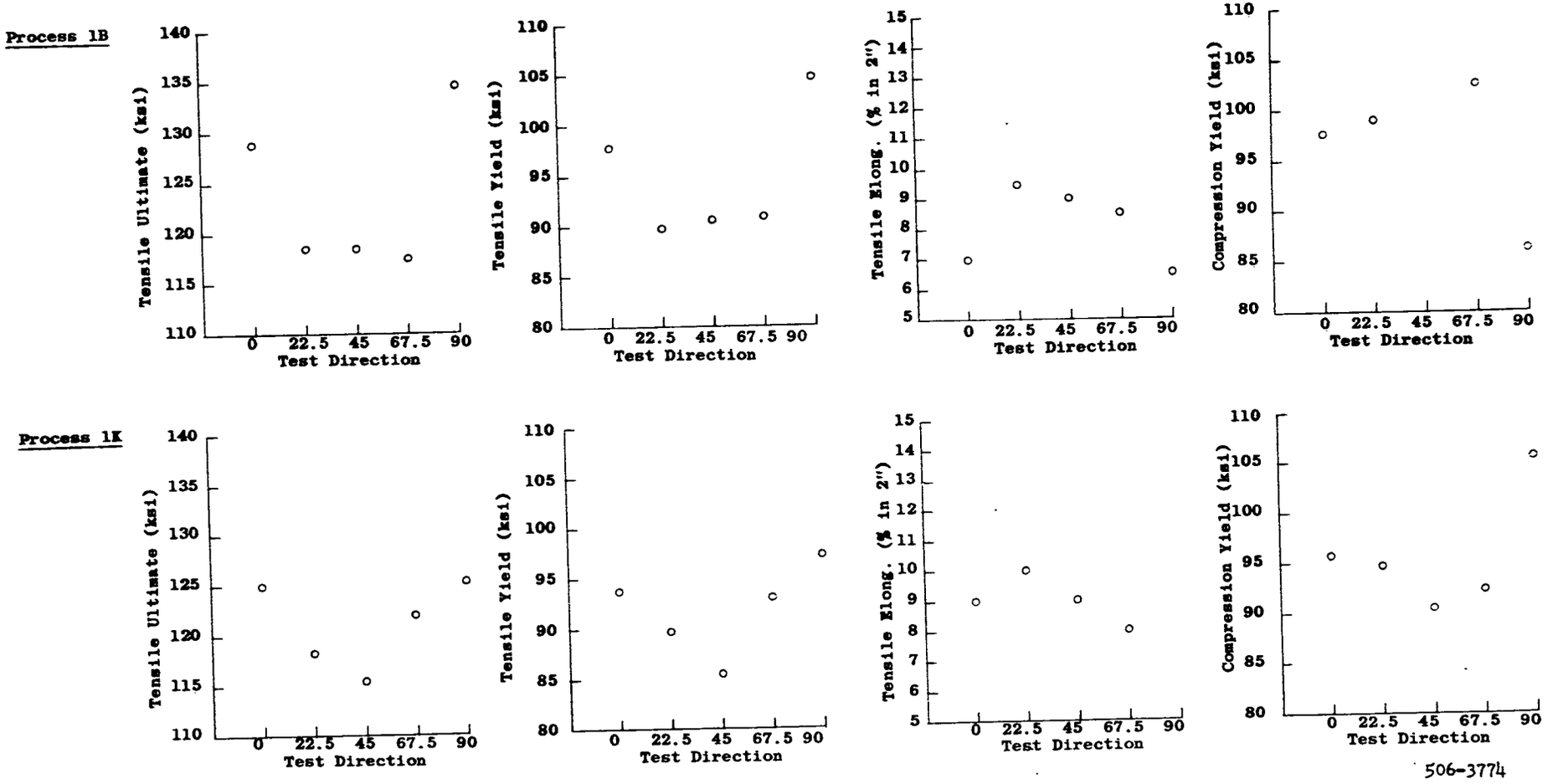
506-3773

Figure 19 Test Results on Solution Treated and Aged .040" Thick Ti-6Al-4V Sheet at 800F - Processes 1B and 1K

Tests - Tension
Compression

Solution Treatment - 1700F, 20', WQ
Age - 1000F, 4 hours

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal



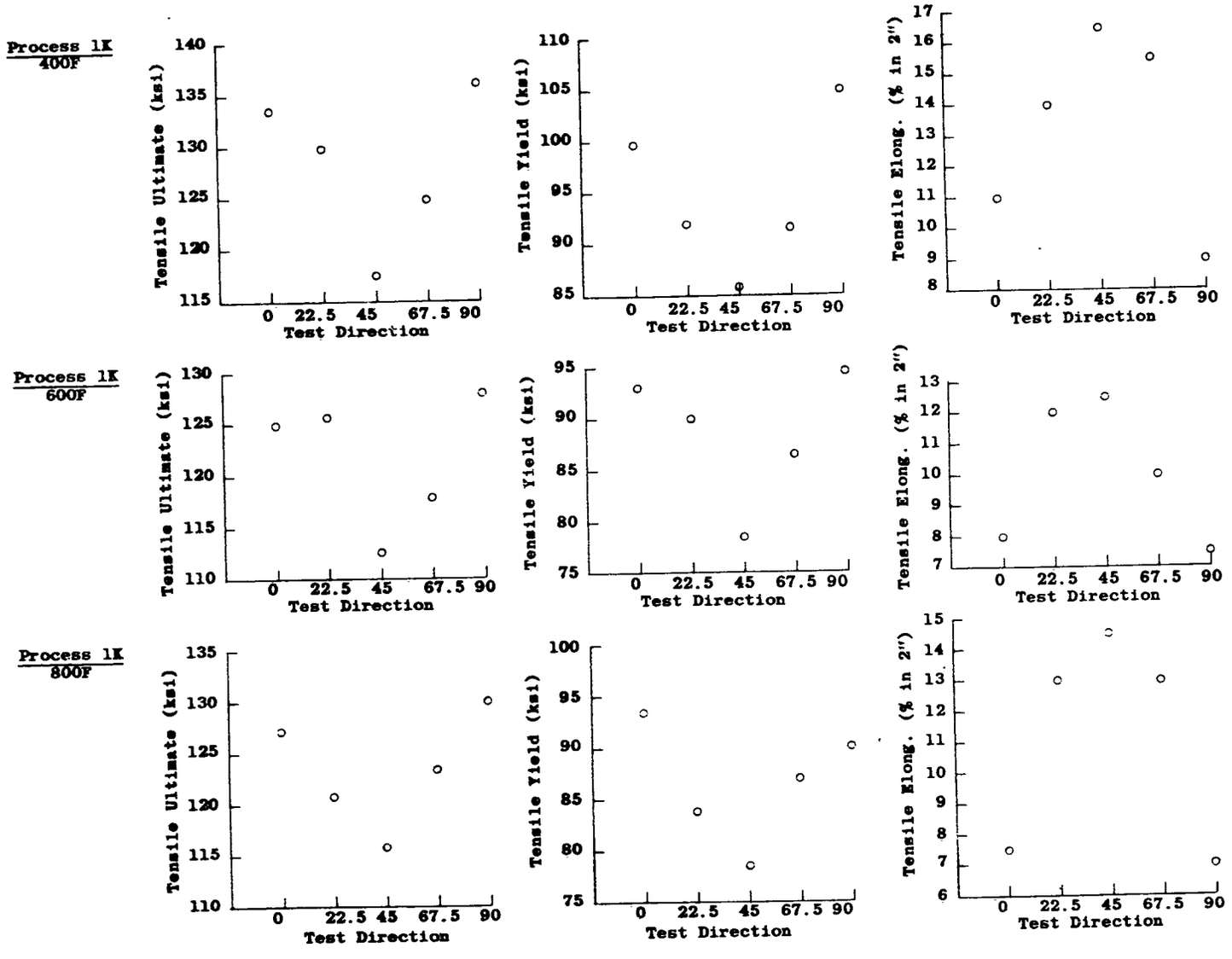
506-3774

Figure 20. Test Results on Solution Treated .040" Thick Ti-6Al-4V Sheet at 400F, 600F, and 800F - Process 1K

Tests - Tension

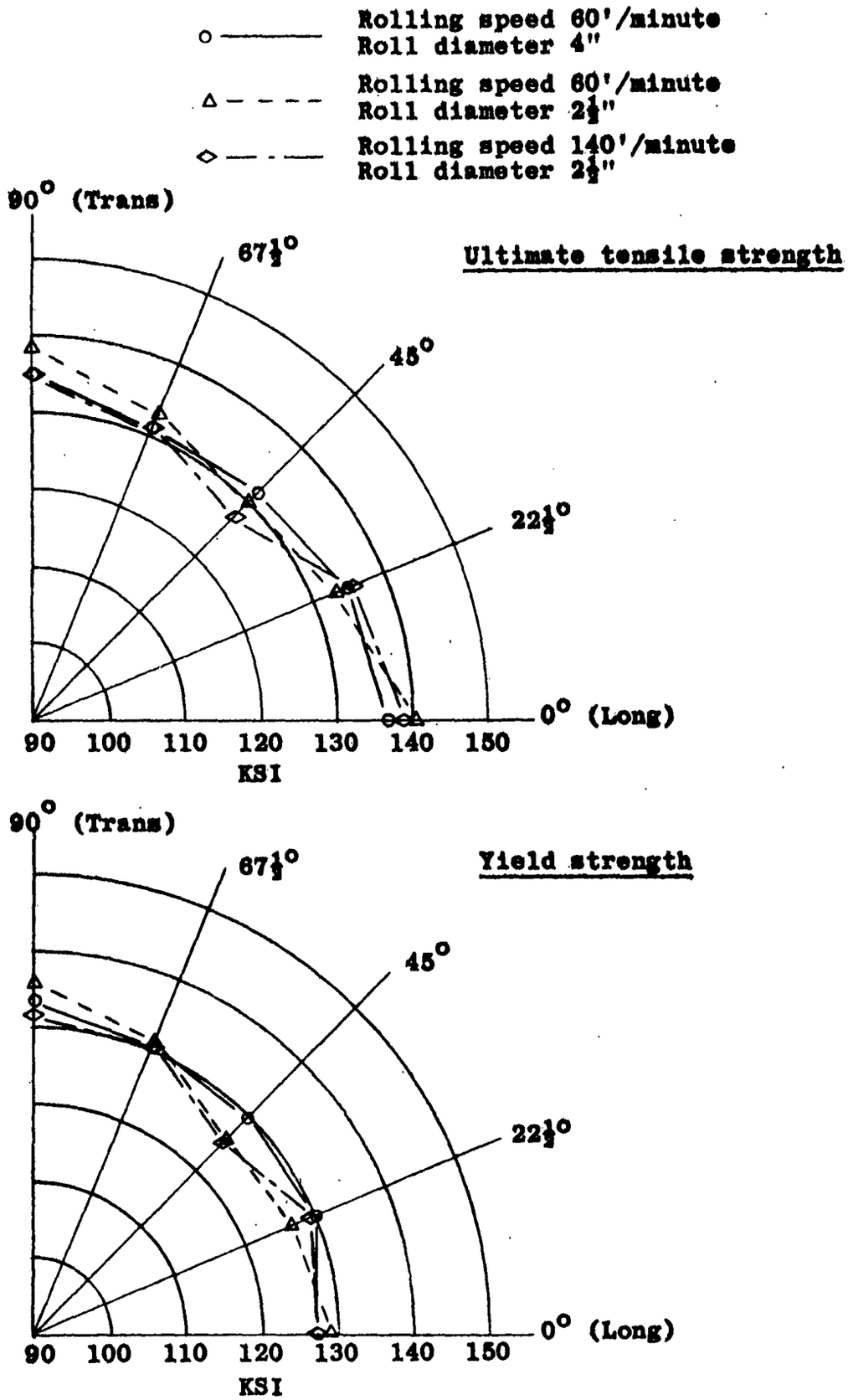
Solution Treatment - 1700F, 20', WQ

Test directions - 0° from longitudinal
22.5° from longitudinal
45° from longitudinal
67.5° from longitudinal
90° from longitudinal



506-3775

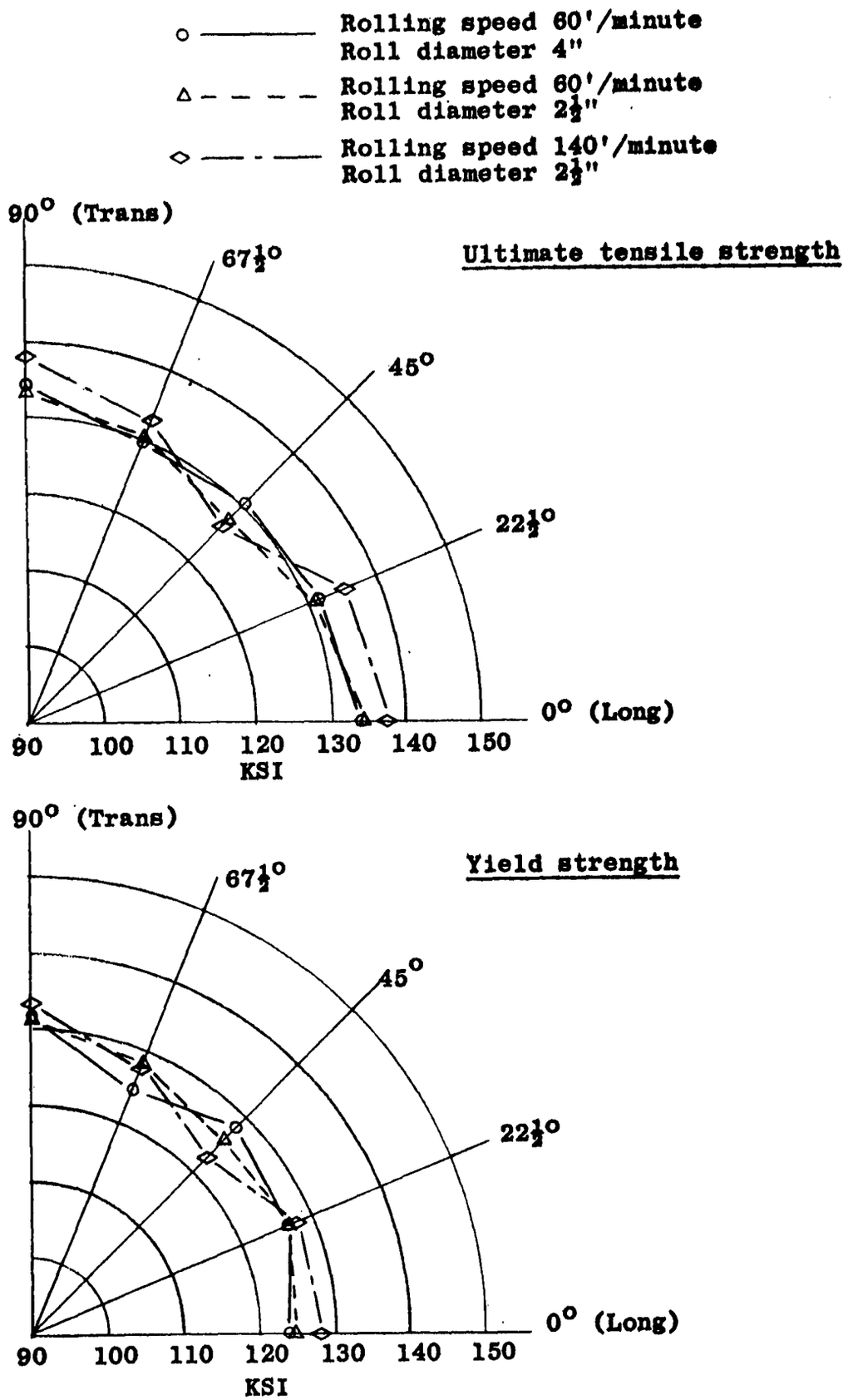
Figure 21. Process 1B - Effect of Rolling Speed and Roll Diameter on Ti-6Al-4V Strip Directionality*



* Averages of duplicate specimens. Specimens tested in the annealed condition (1550F, 5 hours, slow cooled).

506-3780

Figure 22. Process 1K - Effect of Rolling Speed and Roll Diameter on Ti-6Al-4V Strip Directionality*



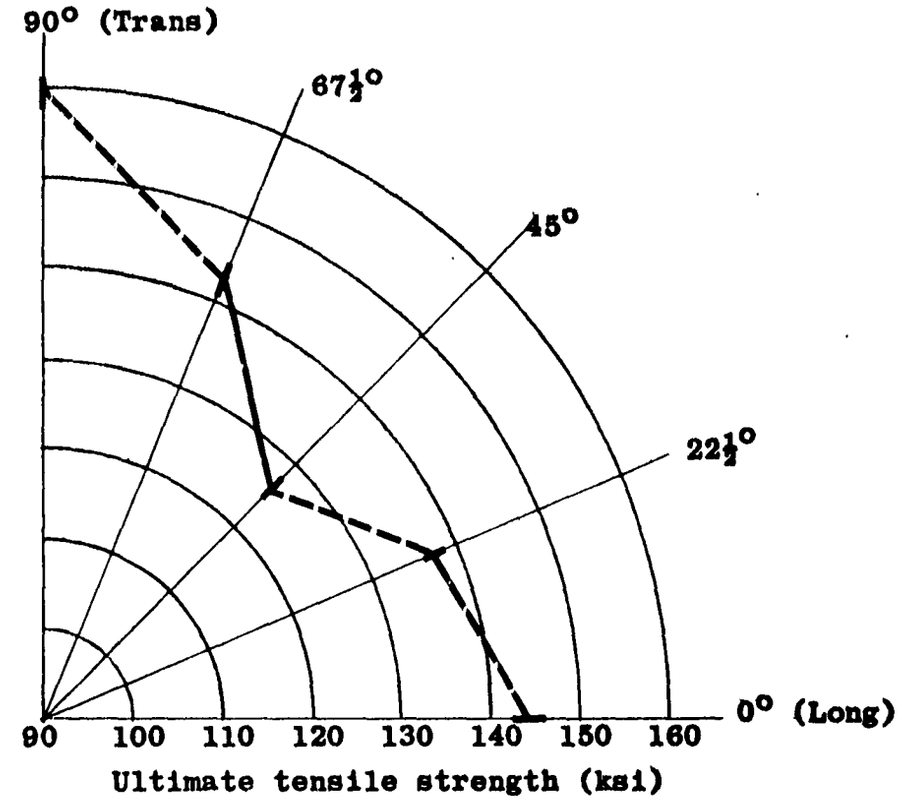
* Averages of duplicate specimens. Specimens tested in the annealed condition (1550F, 5 hours, slow cooled).

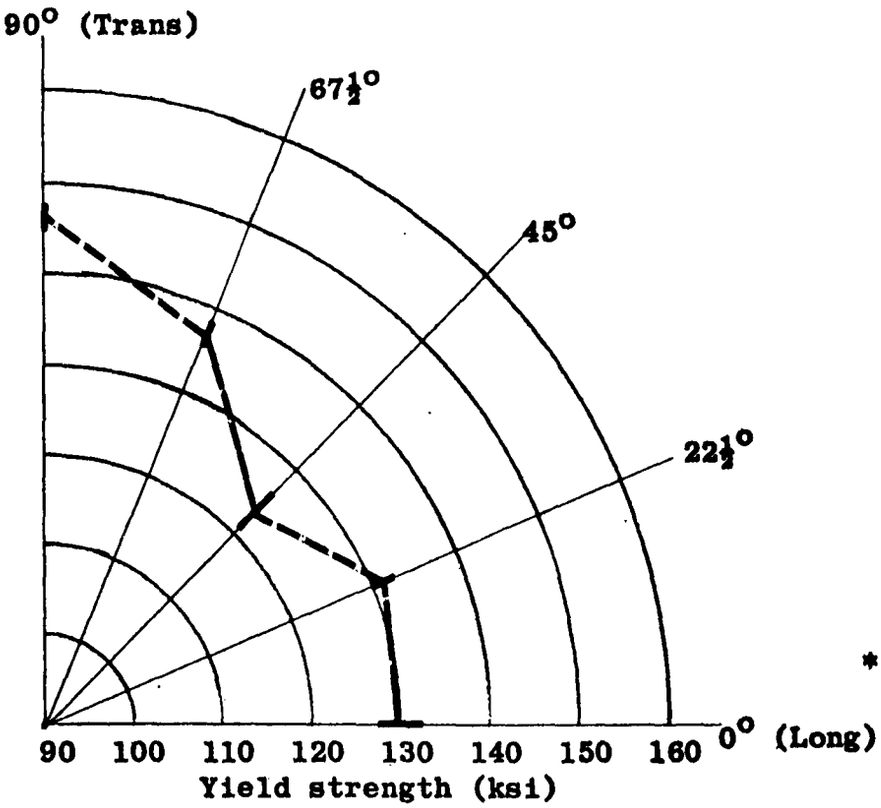
506-3781

Figure 23. Effect of Strip Tension on Ti-6Al-4V Strip Directionality*

Condition - Annealed 1550F, 5 hours, slow cooled.

Range for test values for four combinations of strip tension

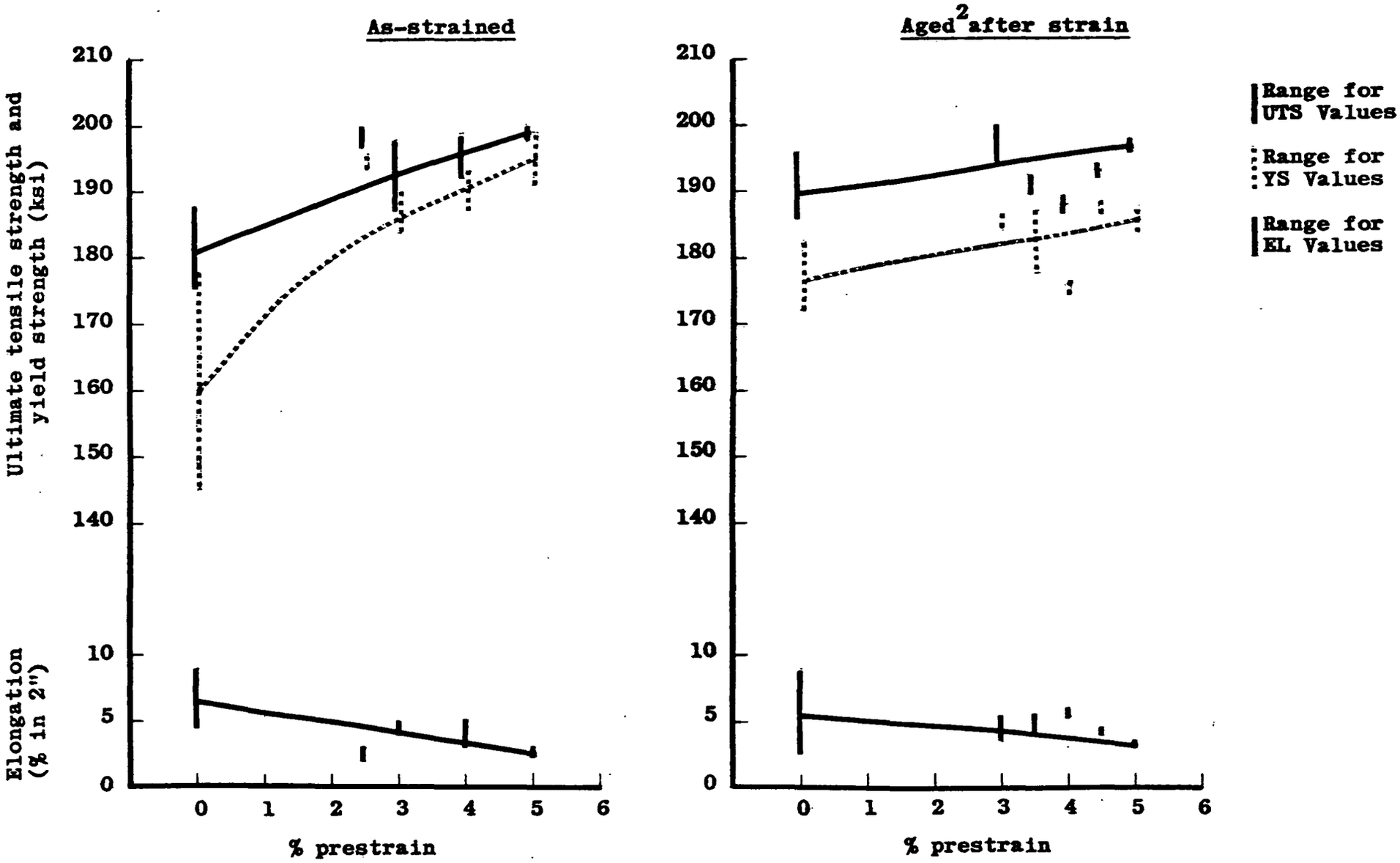




* Averages of duplicate specimens

506-3782

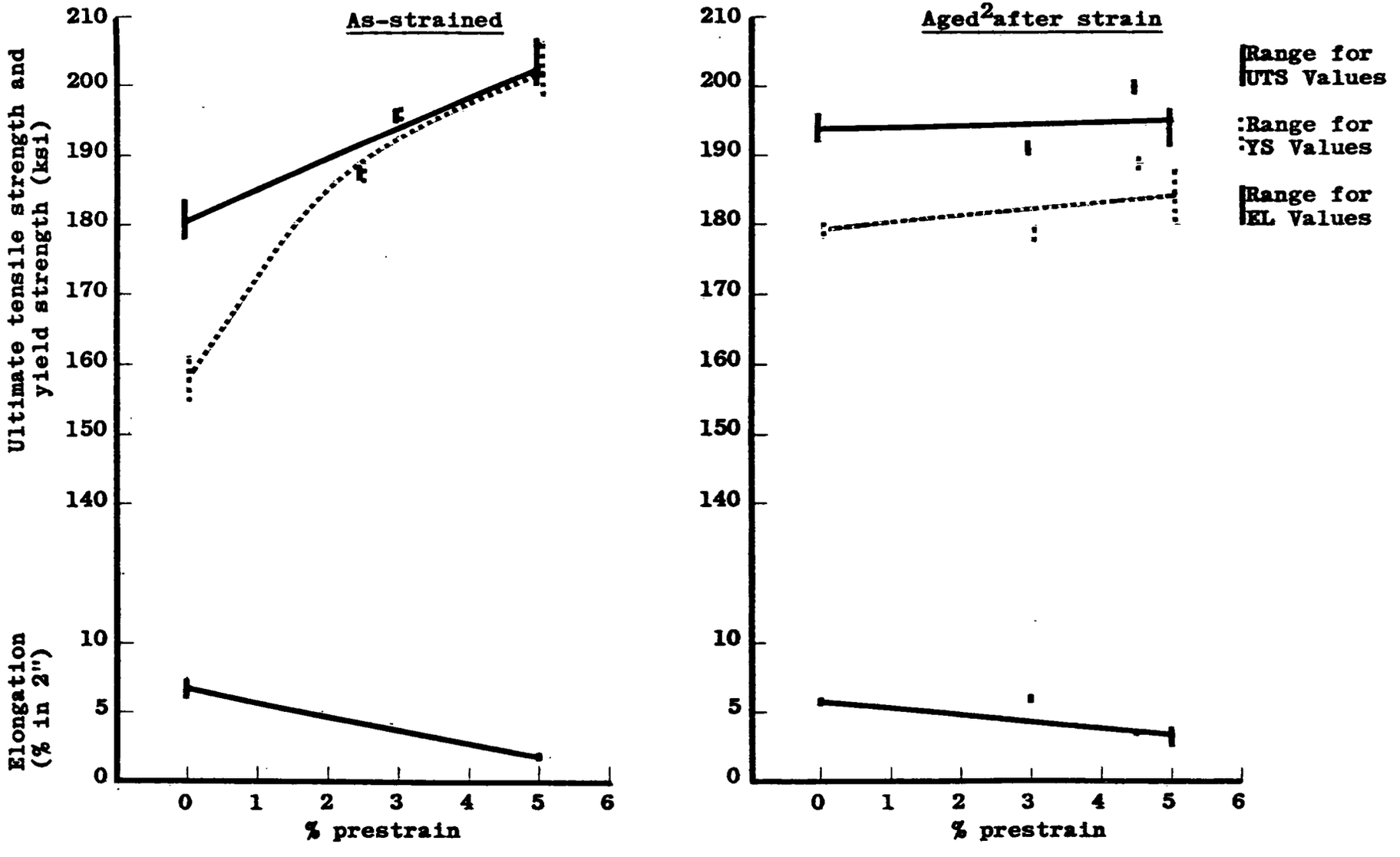
Figure 24 Process $1B_1$ - Effect of Room Temperature Prestrain on Room Temperature Tensile Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.



1 - Five test directions. See table XXI for individual test values.
2 - Four hours at 1000F.

506-3783

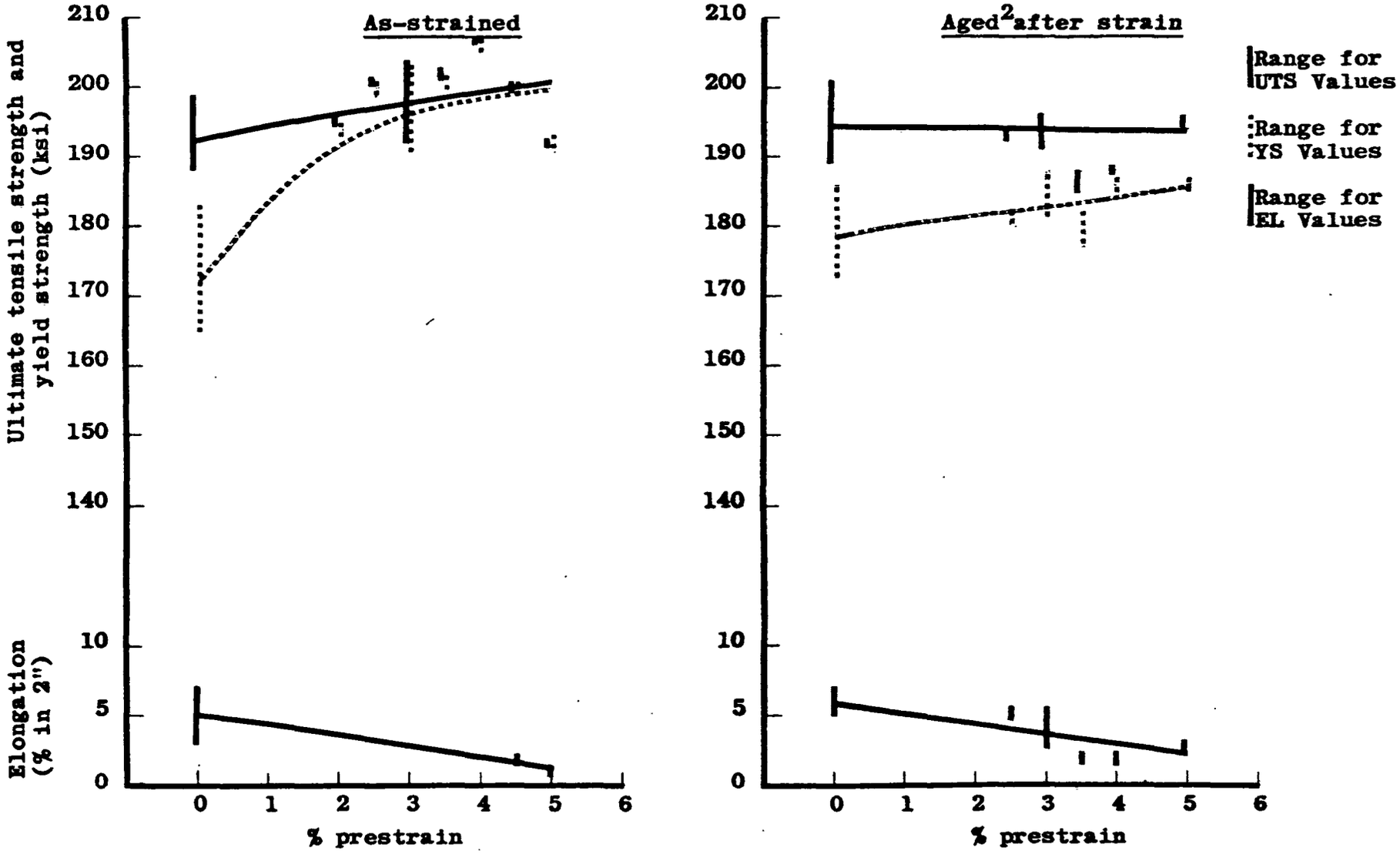
Figure 25. Process 1B - Effect of Prestrain at 400F on Room Temperature Tensile Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.



1 - Five test directions. See table XXI for individual test values.
2 - Four hours at 1000F.

506-3784

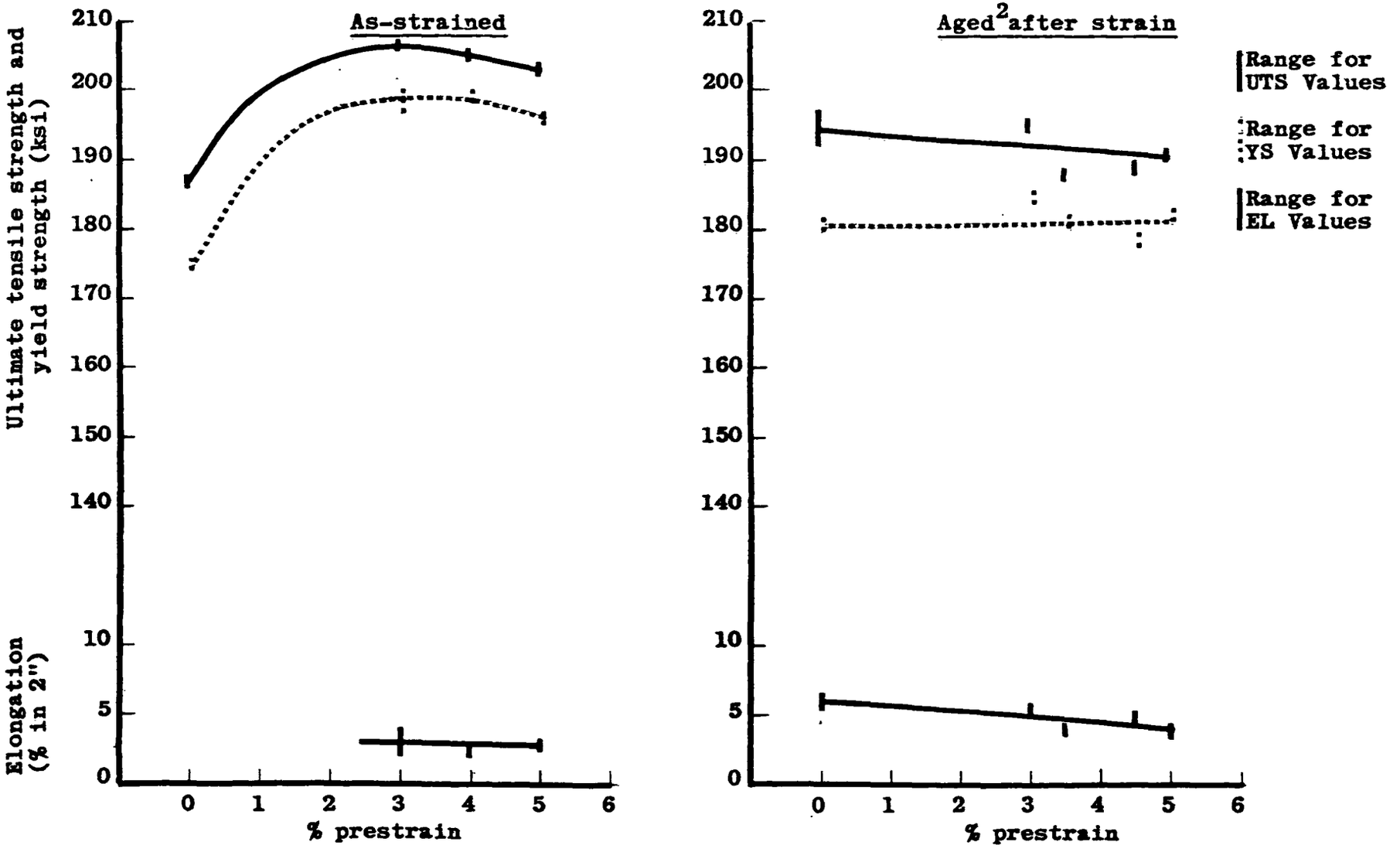
Figure 26. Process 1B - Effect of Prestrain at 700F on Room Temperature Tensile Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.



1 - Five test directions. See table XXI for individual test values.
2 - Four hours at 1000F.

506-3785

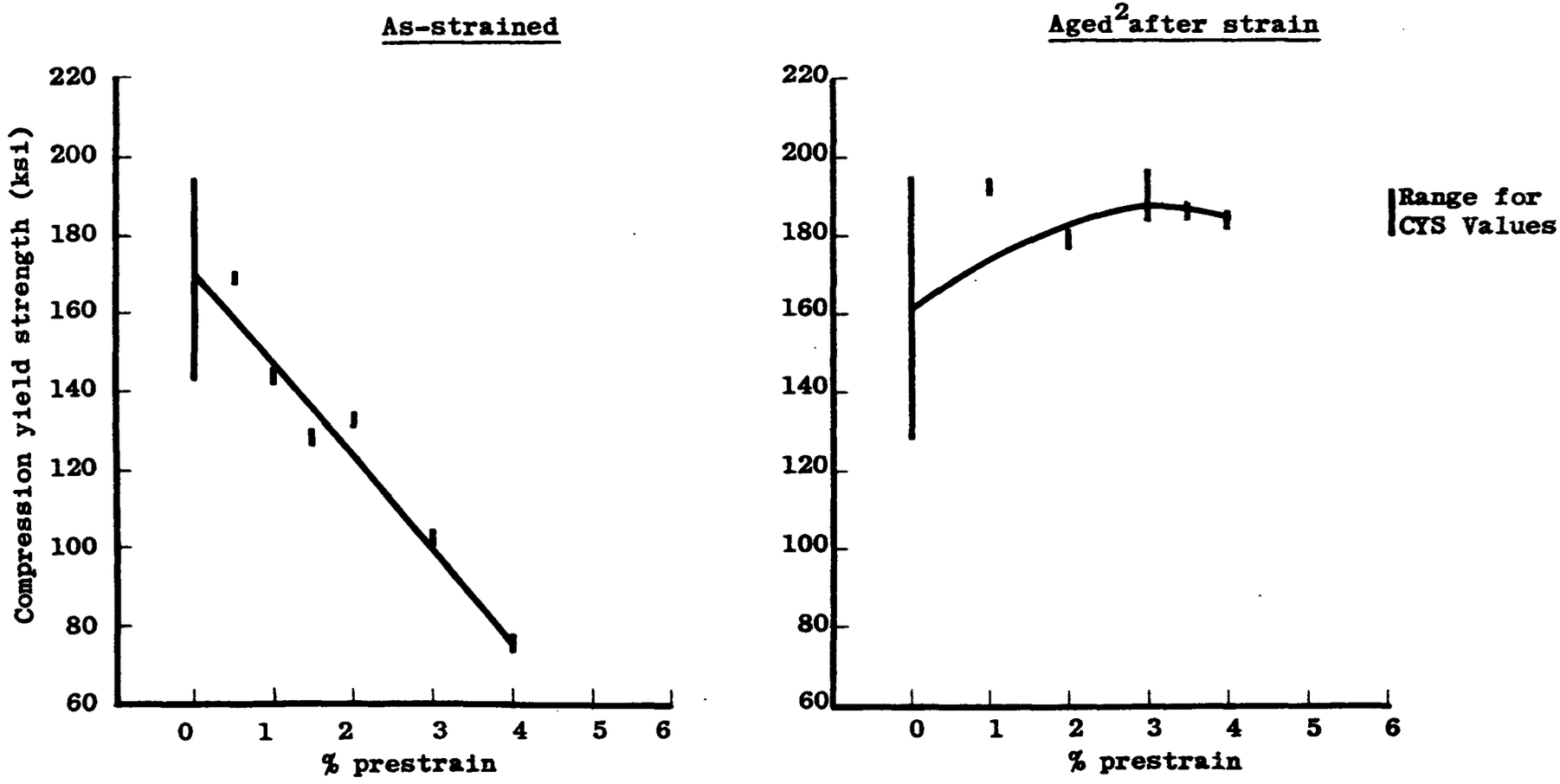
Figure 27. Process 1B - Effect of Prestrain at 1000F on Room Temperature Tensile Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.



1 - Five test directions. See table XXI for individual test values.
2 - Four hours at 1000F.

506-3786

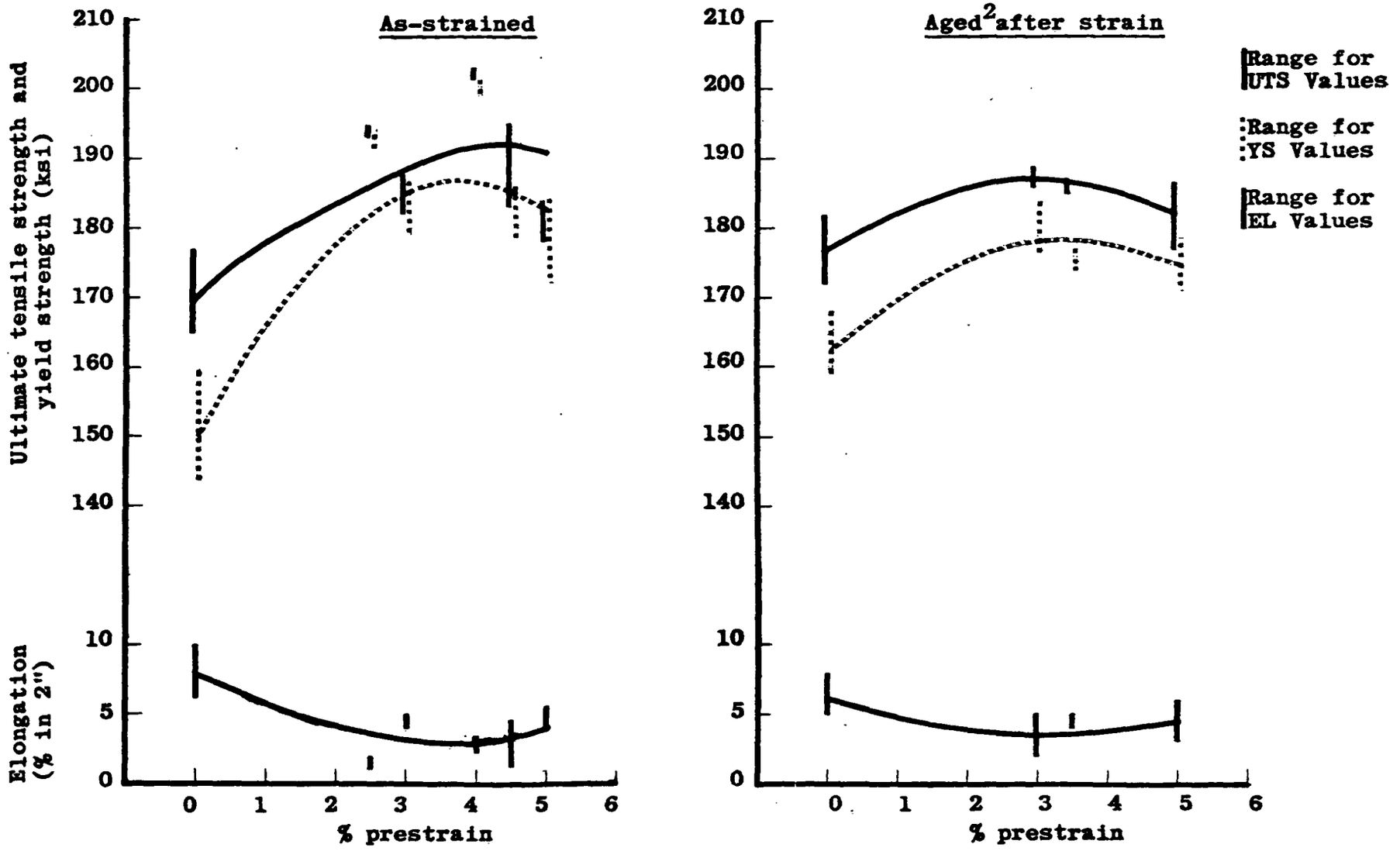
Figure 28. Process 1B - Effect of Room Temperature Prestrain on Room Temperature Compression Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.



1 - Five test directions. See table XXI for individual test values.
2 - Four hours at 1000F.

506-3787

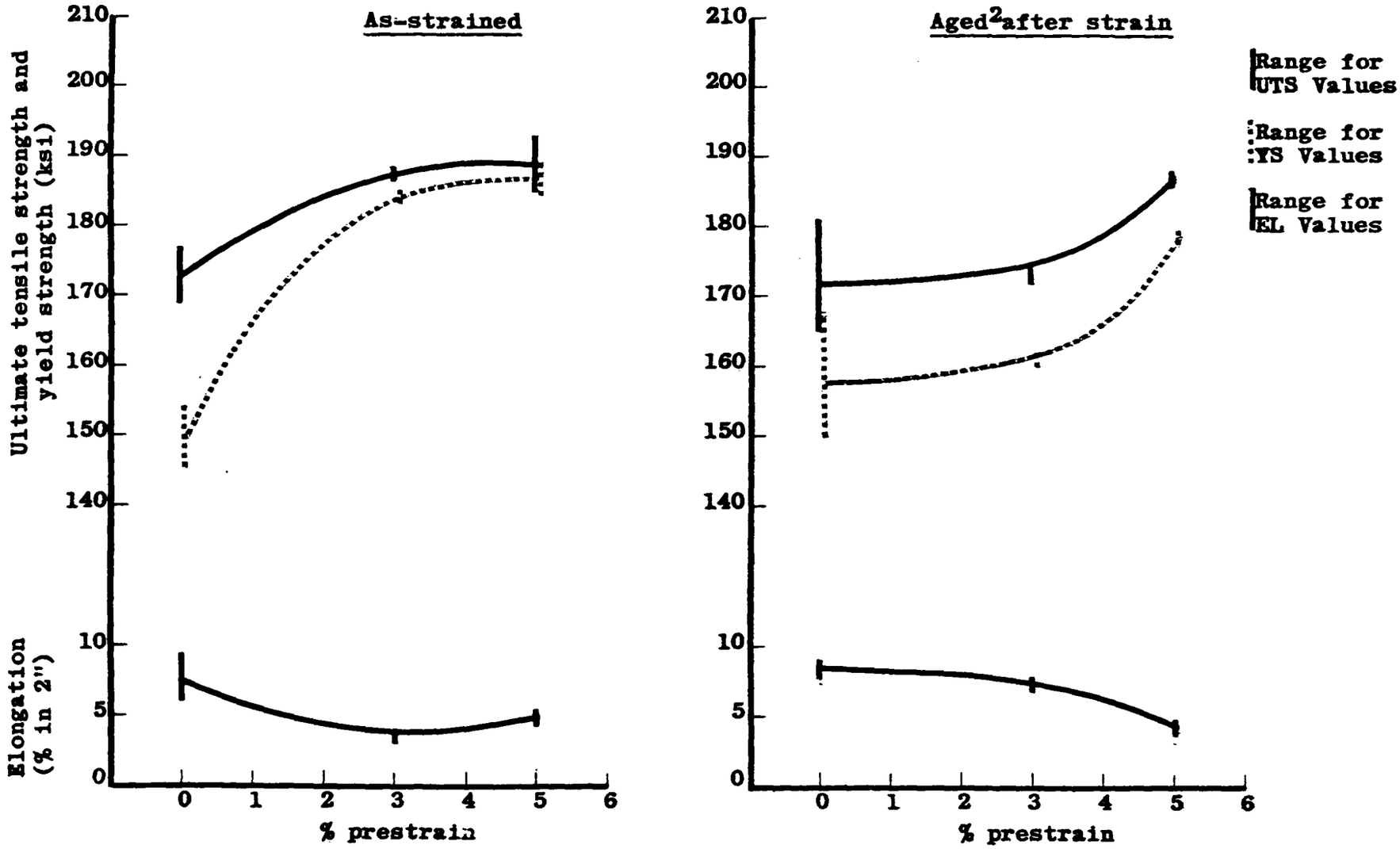
Figure 29. Process 1K - Effect of Room Temperature Prestrain on Room Temperature Tensile Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.



1 - Five test directions. See table XXII for individual test values.
2 - Four hours at 1000F.

506-3788

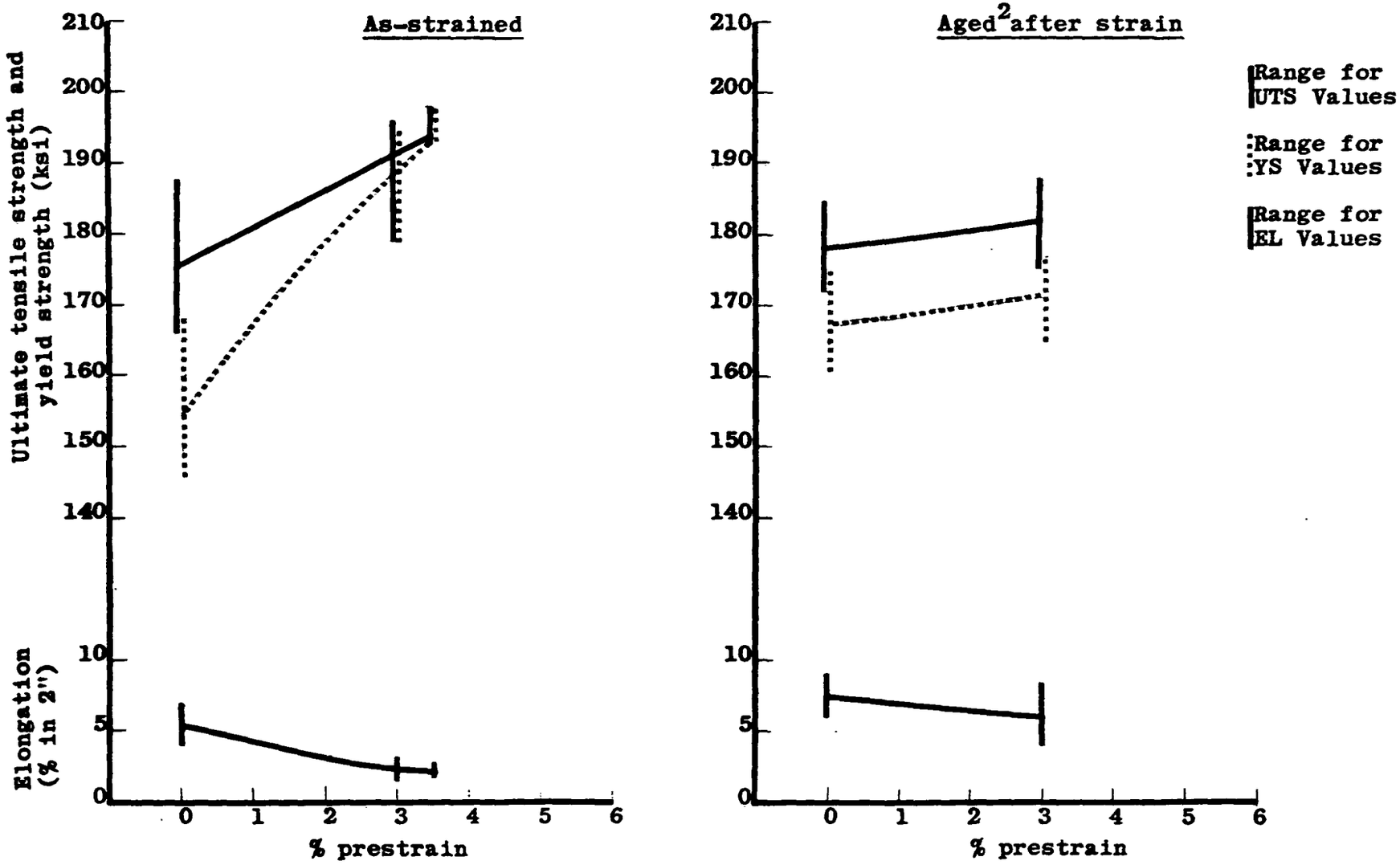
Figure 30. Process 1K - Effect of Prestrain at 400F on Room Temperature Tensile Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.



1 - Five test directions. See table XXII for individual test values.
2 - Four hours at 1000F.

506-3789

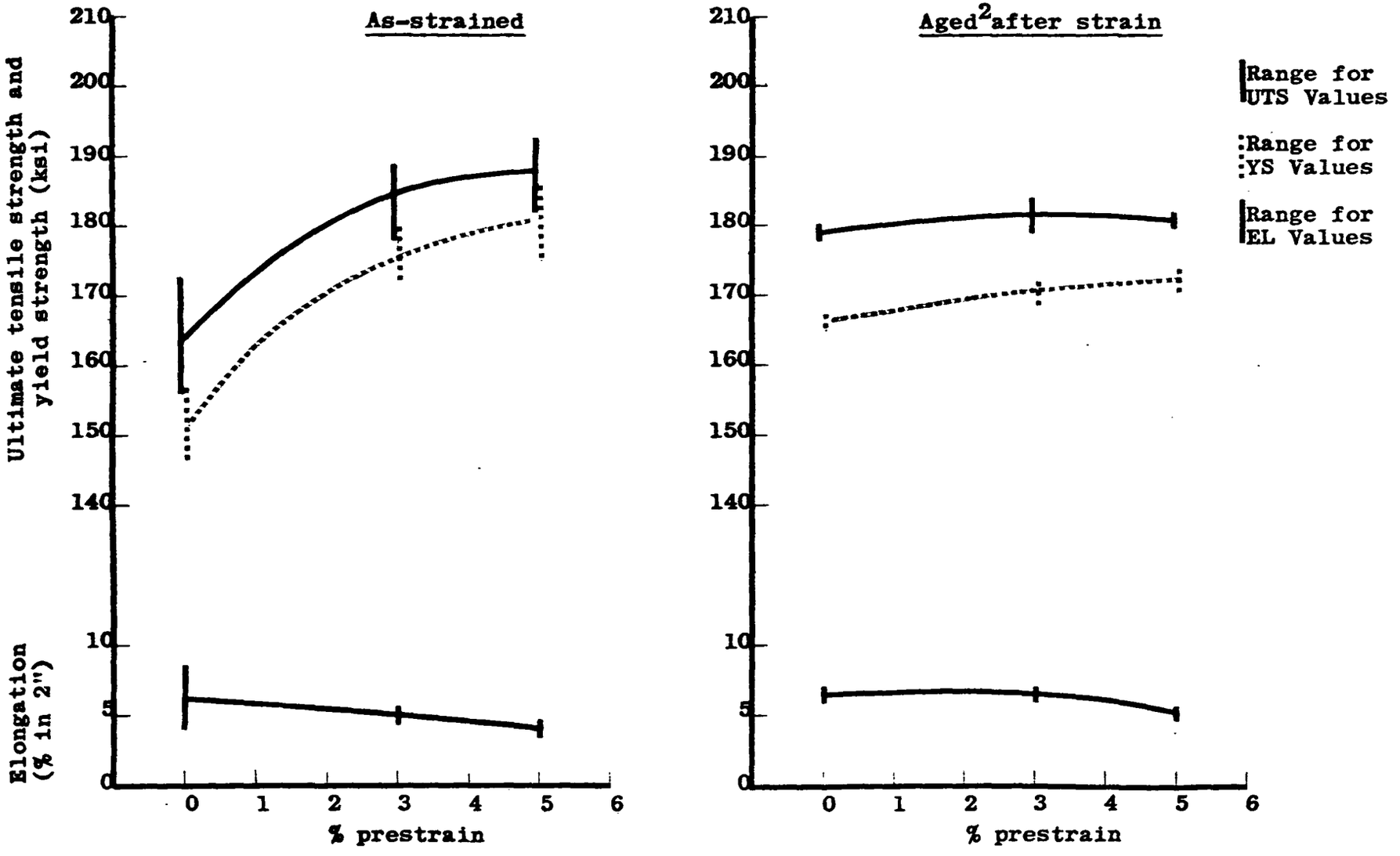
Figure 31. Process 1K - Effect of Prestrain at 700F on Room Temperature Tensile Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.



1 - Five test directions. See table XXII for individual test values.
2 - Four hours at 1000F.

506-3790

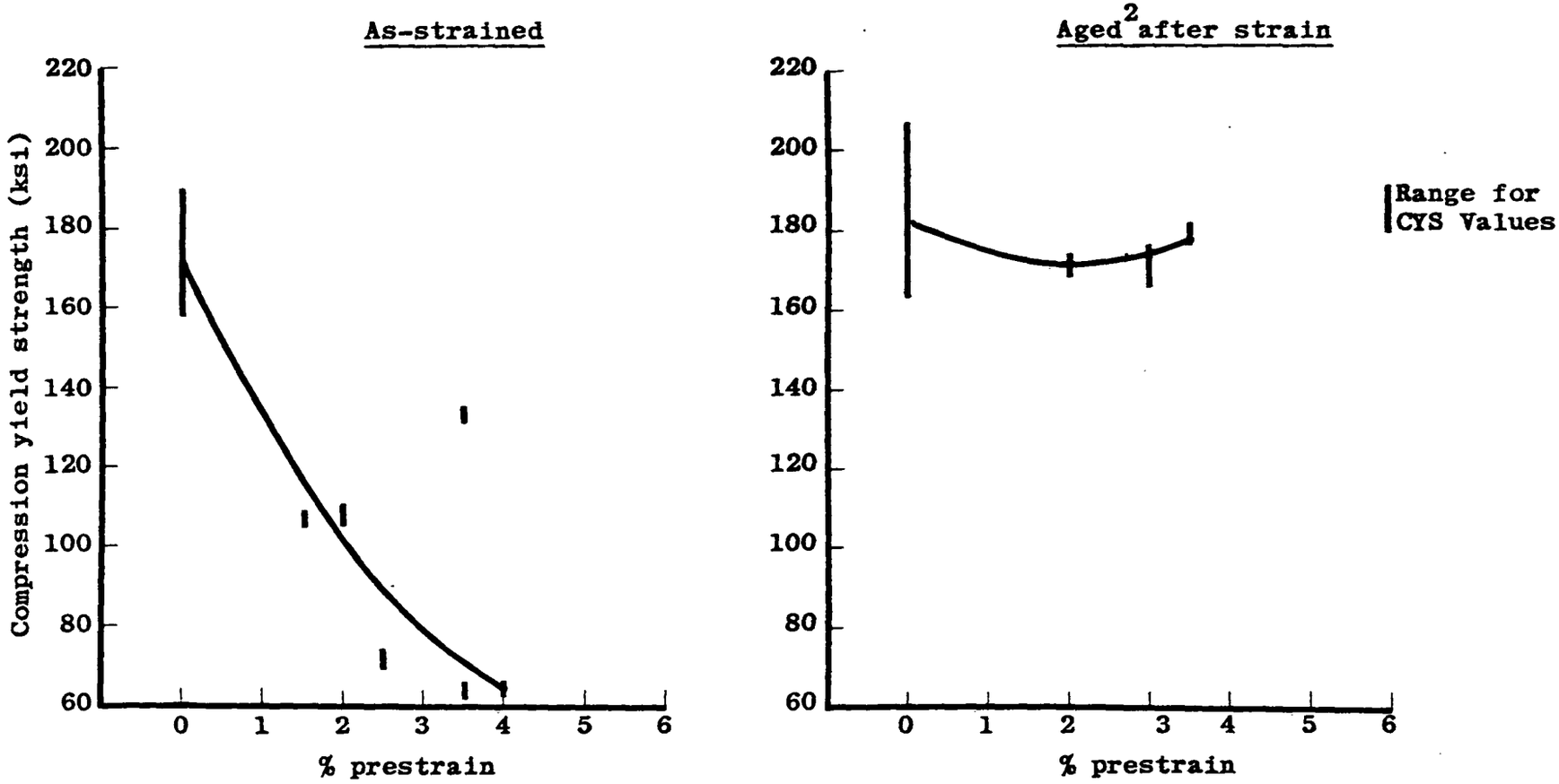
Figure 32. Process 1K - Effect of Prestrain at 1000F on Room Temperature Tensile Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.



1 - Five test directions. See table XXII for individual test values.
2 - Four hours at 1000F.

506-3791

Figure 33. Process 1K - Effect of Room Temperature Prestrain on Room Temperature Compression Properties[1] of Ti-6Al-4V Strip Solution Treated 20 Minutes at 1700F and Water Quenched.

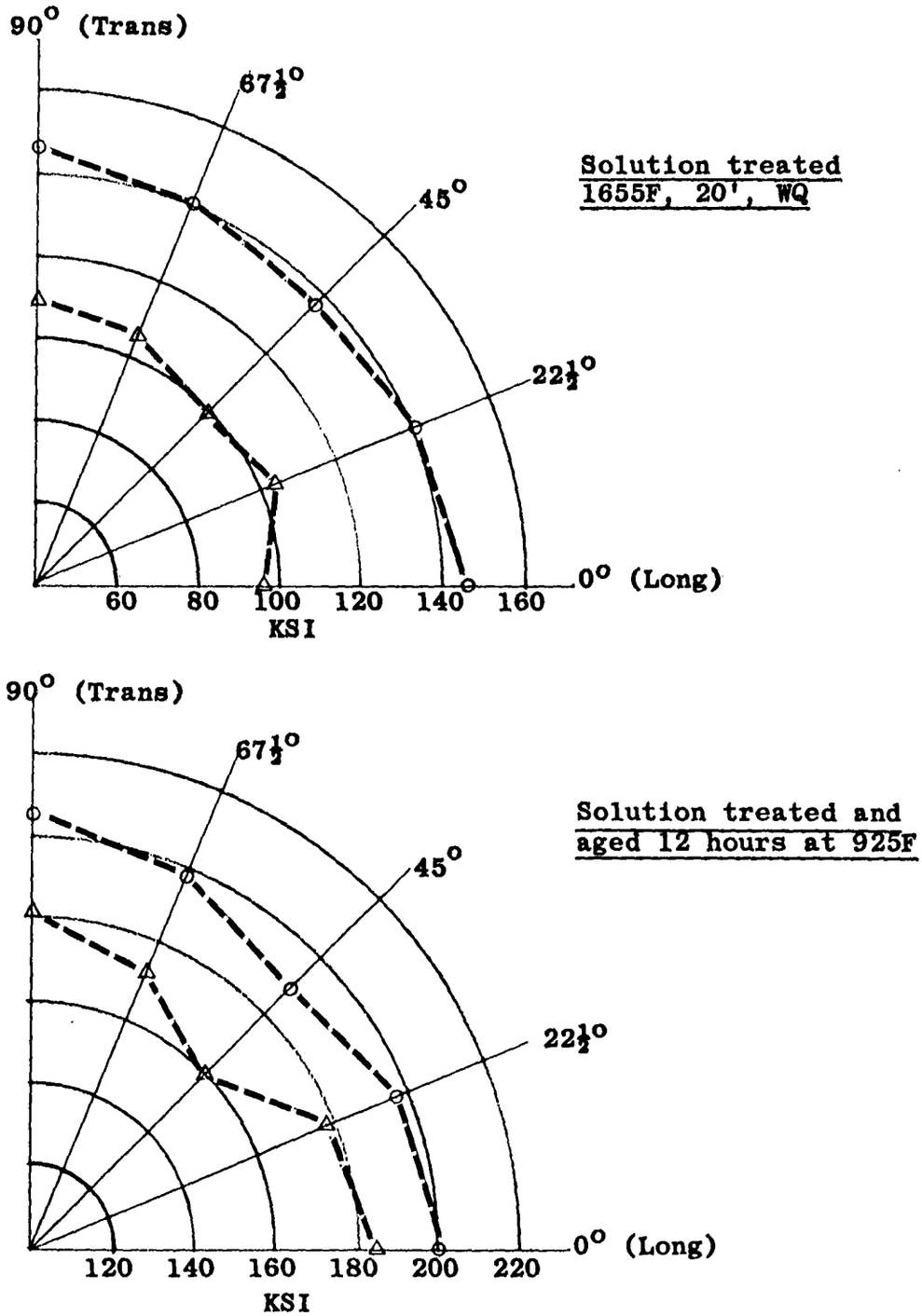


1 - Five test directions. See table XXII for individual test values.
2 - Four hours at 1000F.

506-3792

Figure 34 Mechanical Properties of .040" Ti-4Al-3Mo-1V Strip Finished with a 50% Cold Reduction (Heat R6749)

○ Ultimate tensile strength
△ Yield strength

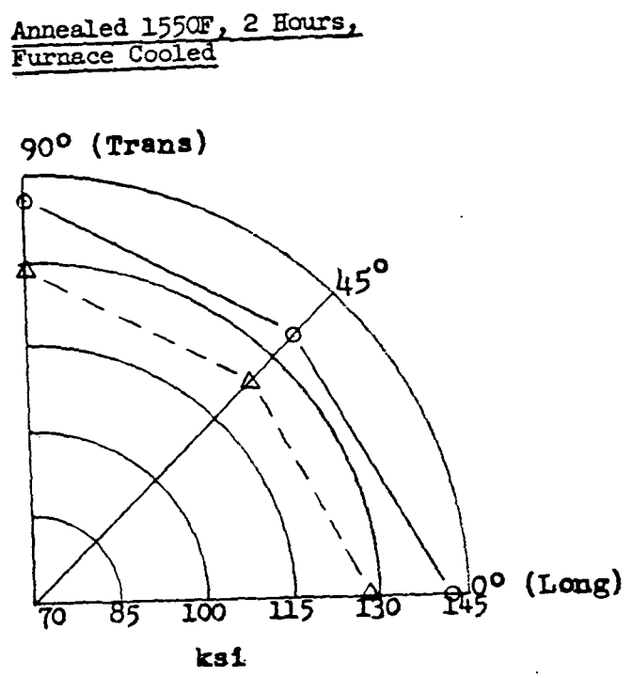


1 - Averages of duplicate specimens.

506-3793

Figure 35 Mechanical Properties[1] of Mill Processed 0.800" Thick Ti-6Al-4V Sheet Bar (Heats R8918 and R8840)

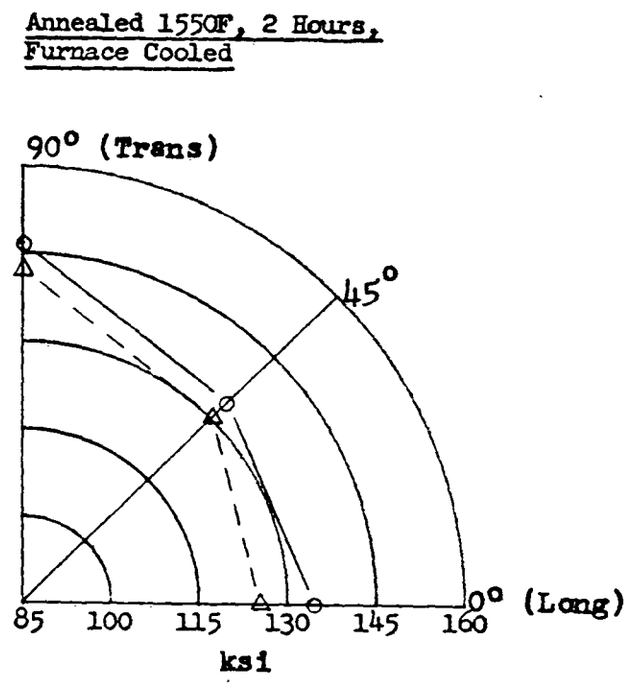
○ ——— Ultimate Tensile Strength
△ — — — 0.2% Offset Yield Strength



1 - Each point is an average of eight test values - duplicate specimens from two test locations from each of two heats (see Table XXX)

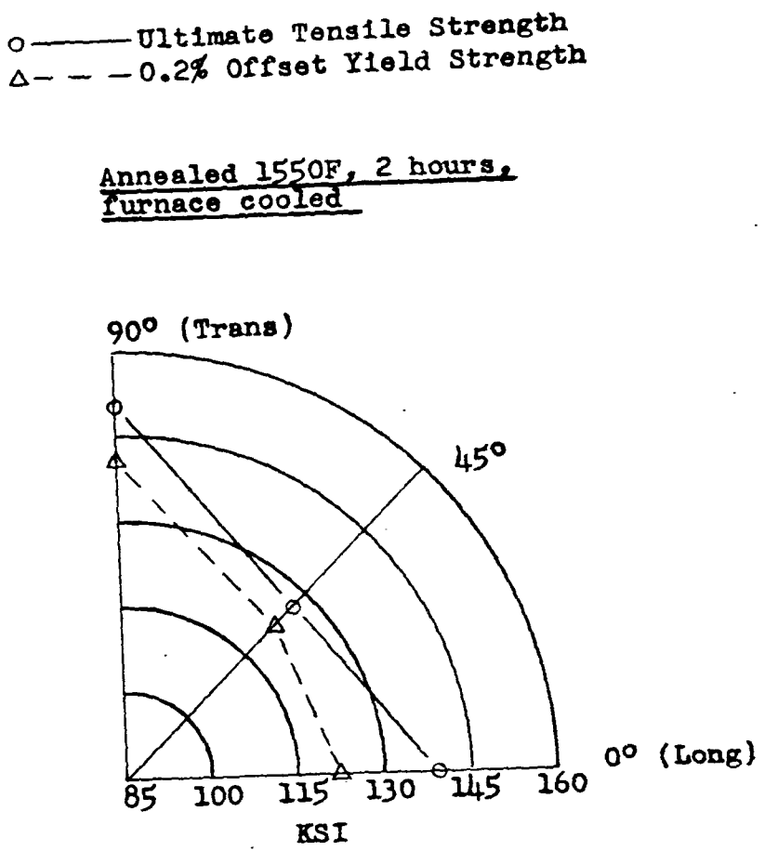
Figure 36 Mechanical Properties[1] of Mill Processed 0.150" Thick Ti-6Al-4V Hot Band (Heat R8840)

o——— Ultimate Tensile Strength
Δ— — —0.2% Offset Yield Strength



1 - Each point is an average of two tensile test values (see Table XXXI)

Figure 37 Mechanical Properties[1] of Mill Processed Ti-6Al-4V Strip (Heat R8918) After Its First Cold Reduction to 0.131" Thick

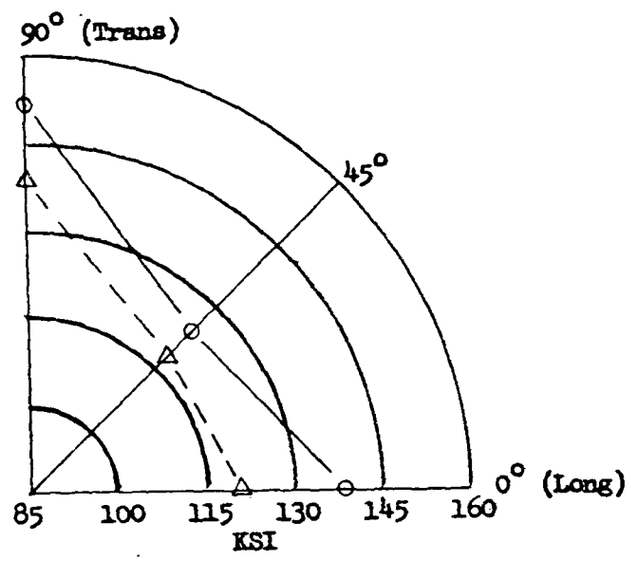


- Each point is an average of two test values (see Table XXXII)

Figure 38 Mechanical Properties[1] of Mill Processed Ti-6Al-4V Strip (Heat R8918) After Its Second Cold Reduction to 0.097" Thick

○ ——— Ultimate Tensile Strength
△ — — — 0.2% Offset Yield Strength

Annealed 1550F, 2 Hours, Furnace Cooled



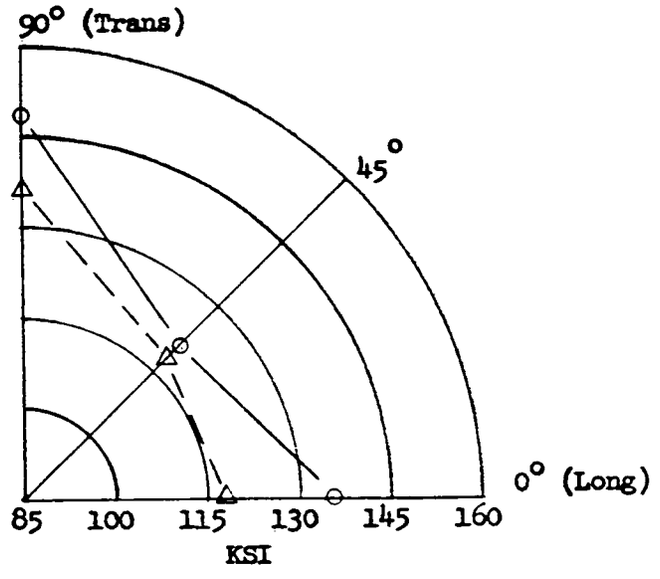
1 - Each point is an average of two test values (see Table XXXIII)

Figure 39 Mechanical Properties[1] of Mill Processed Ti-6Al-4V Strip (Heat 8918) After Its Third Cold Reduction to 0.077" Thick

○ ——— Ultimate Tensile Strength

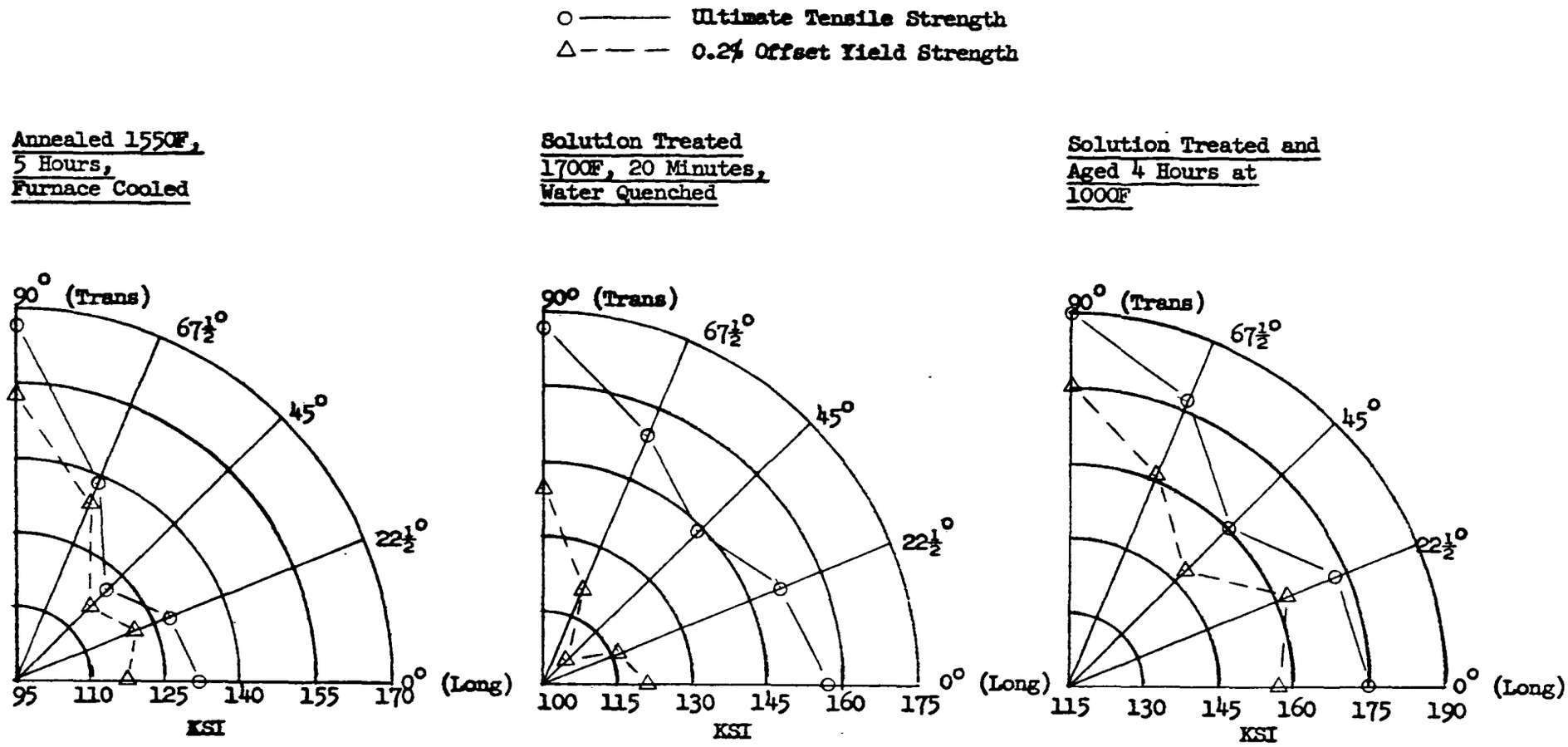
△— — — 0.2% Offset Yield Strength

Annealed 1550F, 2 Hours, Furnace Cooled



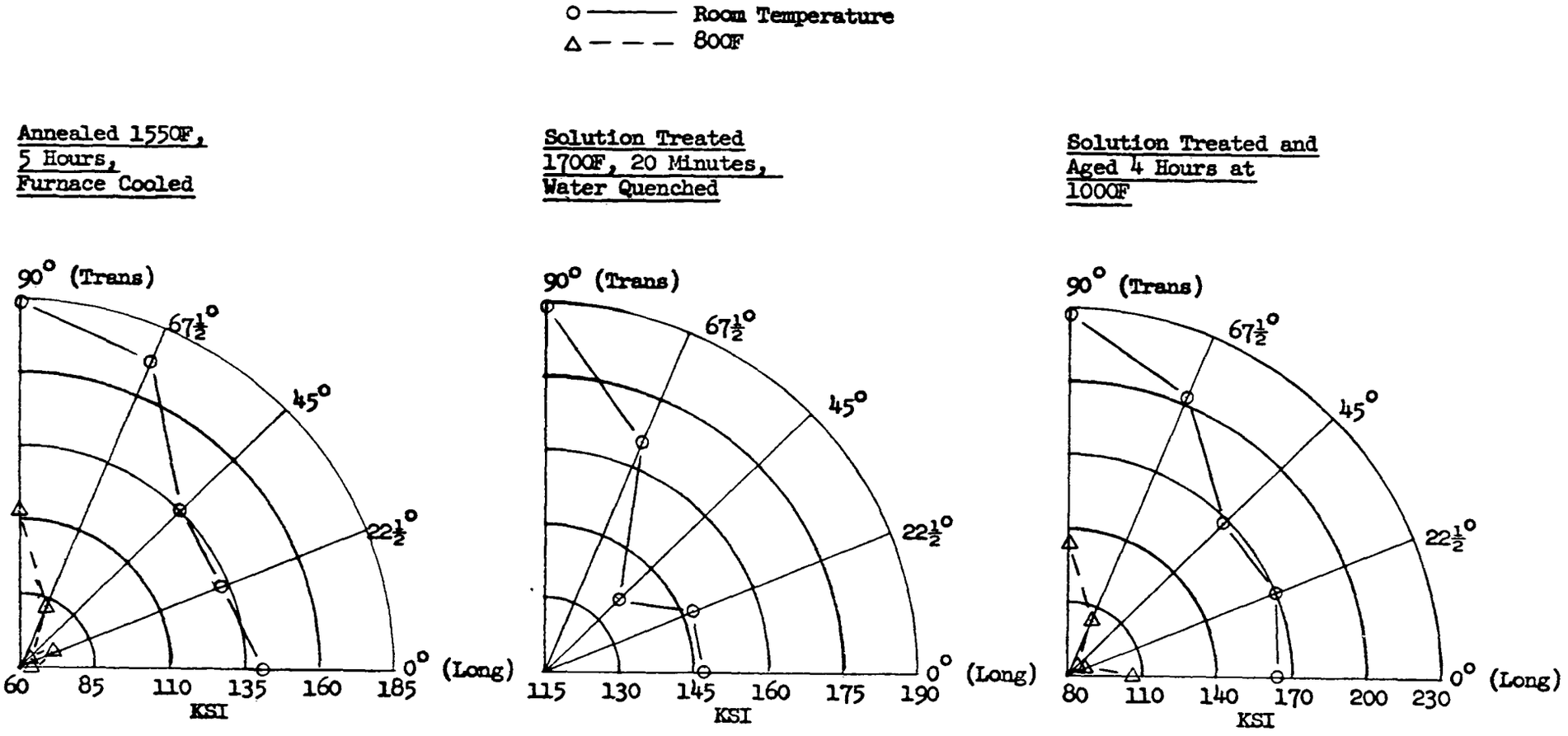
1 - Each point is an average of two test values (see Table XXXIV)

Figure 40 Mechanical Properties[1] of Mill Processed Ti-6Al-4V Strip (Heat R8918) After Its Fourth Cold Reduction to 0.051" Thick



1 - Each point is an average of two test values (see Table XXXV)

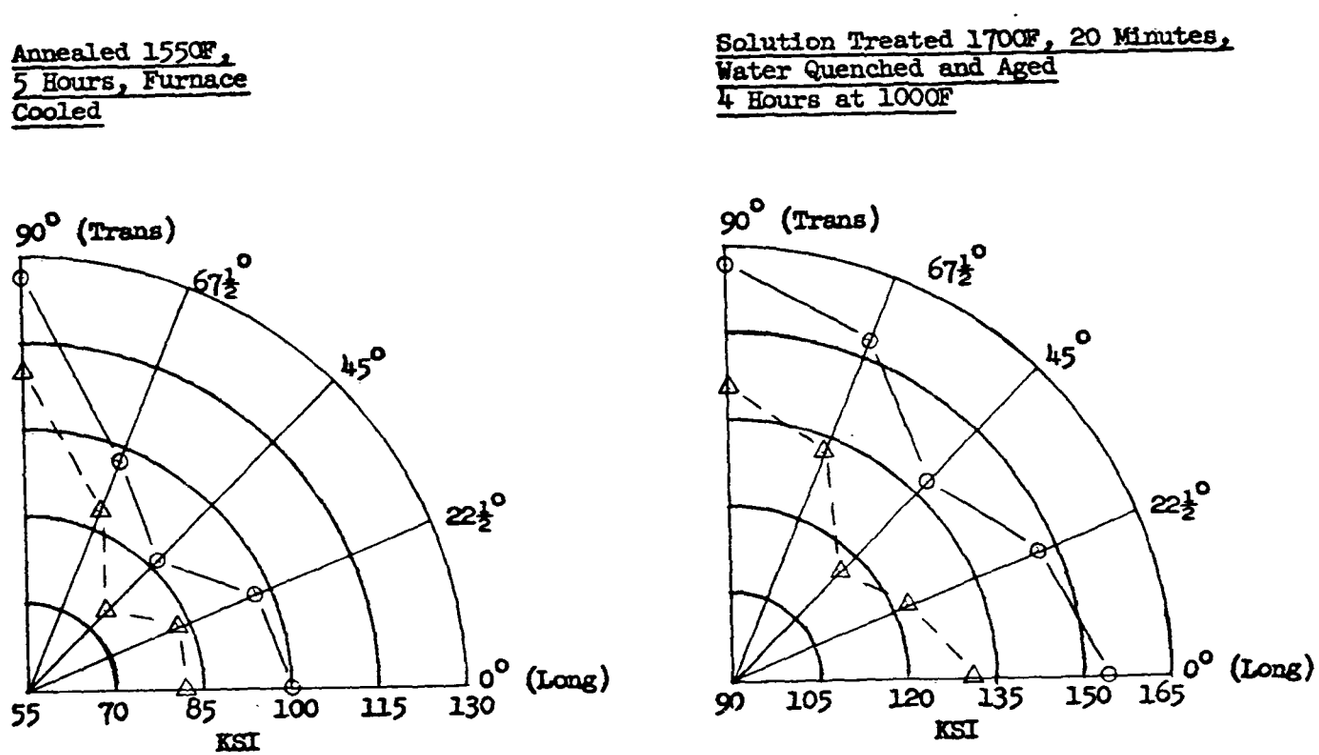
Figure 41 Compression Yield Strength[1] (0.2% Offset) of Mill Processed Ti-6Al-4V Strip (Heat R8918) After Its Fourth Cold Reduction to 0.051" Thick



1 - Each point is an average of two test values (see Table XXXVI)

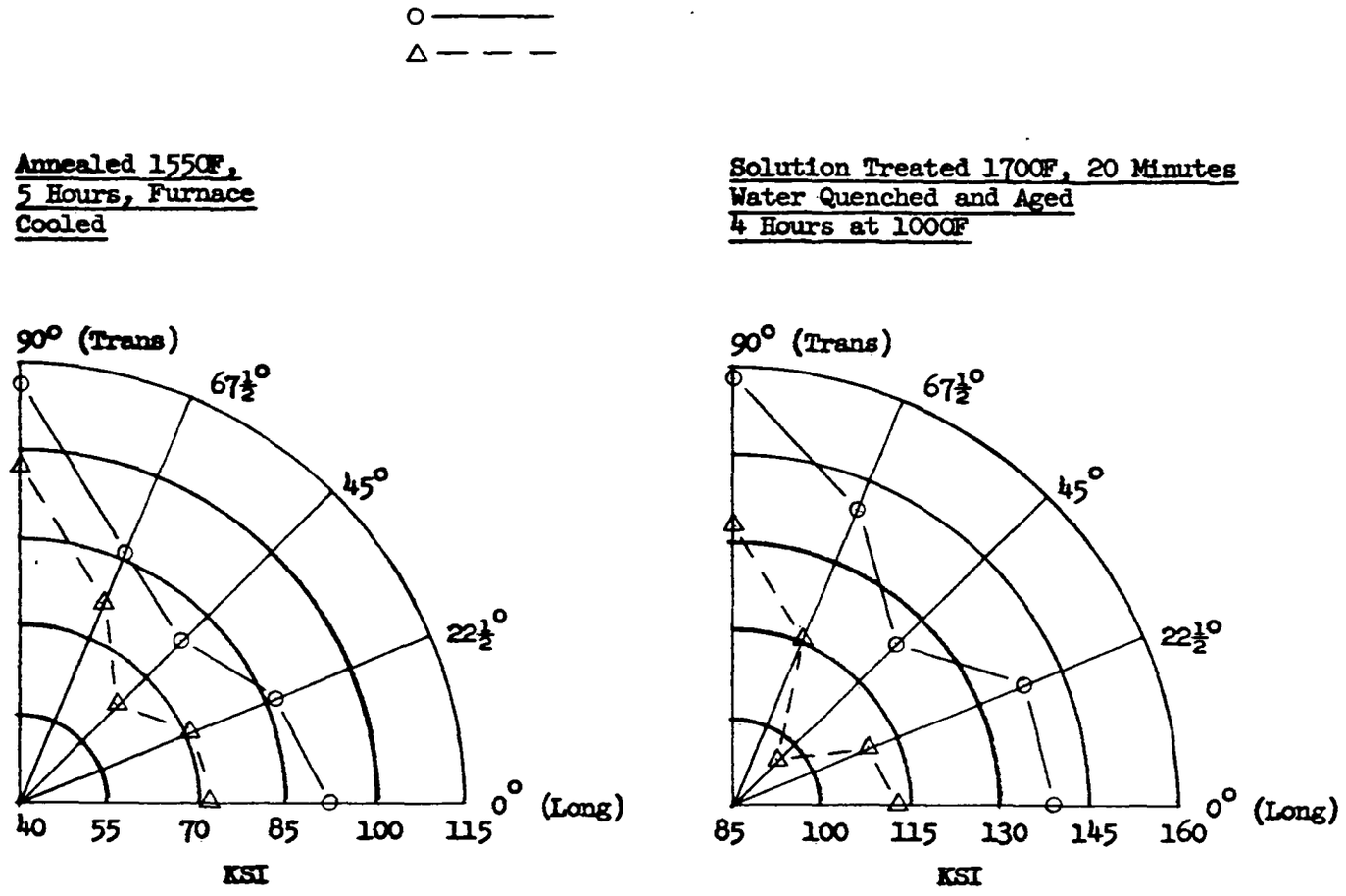
Figure 42 400F Tensile Properties[1] of Mill Processed Ti-6Al-4V Strip (Heat R8918) After Its Fourth Cold Reduction to 0.051" Thick

○ ——— Ultimate Tensile Strength
△ — — — 0.2% Offset Yield Strength



1 - Each point is an average of two test values (see Table XXXVII)

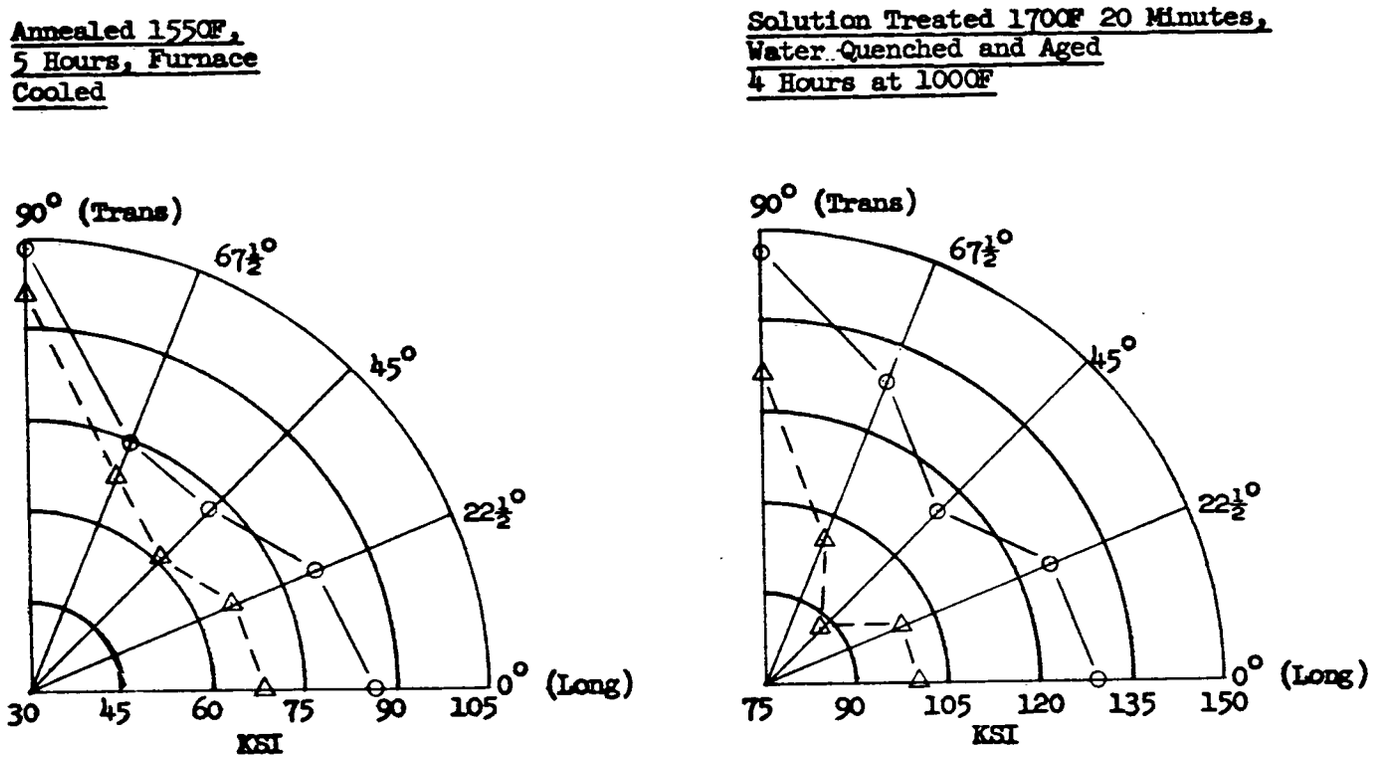
Figure 43 600F Tensile Properties[1] of Mill Processed Ti-6Al-4V Strip (Heat R8918) After Its Fourth Cold Reduction to 0.051" Thick



1 - Each point is an average of two test values (see Table XXXVII)

Figure 44 800F Tensile Properties[1] of Mill Processed Ti-6Al-4V Strip (Heat R8918) After Its Fourth Cold Reduction to 0.051" Thick

○ ——— Ultimate Tensile Strength
△ — — — 0.2% Offset Yield Strength



1 - Each point is an average of two test values (see Table XXXVII)

Figure 45 Pole Figure for Mill Processed Ti-6Al-4V Strip Alpha Phase (Heat R8918 - Annealed Condition)

$(01\bar{1}0)$ Plane

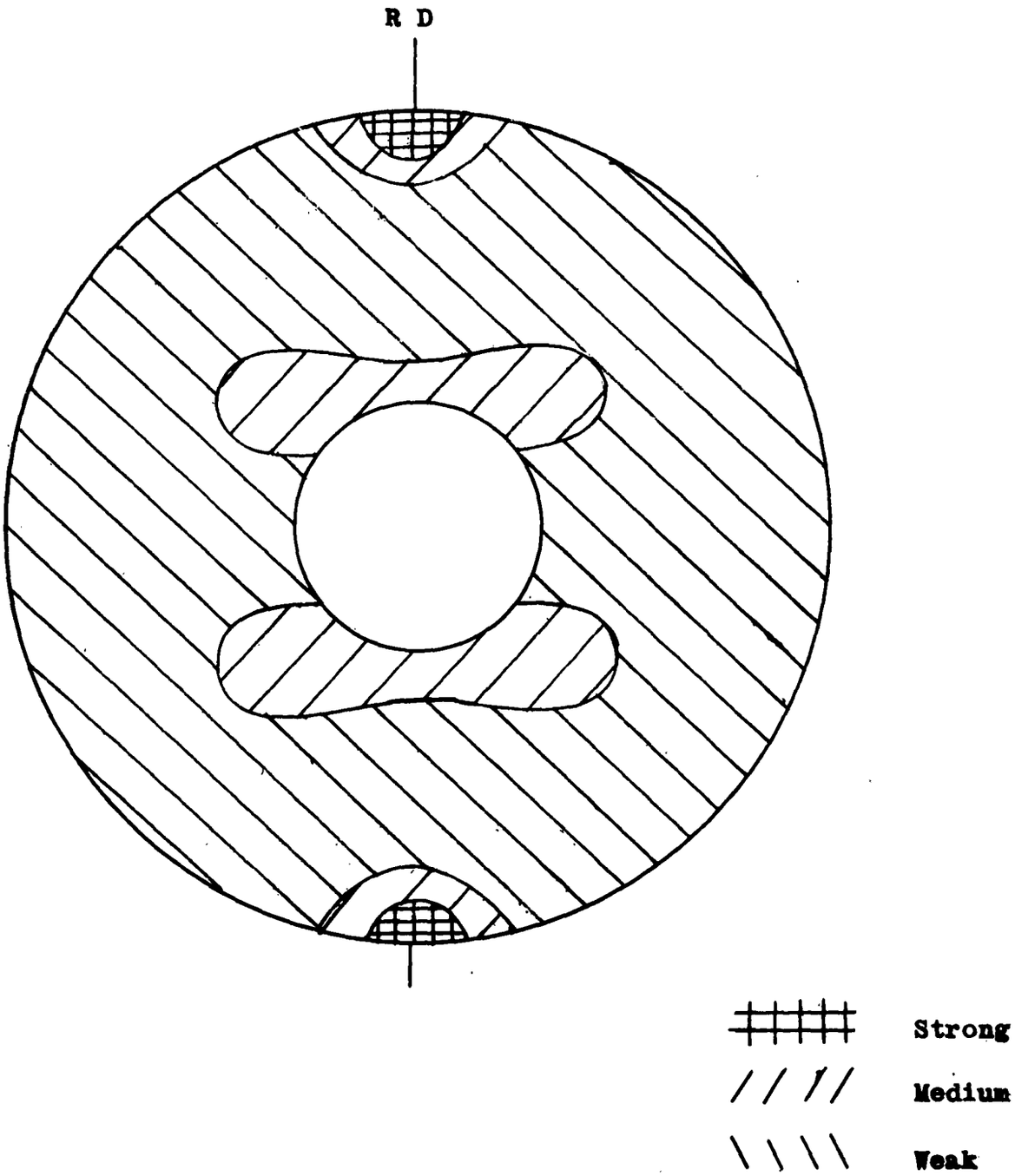


Figure 46 Pole Figure for Mill Processed Ti-6Al-4V Strip Beta Phase (Heat R8918 - Annealed Condition)

(100) Plane

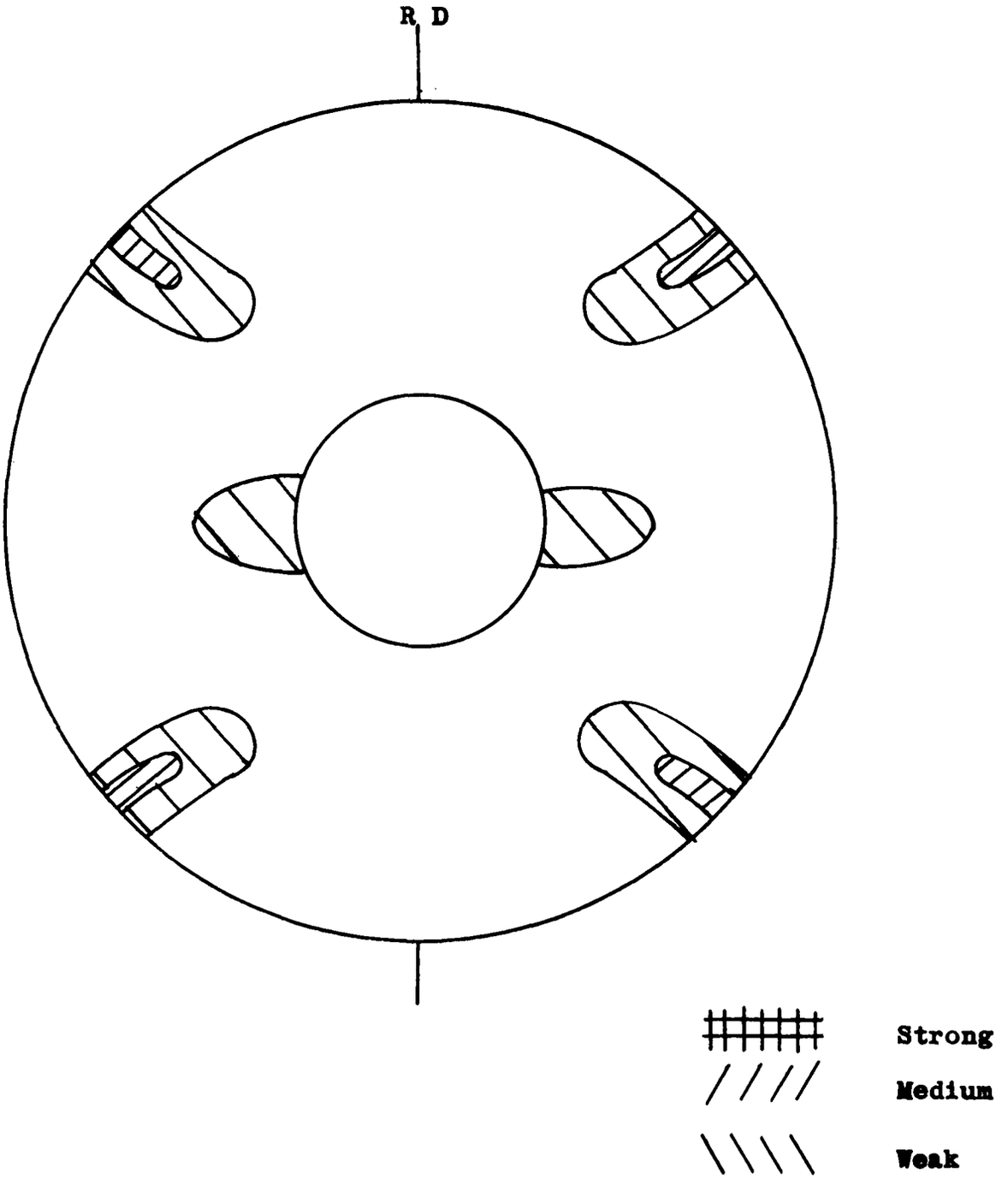
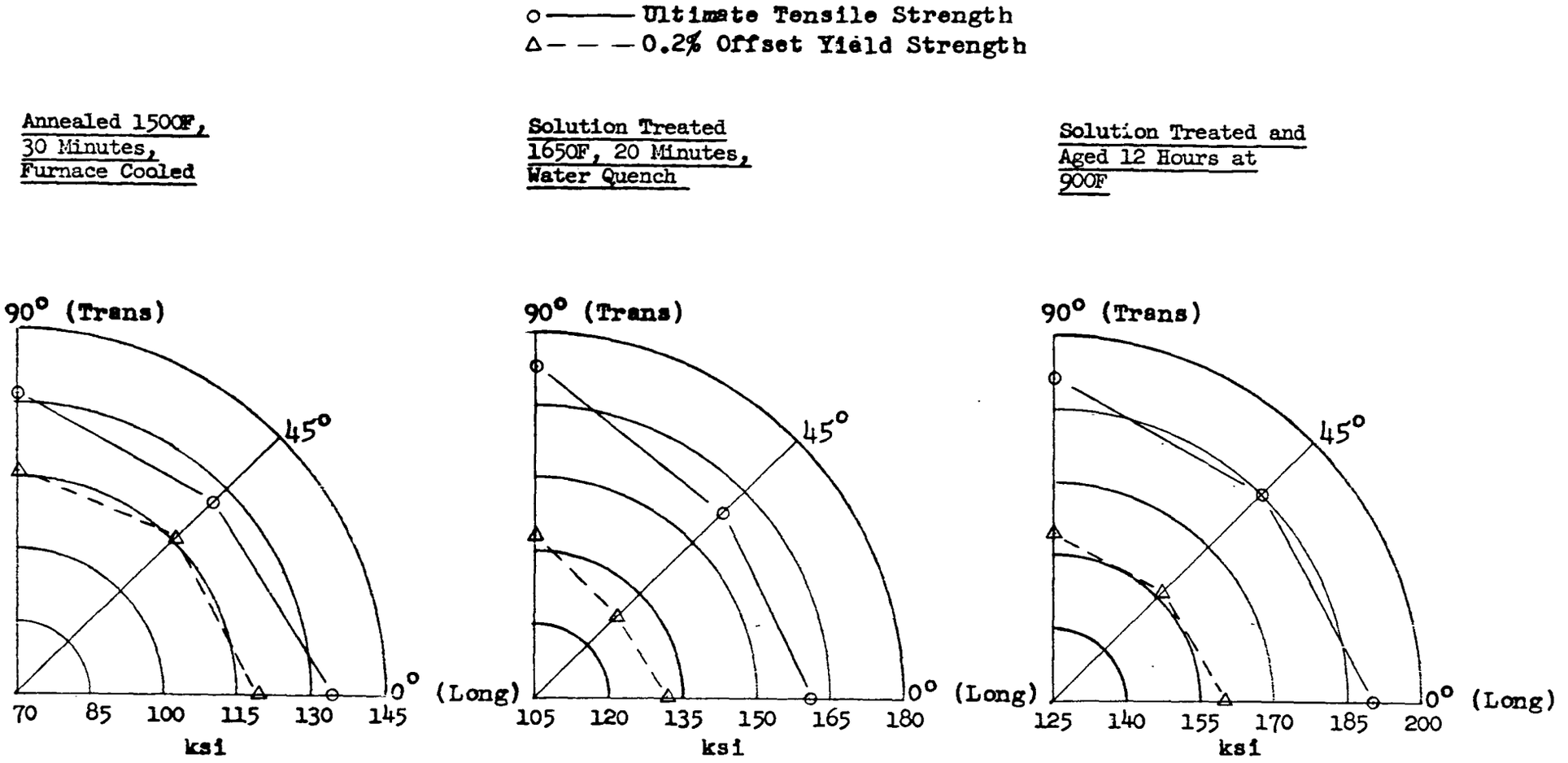
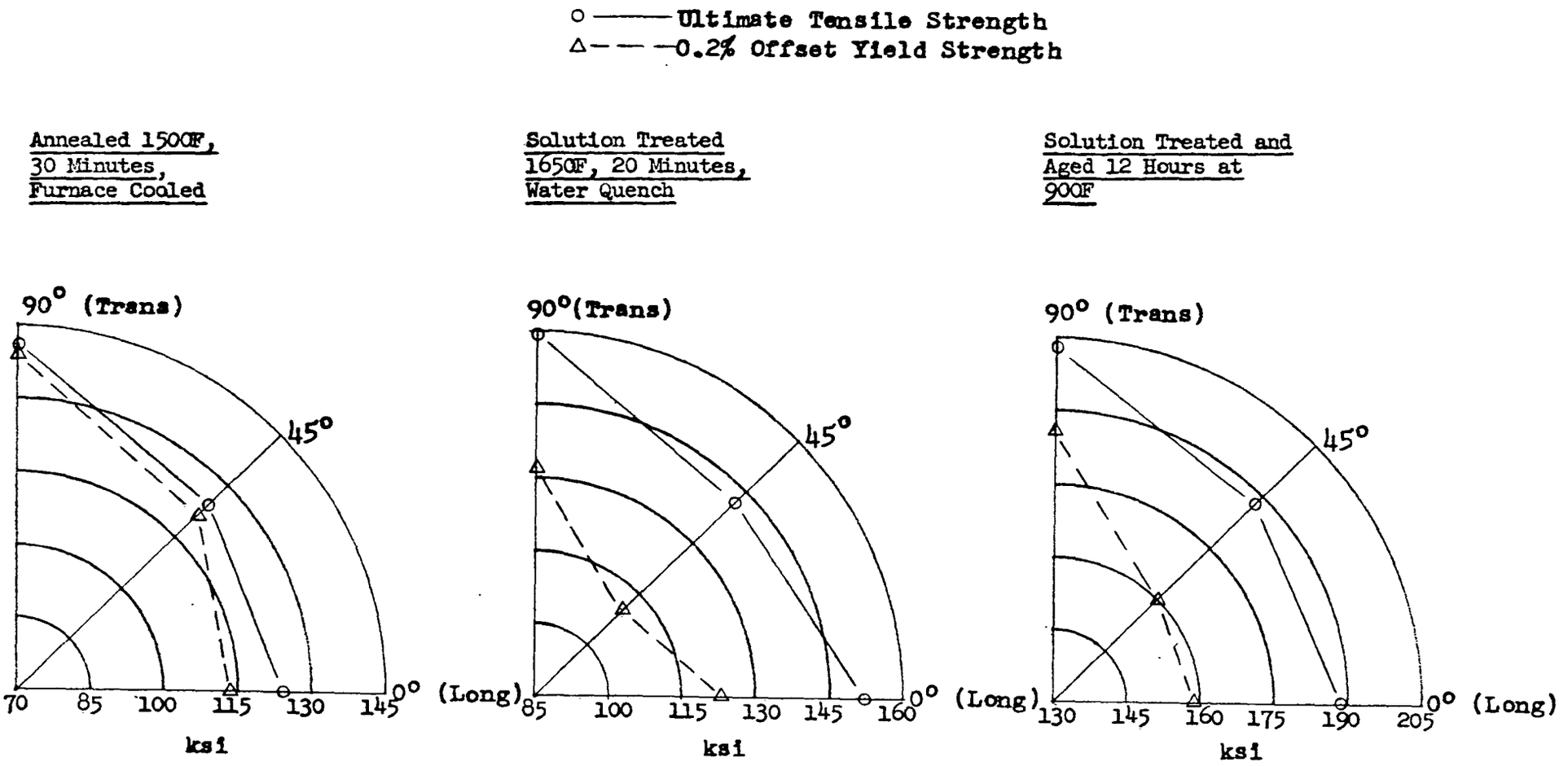


Figure 47 Mechanical Properties[1] of Mill Processed 0.800" Thick Ti-4Al-3Mo-1V Sheet Bar (Heats R8853 and R8865)



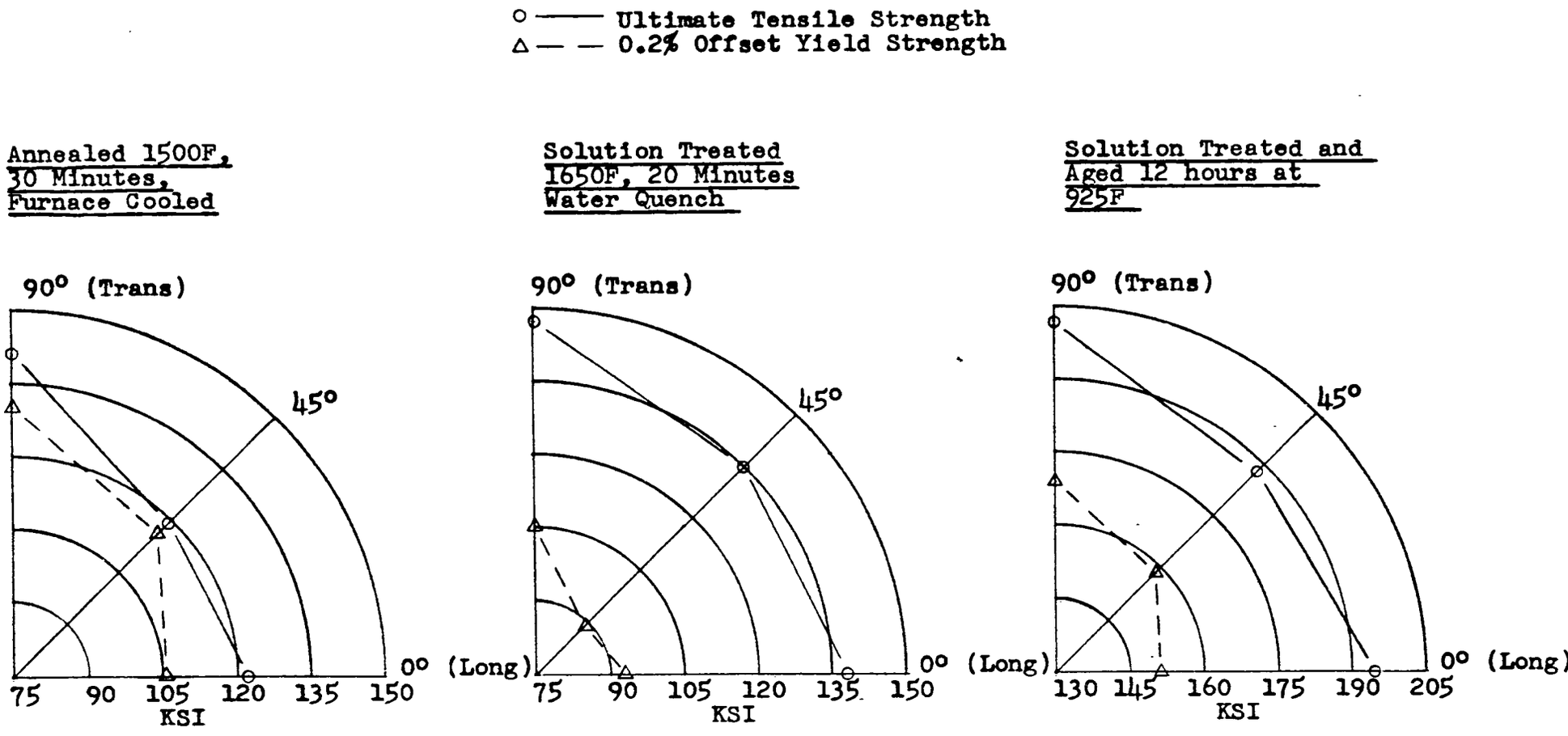
1 - Each point is an average of eight test values - duplicate specimens from two test locations from each of two heats (see Table XXXVIII)

Figure 48 Mechanical Properties[1] of Mill Processed 0.140" Thick Ti-4Al-3Mo-1V Hot Band (Heat R8865)



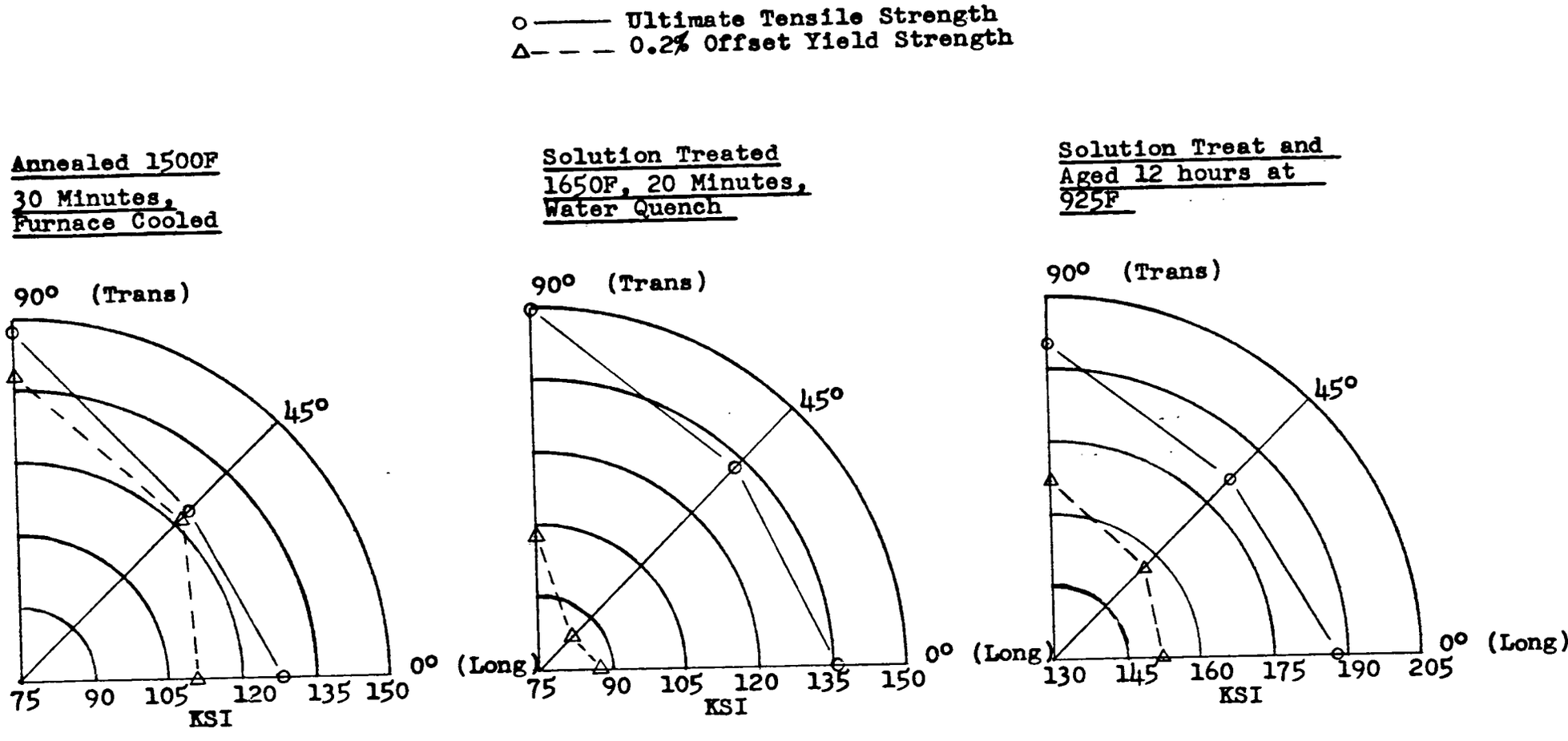
1 - Each point is an average of two tensile test values (see Table XXXIX)

Figure 49 Mechanical Properties[1] of Mill Processed Ti-4Al-3Mo-1V Strip (Heat R8865) After Its First Cold Reduction to 0.110" Thick



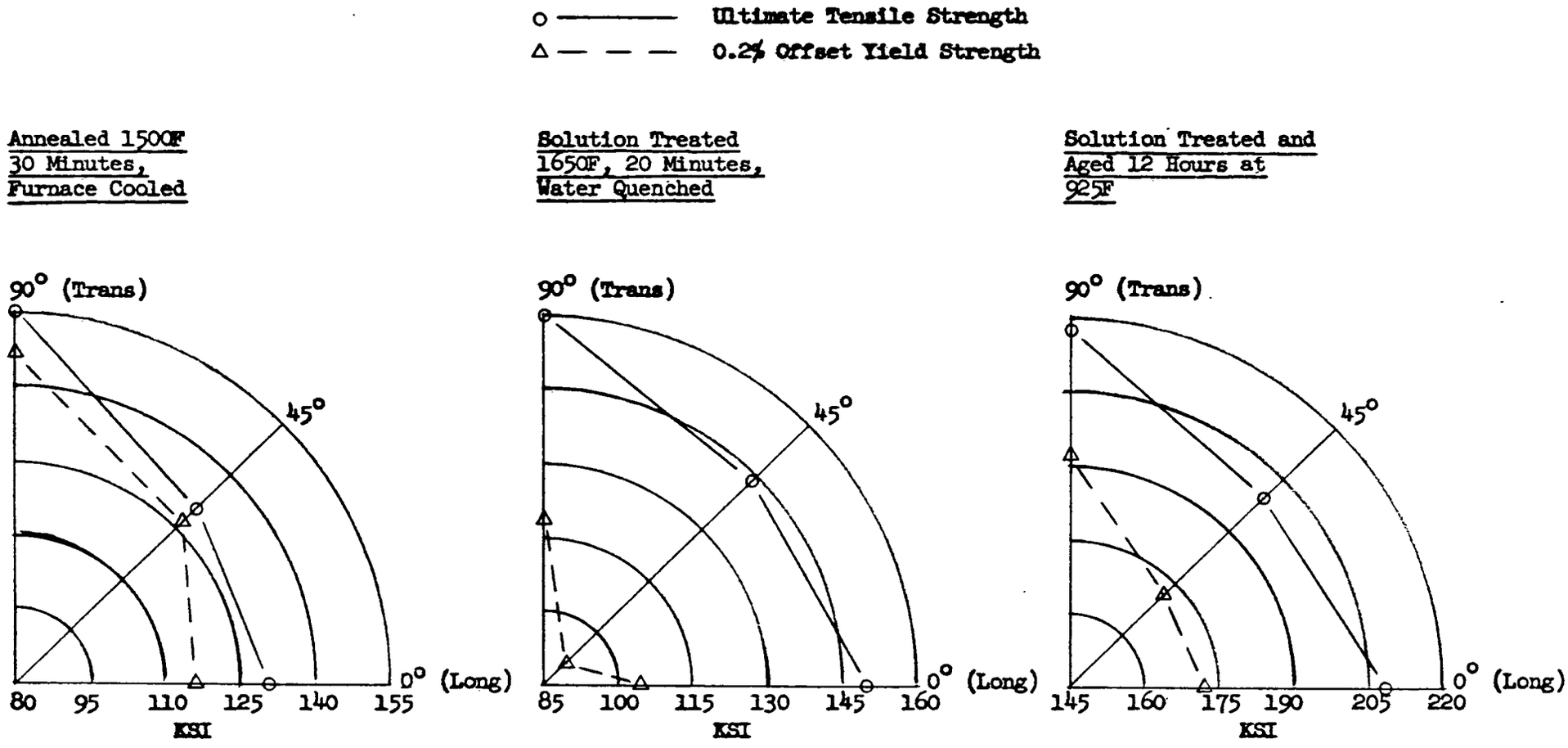
1 - Each Point is an Average of Four Test Values (see Table XL)

Figure 50 Mechanical Properties[1] of Mill Processed Ti-4Al-3Mo-1V Strip (Heat R8865) After Its Second Cold Reduction to 0.078" Thick



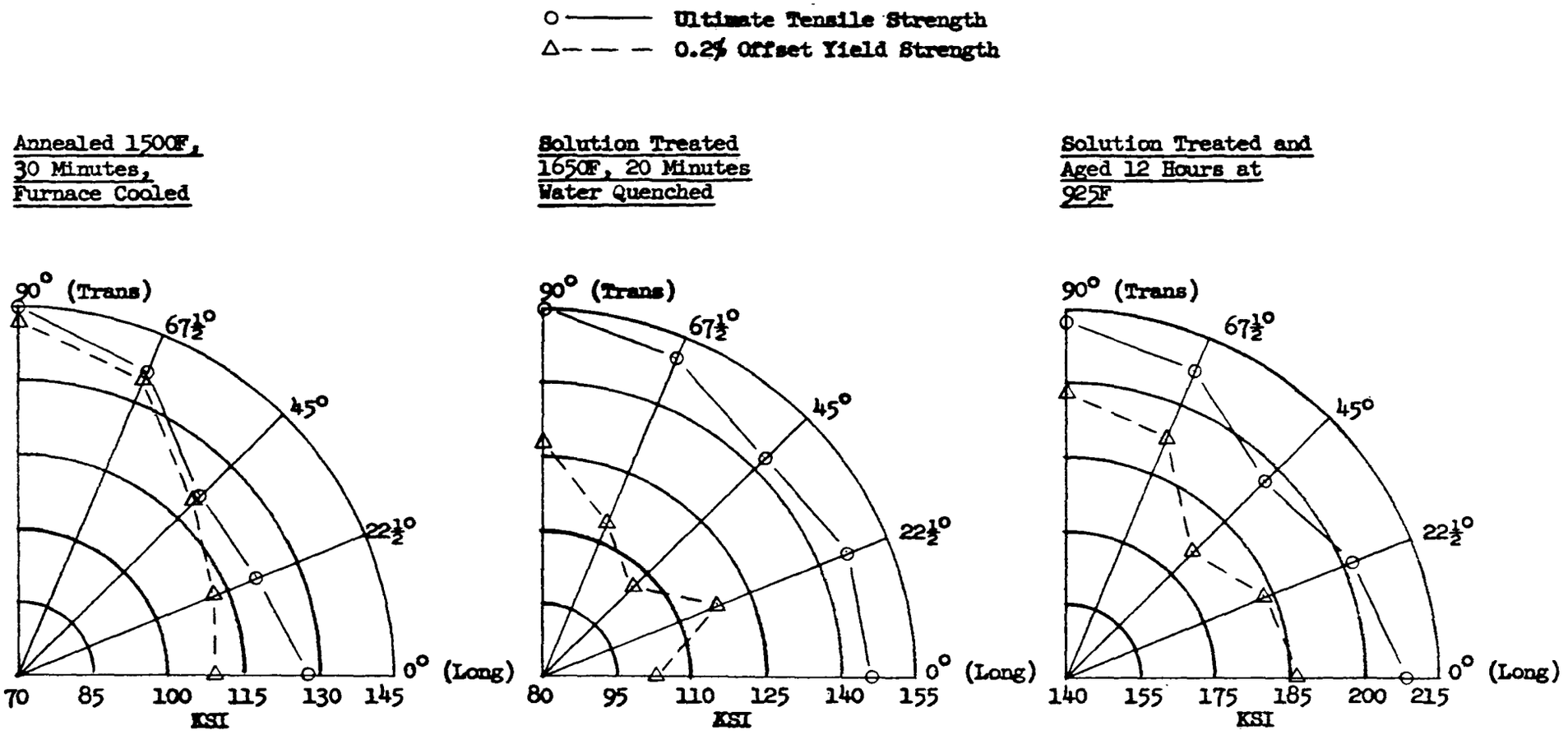
1 - Each point is an average of two test values (see Table XLI)

Figure 51 Mechanical Properties[1] of Mill Processed Ti-4Al-3Mo-1V Strip (Heat R8865) After Its Third Cold Reduction to 0.057" Thick



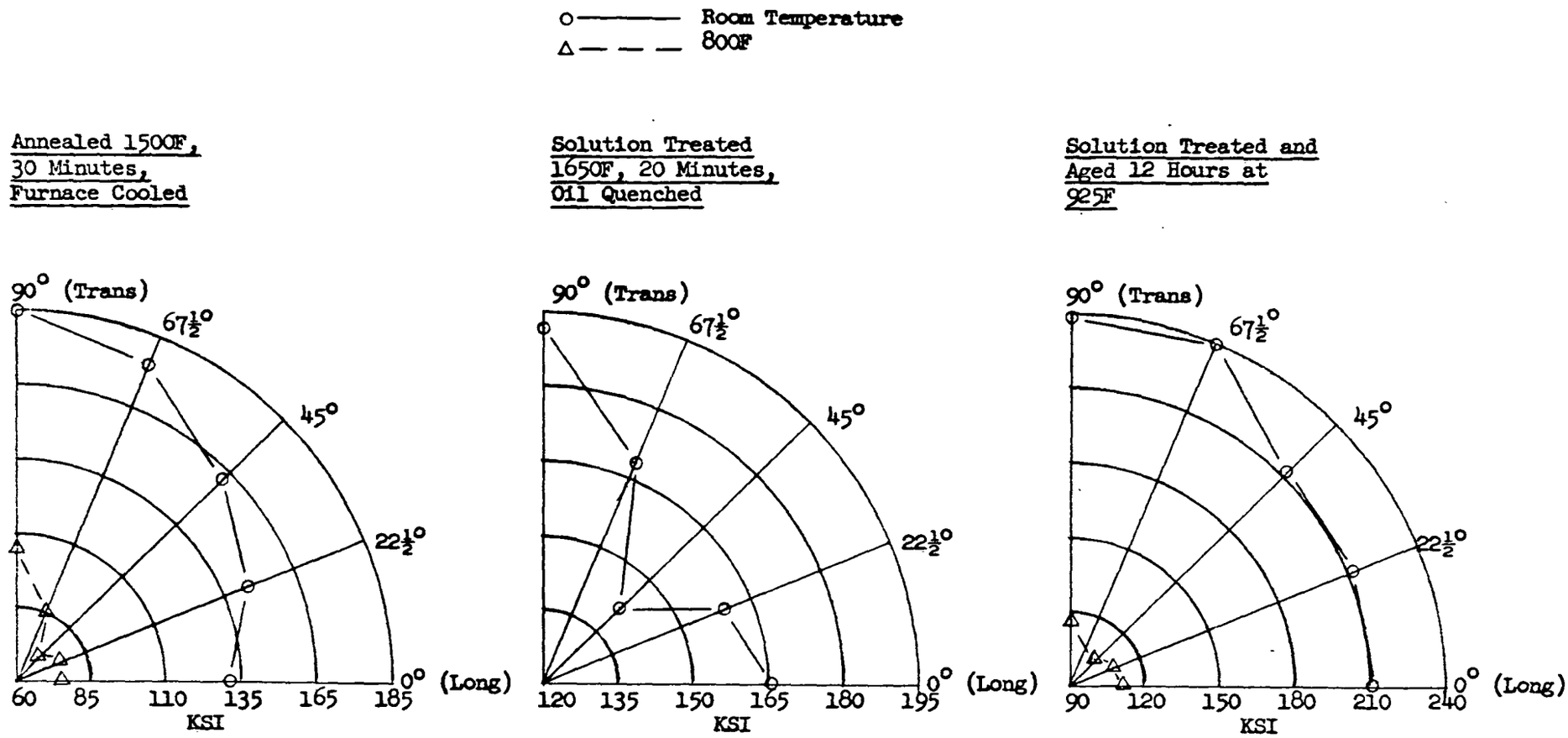
1 - Each point is an average of two test values (see Table XLII)

Figure 52 Mechanical Properties of Mill Processed Ti-4Al-3Mo-1V Strip (Heat R8865) After Its Fourth Cold Reduction to 0.0347 Thick



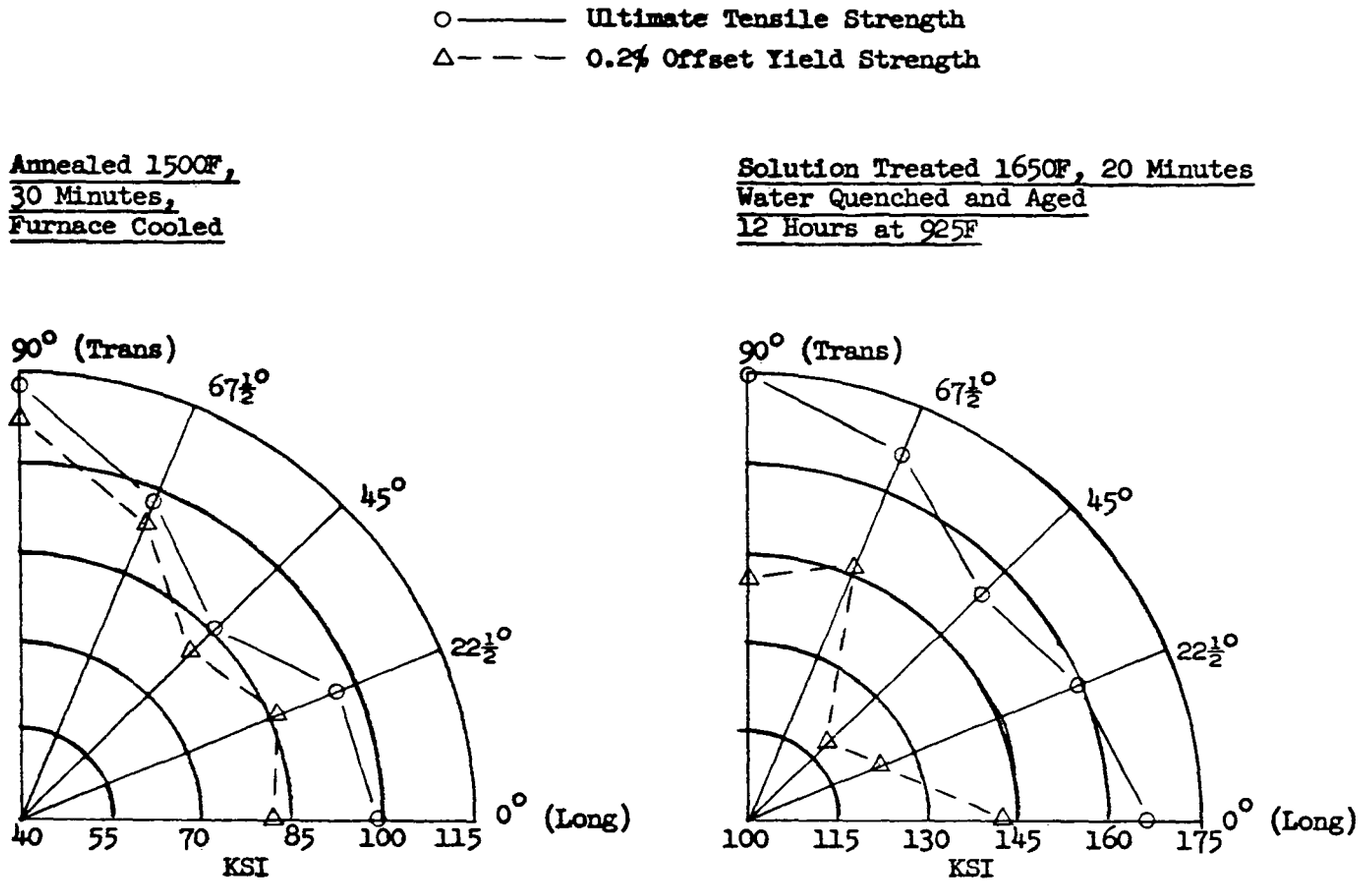
1 - Each point is an average of two test values (see Table XLIII)

Figure 53 Compression Yield Strength[1] (0.2% Offset) of Mill Processed Ti-4Al-3Mo-1V Strip (Heat R8865) After Its Fourth Cold Reduction to 0.034" Thick



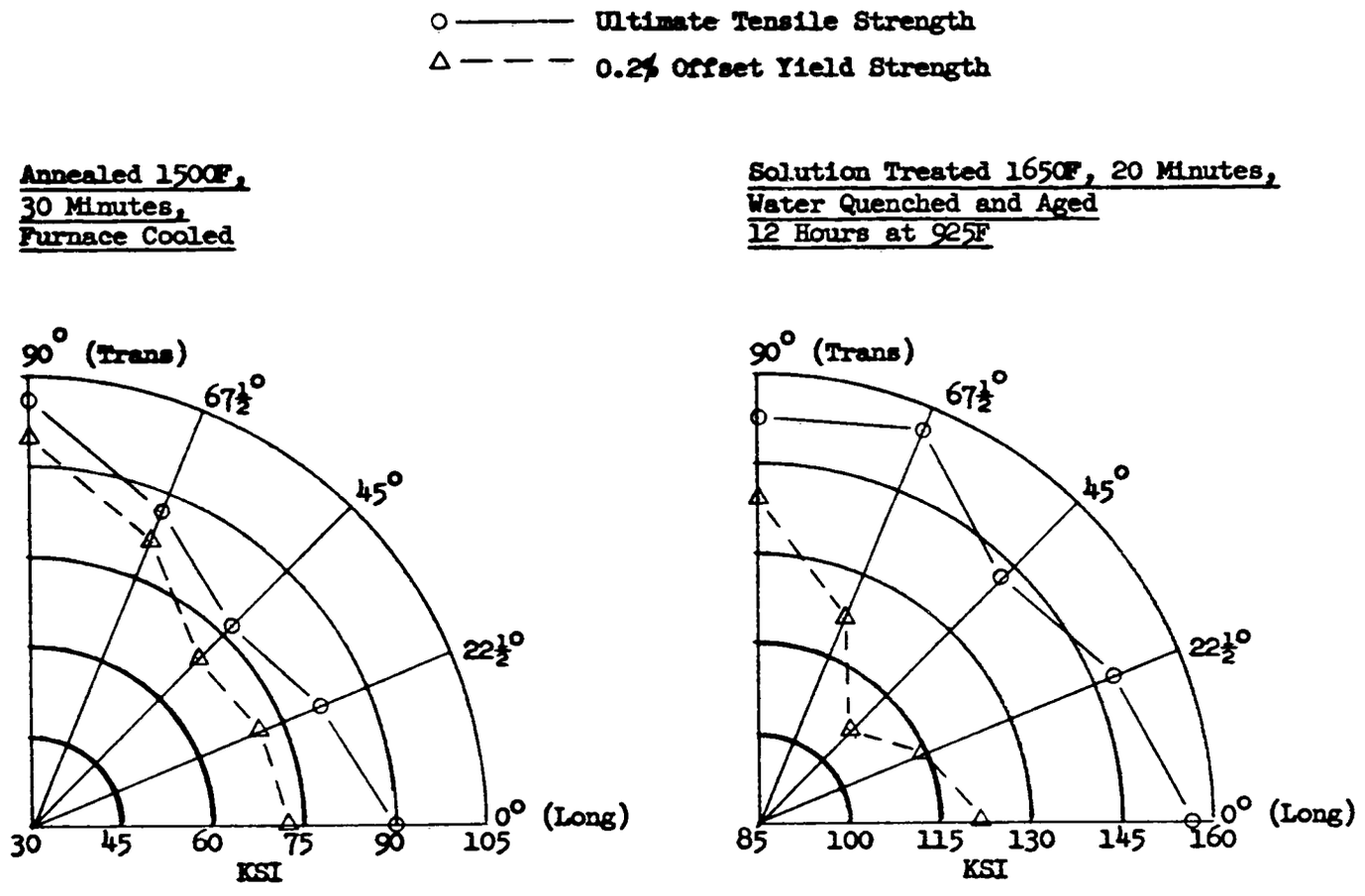
1 - Most points are averages of two test values (see Table XLIV).
2 - Oil quenching (instead of water quenching) was necessary to retain satisfactory flatness in compression test specimens.

Figure 54 400F Tensile Properties of Mill Processed Ti-4Al-3Mo-1V Strip (Heat R8865) After Its Fourth Cold Reduction to 0.034" Thick



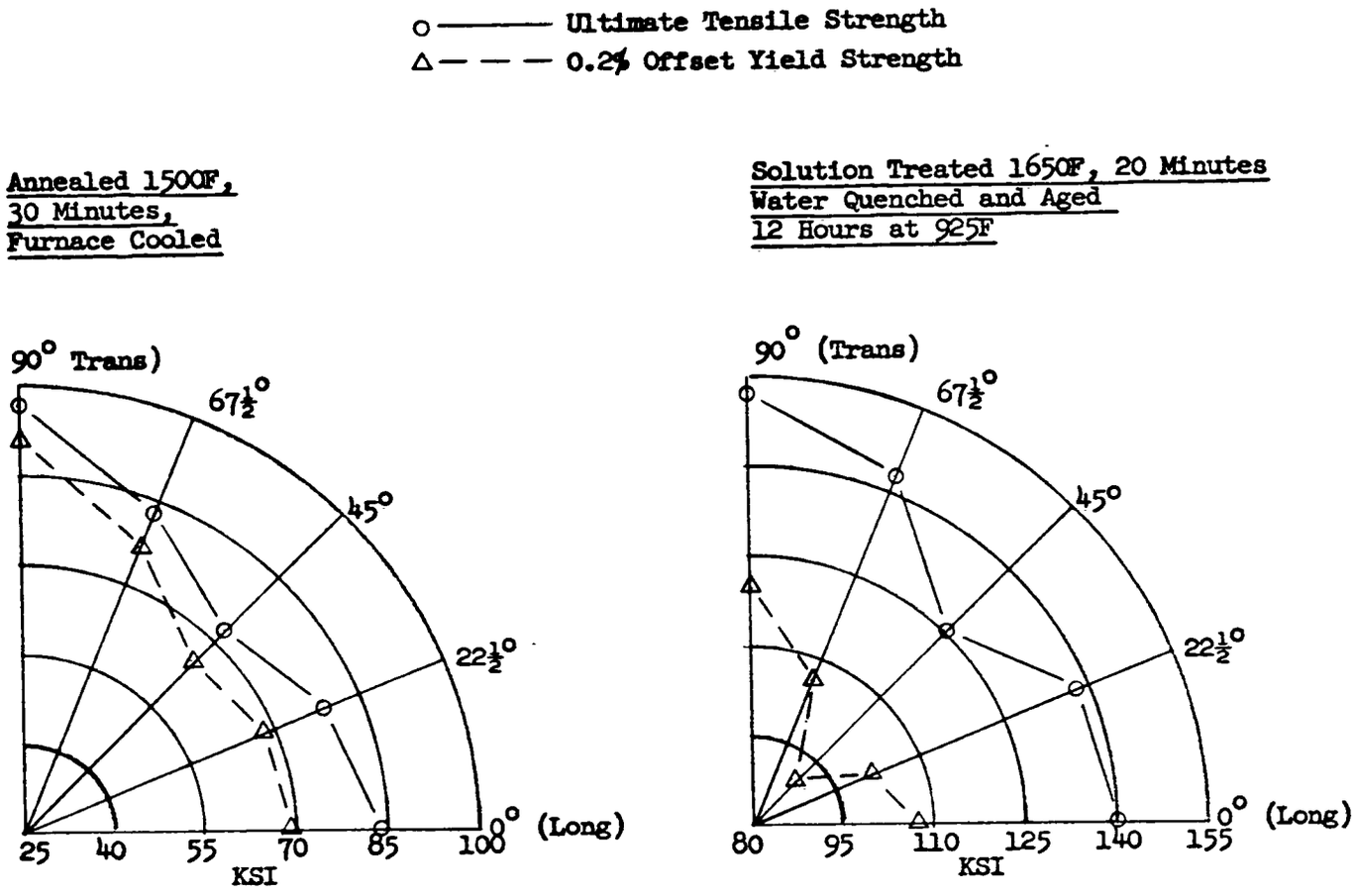
1 - Each point is an average of two test values (see Table XLV).

Figure 55 600F Tensile Properties of Mill Processed Ti-4Al-3Mo-1V Strip (Heat R8865) After Its Fourth Cold Reduction to 0.034" Thick



1 - Each point is an average of two test values (see Table XLV).

Figure 56 800F Tensile Properties[1] of Mill Processed Ti-4Al-3Mo-1V Strip (Heat R8865) After Its Fourth Cold Reduction to 0.034" Thick



1 - Each point is an average of two test values (see Table XLV).

Figure 57 Pole Figure for Mill Processed Ti-4Al-3Mo-1V Strip Alpha Phase (Heat R8865 - Annealed Condition)

$(01\bar{1}0)$ Plane

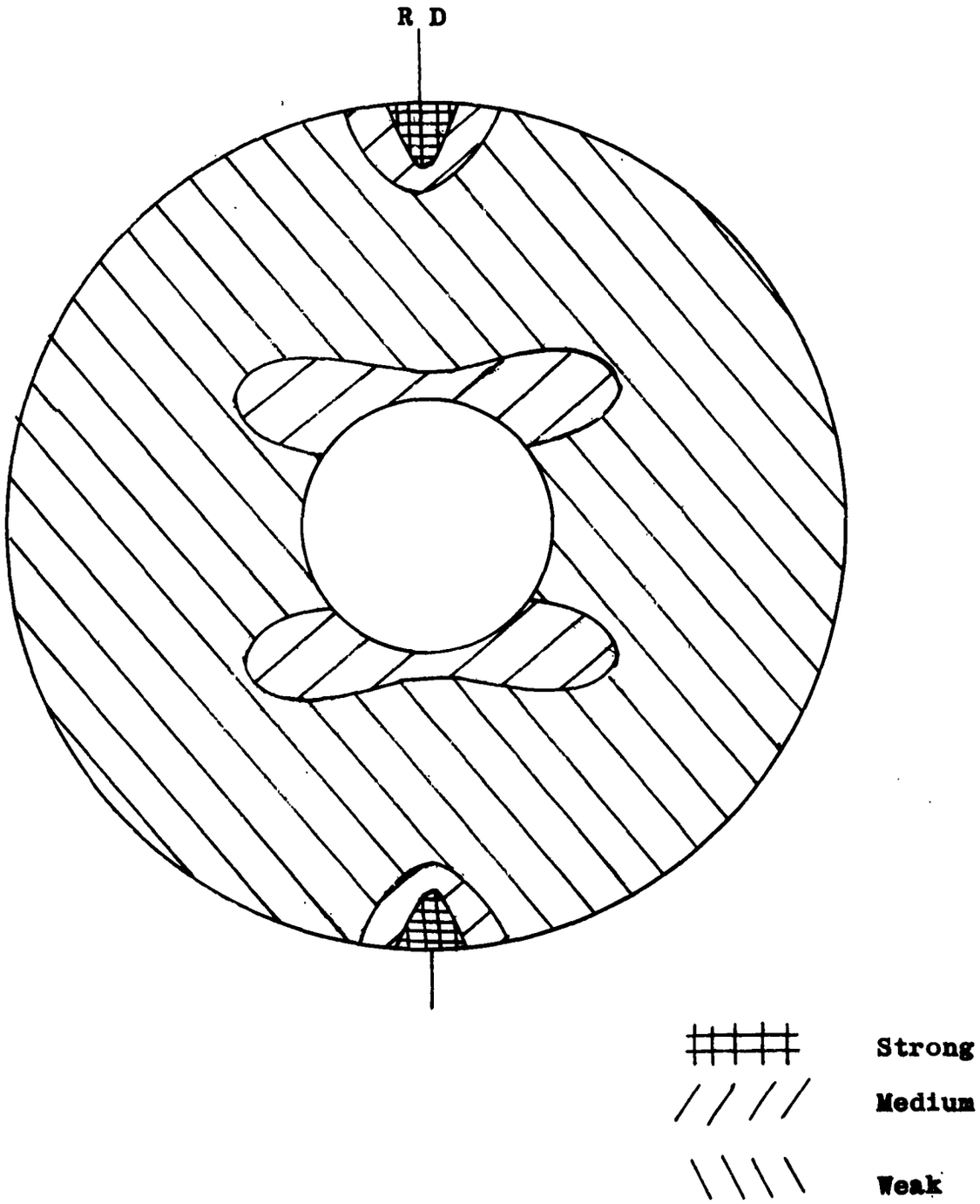


Figure 58 Pole Figure for Mill Processed Ti-4Al-3Mo-1V Strip Beta Phase (Heat R8865 - Annealed Condition)

(100) Plane

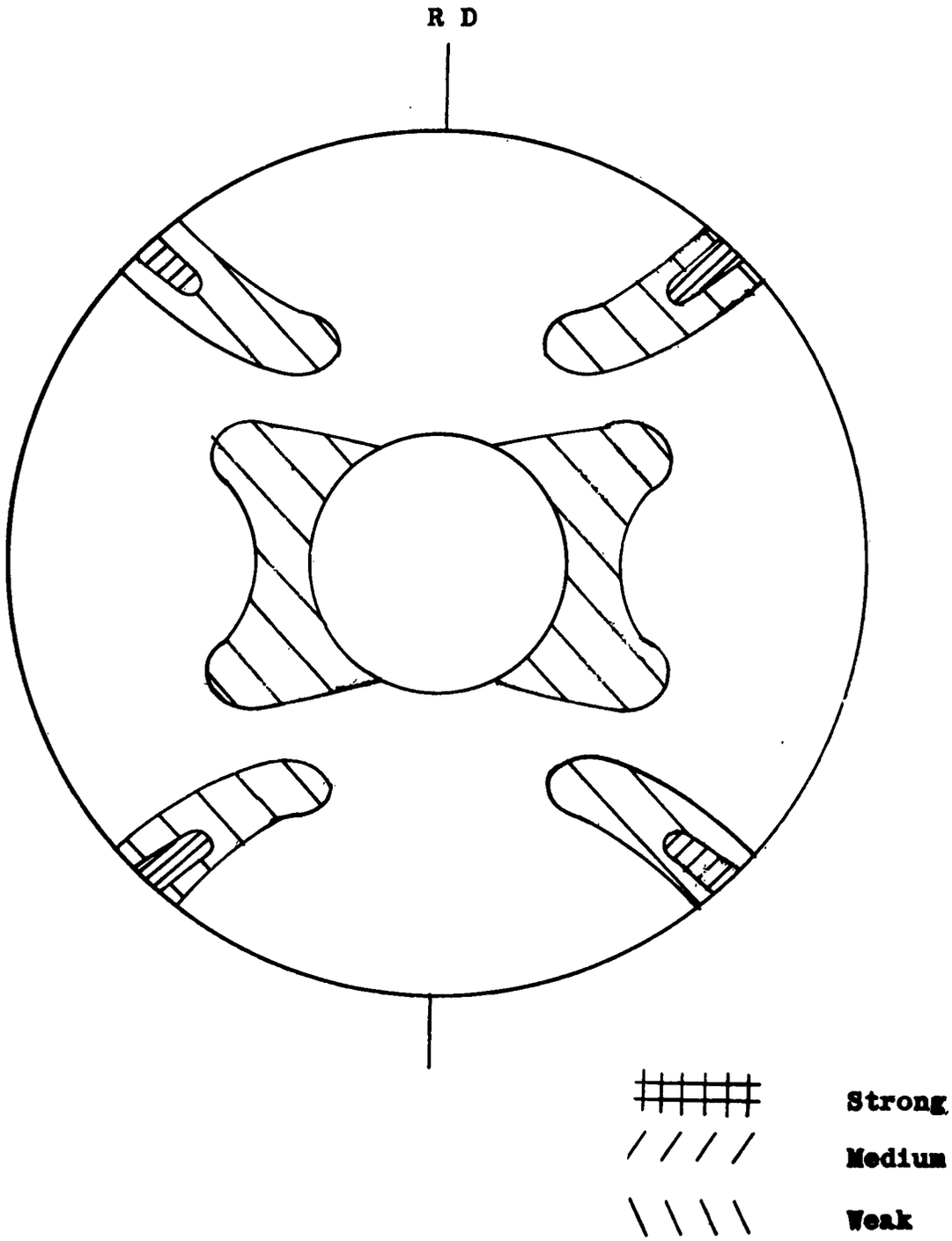
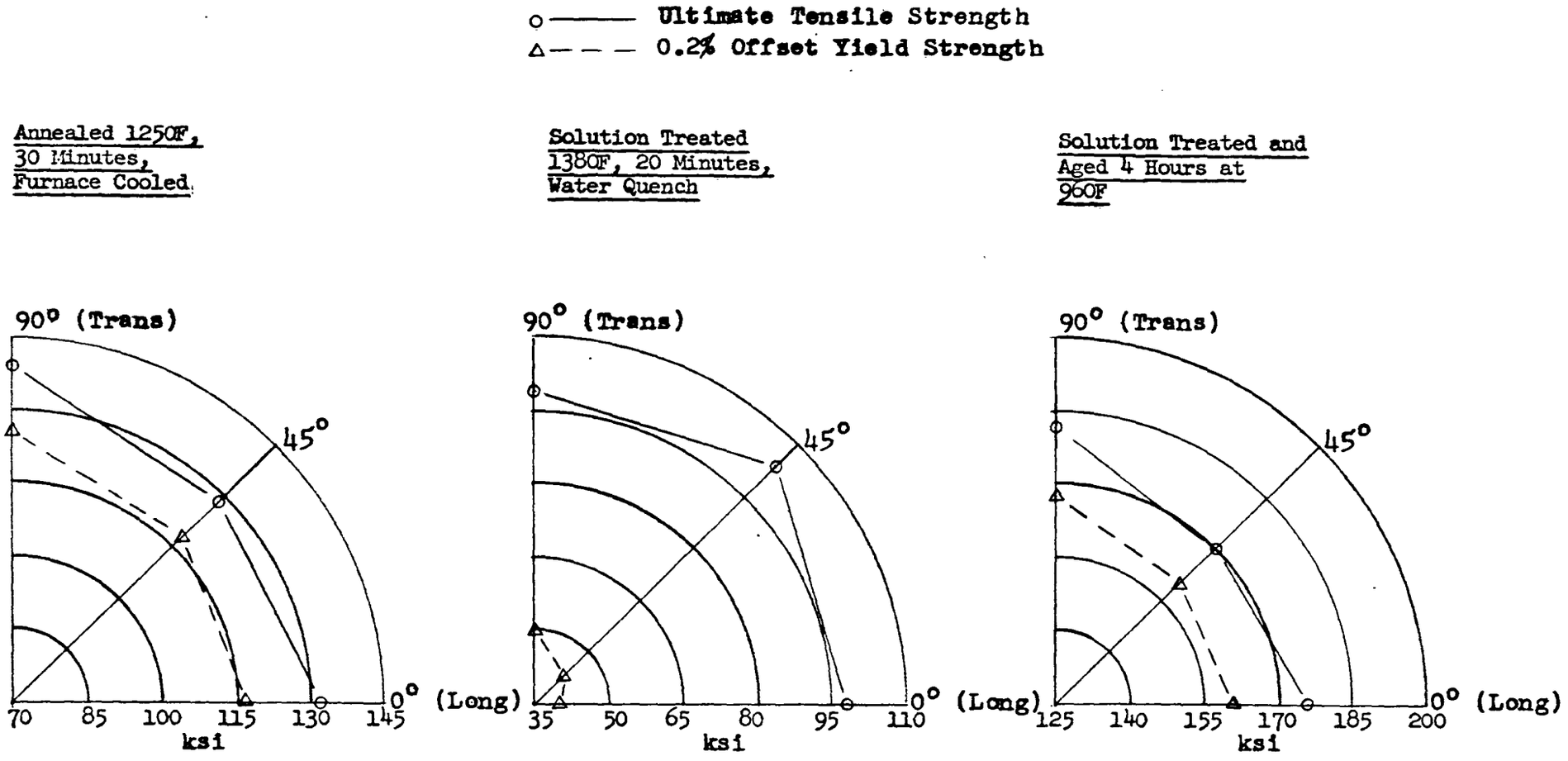
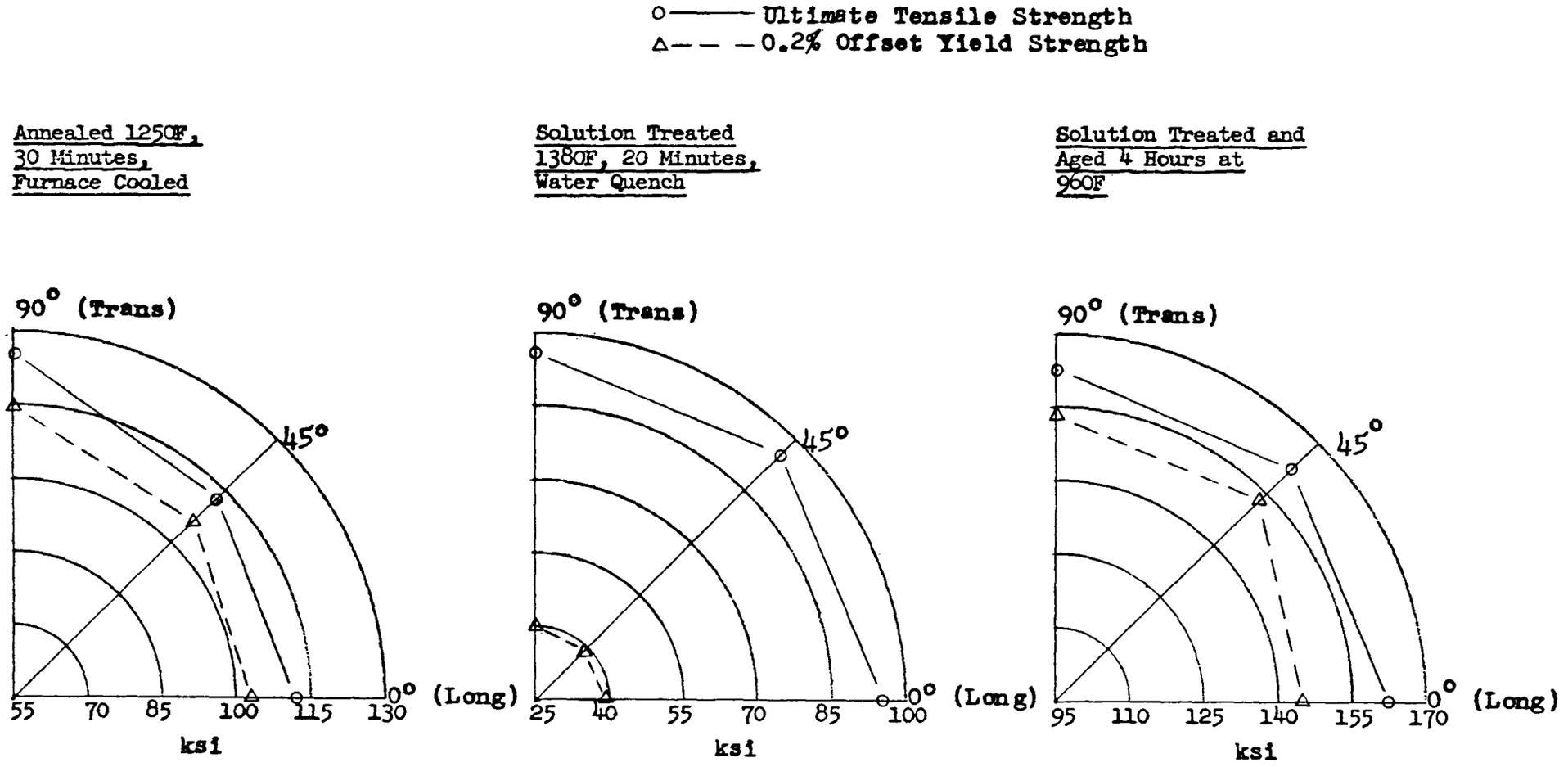


Figure 59 Mechanical Properties[1] of Mill Processed 0.800" Thick Ti-2½Al-16V Sheet Bar (Heats R8848 and R8856)



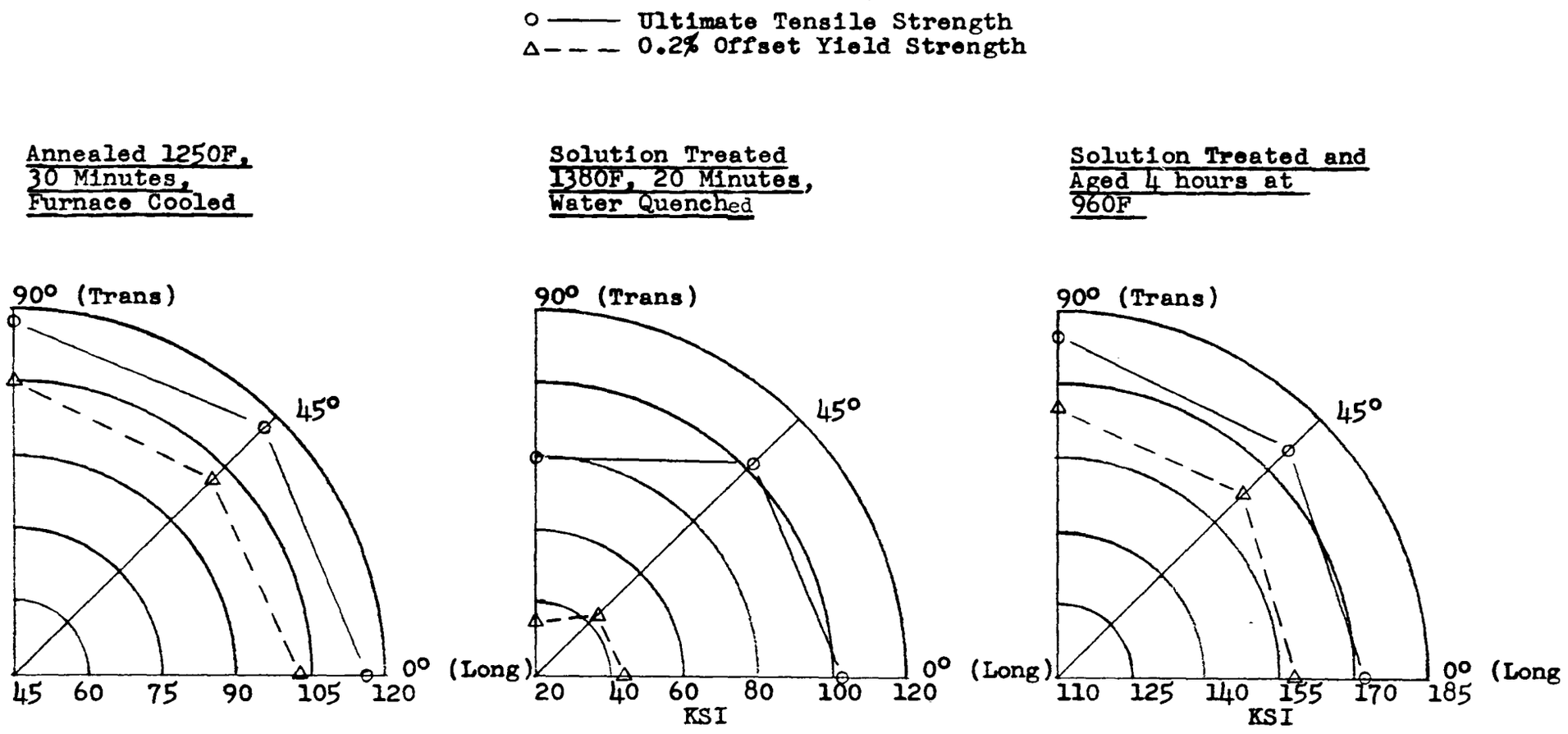
1 - Each point is an average of eight test values - duplicate specimens from two test locations from each of two heats (see Table XLVI)

Figure 60 Mechanical Properties[1] of Mill Processed 0.140" Thick Ti-2½Al-16V Hot Band (Heat R8848)



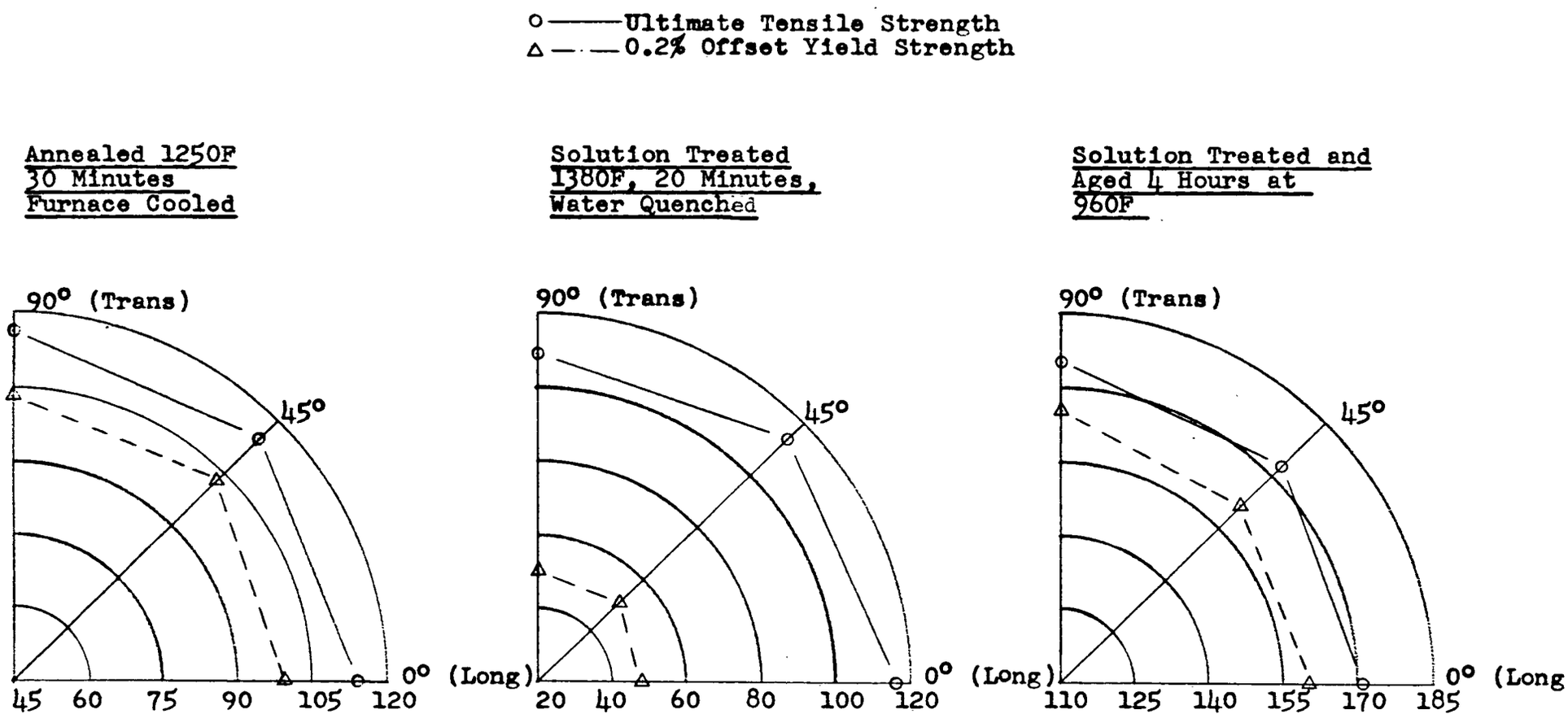
1 - Each point is an average of two tensile test values (see Table XLVII)

Figure 61 Mechanical Properties[1] of Mill Processed Ti-2½Al-16V Strip (Heat R8848) After Its First Cold Reduction to 0.100" Thick



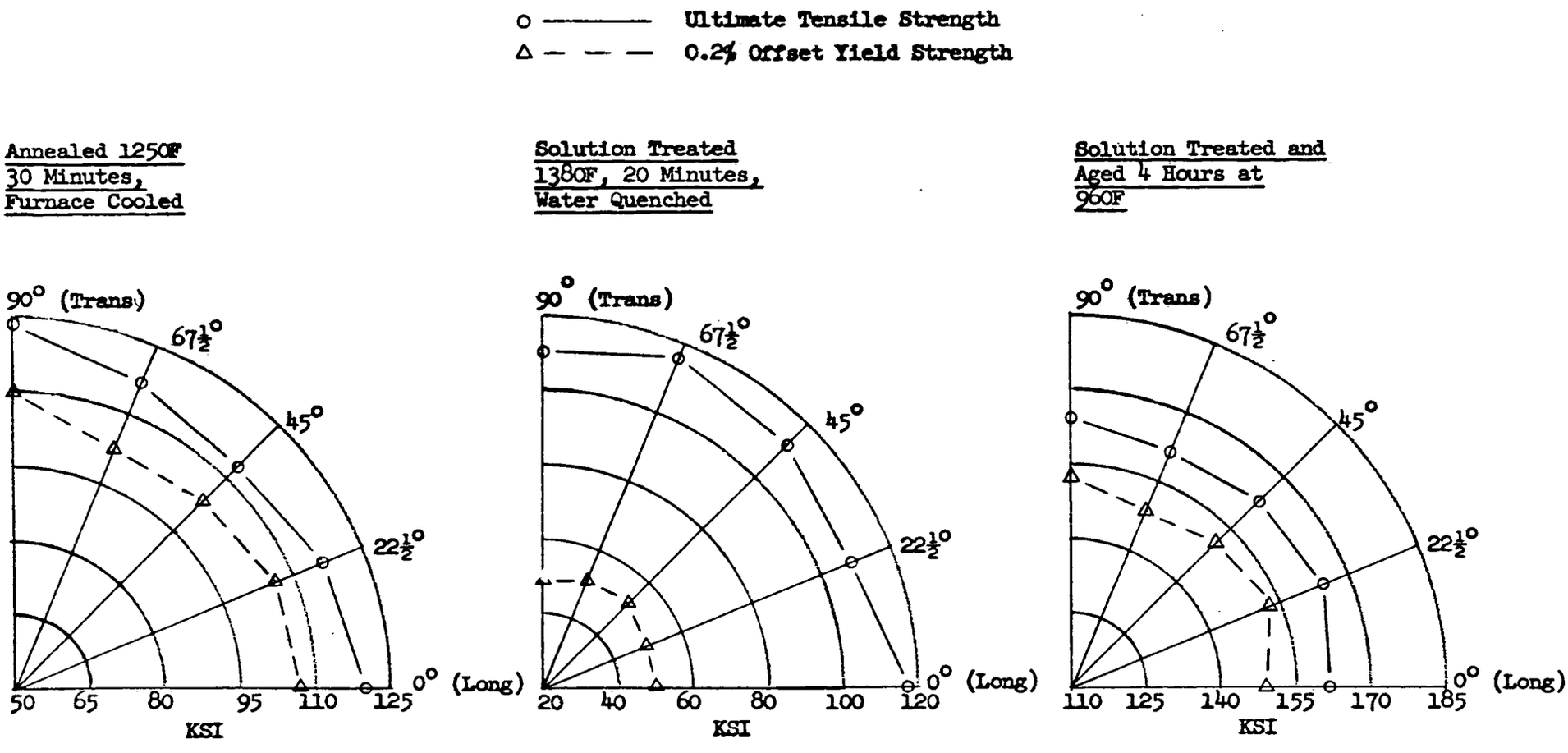
1 - All but four points are averages of two test values (see Table XLVIII)

Figure 62 Mechanical Properties[1] of Mill Processed Ti-2½Al-16V Strip (Heat R8848) After Its Second Cold Reduction to 0.080" Thick



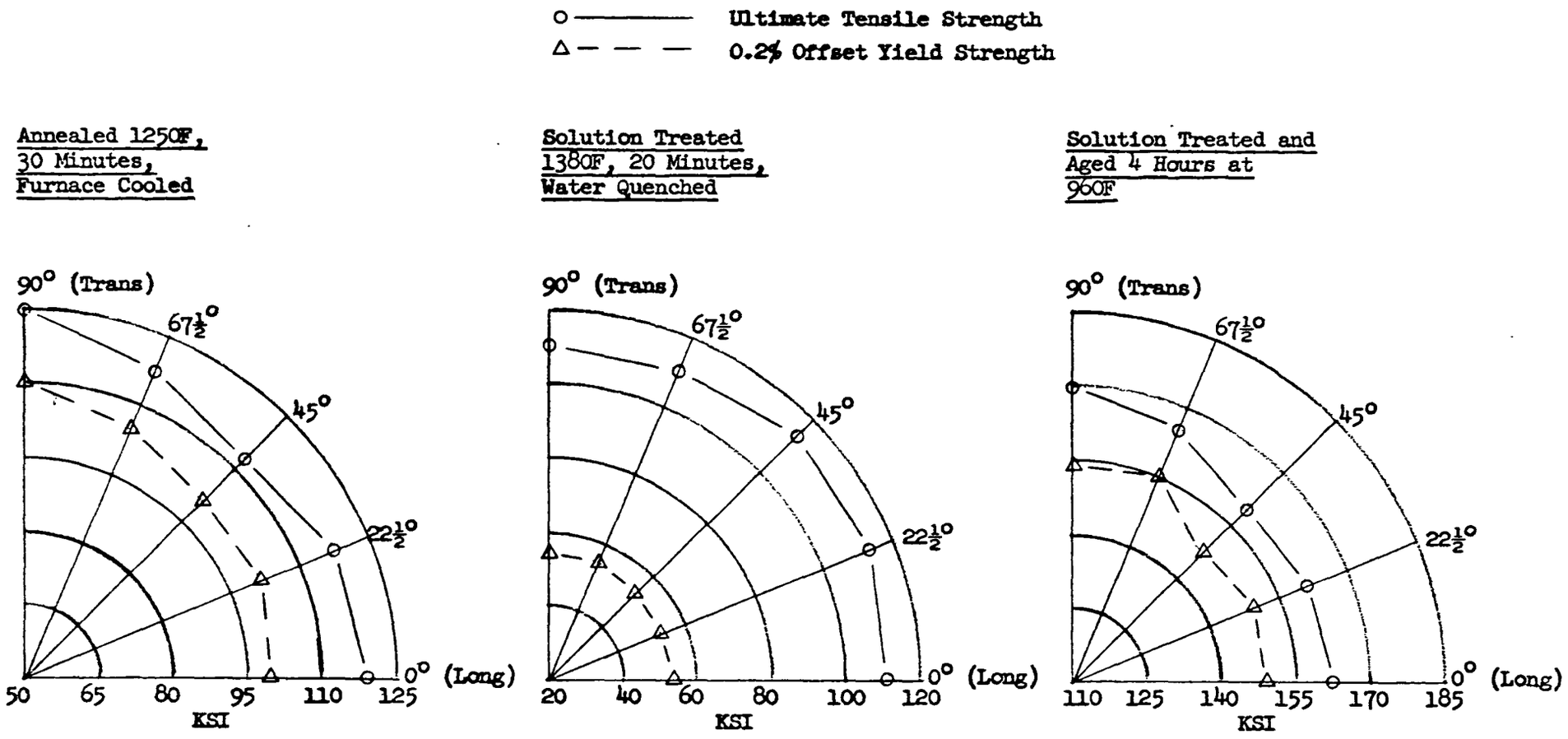
1 - Annealed points are averages of two test values; solution treated and solution treated and aged points are averages of four test values (see Table XLIX)

Figure 63 Mechanical Properties[1] of Mill Processed Ti-2½Al-16V Strip (Heat R8848) After Its Third Cold Reduction to 0.045" Thick



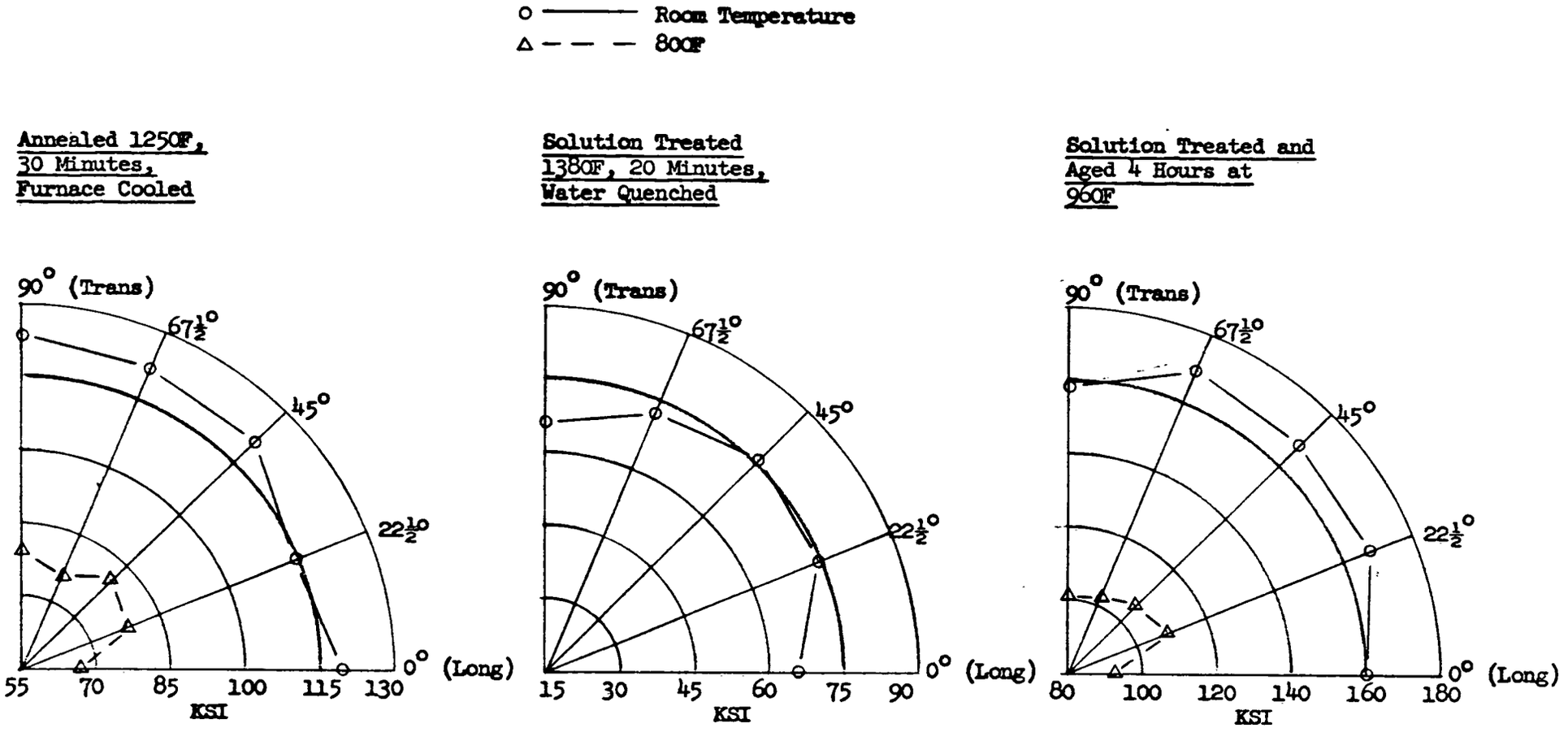
1 - Each point is an average of two test values (see Table L).

Figure 64 Mechanical Properties of Mill Processed Ti-2½Al-16V Strip (Heat R8848) After Its Fourth Cold Reduction to 0.021" Thick



1 - Each point is an average of two test values (see Table LI)

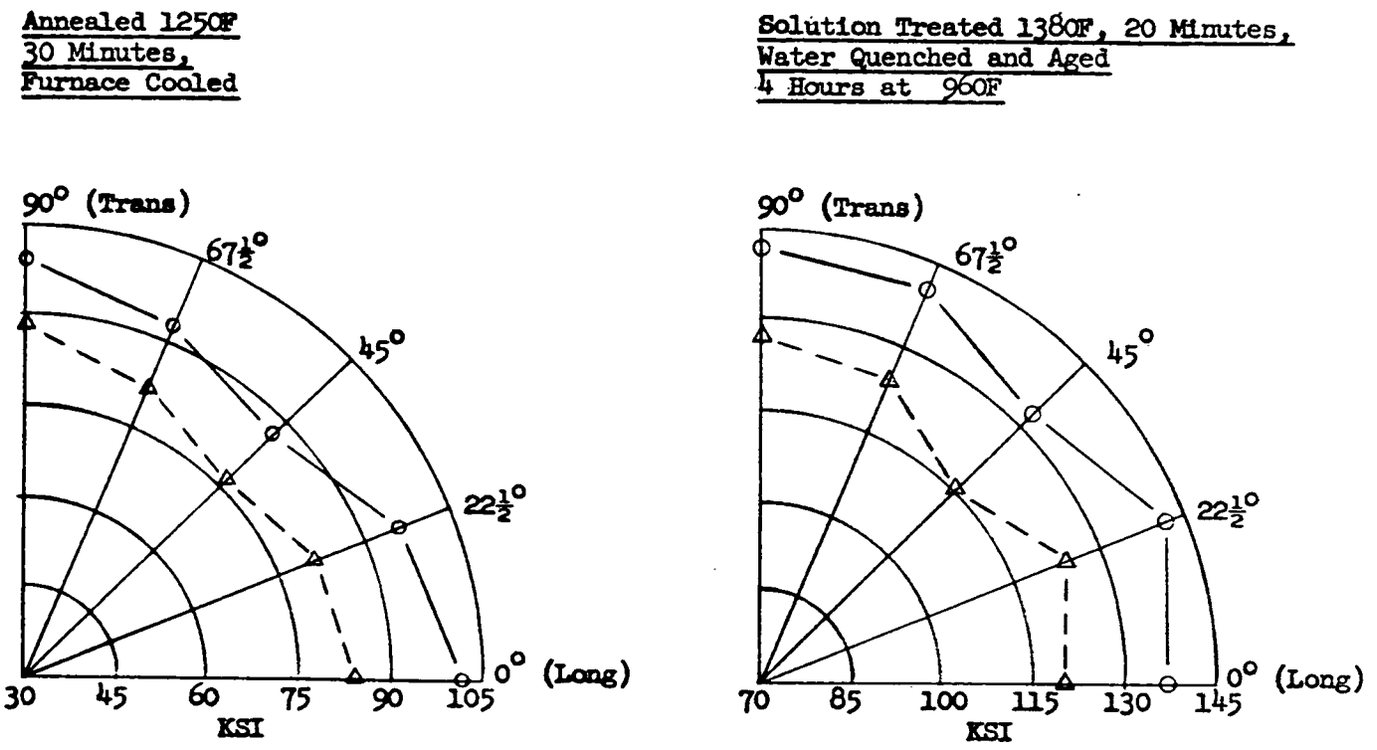
Figure 65 Compression Yield Strength[1] (0.2% Offset) of Mill Processed Ti-2½Al-16V Strip (Heat R8848) After Its Third Cold Reduction to 0.045" Thick



1 - Each point is an average of two test values (see Table LII)

Figure 66 400F Tensile Properties[1] of Mill Processed Ti-2½Al-16V Strip (Heat R8848) After Its Fourth Cold Reduction to 0.021" Thick

○ ——— Ultimate Tensile Strength
△ — — — 0.2% Offset Yield Strength

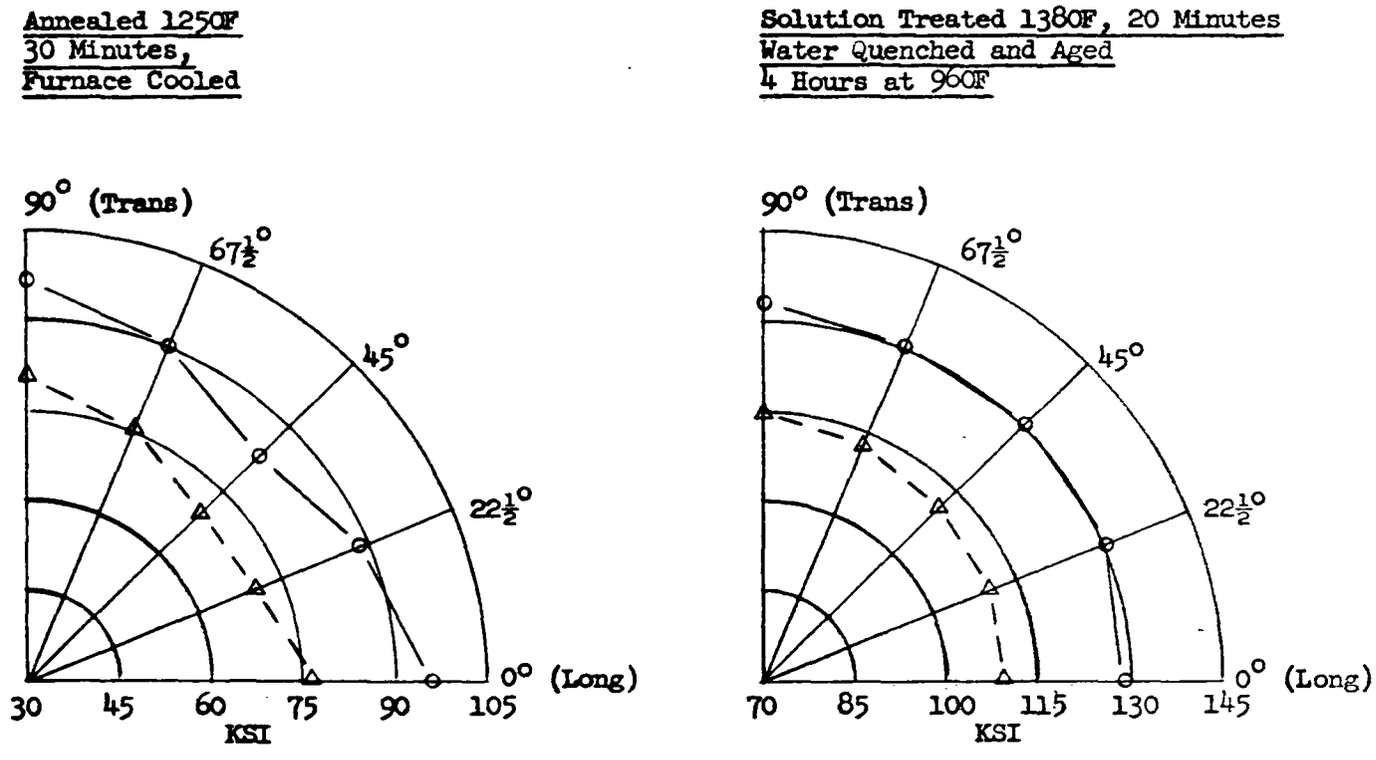


1 - Each point is an average of two test values (See Table LIII)

Figure 67 600F Tensile Properties[1] of Mill Processed Ti-2½Al-16V Strip (Heat R8848) After Its Fourth Cold Reduction to 0.021" Thick

o ——— Ultimate Tensile Strength

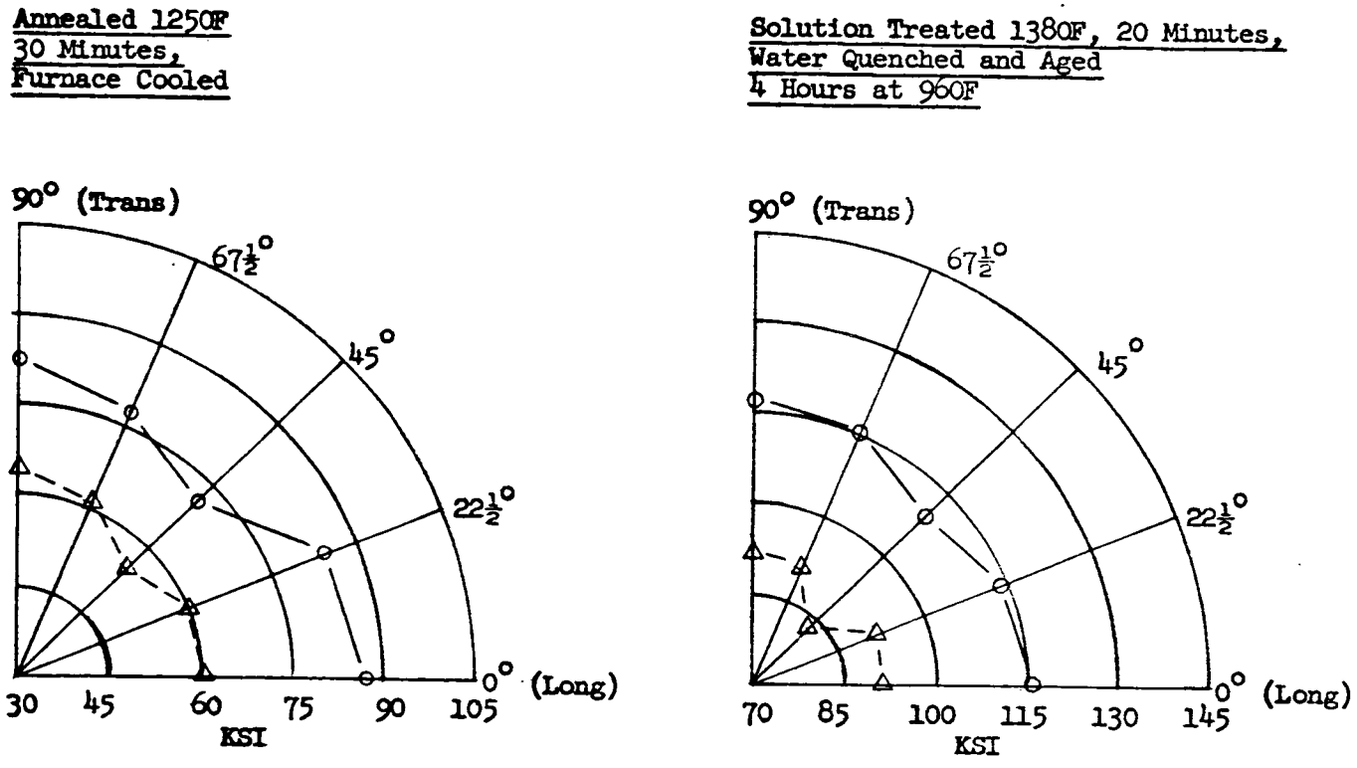
Δ — — — 0.2% Offset Yield Strength



1 - Each point is an average of two test values (see Table LIII)

Figure 68 800F Tensile Properties[1] of Mill Processed Ti-2½Al-16V Strip (Heat R8848) After Its Fourth Cold Reduction to 0.021" Thick

○ ——— Ultimate Tensile Strength
△ — — — 0.2% Offset Yield Strength



1 - Each point is an average of two test values (see Table LIII)

Figure 69 Pole Figure for Mill Processed Ti-2½Al-16V Strip Alpha Phase (Heat R8848 - Annealed Condition)

$(01\bar{1}0)$ Plane

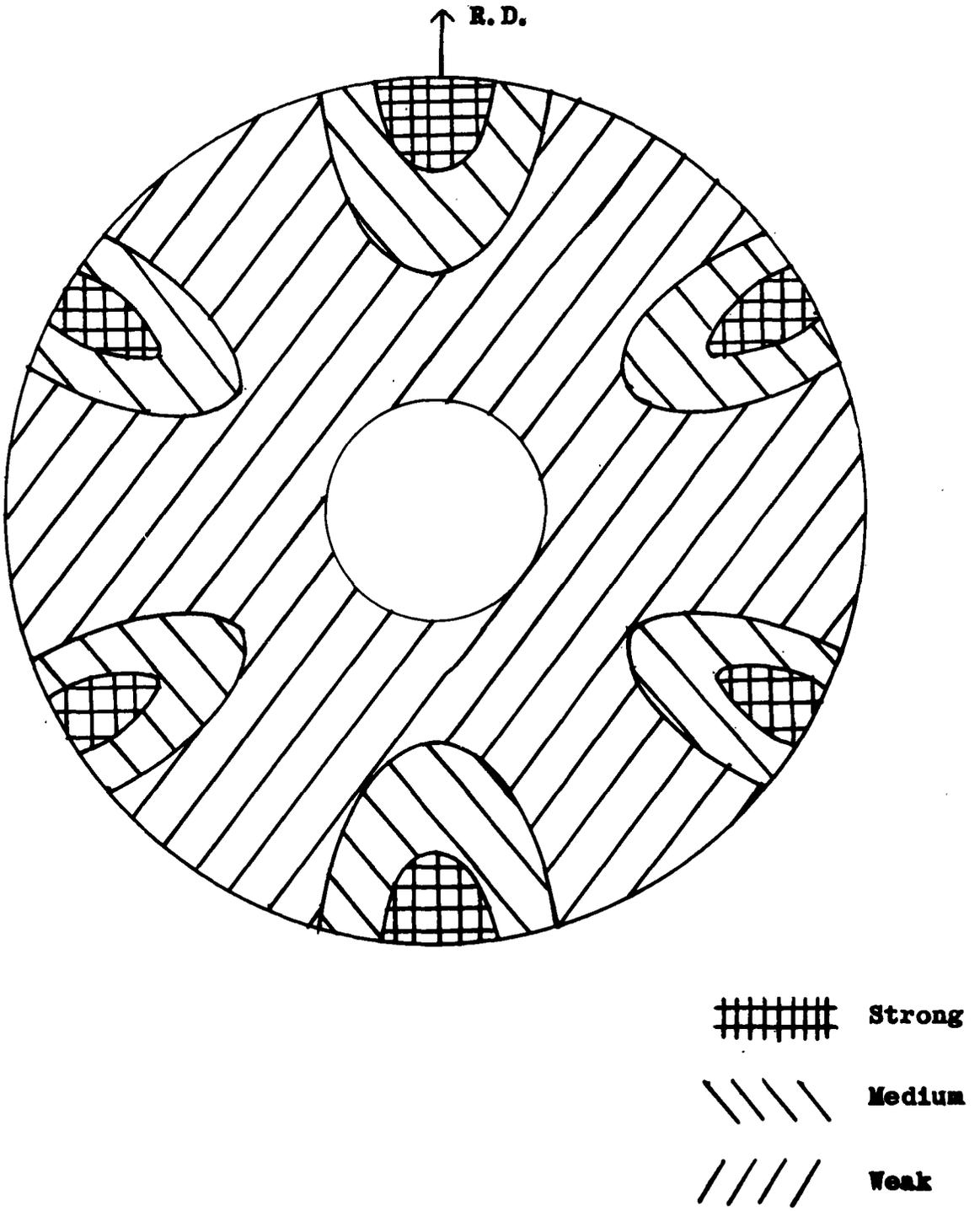
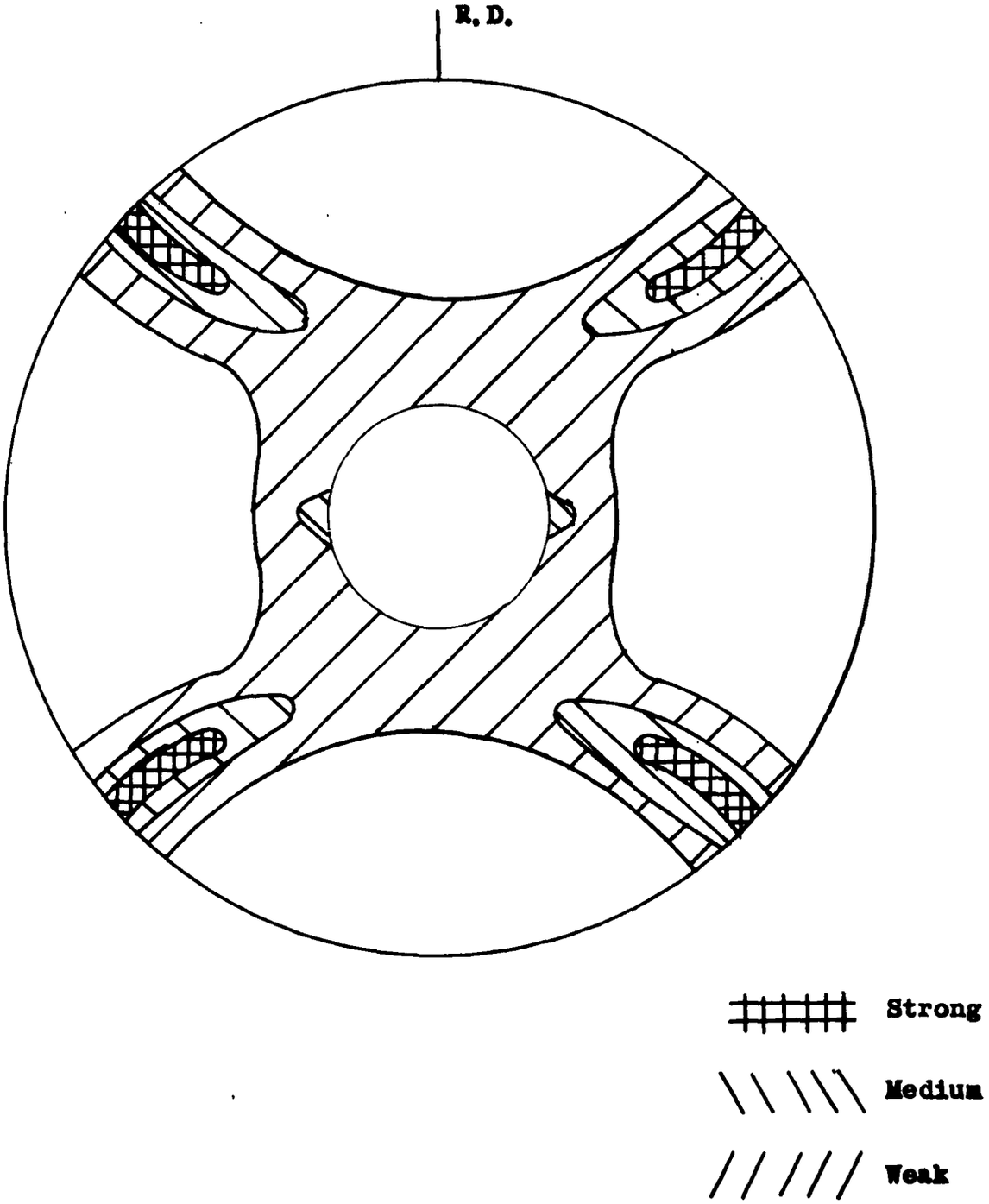


Figure 70 Pole Figure for Mill Processed Ti-2½Al-16V Strip Beta Phase (Heat R8848 - Annealed Condition)

(100) Plane



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Unclassified Report

This manufacturing process development determined techniques for strip processing to minimize high directional mechanical properties in three DOD titanium alloys. Full-scale strip

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