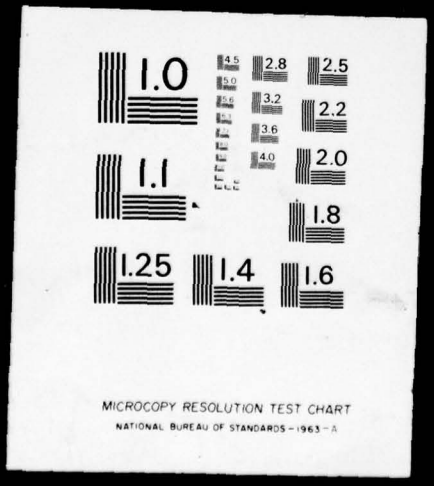
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Manufacturing Methods and Technology

# Improvement of Helicopter Forgings by Controlled Solidification and Thermal-Mechanical Treatments

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A four-task program was conducted to provide information for the development of industrial techniques for producing improved aluminum forgings. These techniques, involving intermediate thermal-mechanical treatment (ITMT) of ingot, were evaluated on the basis of microstructure, mechanical properties, fracture and fatigue properties, and resistance to stress corrosion. The results showed that ITMT forgings have equivalent tensile properties and stress corrosion resistance and at least 20% better fracture toughness and fatigue properties when compared to conventional 7075-T73 forgings.

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# FOREWORD

The Boeing Vertol Company of Philadelphia, Pennsylvania, prepared this report to satisfy the requirements of Contract DAAA25-74-C-0448. This project was accomplished through Frankford Arsenal as part of the U.S. Army Aviation Systems Command Manufacturing Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in production of Army materiel. Comments are solicitated on the potential utilization of the information contained herein as applied to present and/or future production programs. Such comments should be sent to: U.S. Army Aviation Systems Command, ATTN: AMSAV-EXT, P.O. Box 209, St. Louis, Mo. 63166. The U.S. Army Aviation Systems Command project engineer was Mr. James Tutka and the Frankford Arsenal contract technical supervisor was Dr. Jeffrey Waldman.

The Boeing Vertol Company acknowledges the support of the Aluminum Company of America in conducting this program.

Boeing Vertol Company personnel responsible for this program were Leonard J. Marchinski, Director, Structures Technology; Daniel M. Hardy, Program Manager; and Joseph C. Zola, Project Engineer. Aluminum Company of America personnel included Harold Y. Hunsicker, Physical Metallurgy Division Manager; James Staley, Program Manager; and John Vruggink, Project Engineer.

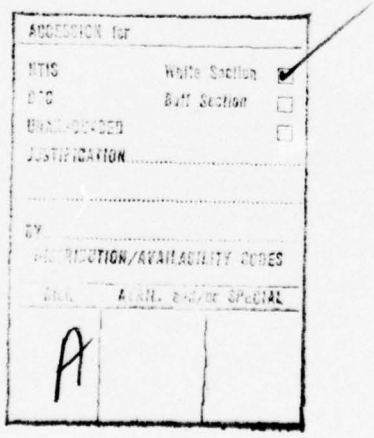


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## INTRODUCTION

In recent years, the aluminum industry has directed an intensive effort toward optimizing strength-toughness-stress-corrosion combinations in 2XXX- and 7XXX-series wrought alloys. Examples are 2419, 2124, 2048, 7050, and 7475 in aluminum-alloy plate and 2419, 7049, 7050, and 7175 in aluminum-alloy forgings. Development of these alloys has included work in the areas of alloy chemistry and processing. Reduction of intermetallic particles, both soluble and insoluble, has been broadly exploited.

Future improvements in structural properties, i.e., increased fracture toughness with no loss in strength, can be achieved through the application of microstructure control to products with optimum alloy chemistries to obtain desirable microstructures not now available with conventional processing methods. There are several approaches to controlling microstructure; they include powder metallurgy for wrought products, refinements in ingot-casting technology, advanced and specific thermomechanical treatments during ingot processing to improve and control grain size and morphology, and thermomechanical treatments following the solution-heat-treat operation which would establish new final precipitate and dislocation structures.

The objective of this program is to develop industrially viable fabrication schedules for producing aluminum-alloy forgings which will possess combinations of strength, fracture toughness, fatigue performance, and resistance to stress-corrosion cracking superior to that of 7075-T73.

## POWDER METALLURGY

The present powder-metallurgy (P/M) approach, i.e., the work of Cebulak[1], has not only concentrated its efforts in the area of high strength and toughness, but has also emphasized resistance to stress-corrosion cracking. The present P/M alloys offer considerable promise of providing superior combinations of the three properties. P/M alloys were not considered in this study because production quantities of P/M wrought products are not now available. Emphasis has been placed on ingot metallurgy approaches, particularly in the areas of thermomechanical treatment.

## FINAL-PROCESSING TMT (FTMT)

References 2 through 7 describe several procedures that involve a combination of thermal and mechanical treatments of 2XXX- and 7XXX-series alloys following solution heat treatment, i.e., prior to or during aging. Such concepts are not new; the T8 tempers of 2XXX alloys have been commercially available for many years. The newer TMT processes differ in that they generally involve preaging at artificial aging temperatures prior to mechanical working. They fall into two general categories:

- Those which seek to improve stress-corrosion resistance while suffering no loss in tensile properties or fracture toughness
- Those which seek to improve tensile strength, while minimizing loss in fracture toughness. These processes have not emphasized stress-corrosion resistance.

The first type, described by Sommer et al[2], involves elevated-temperature working of a T6-type temper to improve stress-corrosion resistance. The second type, described by a number of workers [3-8], produces strength-toughness combinations which may be attractive for certain high-strength applications of sheet or plate but do not require a high degree of resistance to stress-corrosion cracking. If it were possible to develop adequate stress-corrosion resistance using such methods, it is doubtful that these techniques could be adapted to the closed-die-forging practices which are the ultimate goal of this contract effort.
For these reasons, final-processing TMT was not included in this investigation.

## INGOT-PROCESSING TMT (ITMT)

It has been known for some time that a fine, recrystallized grain structure in sheet is a desirable microstructure for high toughness. In sheet form, these structures are usually obtained by cold-rolling prior to and recrystallizing during solution heat treatment.

Producing plate and forgings in a similar manner by cold-working prior to solution heat treatment has not been possible with today's alloys and fabrication procedures, largely because limited ductility prohibits introduction of sufficient cold work. Hence, commercially available, thick-section wrought products often have an unrecrystallized, highly elongated lamellar grain structure which, although desirable for some properties in some directions, is considered detrimental to fracture toughness in the short-transverse direction.

Recently, DiRusso et al[4] and Waldman et al[8] developed novel processes specifically designed to produce a fine-grained, recrystallized structure in 7XXX alloy plate. These processes, referred to as Intermediate Thermal-Mechanical Treatments, (ITMT) including establishing a preliminary structure amenable to recrystallization by applying appropriate thermal treatments prior to working at lower-than-conventional working temperatures (in the case of 7X75 plate, the warm-working temperature was 500°F). The warm working introduces relatively high degrees of strain hardening which promote recrystallization to a relatively fine-grained equiaxial grain structure during a subsequent high-temperature thermal treatment. ITMT methods produce products that have either a recrystallized grain structure or an altered grain structure produced by hot working the previously recrystallized structure; the latter procedure elongates the recrystallized grains. The resulting grain morphology is desirable for good fracture toughness and the general fabrication method involved in achieving this structure may be commercially feasible for forgings. For these reasons, the ITMT approach was selected for this study.

To effectively evaluate the advanced processing for applications to forging of hardware, the special technologies of the material producer and the airframe manufacturer have been combined. The material producer, Aluminum Company of America, applied recently developed methods to forging fabrication and the initial optimization of candidate processes. The airframe manufacturer, the Boeing Vertol Company, performed the final evaluation through structural-properties testing of the two most promising candidates identified by the material producer.

The final evaluation includes side-by-side testing of conventional 7075-T73 for comparison with the Intermediate-Thermal-Mechanical-Treatment alloys to permit a valid assessment of the impact of results on the design of helicopter structure.

## DISCUSSION

The Boeing Vertol Company, with subcontracted support from the Aluminum Company of America, conducted a four-part program to develop industrial techniques for producing improved aluminum-alloy forgings and to evaluate the forgings for use as components in helicopters.

The primary objective of this program is to develop industrial techniques for producing forgings ranging from 1 to 6.7 inches in section thickness and meeting the target properties shown below:

| | | |
|---|---|---|
| Tensile Properties | – | Equivalent to or better than 7075-T73 |
| Toughness | – | 20% better than 7075-T73 |
| Fatigue Properties | – | 20% better than 7075-T73 |
| Stress Corrosion | – | Equivalent to or better than 7075-T73 |

To achieve this objective, four tasks were identified for accomplishment.

### TASK I – SELECT ADVANCED PROCESSES FOR SCALE-UP

Task I was a laboratory-process-optimization effort, concentrating on a combination of alloy-chemistry and alloy-processing method to achieve the best combination of strength, fracture toughness, and resistance to stress-corrosion cracking as indicated by screening tests. Thirty-one advanced-alloy/process combinations or modifications on a 7475 alloy were selected for initial evaluation. The major parameters associated with the advanced processes include chemistry, solidification and homogenization, ingot processing, and thermal/mechanical treatments, and are based primarily on work done by investigators at the Frankford Arsenal, Massachusetts Institute of Technology, and Istituto Sperimentale dei Metalli Leggeri.

One 2 by 8 by 30-inch hand forging with pronounced longitudinal grain-flow characteristics was produced for each of the selected candidate alloy/process combinations. Thermal-mechanical treatment (TMT) was applied during ingot processing to control grain size and grain morphology. The tensile properties, fracture toughness, stress-corrosion resistance, and metallurgical structure of each forging were determined and, on the basis of these results, two optimum TMT practices were selected for scale-up to industrial status.

### TASK II – PRODUCE FORGINGS USING CONVENTIONAL AND SCALED-UP ADVANCED PROCESSES

During Task II, scaled-up forgings for detailed testing were produced at Alcoa's Cleveland Works. The test forgings selected are representative of helicopter structural components and were 17 inches wide with section thicknesses of 6.7, 2.0, and 1.0 inch, respectively (see Figure 1). In addition to these three forgings for each optimum TMT process, conventional 7075-T73 forgings were produced in the same sizes. A total of nine scaled-up forgings were produced and delivered to the Boeing Vertol Company.

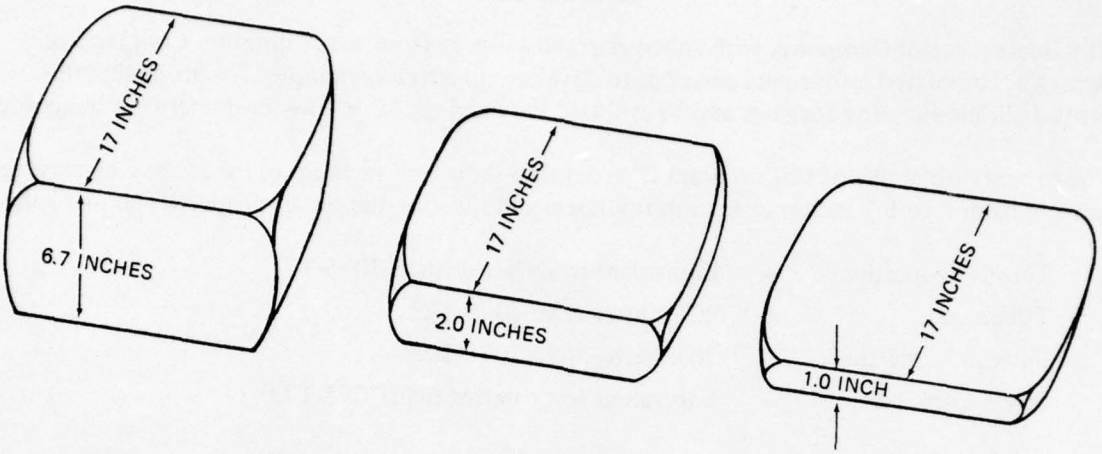



Figure 1. Individual Task II Forgings for Conventional 7075-T73 and 7475-TMT1 and 7475-TMT2 Alloys.

## TASK III – CONDUCT MECHANICAL-PROPERTIES TESTS ON FORGING MATERIAL

In this phase of the program the room-temperature mechanical properties of the nine forgings produced in Task II would be determined by test. The following characteristics would be measured:

a. Tensile properties as determined using ASTM procedures and specimen configuration. Tests would be conducted on specimens with longitudinal grain direction and on specimens with short-transverse grain direction.

b. Fracture-toughness properties would be determined using a compact-specimen configuration and test procedures per ASTM method E399-72T[10]. Properties for the longitudinal and short-transverse grain directions would be established.

c. Fatigue properties would be determined on axially loaded specimens. Constant-amplitude fatigue-stress levels for testing would be selected with the objective of obtaining data over the life range from $10^4$ to $5 \times 10^7$ cycles. The influences of stress ratio (minimum stress/maximum stress), stress concentration, and grain direction would be investigated.

d. Fatigue-crack-propagation properties would be determined using the compact-specimen configuration and constant-amplitude fatigue loading. The influences of an air environment and a salt-solution environment would be investigated. In addition, the properties of the longitudinal and short-transverse grain directions would be determined.

e. Stress-corrosion-resistance properties would be established using Federal Test Method 823 or the latest recommendation of Joint Aluminum Association-ASTM Task Group for stress-corrosion testing of high-strength 7000-series aluminum alloys.

## TASK IV – ANALYZE AND EVALUATE DATA

The objectives of this task are to analyze and evaluate the metallurgical and mechanical-properties data developed in the previous tasks and to assess the impact of improved mechanical properties on the weight and cost of helicopter components.

The influence of the processing on properties will be identified. Primary emphasis will be placed on ranking the candidate processing techniques with respect to their ability to improve tensile, fatigue, fracture, and stress-corrosion-resistance properties. The properties obtained with the advanced-alloy/process combinations will be compared with the properties obtained from the conventionally processed 7075-T73. The parameters used for comparison will include those identified in Table 1.

TABLE 1. COMPARISON OF PROPERTIES

| Basis of Comparison | Parameters for Making Comparison |
|---|---|
| Tensile properties | Tensile ultimate strength<br>Tensile yield strength<br>Elongation<br>Reduction in area |
| Fatigue properties | Fatigue limit at $5 \times 10^7$ cycles<br>S-N curve, fatigue strength as a function of life<br>Goodman diagram, mean-stress/alternating-stress relationship for various constant cyclic lifetimes |
| Fracture properties | Plane-strain fracture toughness per ASTM 399-70T<br>Notched tensile-strength-to-yield-strength ratio |
| Fatigue-crack-propagation properties | Fatigue-crack-growth rate as a function of stress-intensity level |
| Stress-corrosion resistance | Stress levels and times for stress<br>Corrosion cracking as identified from testing according to Federal Test Method 823 or Joint Aluminum Association-ASTM task group for stress-corrosion testing |

Metallurgical analyses will be directed toward understanding the mechanisms relating the processing and resulting microstructure to the mechanical properties. This will help identify the optimum process for a specific application.

The culmination of the program is the evaluation of the candidate materials for application to helicopter components. The evaluation answers the question, "Is it cost-effective to use these advanced processes to produce forgings for helicopter components?" Obviously, the answer

depends on the details of the specific application. One of the objectives of this analytical task is to provide evaluations for some specific applications and to provide the guidelines whereby the cost-effectiveness of other applications can be evaluated.

Many considerations, such as cost, weight, reliability, and maintainability, govern the design of a helicopter structural component. Weight is a basic concern in such applications and results directly from satisfying structural requirements related to parameters such as static strength, fatigue strength, and failsafe or damage-tolerance strength.

Many current and proposed helicopter dynamic-system components are aluminum forgings; typical components are shown in Figure 2. These components are generally sized by fatigue-strength considerations. Advanced processes for aluminum forgings possessing increased fatigue strength have potential for weight savings in direct proportion to the increase in strength.

The weight-savings potential for helicopter components sized to damage-tolerance requirements will also be evaluated.

Typical weight savings will be determined for various loading criteria. The next step is to establish whether the potential weight savings are cost-effective. This will be achieved through consideration of forging costs, the amount of weight saved, the number of components involved, and the value of a unit of weight in the aircraft cost analysis.

Each task is discussed in detail in the following sections.

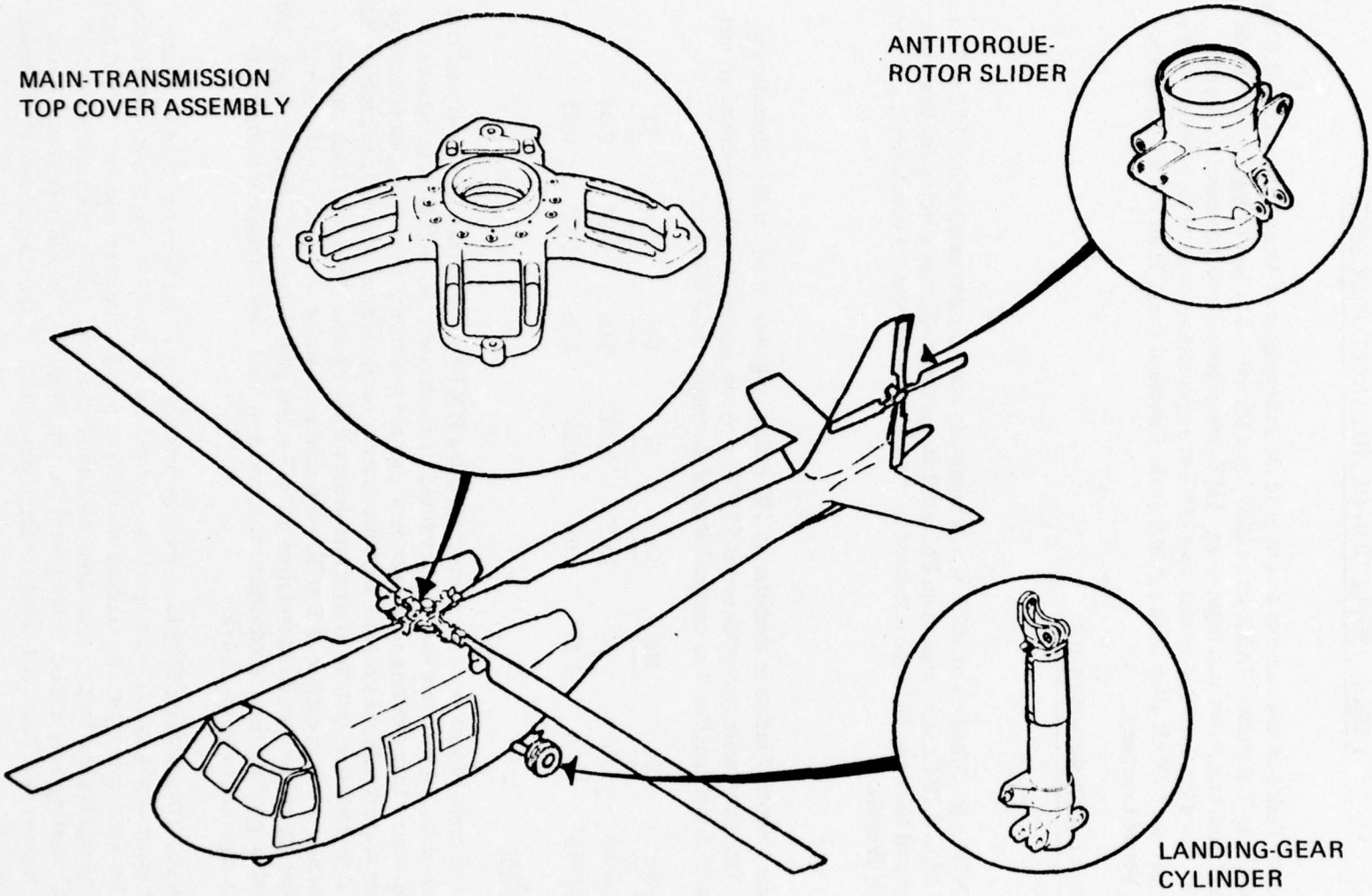



Figure 2. Examples of Forged-Aluminum Components on Current Helicopters.

## TASK I – SELECTION OF ADVANCED PROCESSES

The goal of Task I of this contract was to produce and evaluate at Alcoa Laboratories 1.0- and 2.0-inch-thick, high-purity, 7XXX-series alloy hand forgings. The hand forgings were to be produced from laboratory cast ingot using ITMT-type practices and a commercial forging practice. Based on these evaluations, two ITMT-type procedures were to be selected to produce high-purity 7XXX alloy hand forgings at the Cleveland Forge Plant for testing by the Boeing Vertol Company.

### MATERIAL AND PROCEDURE

#### Alloy

Alloy 7475, a modification of 7075, which nominally contains percentages at 5.70 Zn, 2.25 Mg, 1.55 Cu, 0.20 Cr, 0.12 maximum Fe, and 0.10 maximum Si, was selected for this work. The iron and silicon in 7475 are restricted to the lowest values that are considered to be commercially feasible.

#### Ingot

Direct-chill ingots, 7 inches in diameter by 100 inches long, were used for the fabrication in Task I. The ingots were stress-relieved at 575°F, cropped, scalped to 6.5-inch diameter, and cut into 15.5-inch lengths. The compositions of the ingots are as follows:

| S-No. | Zn | Mg | Cu | Cr | Fe | Si | Ti |
|---|---|---|---|---|---|---|---|
| 426669 | 5.96 | 2.31 | 1.63 | 0.20 | 0.06 | 0.04 | 0.01 |
| 437666 | 5.84 | 2.23 | 1.69 | 0.20 | 0.06 | 0.05 | 0.03 |

#### Fabrication

Two broad types of structures were produced using ITMT-type practices: (1) a recrystallized structure, and (2) a structure that was produced by moderately hot-working a structure that had been recrystallized during an intermediate thermal treatment. In addition, hand forgings having an unrecrystallized structure were produced for comparison. Attempts to produce the desired fine-grained recrystallized structure proceeded in phases. The initial trials employed warm-forging at a temperature of 500°F, the temperature which was found to produce the target fine-grained recrystallized structure in 7475 rolled plate using ITMT-type practices. When this failed to produce the desired structure, succeeding trials were carried out using warm-forging temperatures below 500°F.

The 1.0- and 2.0-inch-thick 7475 hand forgings produced in Task I were obtained by a combination of upsetting and drawing operations carried out at various temperatures. The forging operations were carried out, maintaining as closely as possible the desired temperature in each case by suspending the forging operations when the temperature of the billet increased 50°F above the starting temperature, holding until the temperature of the billet decreased to the starting temperature, then continuing the forging operation. If the temperature of the billet

decreased 25°F below the starting temperature during forging, the forging operation was stopped and the billet was reheated to the starting temperature; the forging operation was then continued.

The deformation introduced during each of the forging steps was measured by the value N (N = original dimension in the direction of greatest reduction/final dimension in the direction of greatest reduction). In many of the forging sequences, several N values are required to describe the deformation obtained because the billet was deformed in several directions between succeeding thermal treatments.

The size of the starting ingot sections was restricted by the capacity of the forging press, the size of the dies, and the maximum L/D ratio allowed for upsetting operations. In upsetting an ingot section or forging billet, the relationship between the length of the section in the direction of upsetting and the smallest dimension perpendicular to the direction of upsetting (L/D) is critical. To obtain the proper metal flow, the L/D ratio must be no greater than 3 and in most commercial forging operations involving upsetting the L/D ratio is a maximum of 2.4. In the forging work in Task I, a maximum L/D ratio of 2.4 was used.

The practices used in Phase I to fabricate 1.0- and 2.0-inch-thick 7475-T7X hand forgings by ITMT-type practices are described in detail in Tables 2 and 3. Alloy 7475 hand forgings 1.0 and 2.0 inches thick having an unrecrystallized structure were also produced. Practices patterned after the Frankford Arsenal ITMT (FA-ITMT) plate practice (forgings S-426669-7 and -13) were also included in Phase I. The target fine-grained recrystallized structure was not obtained in the hand forgings fabricated in this phase (500°F forging temperature); consequently lower forging temperatures were investigated in Phase II.

The practices used in Phase II to fabricate 1.0- and 2.0-inch-thick forgings by ITMT-type procedures are described in Tables 4 and 5. These practices evaluated warm-forging temperatures of 350–400°F in conjunction with the same thermal treatments and forging sequences used in Phase I. The target fine-grained recrystallized structure was again not obtained in the hand forgings fabricated in Phase II. The use of the 350°F temperature taxed the capacity of the forging press so this temperature was not used in Phase III. Thus, other thermal treatments and forging sequences were evaluated in Phase III.

The practices used in Phase III to fabricate 1.00- to 2.25-inch-thick forgings by ITMT-type practices are described in Tables 6 and 7. A practice patterned after the Instituto Sperimentale dei Metalli Leggeri (ISML-ITMT) plate practice (forgings S-437666-26A and -26B) and variations in the warm-forging sequences at 400°F were tried in Phase III. Several thicknesses of finished hand forgings were fabricated from the same ingot section by producing stepped hand forgings. An acceptable fine-grained recrystallized structure was obtained in the 1.0-inch-thick portion of a 7475-T7X hand forging produced in Phase III.

The forging practices used in Phases I, II, and III are described pictorially in Figures 3 through 33.

### Thermal Treatments

A temperature of 960°F was used for the majority of the ingot preheats*, billet reheats, recrystallization, and solution-heat treatments in this work because prior Alcoa work demonstrated beneficial effects of the 960°F treatments on fracture toughness. (Refer to U.S. Patent No. 3, 791, 880). Work at Alcoa under U.S. Army Contract DAAA25-73-C-0657 showed no adverse effects of a 960°F temperature on the recrystallized grain size of 7475 plate produced using ITMT-type practices. All thermal treatments were carried out using circulating-air furnaces.

Sections of the 1.00- to 2.25-inch-thick 7475 hand forgings were solution-heat-treated, quenched, and artificially aged as indicated in Tables 2 through 7 and in Figure 34.

### Grain-Size Determination

The grain dimensions were determined at the T/2 location of the 1.00- to 2.25-inch-thick forgings from grain counts made microscopically using the linear-intercept method. The locations of samples used for the grain counts are shown in Figure 34.

### Property Determination

The location, number, and type of specimens used to determine the properties of the forgings are described in Figure 35. The notched-tensile and compact-tension fracture-toughness specimen configurations are shown in Figures 36 and 37. Short-transverse mechanical properties could be determined only on the 2.00- to 2.25-inch-thick forgings because of specimen size limitations.

The resistance to stress-corrosion cracking of selected forgings was determined by exposing stressed specimens to a 3.5-percent NaCl solution by alternate immersion for 84 days as described by Federal Test Method 823. Triplicate longitudinal 0.125-inch-diameter threaded-end tensile specimens from 1.0- and 2.0-inch-thick forgings, similar short-transverse specimens from 2.0-inch-thick forgings, and triplicate short-transverse 0.75-inch-diameter C-rings from 1.0-inch-thick forgings were exposed stressed at a level of 45 ksi.

## RESULTS AND DISCUSSION

Grain counts, mechanical-property, and corrosion data are presented in Tables 8 through 16 The mechanical-property values reported are the results of single tests made on the samples aged by each practice. In the following paragraphs, the effects of forging practice on grain dimensions are discussed first, next the effects of yield strength on the mechanical properties, then the relationship between grain structure and the mechanical properties and the effect of grain structure on the resistance to stress-corrosion cracking.

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*The use of 960°F thermal treatments on the nonhomogeneous material requires a preheat at lower temperature to eliminate nonequilibrium phases.

## ITMT Forging Variables Versus Grain Dimensions

The ITMT-type forging practices in Task I were used to evaluate the merits of nonconventional-type processing and explore the possibility of developing a commercially viable ITMT process to produce a fine-grained recrystallized structure in 7475-T73 hand forgings. The forging practices used were designed to determine whether ITMT practices could produce 7475 hand forgings having a fine-grained recrystallized structure and were not designed to optimize or completely survey the effects of individual fabricating variables. The warm-forging temperature, reduction during warm forging, and reduction during the ingot breakdown by hot-forging at 750°F were not changed in a systematic fashion, and thus the individual effect of each fabricating variable on the grain dimensions of the hand forging is difficult to determine.

The grain counts, average grain dimensions calculated from the grain counts, and the fabricating variables for the forgings produced using ITMT practices are given in Table 16. Three-dimensional photomicrographs at 100X showing the grain structures obtained are included as Figures 3 through 33. The grain thickness, grain width, grain length, and aspect ratio (grain length/grain thickness) of the recrystallized 7475-T7X hand forgings in Table 16 are plotted as functions of the reduction applied during the warm-forging operation (N) in Figure 38. For the forgings produced using sequential warm-forging operations, the value for N used in the plots is the sum of the N values for each separate forging operation.

While no significant relationships were evident between the grain dimensions in the 1.00- to 2.25-inch-thick 7475-T7X ITMT hand forgings and the reductions applied during warm-forging, generalizations concerning the forging operations and the grain structure obtained in the 7475-T7X ITMT hand forgings can be made:

1. Forging the ingot at 750°F prior to warm-forging was beneficial in obtaining a fine-grained recrystallized structure.

2. Warm-forging at a temperature of 400°F produced a finer-grained recrystallized structure in the hand forging than did warm-forging at a temperature of 500°F.

3. Increasing the amount of warm-forging at temperatures of 400°F and 500°F decreased the grain thickness of the recrystallized structure in the forgings.

4. Subsequent forging at 750°F of the prior recrystallized structure increased the aspect ratio of the grains, i.e., decreased the grain thickness and increased the grain length.

5. Reductions of up to N = 9.1 at a warm-forging temperature of 550°F and up to N = 4.4 at a warm-forging temperature of 500°F did not produce a recrystallized structure in the hand forging when the ingot was not initially forged at 750°F.

## Mechanical Properties Versus Yield Strength

Ductility and toughness often correlate with yield strength. Consequently, percentage elongation and reduction-in-area values, notched-tensile-strength/yield-strength ratios, and $K_Q$ values (Tables 8 through 14) were plotted as functions of yield strength for the longitudinal

properties in Figure 39, and for the short-transverse properties in Figure 40. The only consistent relationship found was between longitudinal notched-tensile-strength/yield-strength ratio and the yield strength. The longitudinal notched-tensile-strength ratio decreased with increasing yield strength.

The longitudinal and short-transverse yield strengths were well above the minimum yield strengths specified for 7075-T73 hand forgings up to 3.00-inches in thickness (longitudinal 56.0 ksi and short-transverse 52.0 ksi).

## Grain Structure Versus Mechanical Properties

The use of several second-step aging practices provided three sets of mechanical properties for each forging. To minimize the number of data points for graphical analyses to determine the effect of grain dimensions on ductility and toughness, the average elongations and reduction-in-area values and the average notched-tensile-strength/yield-strength ratios for each ITMT forging (Tables 8 through 12), along with maximum and minimum values, were plotted as functions of the grain dimensions. Single $K_Q$ values were also plotted.

The data for the longitudinal direction (Figures 41 through 46) show no consistent change in the elongation, reduction-in-area, notched-tensile-strength/yield-strength ratio, or $K_Q$ values with decreasing grain thickness, decreasing grain width or thickness, or with increasing grain aspect ratios. However, there is an indication that the longitudinal reduction in area increases with decreasing grain thickness.

The short-transverse data (Figures 47 through 50) show that the only consistent change in ductility and toughness with variations in grain dimensions is in the reduction in area and notched-tensile-strength/yield-strength ratio. The reduction in area increased with decreasing grain thickness and the notched-tensile-strength/yield-strength ratio decreased with decreasing grain length or width.

## Grain Structure Versus Stress-Corrosion Cracking

The results of accelerated stress-corrosion tests of longitudinal and short-transverse specimens are summarized in Tables 14 and 15, respectively. The results predict that the resistance to stress-corrosion cracking will be relatively high for 7475 hand forgings having a recrystallized-plus-hot-worked structure, a recrystallized structure, or an unrecrystallized structure when aged 24 hours at 250°F plus 8 hours at 350°F. Longitudinal and short-transverse specimens from all forgings tested satisfied the 30-day, 3.5-percent NaCl alternate-immersion-capability test specified for 7075-T73 forgings in MIL-A-22771D.

## COMMENTARY

The results of the work carried out in Task I of this contract showed the following:

1. An ITMT-type practice of hot-forging at 750°F, warm-forging at 400°F, and recrystallizing at a temperature of 960°F produced a fine-grained recrystallized structure in 7475-T7X hand forgings.

2. The longitudinal and short-transverse tensile, ductility, and notched-tensile-strength/yield-strength ratios were similar for 7475-T7X hand forgings having a recrystallized-plus-hot-worked structure and an unrecrystallized structure.

3. The longitudinal notched-tensile-strength/yield-strength ratios and $K_Q$ values obtained on 7475-T7X hand forgings, regardless of the structure, were superior to similar properties of 7075 hand forgings at the same strength level.

## TABLE 2. FORGING PRACTICES USED TO FABRICATE 1-INCH-THICK 7475-T7X HAND FORGINGS IN PHASE I

| Forging Operation | | | | | 6.5 $\phi$ x 15.5-In. Ingot Section | | | | Forged Billet | | | | | Recrystallization | | Forging by Drawing at 750°F, | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grain Count, G/mm | | | | Forging Operation | | | | | Forging Operation | | | | | Reduction, | Solution-Heat-Treat |
| S-No. | Size (in.) | X | Y | Z | Thermal Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Thermal Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Thermal Treatment | N | Temperature (°F) |
| 426669-8 | 1x8x64 | 4 | 2 | 24 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 2.3 | 7x8x9 | A | 500 | Draw | 7.0 | 1x8x64 | 10 hr/960°F | None | 2 hr/960 |
| 426669-9 | 1x8x64 | 8 | 3 | 24 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 4.0 | 4x8x16 | A | 500 | Draw | 4.0 | 1x8x64 | 10 hr/960°F | None | 2 hr/960 |
| 426669-10 | 1x8x64 | 5 | 3 | 20 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 8.0 | 2x8x32 | A | 500 | Draw | 2.0 | 1x8x64 | 10 hr/960°F | None | 2 hr/960 |
| 426669-11 | 1x8x64 | 3 | 2 | 40 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 2.3 | 7x8x9 | A | 500 | Draw | 4.1 | 1.7x8x38 | 10 hr/960°F | 1.7 | 2 hr/960 |
| 426669-12 | 1x8x64 | 5 | 2 | 43 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 4.6 | 3.5x8x16 | A | 500 | Draw | 2.1 | 1.7x8x38 | 10 hr/960°F | 1.7 | 2 hr/960 |
| 426669-13 | 1x8x64 | 1 | 1 | 19 | B | 500 | Upset & draw | 9.1 | → | | | | | 1.7x8x38 | 10 hr/860°F | 1.7 | 2 hr/860 |
| 426669-14 | 1x8x64 | Unrecrystallized | | | → | | | | | | | | | | | | 2 hr/960 |

NOTES:
1. Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; B heated 20 hours at 860°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
2. Forged-billet thermal treatment: A heated 2 hours 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
3. All thermal treatments carried out in circulating-air furnaces.

## TABLE 3. FORGING PRACTICES USED TO FABRICATE 2-INCH-THICK 7475-T7X HAND FORGINGS IN PHASE I

| Final Forging | | | | | | 6.5 ϕ x 15.5-In. Ingot Section | | | Forged Billet | | | | | | | | Forging by Drawing at 750°F | Solution - Heat-Treat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grain Count, G/mm | | | | Forging Operation | | | | | Forging Operation | | | Recrystallization | | | | |
| S-No. | Size (in.) | X | Y | Z | Thermal Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Thermal Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Thermal Treatment | | Reduction, N | Temperature (°F) |
| 426669-1 | 2x8x32 | 1 | 1 | 36 | A | 750 | Upset & draw | 2.8 | | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 2.3 | 7x8x9 | A | 500 | Draw | 2.0 | 3.5x8x18 | 10 hr/960°F | | 1.8 | 2 hr/960 |
| 426669-2 | 2x8x32 | 7 | 2 | 19 | A | 750 | Upset & draw | 2.8 | | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 4.0 | 4x8x16 | A | 500 | Draw | 2.0 | 2x8x32 | 10 hr/960°F | | None | 2 hr/960 |
| 426669-3 | 2x8x32 | 1 | 1 | 6 | A | 750 | Upset & draw | 2.8 | | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 2.0 | 8x8x8 | A | 500 | Draw | 4.0 | 2x8x32 | 10 hr/960°F | | None | 2 hr/960 |
| 426669-5 | 2x8x32 | 1 | 1 | 28 | A | 750 | Upset & draw | 2.8 | | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 2.0 | 8x8x8 | A | 500 | Draw | 2.0 | | | | | |
| | | | | | | | | | | | 500 | Upset & draw | 2.3 | 3.5x8x18 | 10 hr/960°F | | 1.8 | 2 hr/960 |
| 426669-6 | 2x8x32 | 4 | 2 | 24 | A | 750 | Upset & draw | 2.8 | | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 2.0 | 8x8x8 | A | 500 | Draw | 2.0 | | | | | |
| | | | | | | | | | | | 500 | Upset & draw | 2.3 | | | | | |
| | | | | | | | | | | | 500 | Upset & draw | 2.7 | 3x8x21 | 10 hr/960°F | | 1.5 | 2 hr/960 |
| 426669-7 | 2x8x32 | Unrecry | | | B | 500 | Upset & draw | 4.4 | → | | | | | 3.5x8x18 | 10 hr/860°F | | 1.8 | 2 hr/860 |
| 426669-15 | 2x8x32 | Unrecry | | | | → | | | | | | | | | | | | 2 hr/960 |
| 426669-16 | 2x8x32 | 3 | 2 | 17 | A | 750 | Upset & draw | 2.8 | | | | | | | | | | |
| | | | | | | | Upset & draw | 2.3 | 7x8x9 | A | 500 | Draw | 1.8 | | | | | |
| | | | | | | | | | | | 500 | Upset & draw | 4.0 | 2x8x32 | 10 hr/960°F | | None | 2 hr/960 |

NOTES:

1. Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; B heated 20 hours at 860°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
2. Forged-billet thermal treatment: A heated 2 hours 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
3. All thermal treatments carried out in circulating-air furnaces.

## TABLE 4. FORGING PRACTICES USED TO FABRICATE 1-INCH-THICK 7475-T7X HAND FORGINGS IN PHASE II

| Final Forging | | | | | 6.5 $\phi$ x 15.5-In. Ingot Section | | | | Forged Billet | | | | | Recrystallization | | Forging by Drawing at 750°F, Reduction, N | Solution-Heat-Treat Temperature (°F) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grain Count, G/mm | | | | Forging Operation | | | | | Forging Operation | | | | | | |
| S-No. | Size (in.) | X | Y | Z | Thermal Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Thermal Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Thermal Treatment | | |
| 426669-17 | 1x8x64 | 2 | 2 | 24 | B | 400 | Upset & draw | 15.5 | → | | | | | 1x8x64 | 10 hr/860°F | None | 2 hr/860 |
| 426669-18 | 1x8x64 | 5 | 3 | 25 | C | 400 | Upset & draw | 15.5 | → | | | | | 1x8x64 | 10 hr/960°F | None | 2 hr/960 |
| 426669-19 | 1x8x64 | 6 | 3 | 50 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 3.1 | 5x8x13 | A | 400 | Upset & draw | 7.7 | 1.7x8x38 | 10 hr/960°F | 1.7 | 2 hr/960 |
| 426669-20 | 1x8x64 | 6 | 3 | 16 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 3.1 | 5x8x13 | A | 400 | Upset & draw | 13 | 1x8x64 | 10 hr/960°F | None | 2 hr/960 |
| 426669-22 | 1x8x64 | 2 | 1 | 22 | B | 400 | Upset & draw | 9.1 | → | | | | | 1.7x8x38 | 10 hr/860°F | 1.7 | 2 hr/860 |
| 426669-23 | 1x6x85 | 3 | 2 | 30 | B | 350 | Upset & draw | 15.5 | → | | | | | 1x6x85 | 10 hr/860°F | None | 2 hr/860 |

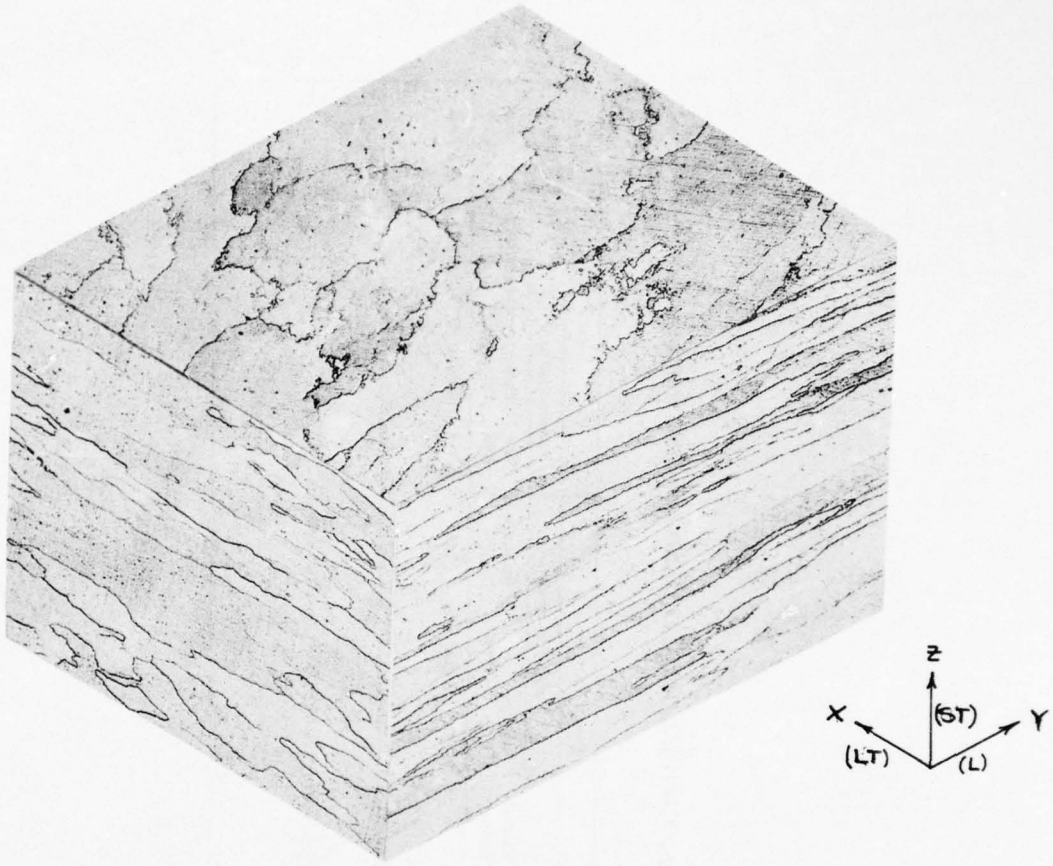
NOTES:

1. Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; B heated 20 hours at 860°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F; C heated 6 hours at 860°F plus 20 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
2. Forged-billet thermal treatment: A heated 2 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
3. All thermal treatments carried out in circulating-air furnaces.

## TABLE 5. FORGING PRACTICE USED TO FABRICATE 2-INCH-THICK 7475-T7X HAND FORGING IN PHASE II

| Final Forging | | | | | 6.5 $\phi$ x 15.5-In. Ingot Section | | | | Forged Billet | | | | | | | Forging by Drawing at 750°F, Reduction, N | Solution – Heat-Treat Temperature (°F) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grain Count, G6mm | | | | Forging Operation | | | | | Forging Operation | | | Recrystallization | | | |
| S-No. | Size (in.) | X | Y | Z | Thermal Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Thermal Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Thermal Treatment | | |
| 426669-21 | 2x8x32 | 15 | 7 | 32 | A | 750<br>750 | Upset & draw<br>Upset & draw | 2.8<br>3.1 | 5x8x13 | A | 400 | Upset & draw | 6.5 | 2x8x32 | 10 hr/960°F | None | 2 hr/960 |

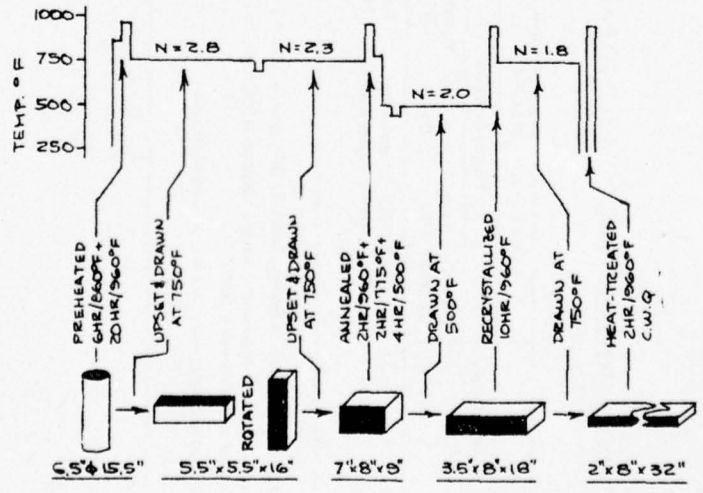
NOTES:
1. Ingot thermal treatment: A heated 6 hours at 860°F plus 20 hours at 960°F.
2. Forged-billet thermal treatment: A heated 2 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
3. All thermal treatments carried out in circulating-air furnaces.




MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING



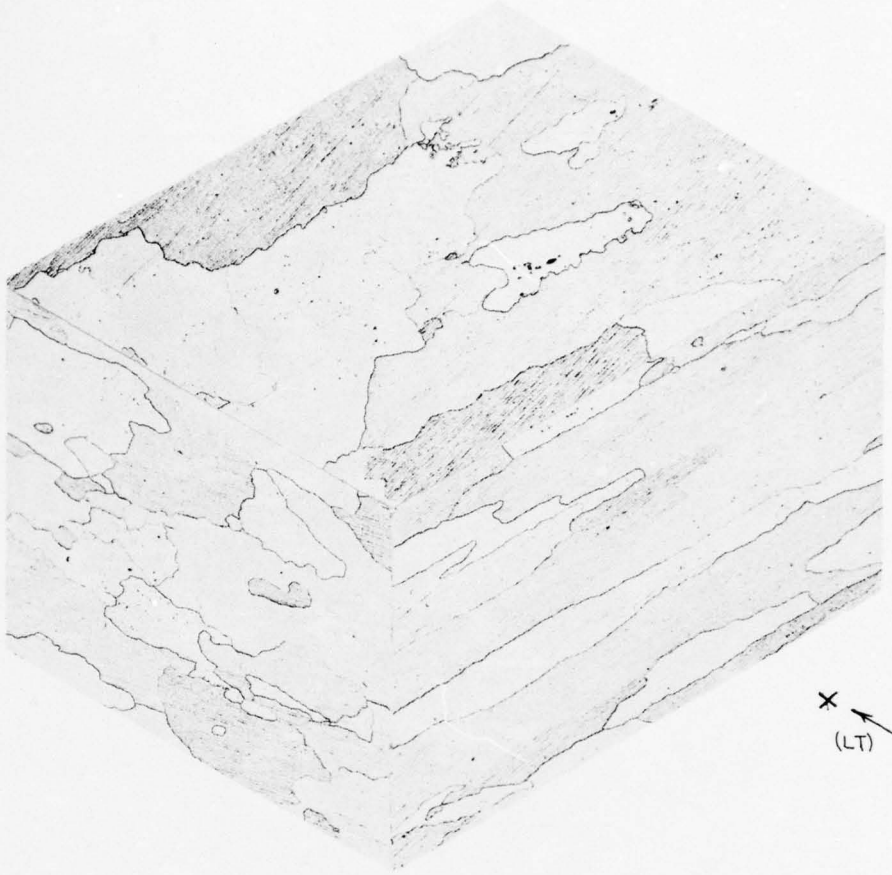

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 1 | 1 | 36 | 36 |

PROPERTIES

| 2ND STEP AGE | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TS KSI | YS KSI | EL % | R/A % | NTS KSI | NTS/YS | TS KSI | YS KSI | EL % | R/A % | NTS KSI | NTS/YS |
| 4HR/350°F | 77.3 | 70.7 | 15.7 | 43 | 102.1 | 1.44 | 77.4 | 70.1 | 10.9 | 18 | 101.1 | 1.44 |
| 6HR/350°F | 74.5 | 66.4 | 17.1 | 45 | 101.1 | 1.52 | 75.1 | 63.8 | 9.4 | 18 | 99.1 | 1.55 |
| 8HR/350°F | 72.9 | 64.2 | 18.6 | 46 | 102.7 | 1.60 | 72.1 | 60.8 | 7.8 | 11 | 91.9 | 1.51 |

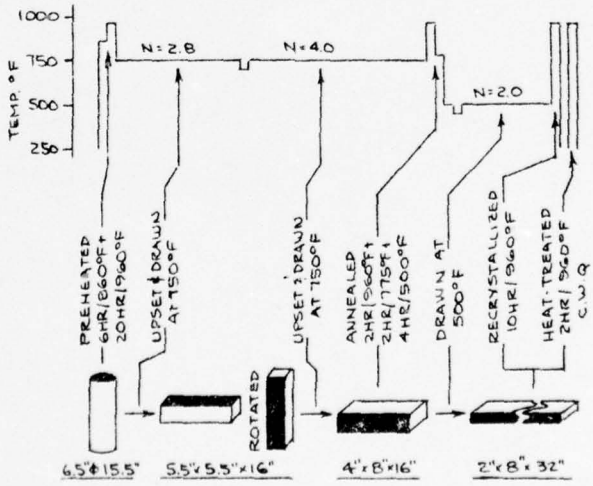
Figure 3. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-1.




MAG. 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING



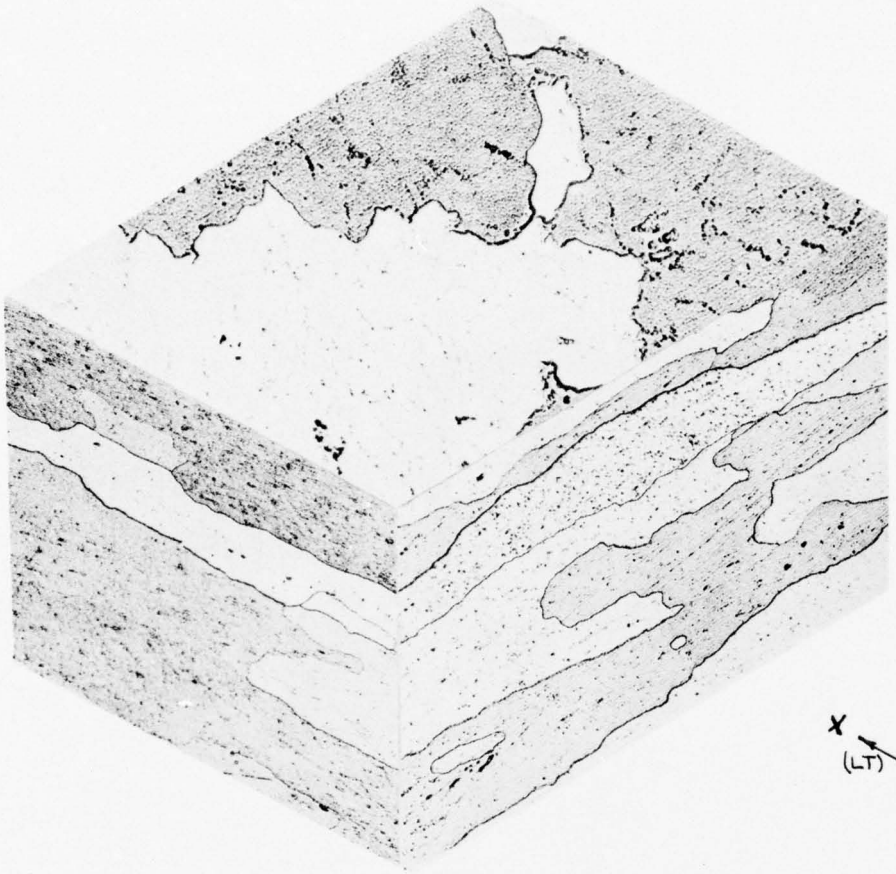

GRAIN COUNTS

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 7 | 2 | 19 | 266 |

PROPERTIES

| 2ND STEP AGE | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T.S. KSI | Y.S. KSI | EL % | R/A % | N.T.S. KSI | N.T.S. / T.S. | T.S. KSI | Y.S. KSI | EL % | R/A % | N.T.S. KSI | N.T.S. / Y.S. |
| 4HR/350°F | 78.3 | 70.7 | 14.3 | 19 | 103.2 | 1.46 | 79.1 | 68.7 | 6.2 | 6 | 89.9 | 1.31 |
| 6HR/350°F | 76.9 | 67.9 | 12.9 | 24 | 98.6 | 1.45 | 78.4 | 66.4 | 9.4 | 11 | 91.9 | 1.38 |
| 8HR/350°F | 74.9 | 65.4 | 13.6 | 30 | 99.1 | 1.51 | 73.1 | 65.7 | 4.7 | 6 | 93.0 | 1.42 |

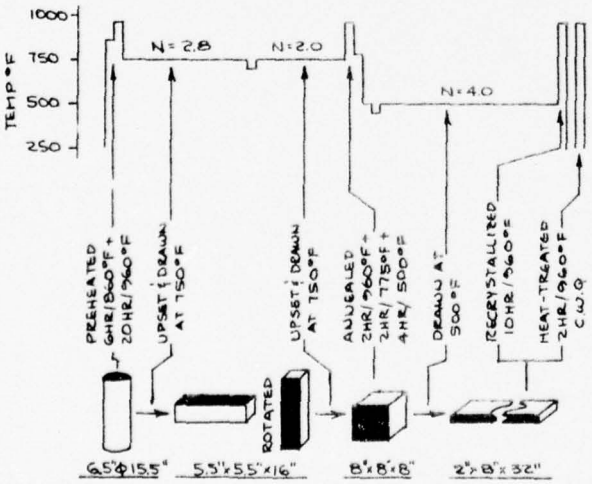
Figure 4. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-2.




MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING



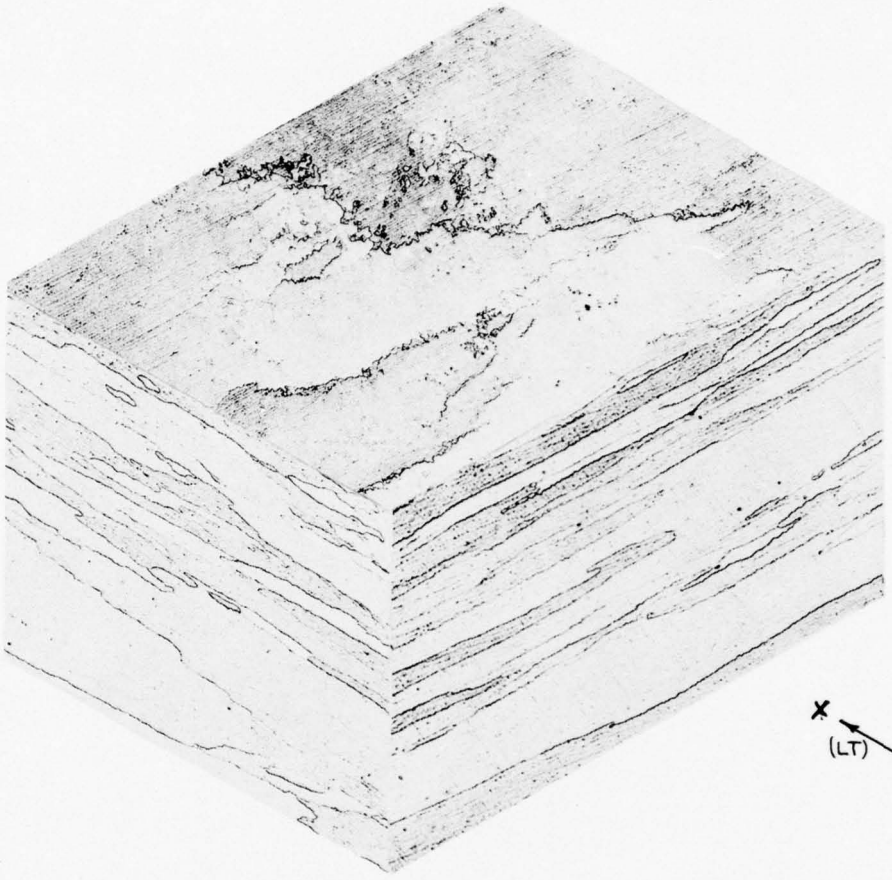

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 1 | 1 | 6 | 6 |

PROPERTIES

| | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ZUP STED AGE | T.S. KSI | Y.S. KSI | EL % | R/A % | NTS KSI | NTS Y.S. | T.S. KSI | Y.S. KSI | EL % | R/A % | NTS KSI | NTS Y.S. |
| 4HR/350°F | 77.3 | 70.9 | 14.5 | 27 | 98.6 | 1.39 | 74.6 | 67.9 | 4.7 | 7 | 90.4 | 1.33 |
| 6HR/350°F | 75.1 | 67.4 | 14.3 | 30 | 98.6 | 1.46 | 73.6 | 63.1 | 7.8 | 7 | 99.6 | 1.57 |
| 8HR/350°F | 73.9 | 65.9 | 13.6 | 30 | 99.6 | 1.51 | 73.1 | 62.7 | 7.8 | 11 | 95.0 | 1.52 |

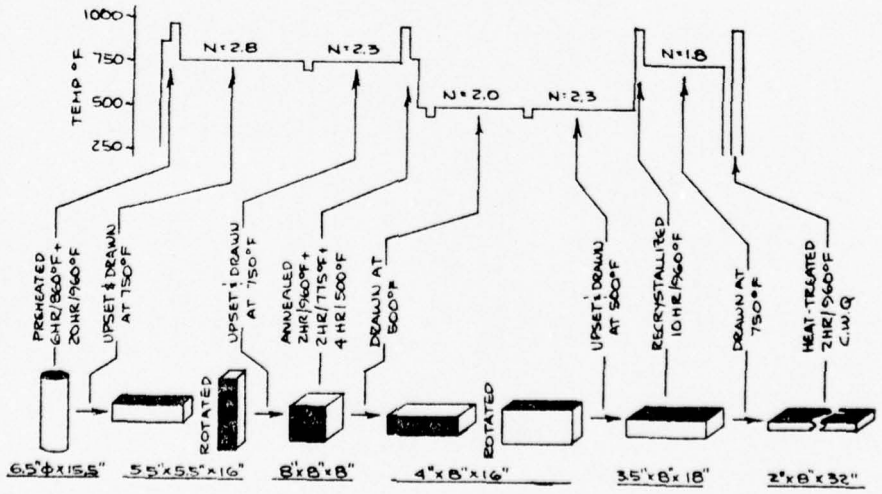
Figure 5. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-3.




MAG 100X

KELLERS ETCH

2.00" THICK 7475-T7X HAND FORGING



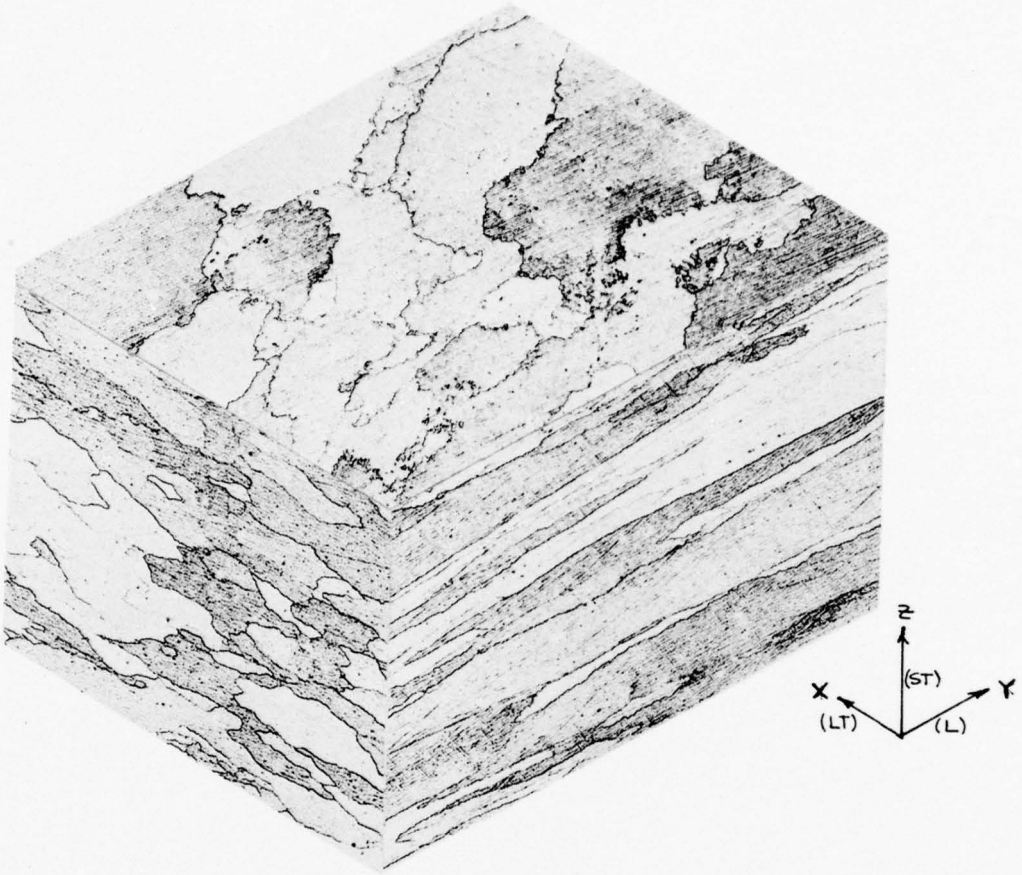

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM3 |
|---|---|---|---|
| X | Y | Z | XYZ |
| 1 | 1 | 28 | 28 |

PROPERTIES

| 2ND STEP AGE | LONGITUDINAL T.S. KSI | Y.S. KSI | EL % | R/A % | NTS KSI | NTS Y.S. | SHORT-TRANSVERSE T.S. KSI | Y.S. KSI | EL % | R/A % | NTS KSI | NTS Y.S. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 HR/350°F | 77.3 | 70.9 | 13.6 | 29 | 100.6 | 1.42 | 76.4 | 67.9 | 9.4 | 15 | 96.5 | 1.42 |
| 6 HR./350°F | 74.3 | 66.9 | 17.9 | 47 | 101.1 | 1.51 | 74.9 | 64.9 | 10.9 | 19 | 100.6 | 1.55 |
| 8HR/350°F | 72.5 | 64.7 | 17.9 | 47 | 100.6 | 1.55 | 73.6 | 61.9 | 7.8 | 10 | 80.7 | 1.30 |

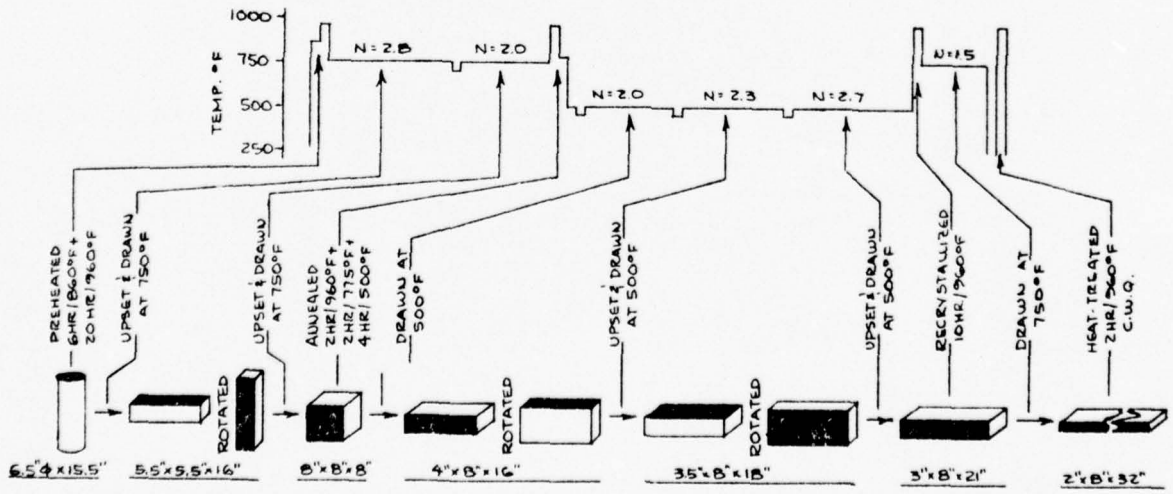
Figure 6. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-5.




MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING



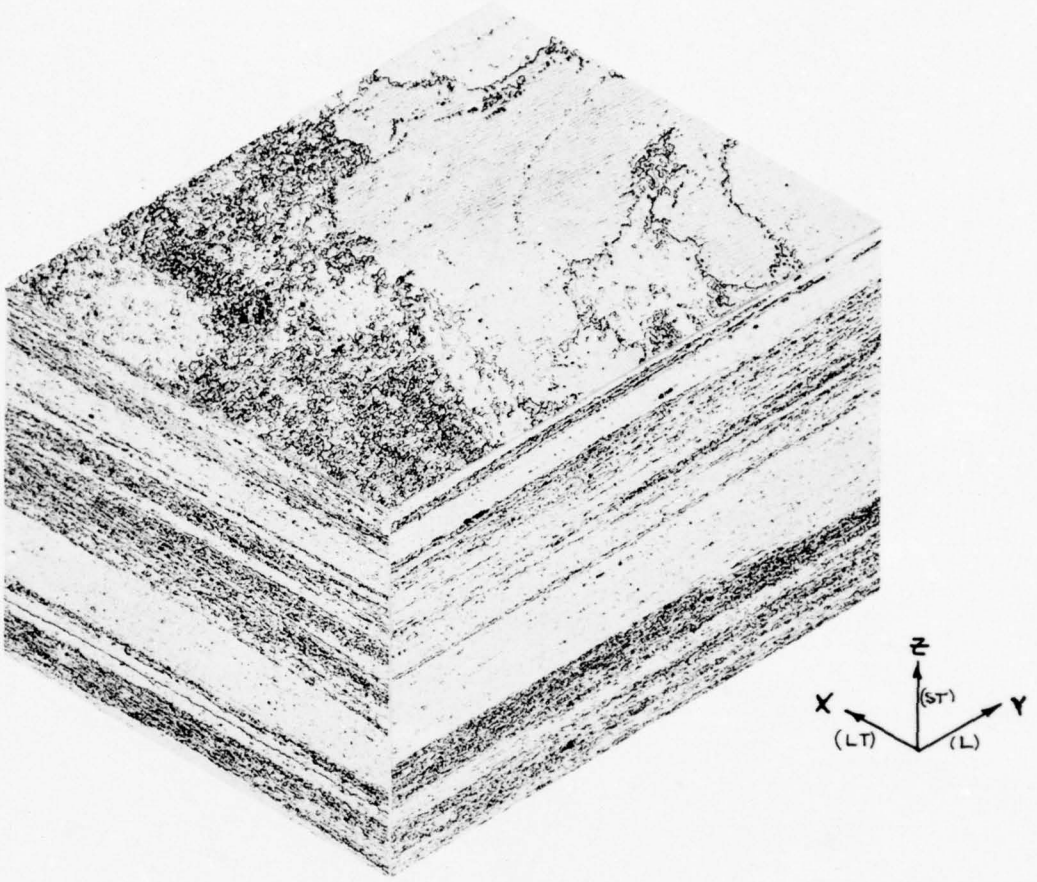

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 4 | 2 | 24 | 192 |

PROPERTIES

| 2ND STEP AGE | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T.S. KSI | Y.S. KSI | EL % | R/A % | NTS KSI | NTS/YS | T.S. KSI | Y.S. KSI | EL % | R/A % | NTS KSI | NTS/YS |
| 4 HR/350°F | 78.5 | 72.2 | 15.0 | 35 | 102.1 | 1.41 | 77.1 | 69.0 | 6.2 | 7 | 94.5 | 1.37 |
| 6 HR/350°F | 76.7 | 68.7 | 17.1 | 44 | 101.6 | 1.48 | 75.9 | 64.9 | 9.4 | 14 | 96.5 | 1.49 |
| 8 HR/350°F | 74.5 | 66.4 | 15.7 | 47 | 96.0 | 1.45 | 73.9 | 62.3 | 7.8 | 15 | 96.0 | 1.54 |

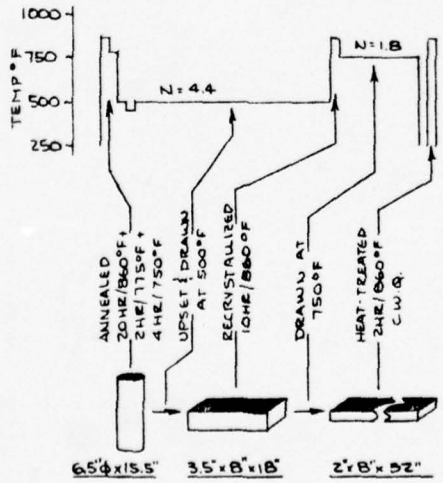
Figure 7. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-6.




MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING

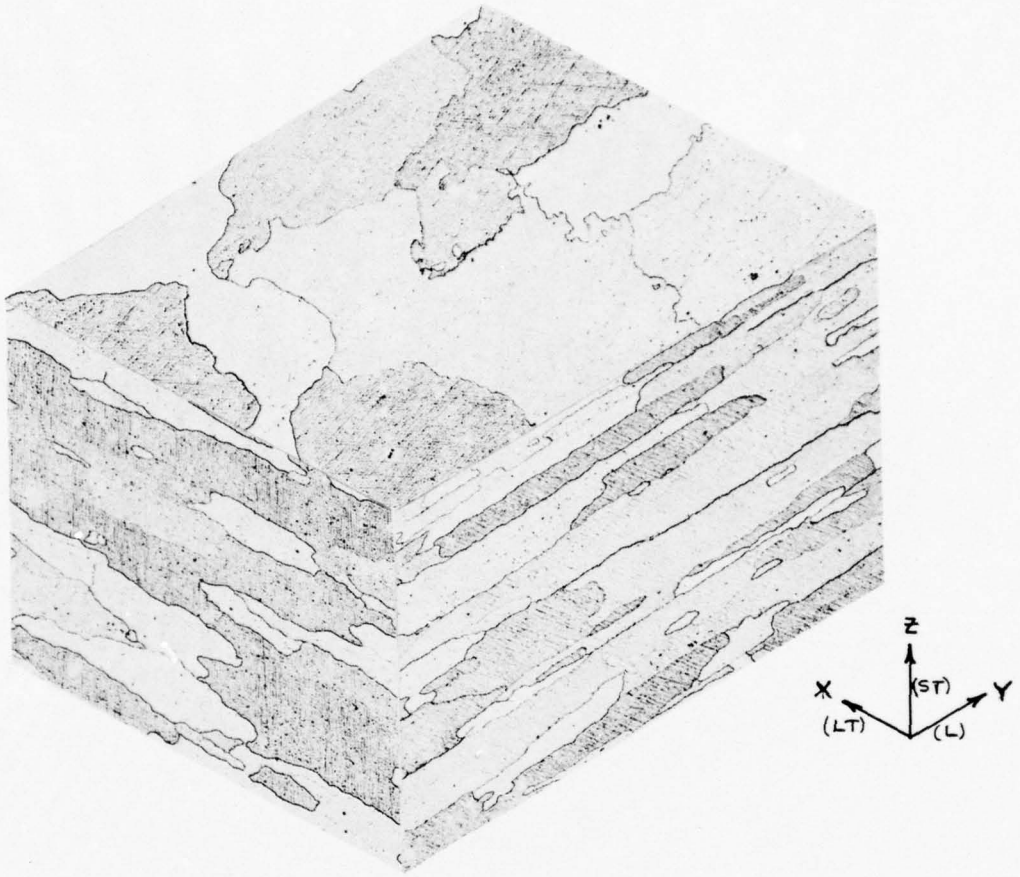



GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| UNRECRYSTALLIZED | | | |

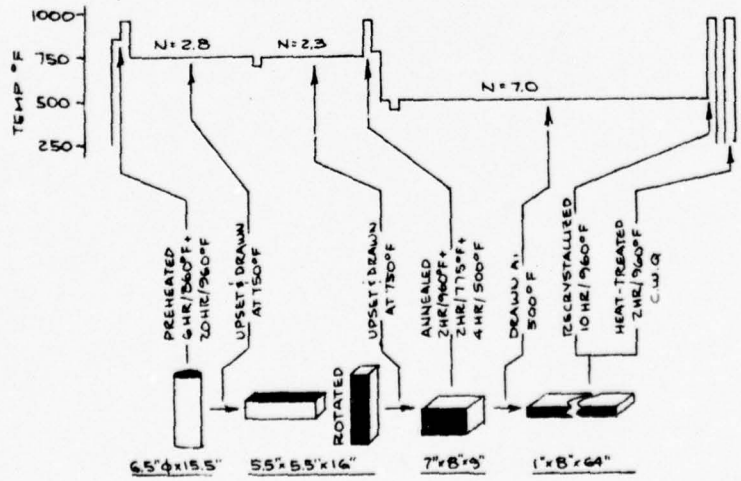
| 2ND STEP AGE | LONGITUDINAL TS KSI | YS KSI | EL % | R/A % | NTS KSI | NTS YS | SHORT-TRANSVERSE TS KSI | YS KSI | EL % | R/A % | NTS KSI | NTS YS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4HR/350°F | 73.3 | 64.9 | 14.3 | 33 | 95.0 | 1.46 | 74.1 | 66.3 | 7.8 | 6 | 91.9 | 1.41 |
| 6HR/350°F | 70.9 | 61.2 | 14.3 | 32 | 92.4 | 1.51 | 69.7 | 60.4 | 12.6 | 29 | 91.4 | 1.51 |
| 8HR/350°F | 70.7 | 60.4 | 15.0 | 29 | 95.0 | 1.57 | 70.6 | 57.8 | 10.9 | 20 | 86.8 | 1.48 |

Figure 8. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-7.




MAG 100X KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING



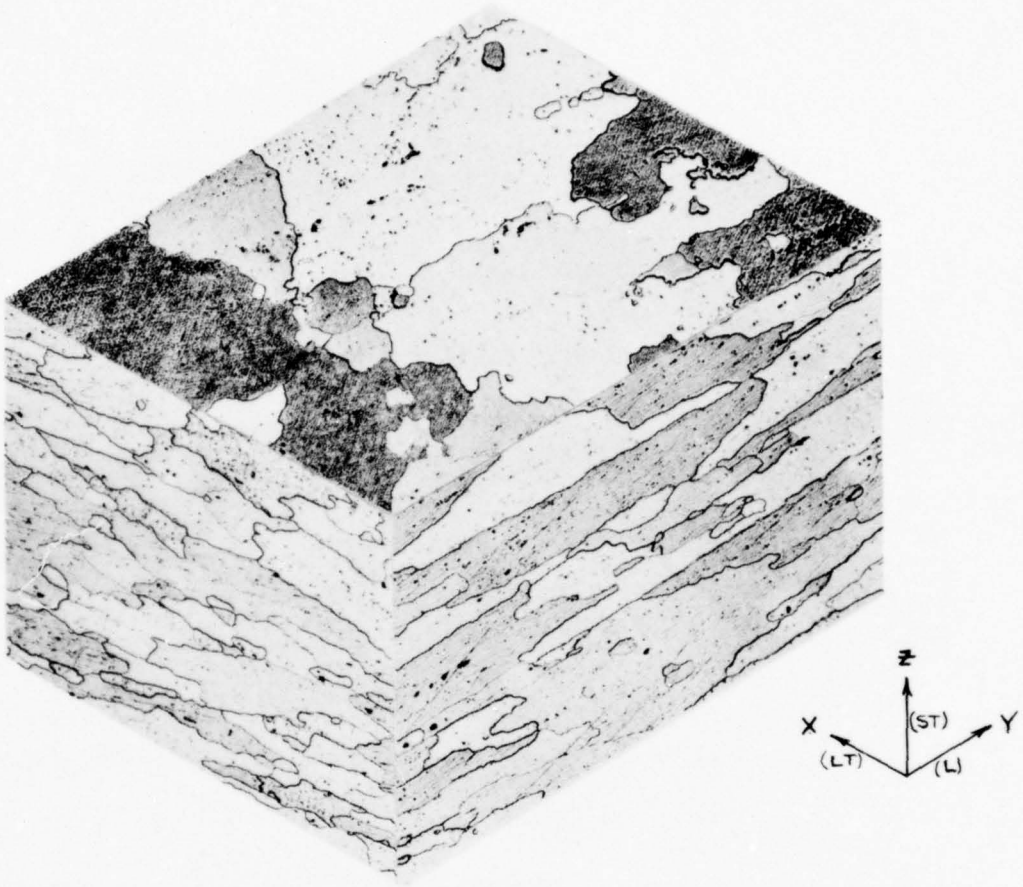

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 4 | 2 | 22 | 176 |

PROPERTIES LONGITUDINAL

| 2ND STEP AGE | TYS KSI | YS KSI | EL % | R/A % | NTS KSI | NTS/E |
|---|---|---|---|---|---|---|
| 4 HR/350°F | 77.1 | 70.2 | 15.7 | 42 | 107.8 | 1.54 |
| 6 HR/350°F | 74.7 | 68.4 | 16.4 | 43 | 105.2 | 1.54 |
| 8 HR/350°F | 75.9 | 64.9 | 15.0 | 37 | 105.2 | 1.62 |

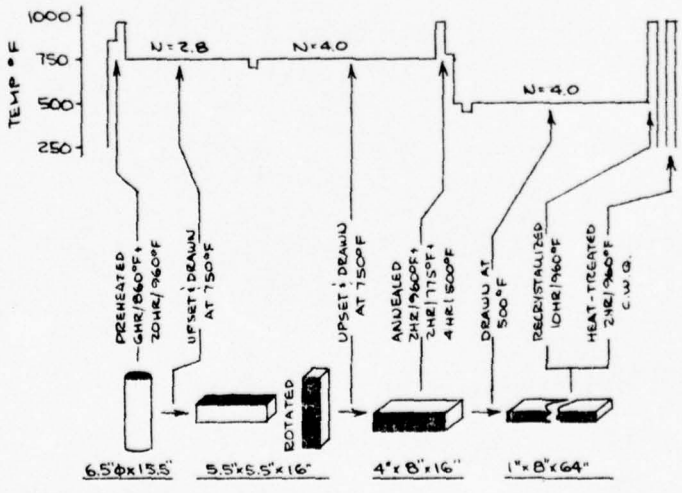
Figure 9. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-8.




MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING



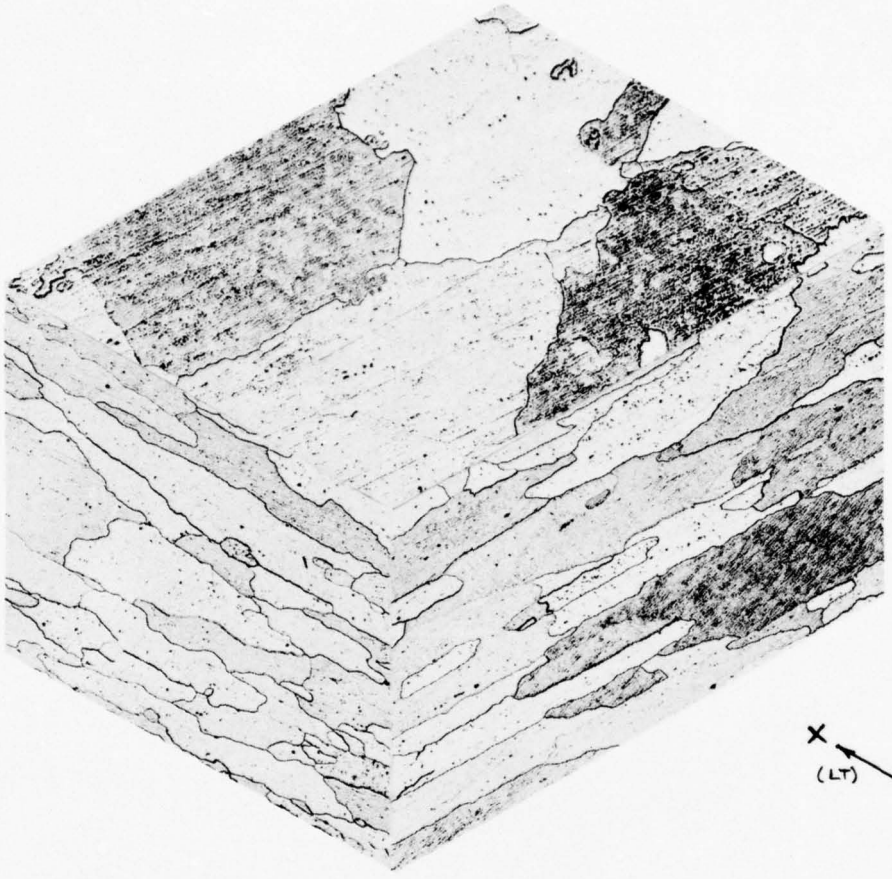

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 8 | 3 | 24 | 576 |

PROPERTIES LONGITUDINAL

| 2ND STEP AGE | TS KSI | YS KSI | EL % | R/A % | NTS KSI | NTS YS |
|---|---|---|---|---|---|---|
| 4 HR/350°F | 79.3 | 72.4 | 14.3 | 36 | 107.3 | 1.48 |
| 6HR/350°F | 76.7 | 69.2 | 16.4 | 31 | 106.7 | 1.54 |
| 8HR/350°F | 75.3 | 66.7 | 15.0 | 39 | 105.7 | 1.58 |

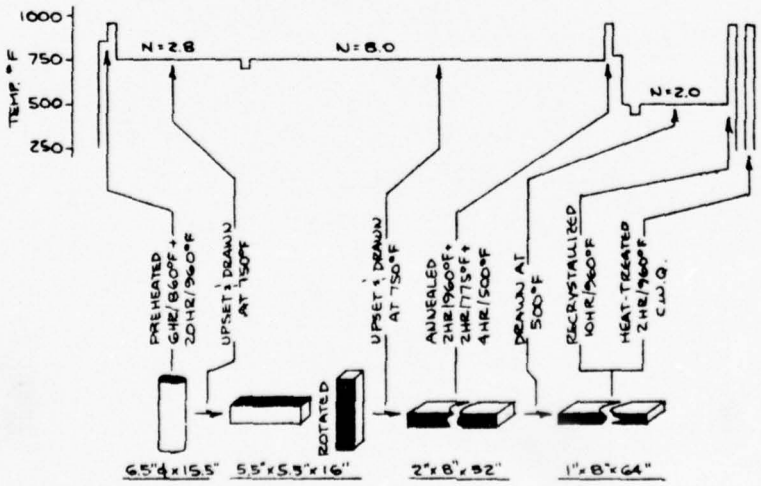
Figure 10. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-9.




MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING



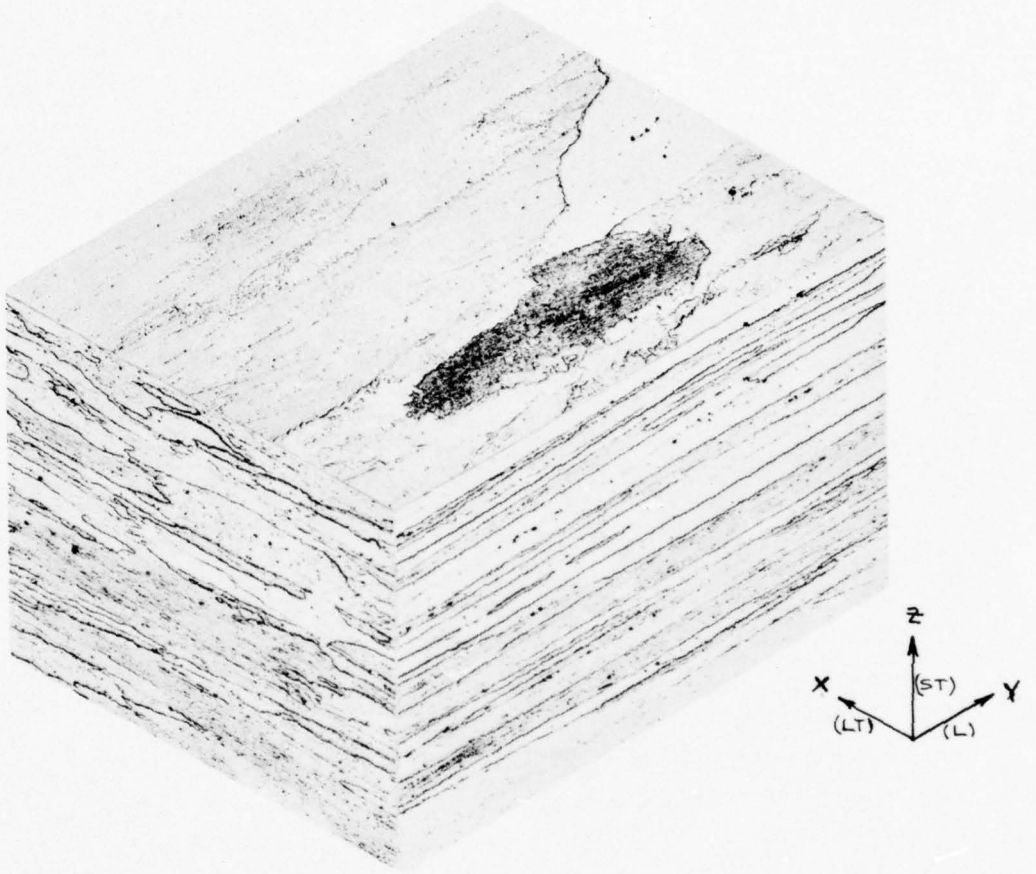

GRAIN COUNTS

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 5 | 3 | 20 | 300 |

PROPERTIES LONGITUDINAL

| 2ND STEP AGE | T.S. KSI | Y.S. KSI | EL % | R/A % | NTS KSI | NYS Y/M |
|---|---|---|---|---|---|---|
| 4 HR/350°F | 76.5 | 70.2 | 15.7 | 43 | 106.2 | 1.51 |
| 6 HR./350°F | 74.3 | 68.2 | 15.0 | 47 | 103.7 | 1.52 |
| 8 HR/350°F | 74.5 | 65.9 | 15.0 | 38 | 104.2 | 1.58 |

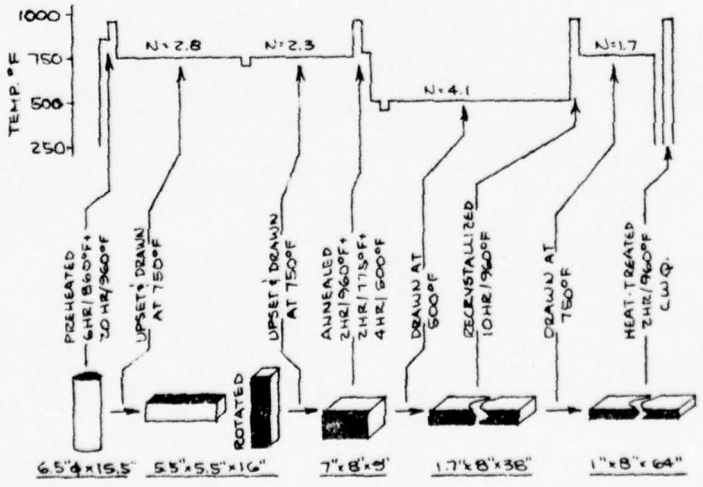
Figure 11. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-10.




MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING



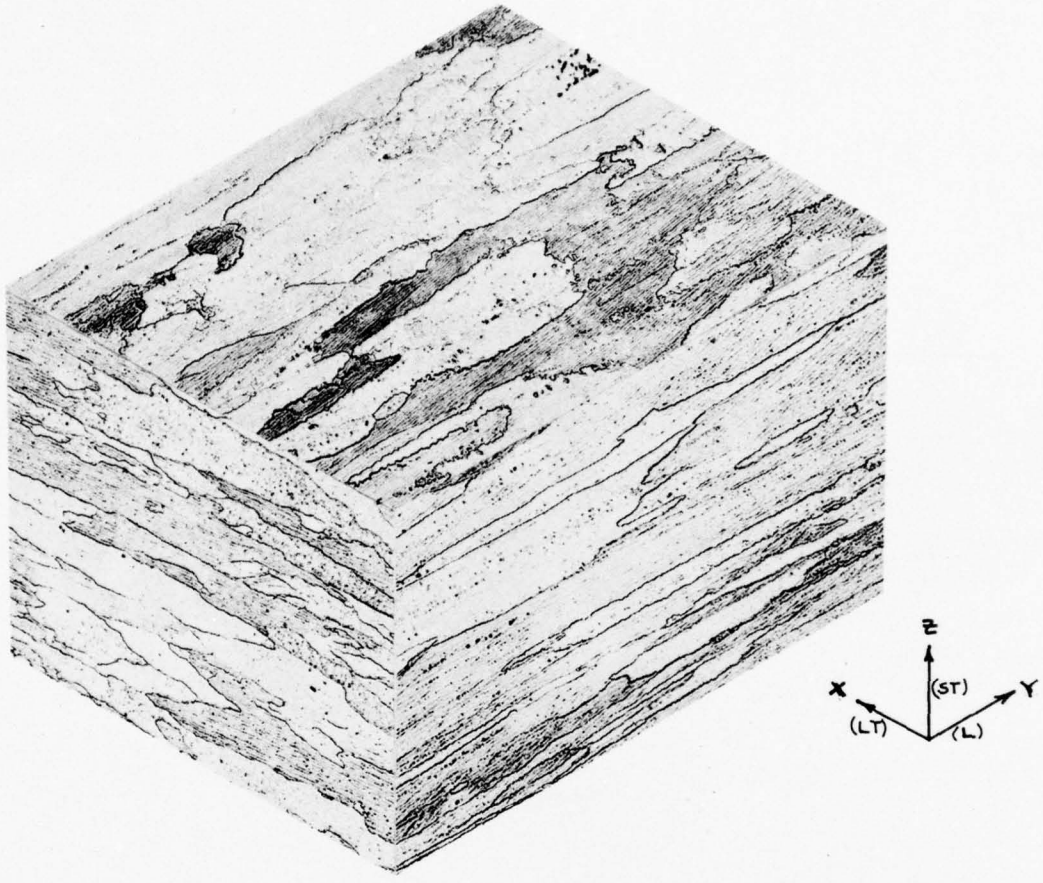

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 5 | 2 | 40 | 240 |

PROPERTIES

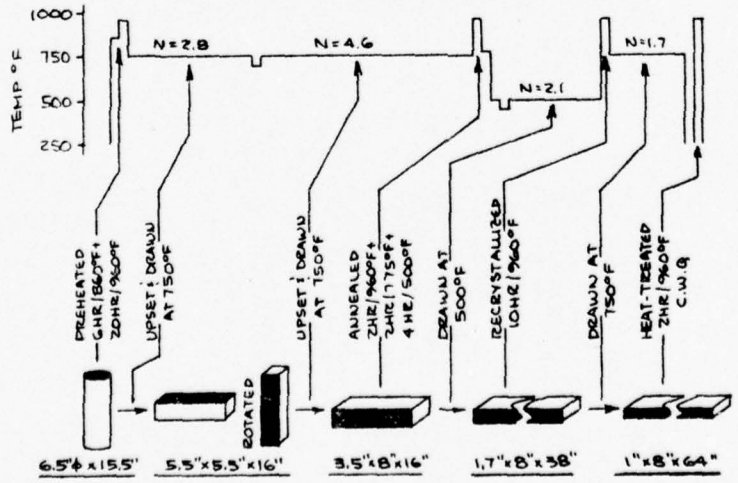
| 2ND STEP AGE | LONGITUDINAL TS KSI | YS KSI | EL % | R/A % | NTS KSI | NTS/YS |
|---|---|---|---|---|---|---|
| 4 HR/350°F | 78.7 | 72.7 | 17.1 | 47 | 109.3 | 1.50 |
| 6 HR/350°F | 74.3 | 66.9 | 17.9 | 57 | 108.3 | 1.62 |
| 8 HR/350°F | 75.1 | 66.4 | 16.4 | 46 | 103.7 | 1.56 |

Figure 12. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-11.




MAG 100X KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING



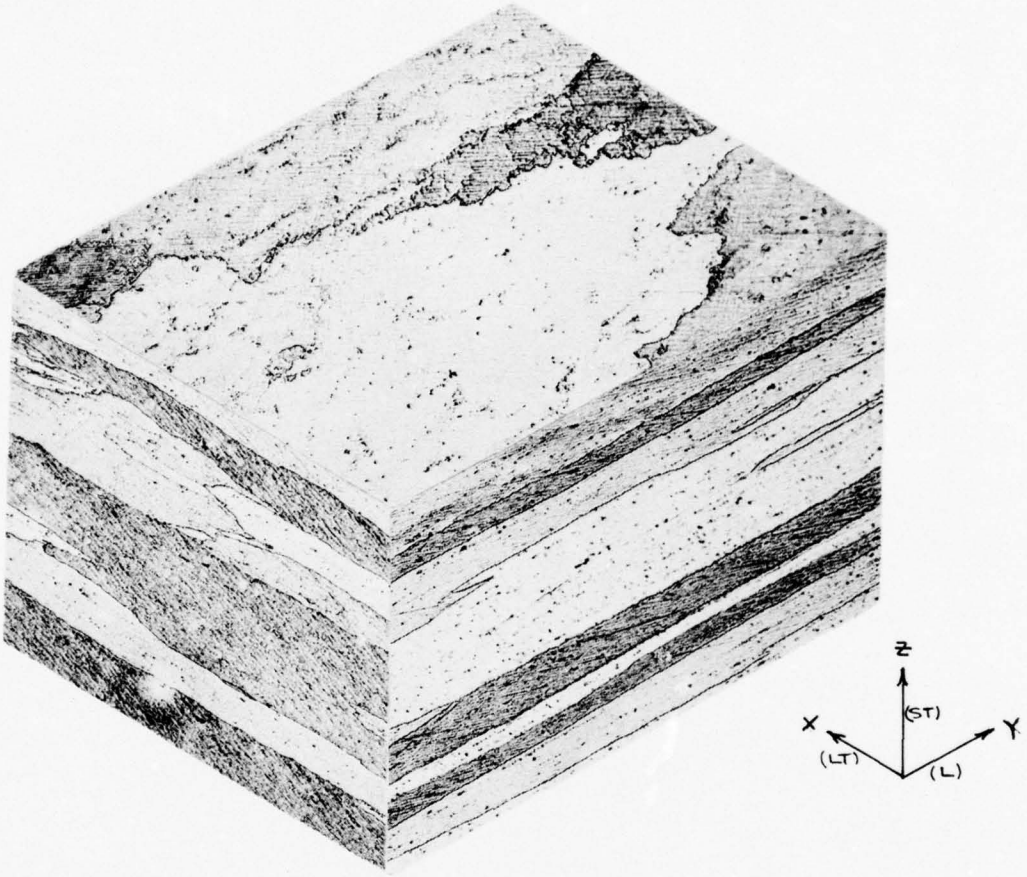

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 5 | 2 | 43 | 430 |

PROPERTIES LONGITUDINAL

| 2ND STEP AGE | TS KSI | YS KSI | EL % | R/A % | NTS KSI | NTS YS |
|---|---|---|---|---|---|---|
| 4HR/350°F | 78.5 | 71.9 | 16.4 | 51 | 107.3 | 1.49 |
| 6HR/350°F | 76.7 | 68.7 | 17.9 | 51 | 107.8 | 1.57 |
| 8HR/350°F | 77.7 | 69.7 | 17.9 | 53 | 107.3 | 1.54 |

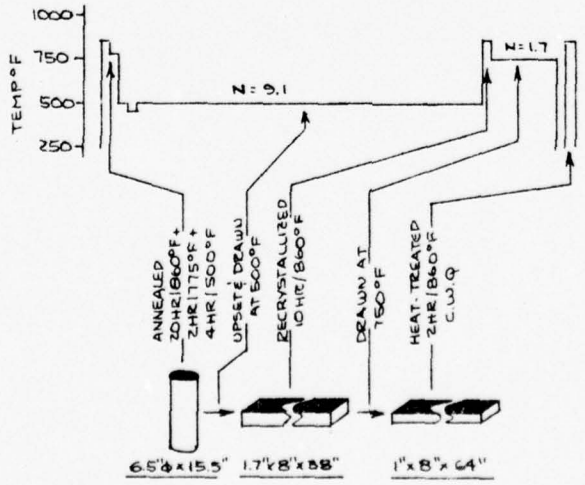
Figure 13. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-12.




MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING



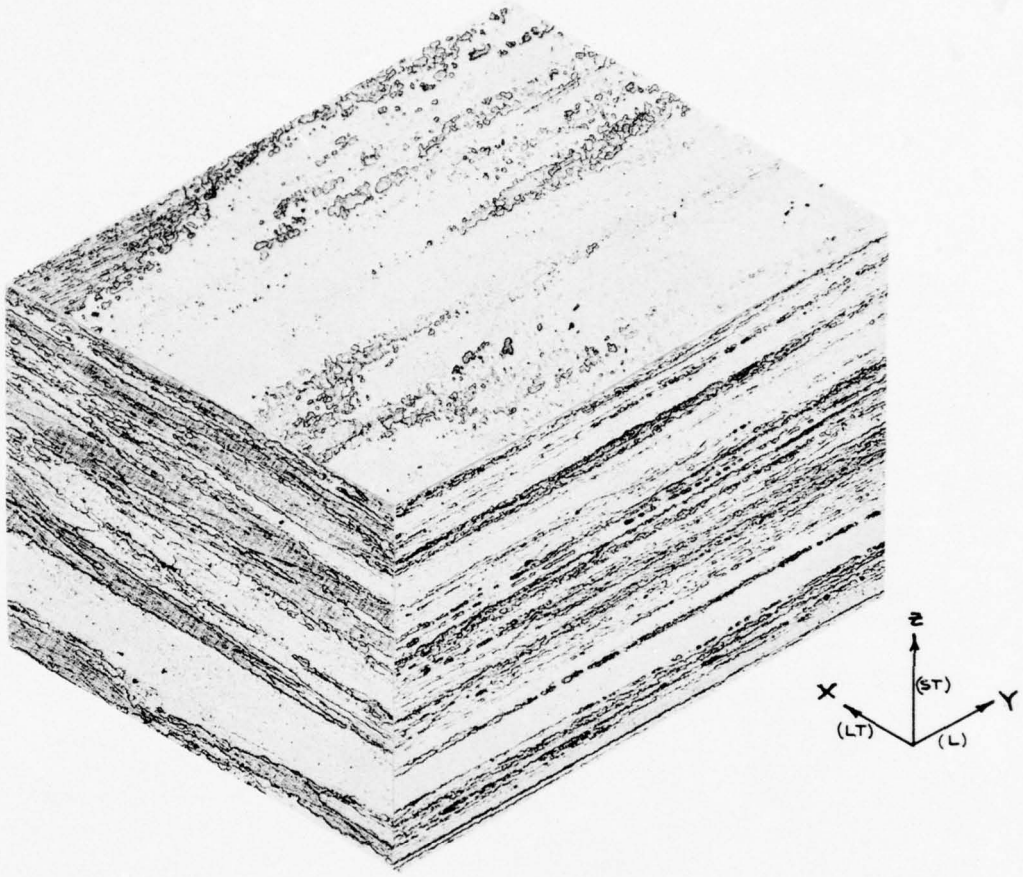

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 1 | 1 | 19 | 19 |

PROPERTIES LONGITUDINAL

| 2ND STEP AGE | TS KSI | YS KSI | EL % | RA % | NTS KSI | NTS TS |
|---|---|---|---|---|---|---|
| 4HR/350°F | 76.1 | 67.7 | 15.0 | 42 | 103.2 | 1.52 |
| 6HR/350°F | 73.9 | 63.7 | 15.7 | 42 | 100.6 | 1.58 |
| 8HR/350°F | 73.1 | 62.4 | 15.7 | 41 | 100.6 | 1.52 |

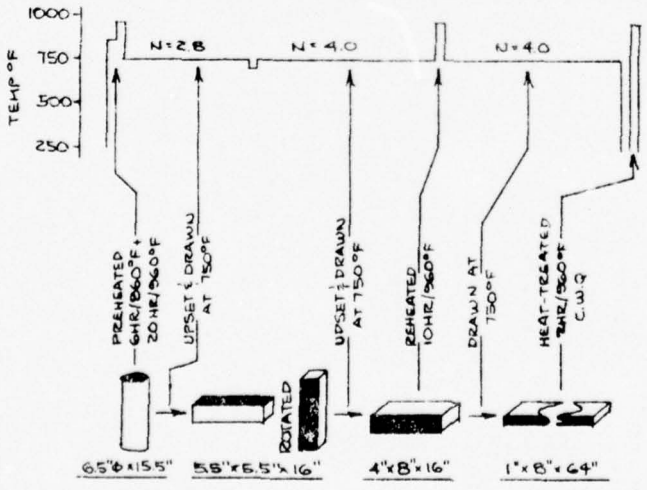
Figure 14. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-13.




MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING



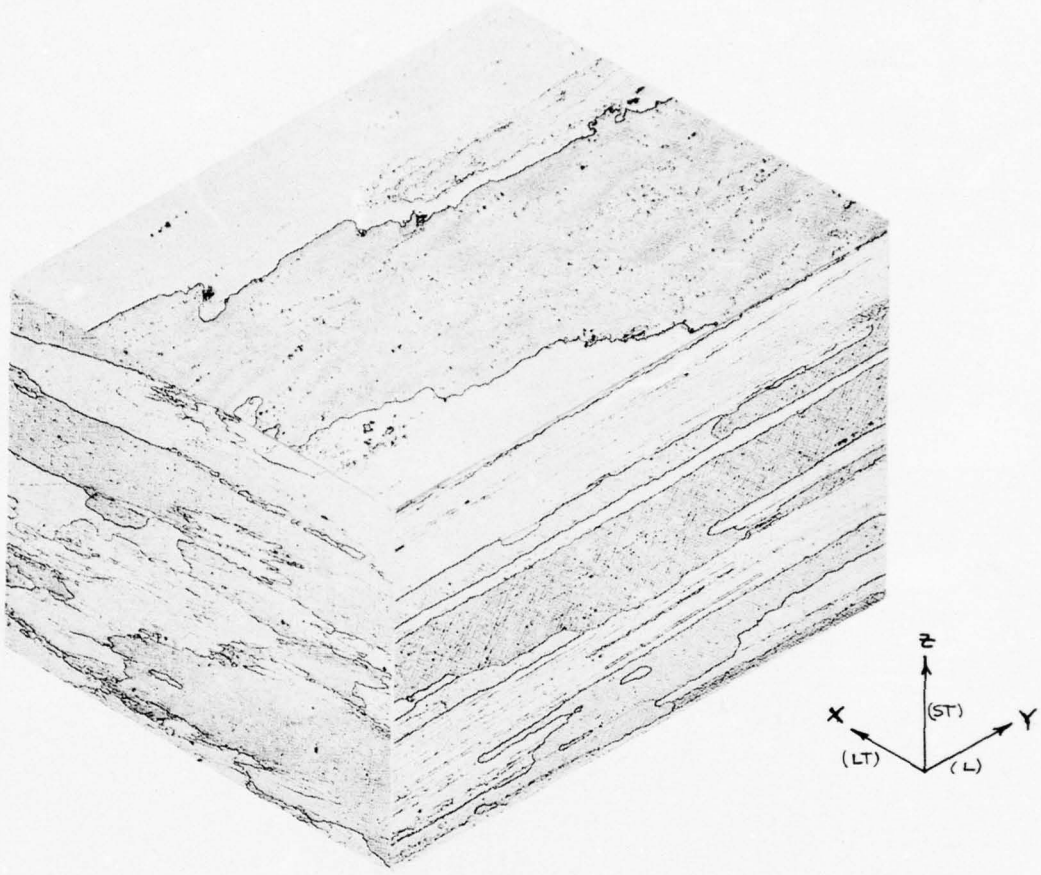

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |

UNRECRYSTALLIZED

| 2NP STEP AGE | PROPERTIES LONGITUDINAL T.S. KSI | Y.S. KSI | EL % | R/A % | N.T.S. KSI | N.T.S. Y.S. |
|---|---|---|---|---|---|---|
| 4HR/350°F | 78.9 | 72.4 | 15.7 | 48 | 106.7 | 1.47 |
| 6HR/350°F | 75.7 | 67.9 | 16.4 | 50 | 103.2 | 1.52 |
| 8HR/350°F | 74.7 | 67.2 | 17.9 | 50 | 104.2 | 1.55 |

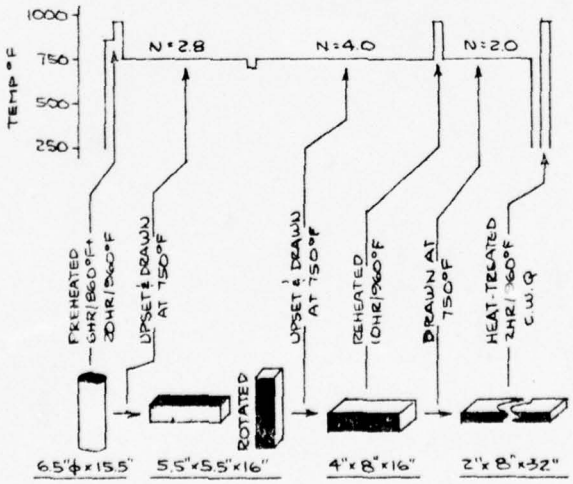
Figure 15. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-14.




MAG 100X

KELLER'S ETCH

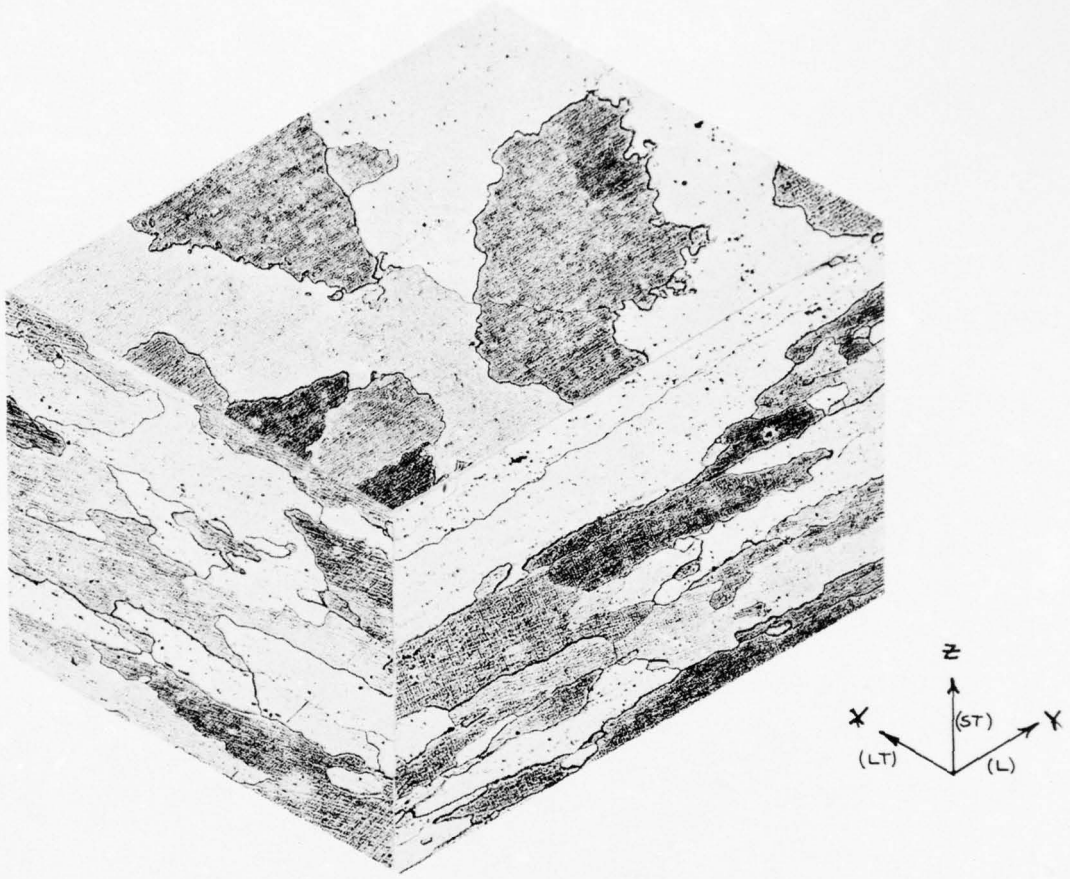
2.00" THICK 7475-T7X HAND FORGING




| GRAIN COUNT | | | | | |
|---|---|---|---|---|---|
| GRAINS/MM | | | GRAINS/MM³ | | |
| X | Y | Z | X Y Z | | |
| UNRECRYSTALLIZED | | | | | |

| 2ND STEP AGE | PROPERTIES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
| | TYS KSI | YS KSI | EL % | R/A % | UTS KSI | UTS/YS | TYS KSI | YS KSI | EL % | R/A % | UTS KSI | UTS/YS |
| 4HR / 350°F | 78.7 | 72.2 | 12.9 | 27 | 101.6 | 1.41 | 77.1 | 70.1 | 7.8 | 2.9 | 103.2 | 1.47 |
| 6HR / 350°F | 76.7 | 69.2 | 15.0 | 41 | 103.7 | 1.50 | 75.9 | 67.9 | 4.7 | 2 | 103.7 | 1.53 |
| 8HR / 350°F | 73.1 | 64.4 | 17.9 | 49 | 99.1 | 1.54 | 72.4 | 64.9 | 7.8 | 5 | 95.5 | 1.47 |

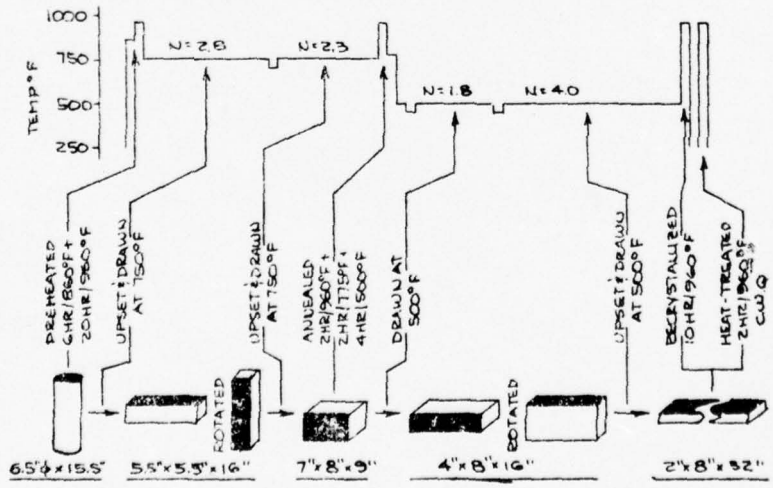
Figure 16. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-15.




MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING

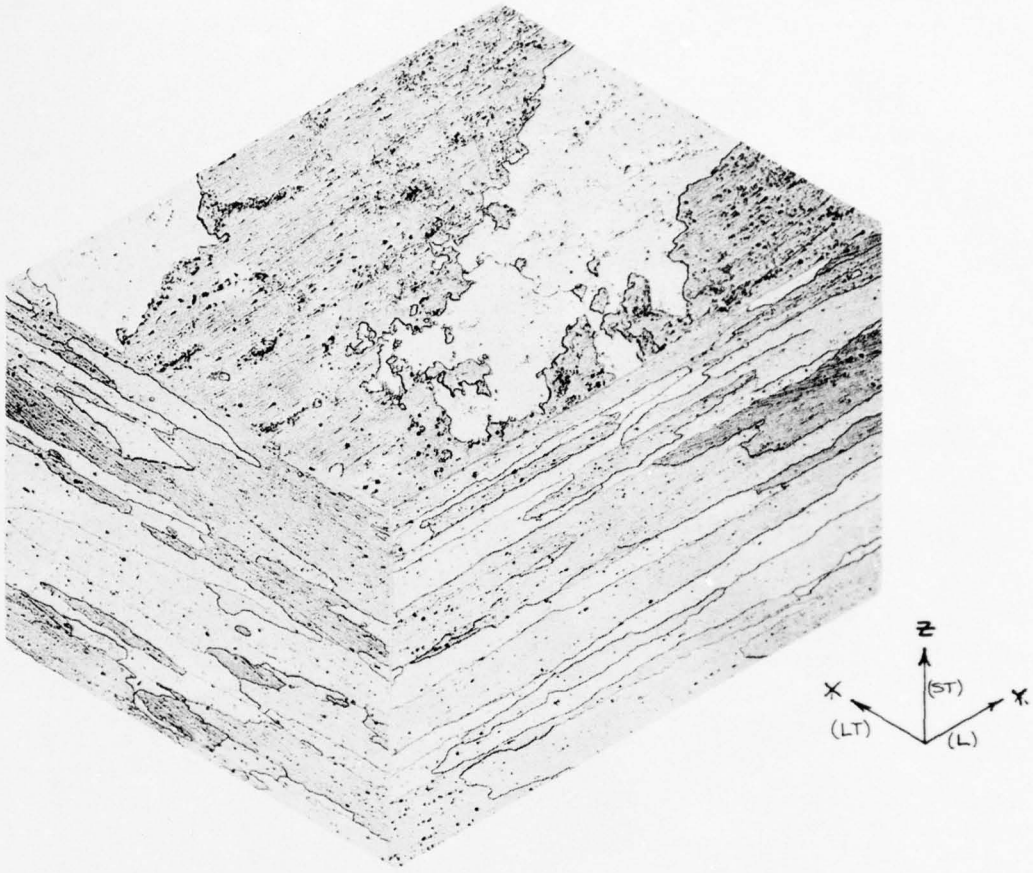



GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 3 | 2 | 17 | 102 |

| 2ND STEP AGE | PROPERTIES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
| | T.S. KSI | Y.S. KSI | EL % | R/A % | N.T.S. KSI | N.T.S. Y.F. | T.S. KSI | Y.S. KSI | EL % | R/A % | N.T.S. KSI | N.T.S. Y.F. |
| 4 HR/350°F | 76.1 | 68.7 | 12.6 | 24 | 100.6 | 1.46 | 75.1 | 66.4 | 7.8 | 10 | 84.8 | 1.28 |
| 6 HR/350°F | 74.9 | 65.9 | 12.1 | 23 | 99.6 | 1.51 | 73.6 | 61.9 | 9.4 | 10 | 85.8 | 1.38 |
| 8 HR/350°F | 72.7 | 63.2 | 12.1 | 25 | 92.4 | 1.46 | 73.9 | 62.3 | 10.9 | 7 | 94.0 | 1.51 |

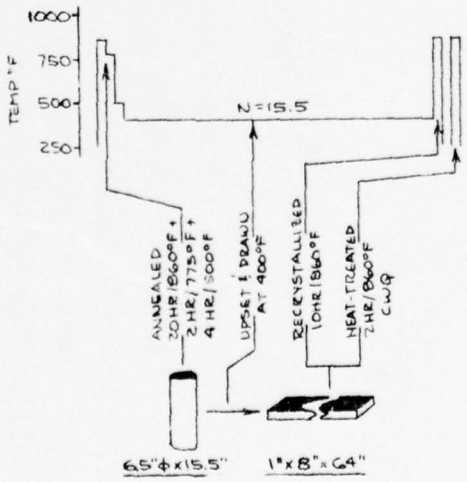
Figure 17. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-16.




MAG 100X

KELLER'S ETCH

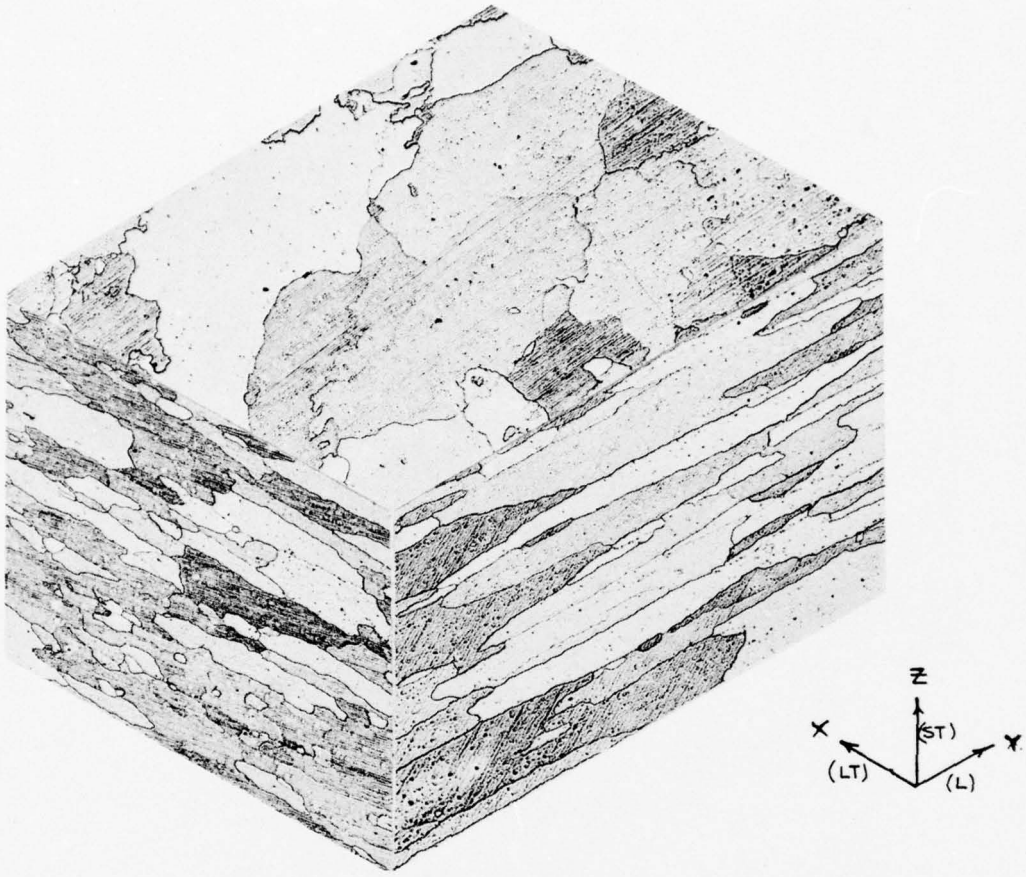
1.00" THICK 7475-T7X HAND FORGING




| GRAIN COUNT | | | |
|---|---|---|---|
| GRAINS/MM | | | GRAINS/MM³ |
| X | Y | Z | XYZ |
| 2 | 2 | 24 | 96 |

| 2ND STEP AGE | PROPERTIES LONGITUDINAL | | | | | |
|---|---|---|---|---|---|---|
| | T.S. KSI | Y.S. KSI | EL % | R/A % | UTS KSI | UTS/YS |
| 4HR/350°F | 76.1 | 67.4 | 14.3 | 38 | 102.7 | 1.52 |
| 6HR/350°F | 75.9 | 65.2 | 17.1 | 43 | 99.6 | 1.53 |
| 8HR/350°F | 73.1 | 62.9 | 13.6 | 40 | 99.3 | 1.58 |

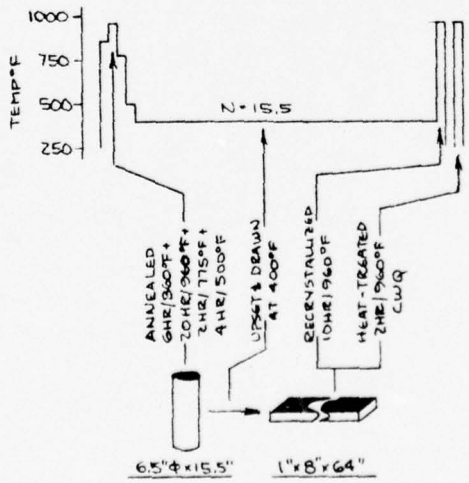
Figure 18. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-17.




MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING

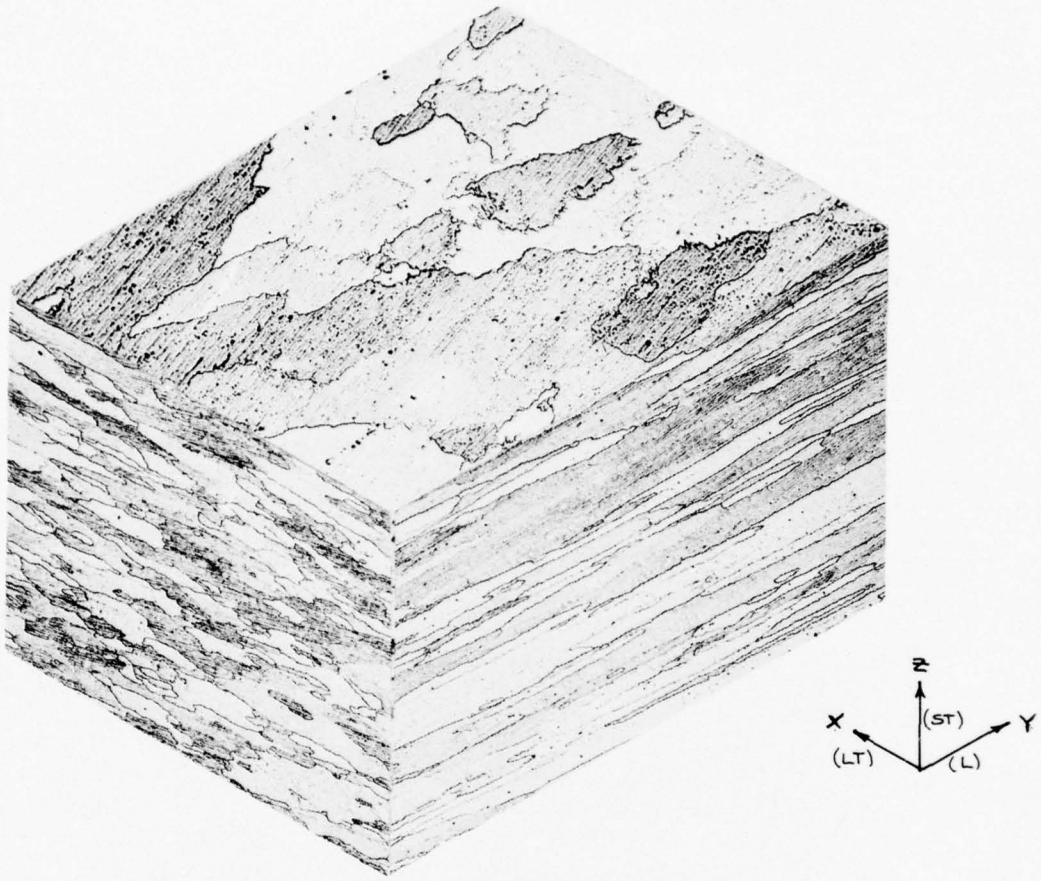



GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 5 | 3 | 25 | 375 |

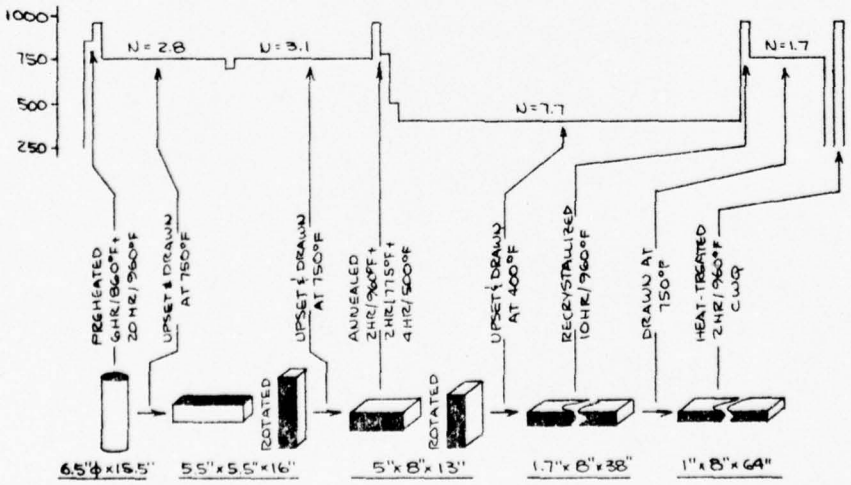
| 2ND STEP AGE | PROPERTIES LONGITUDINAL | | | | | |
|---|---|---|---|---|---|---|
| | TYS KSI | YS KSI | EL % | R/A % | NTS/YS | NTS/TS |
| 4HR/350°F | 77.9 | 71.2 | 15.7 | 38 | 104.7 | 1.47 |
| 6HR/350°F | 76.1 | 68.4 | 15.7 | 38 | 103.2 | 1.51 |
| 8HR/350°F | 73.5 | 65.4 | 15.7 | 45 | 102.7 | 1.57 |

Figure 19. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-18.




MAG 100X KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING



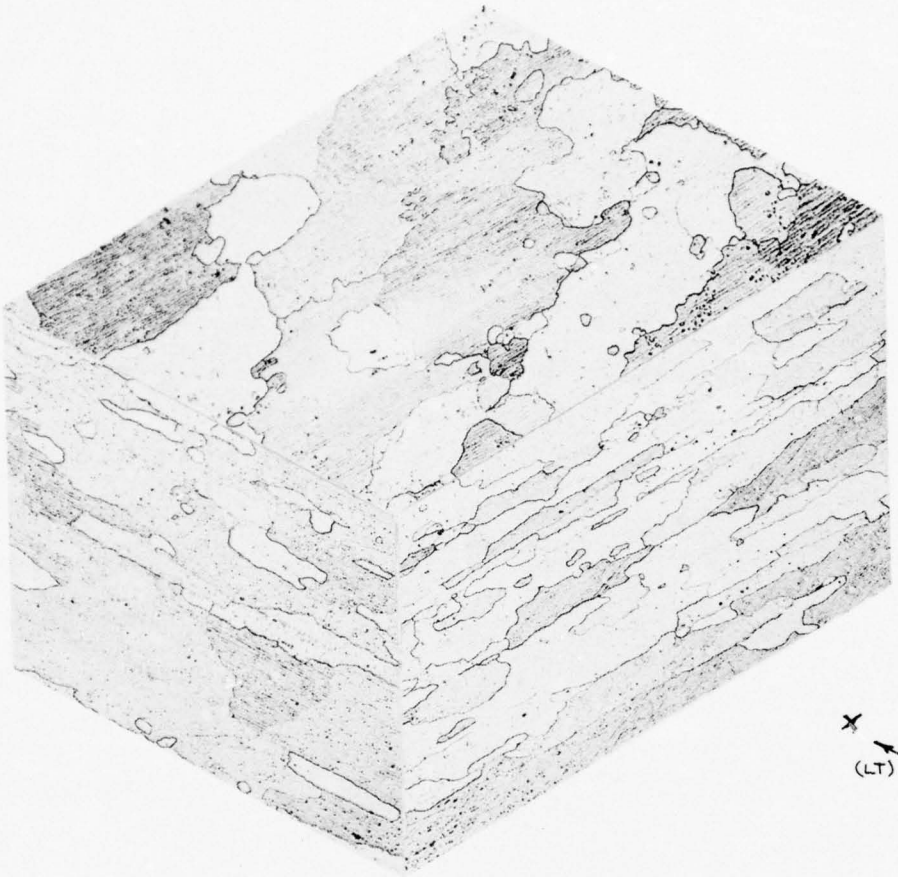

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 6 | 3 | 50 | 900 |

PROPERTIES LONGITUDINAL

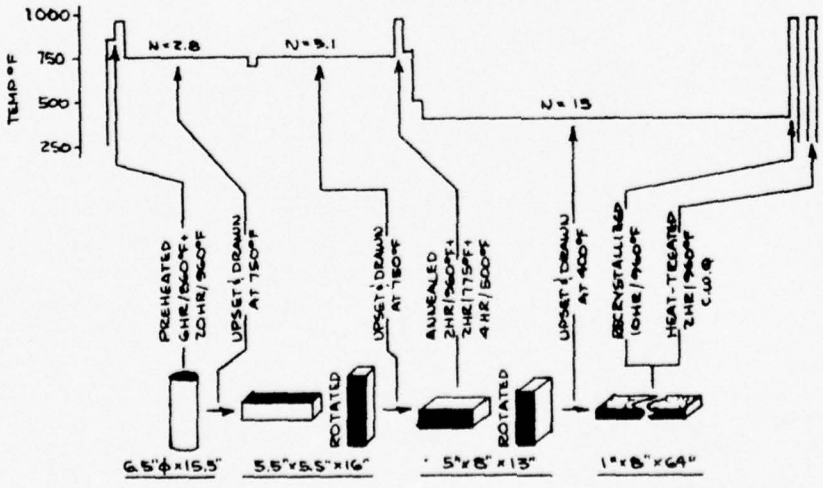
| 2ND STEP AGE | T.S. KSI | Y.S. KSI | EL % | R/A % | U.T.S. KSI | U.T.S. % |
|---|---|---|---|---|---|---|
| 4 HR/350°F | 78.9 | 72.3 | 15.0 | 41 | 109.8 | 152 |
| 6 HR/350°F | 77.5 | 69.4 | 15.7 | 45 | 106.7 | 154 |
| 8 HR/350°F | 76.1 | 66.9 | 17.1 | 51 | 102.7 | 154 |

Figure 20. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-19.




MAG 100X
1.00" THICK 7475-T7X HAND FORGING

KELLERS ETCH



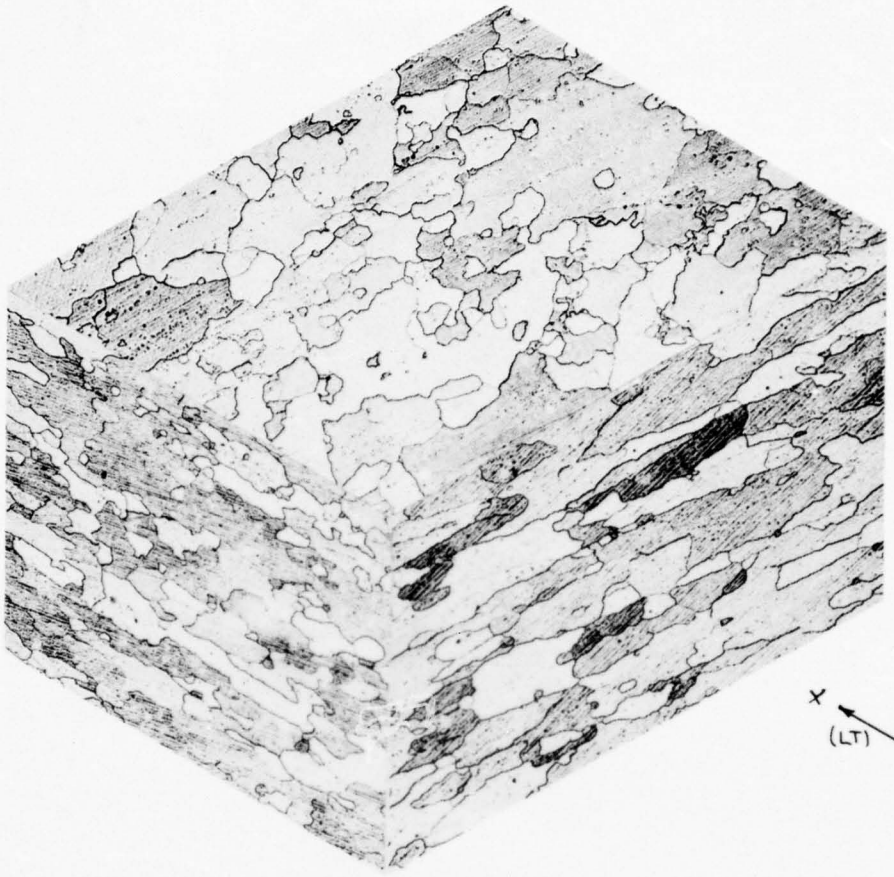

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 6 | 3 | 16 | 288 |

PROPERTIES
LONGITUDINAL

| 2ND STEP AGE | T.S. KSI | Y.S. KSI | e/D % | R/A % | NTS KSI | NTS KSI |
|---|---|---|---|---|---|---|
| 4HR/350°F | 74.3 | 66.9 | 14.3 | 29 | 98.1 | 1.47 |
| 6HR/350°F | 74.4 | 66.7 | 15.7 | 39 | 96.5 | 1.45 |
| 8HR/350°F | 73.9 | 64.4 | 16.7 | 39 | 97.5 | 1.51 |

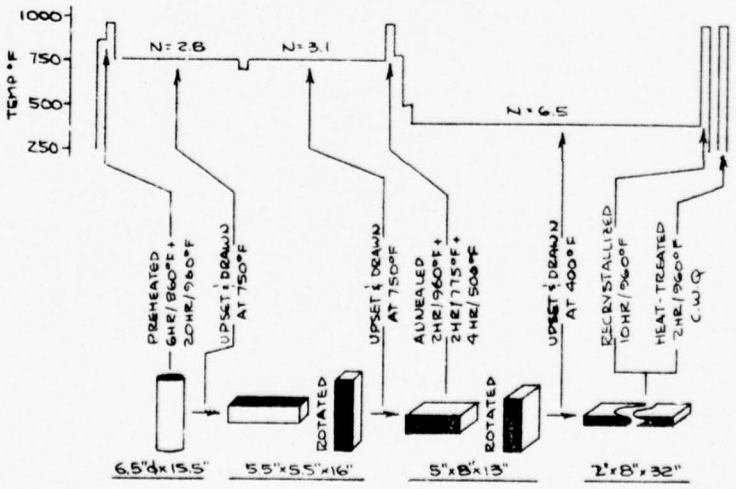
Figure 21. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-20.




MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING

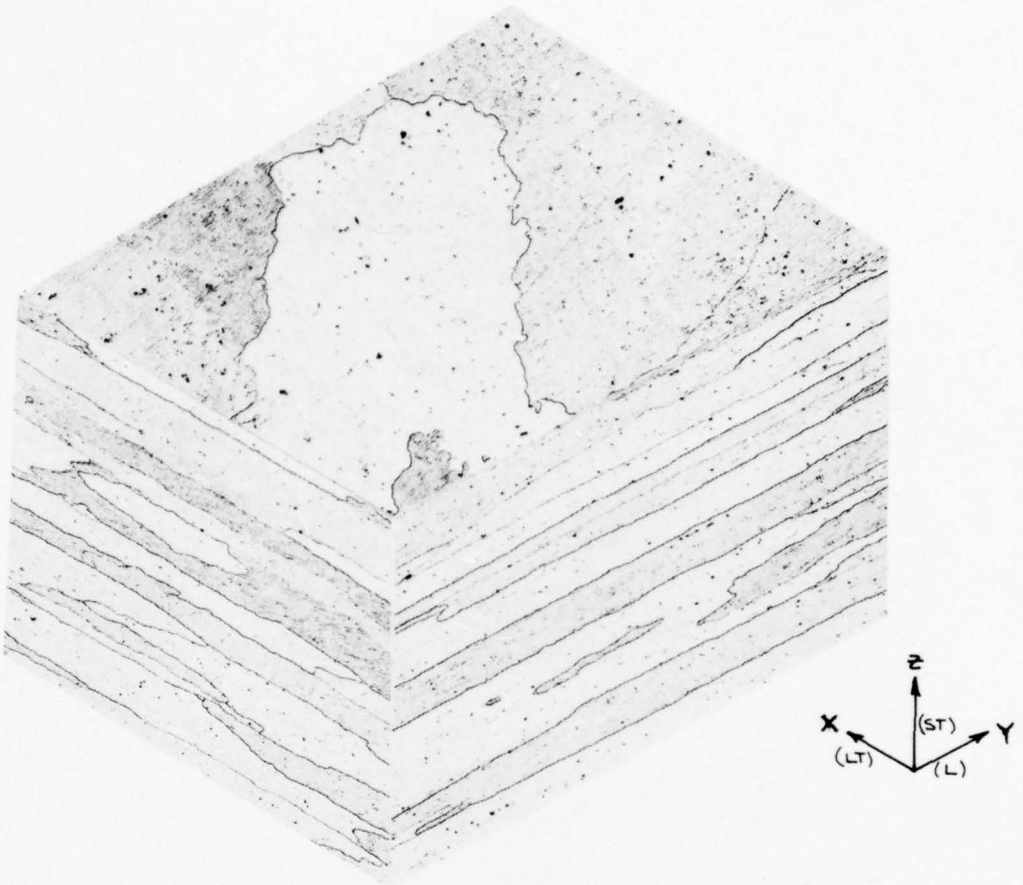



GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 15 | 7 | 32 | 3360 |

| 2WP STEP AGE | PROPERTIES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
| | T.S. KSI | Y.S. KSI | EL % | R/A % | UTS KSI | UTS YS | T.S. KSI | Y.S. KSI | EL % | R/A % | UTS KSI | UTS YS |
| 4HR/350°F | 77.4 | 69.7 | 11.4 | 20 | 93.0 | 1.33 | 72.6 | 64.5 | 9.3 | 16 | 86.8 | 1.35 |
| 6HR/350°F | 75.1 | 66.7 | 12.9 | 27 | 91.9 | 1.38 | 73.4 | 64.2 | 12.5 | 19 | 86.3 | 1.34 |
| 8HR/350°F | 72.3 | 62.7 | 12.9 | 28 | 91.9 | 1.47 | 71.1 | 60.0 | 7.8 | 11 | 83.2 | 1.39 |

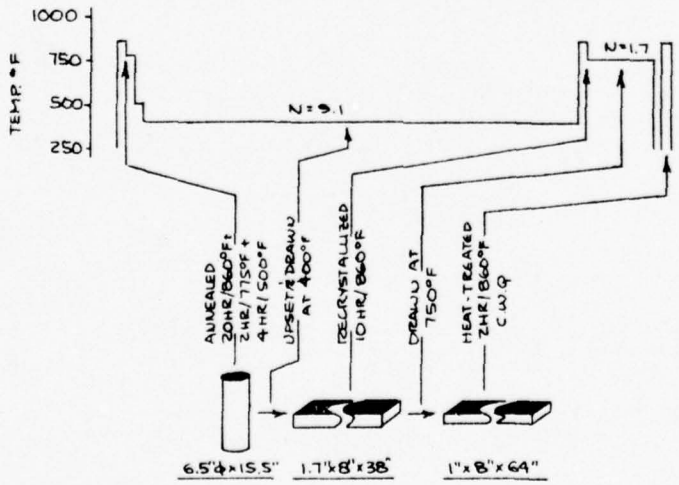
Figure 22. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-21.




MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING




GRAIN COUNT

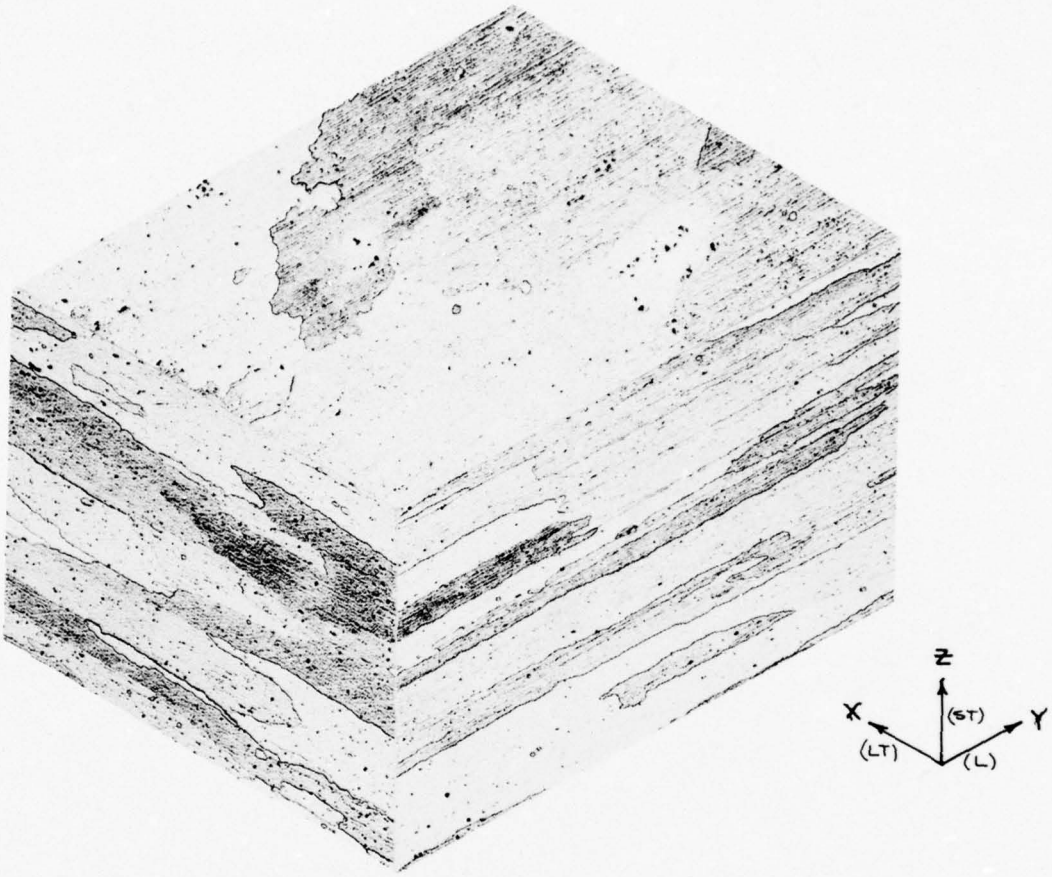
| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 2 | 1 | 22 | 44 |

PROPERTIES

LONGITUDINAL

| 2ND STEP AGE | T.S. KSI | Y.S. KSI | EL % | RA % | NTS KSI | NTS Y.S. |
|---|---|---|---|---|---|---|
| 4HR/350°F | 77.9 | 69.2 | 15.7 | 39 | 102.1 | 1.48 |
| 6HR/350°F | 75.9 | 66.2 | 15.7 | 44 | 100.6 | 1.52 |
| 8HR/350°F | 73.7 | 63.4 | 15.0 | 47 | 99.1 | 1.56 |

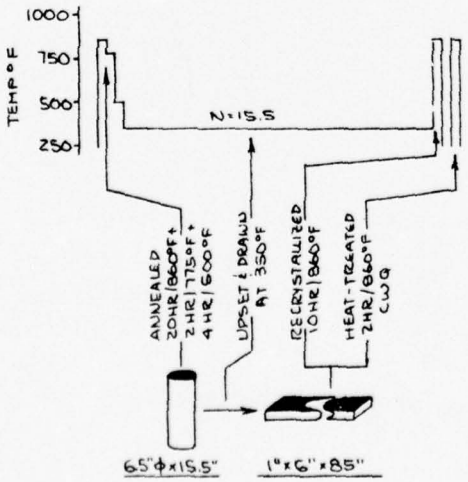
Figure 23. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-22.




MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING




GRAIN COUNT

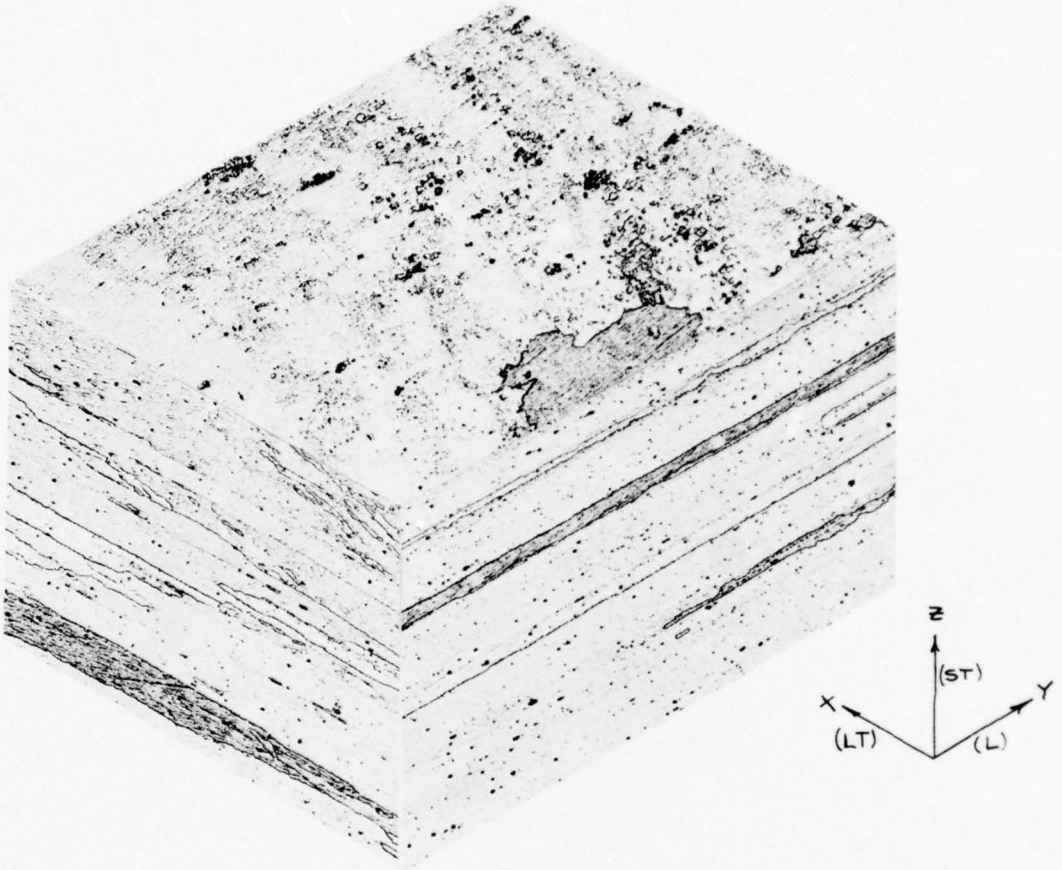
| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 3 | 2 | 30 | 180 |

PROPERTIES

LONGITUDINAL

| 2ND STEP AGE | T.S. KSI | Y.S. KSI | EL % | R/C | N.T.S. KSI | N.T.S. T.S. |
|---|---|---|---|---|---|---|
| 4HR/350°F | 73.3 | 64.9 | 15.7 | 38 | 97.5 | 1.50 |
| 6HR/350°F | 74.1 | 64.1 | 15.7 | 41 | 102.1 | 1.59 |
| 8HR/350°F | 71.1 | 60.4 | 15.7 | 44 | 98.6 | 1.63 |

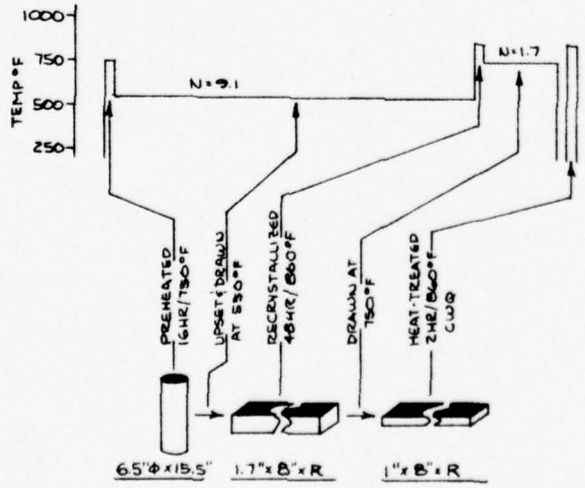
Figure 24. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-23.




MAG 100X

KELLER'S ETCH

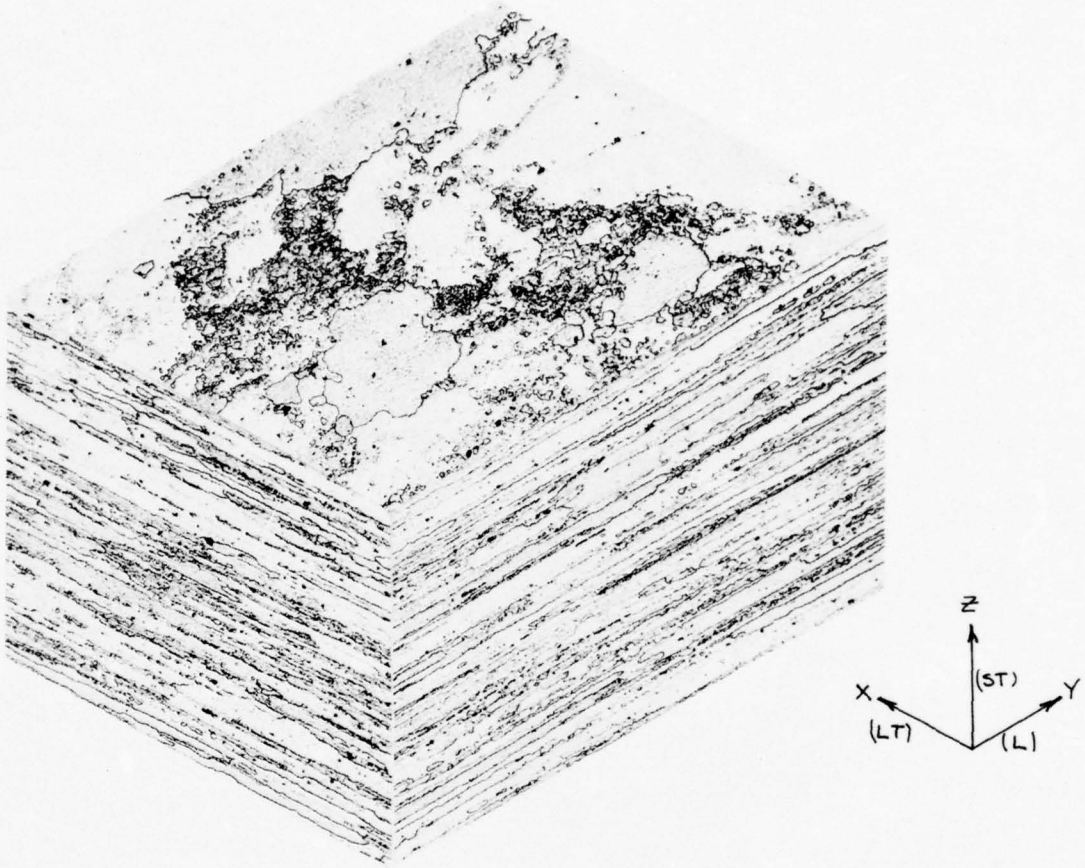
1.00" THICK 7475-T7X HAND FORGING




| GRAIN COUNT | | | | | |
|---|---|---|---|---|---|
| GRAINS/MM | | | GRAINS/MM³ | | |
| X | Y | Z | XYZ | | |
| UNRECRYSTALLIZED | | | | | |

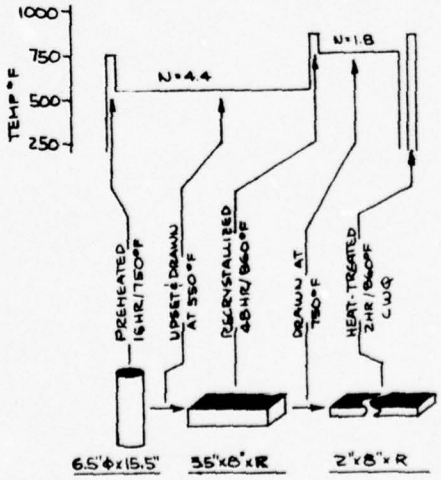
| | PROPERTIES LONGITUDINAL | | | | | |
|---|---|---|---|---|---|---|
| 200 STEP AGE | T.S. KSI | Y.S. KSI | EL % | R/A % | UTS KSI | UTS Y.S. |
| 4HR/350°F | 73.7 | 66.9 | 15.7 | 46 | 95.0 | 1.42 |
| 6HR/350°F | 71.9 | 61.9 | 15.7 | 45 | 99.6 | 1.53 |

Figure 25. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-437666-26A.




MAG 100X KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING

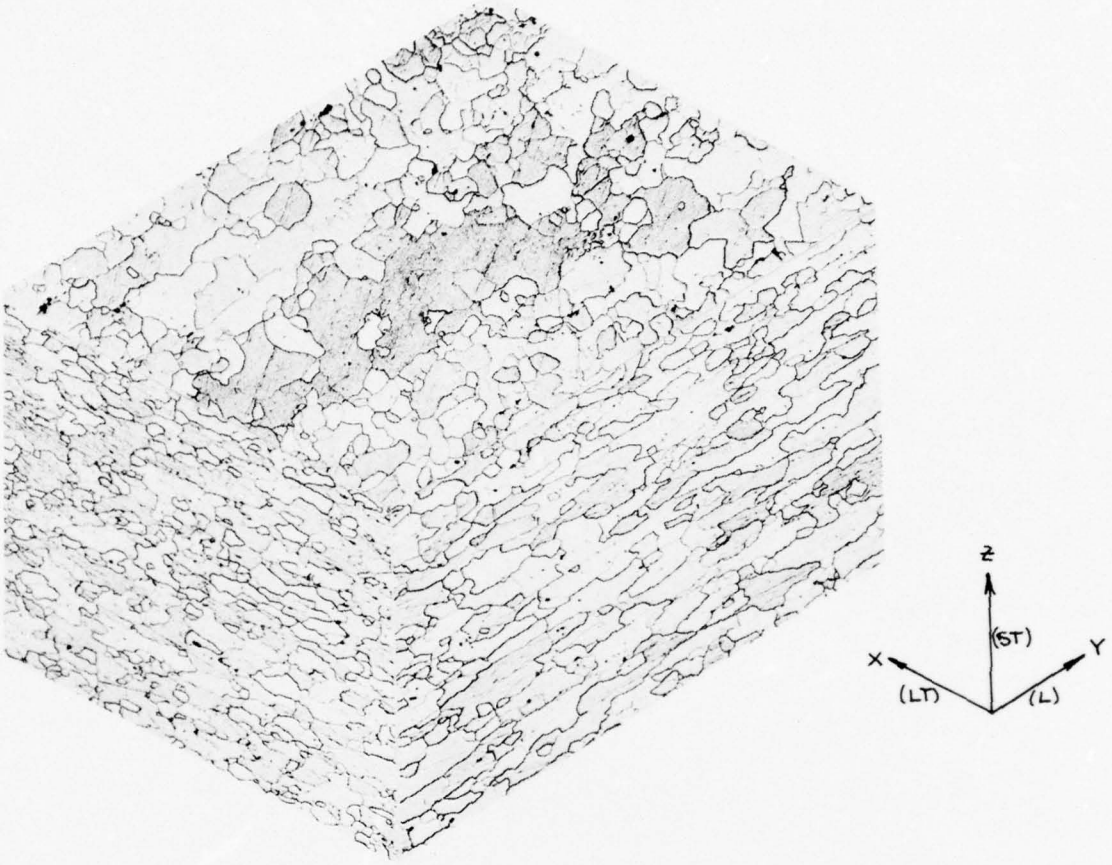



GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| UNRECRYSTALLIZED | | | |

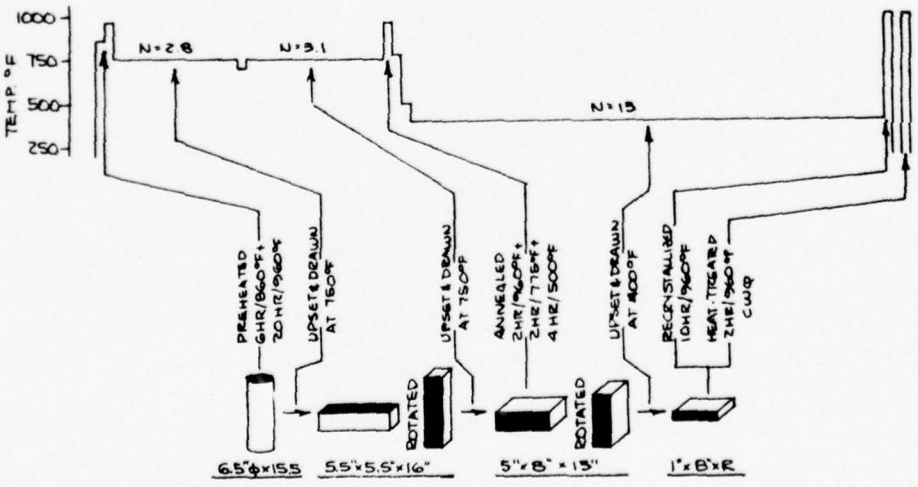
| | PROPERTIES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
| 2UP STEP AGE | T.S. KSI | Y.S. KSI | EL. % | R/A % | U.T.S. KSI | U.T.S. Y.S. | T.S. KSI | Y.S. KSI | EL. % | R/A % | U.T.S. KSI | U.T.S. Y.S. |
| 4HR/350°F | 74.5 | 67.4 | 15.7 | 48 | 98.6 | 1.46 | 71.8 | 67.0 | 3.1 | 6 | 93.0 | 1.39 |
| 6HR/350°F | 71.9 | 63.7 | 15.7 | 48 | 96.2 | 1.51 | 72.3 | 67.2 | 3.1 | 7 | 88.9 | 1.32 |
| 8HR/350°F | 70.3 | 61.1 | 17.1 | 50 | 95.5 | 1.56 | 72.0 | 62.5 | 6.3 | 10 | 88.4 | 1.41 |

Figure 26. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-437666-26B.




MAG 100X KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING

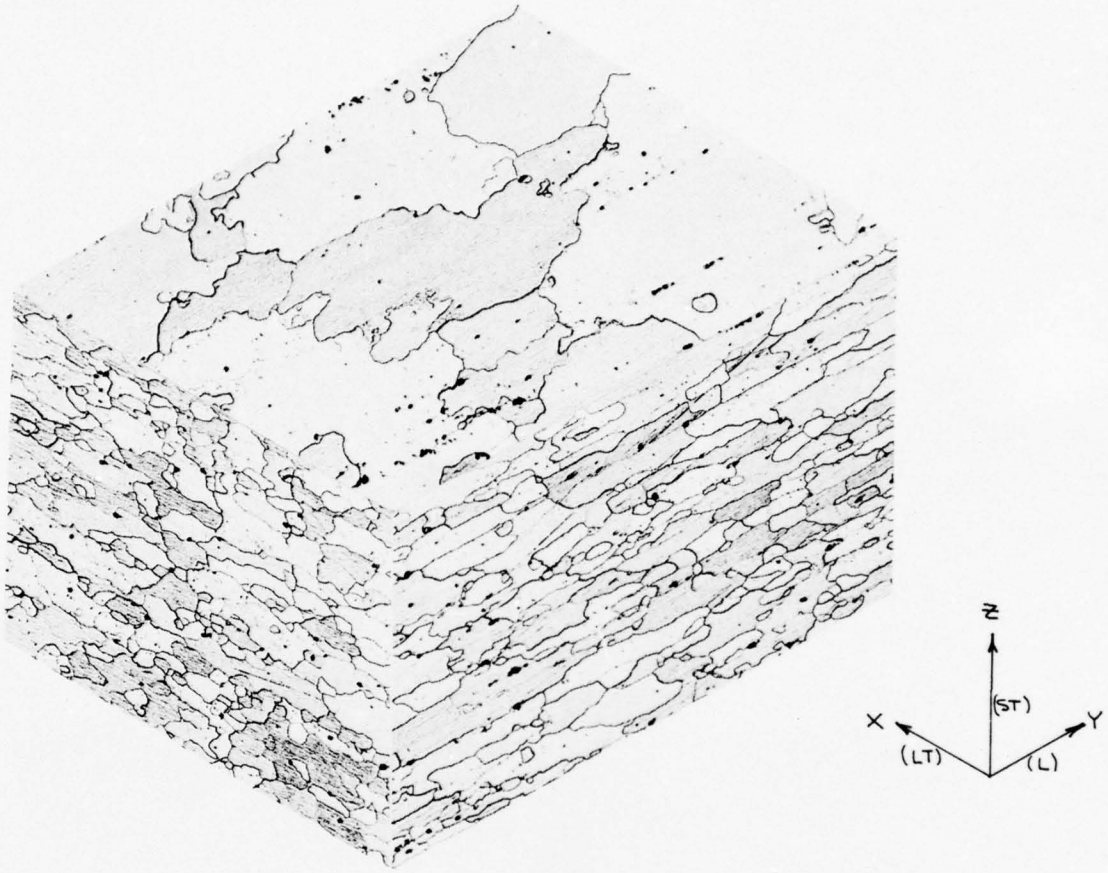



GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 26 | 16 | 53 | 22,048 |

| 2UD STEP AGE | PROPERTIES LONGITUDINAL | | | | | |
|---|---|---|---|---|---|---|
| | T.S. KSI | Y.S. KSI | E.L. % | R/A % | K1C KSI√in | K1SCC KSI√in |
| 4HR/350°F | 75.1 | 68.1 | 16.4 | 48 | 100.6 | 1.48 |
| 8HR/350°F | 72.3 | 64.2 | 16.4 | 50 | 97.5 | 1.52 |

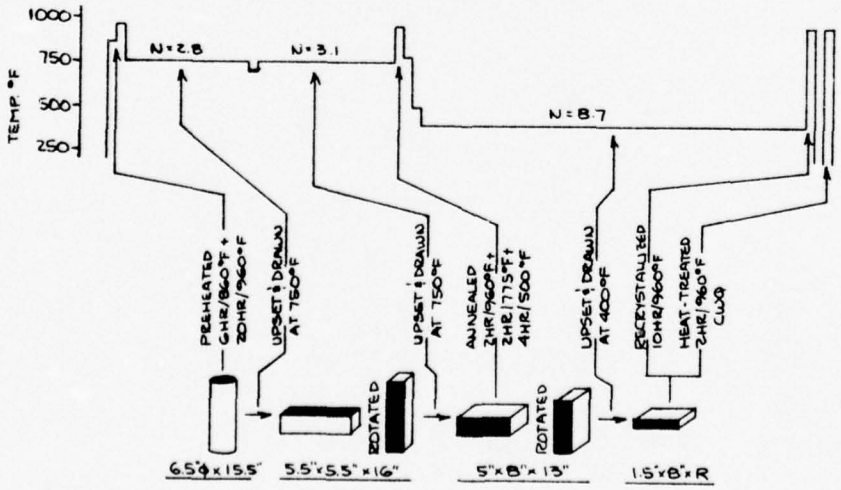
Figure 27. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-437666-27A.




MAG 100X

KELLER'S ETCH

1.5" THICK 7475-T7X HAND FORGING

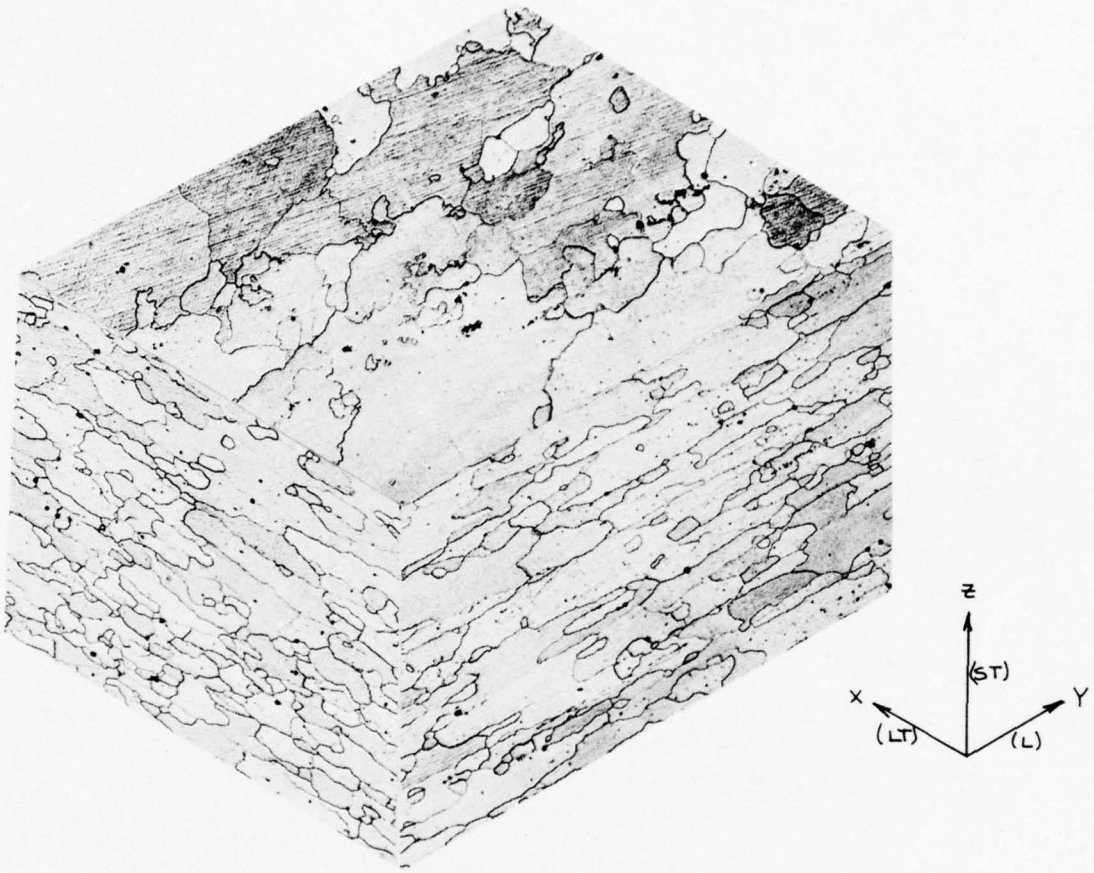



GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| x | y | z | XYZ |
| 23 | 14 | 44 | 14,168 |

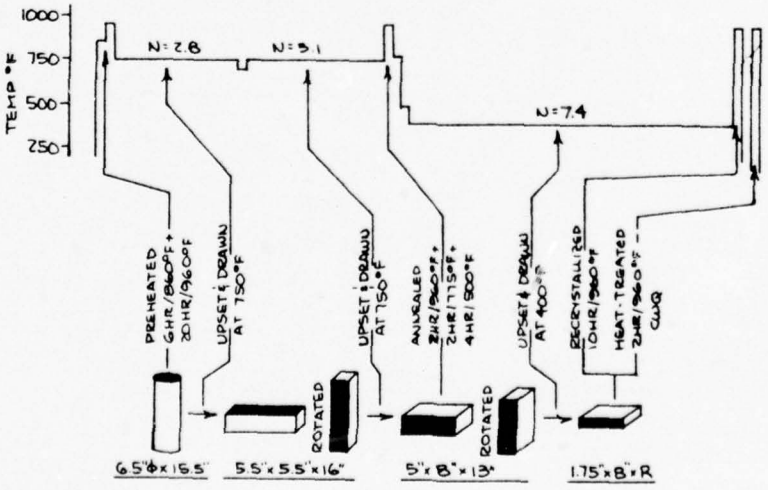
| 2ND STEP AGE | PROPERTIES LONGITUDINAL | | | | | |
|---|---|---|---|---|---|---|
| | TS KSI | YS KSI | EL % | R/A % | UTS MPa | UTS YS |
| 4HR/350°F | 75.5 | 68.7 | 14.3 | 34 | 100.6 | 1.46 |
| 8HR/350°F | 72.5 | 64.0 | 15.0 | 35 | 95.5 | 1.49 |

Figure 28. Microstructure, Properties, and Forging Practice for 1.5-Inch-Thick 7475-T7X Hand Forging S-437666-27B.




MAG 100X KELLER'S ETCH

1.75" THICK 7475-T7X HAND FORGING



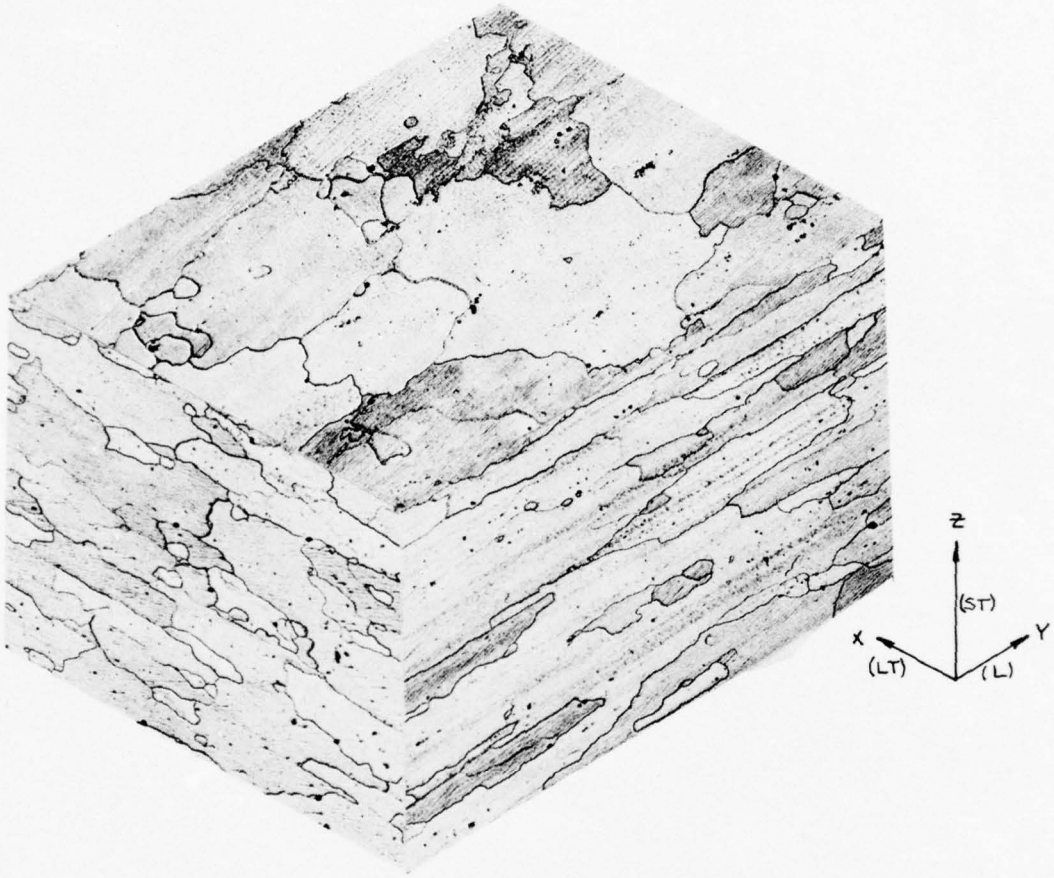

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 14 | 10 | 41 | 5,740 |

PROPERTIES LONGITUDINAL

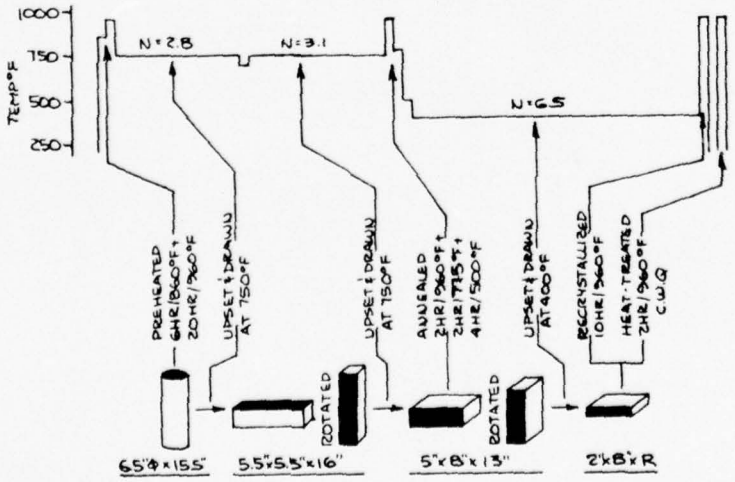
| 2ND STEP AGE | TYS KSI | YS KSI | EL % | RA % | UTS KSI | NTS |
|---|---|---|---|---|---|---|
| 4HR/350°F | 75.3 | 67.7 | 14.3 | 34 | 99.1 | 1.46 |
| 8HR/350°F | 72.5 | 63.4 | 15.7 | 36 | 97.5 | 1.54 |

Figure 29. Microstructure, Properties, and Forging Practice for 1.75-Inch-Thick 7475-T7X Hand Forging S-437666-27C.




MAG 100X KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING



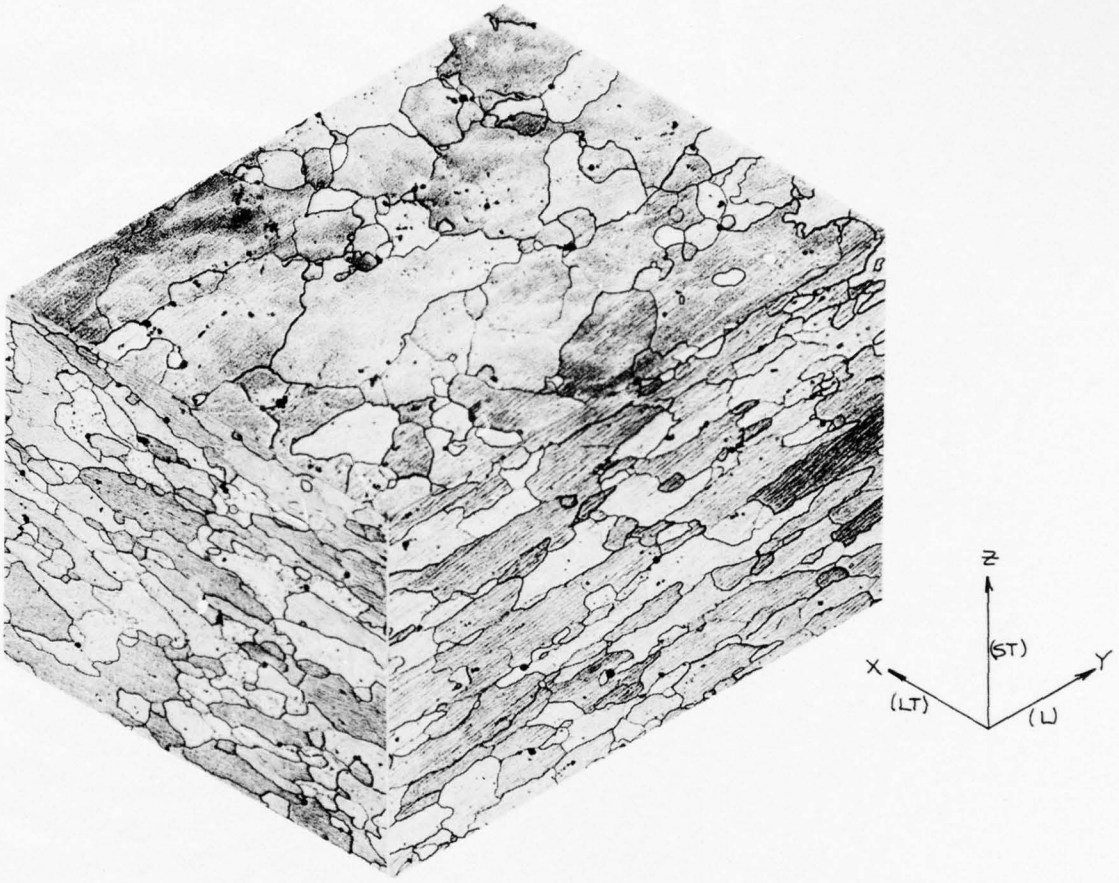

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 10 | 5 | 25 | 1,250 |

PROPERTIES

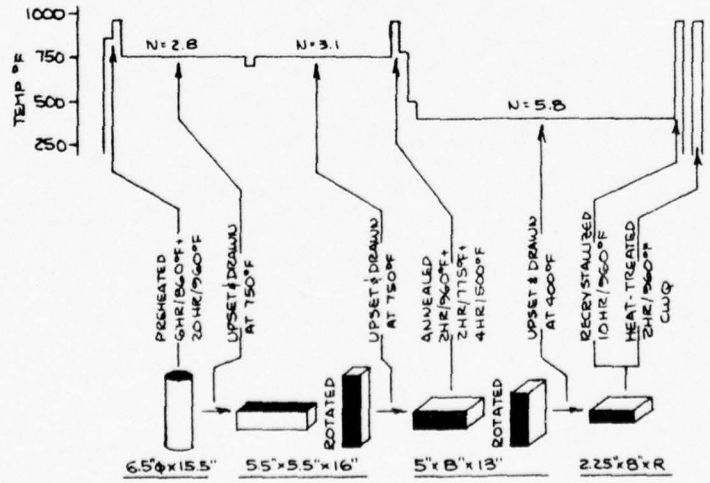
| 2ND STEP AGE | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T.S. KSI | Y.S. KSI | EL % | R/A % | U.T.S. KSI | U.T.S. Y.S. | T.S. KSI | Y.S. KSI | EL % | R/A % | U.T.S. KSI | U.T.S. Y.S. |
| 4HR/350°F | 74.3 | 66.7 | 15.7 | 36 | 101.1 | 1.52 | 74.1 | 66.0 | 12.5 | 24 | 90.4 | 1.37 |
| 8HR/350°F | 72.5 | 62.9 | 15.7 | 36 | 93.7 | 1.49 | 73.9 | 65.7 | 12.5 | 22 | 91.9 | 1.40 |

Figure 30. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-437666-27D.




MAG 100X KELLER'S ETCH

2.25" THICK 7475-T7X HAND FORGING



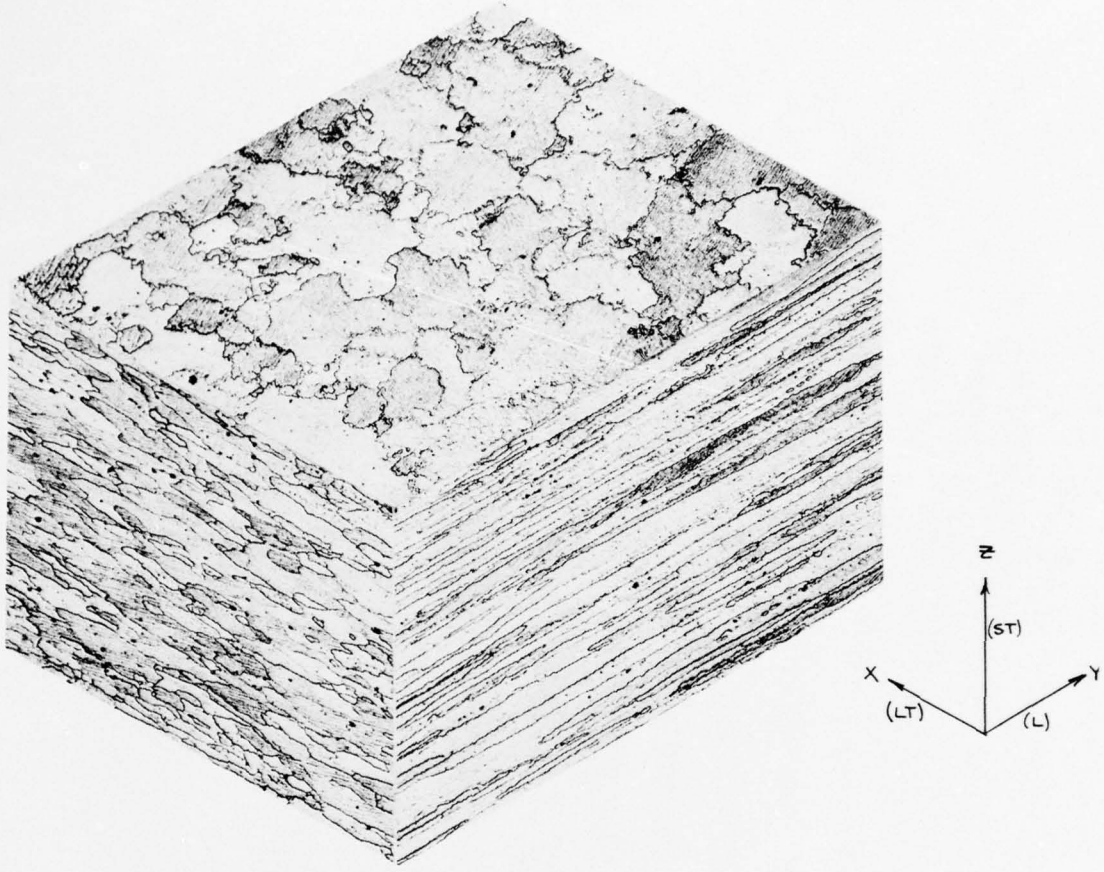

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 17 | 10 | 29 | 4,930 |

PROPERTIES

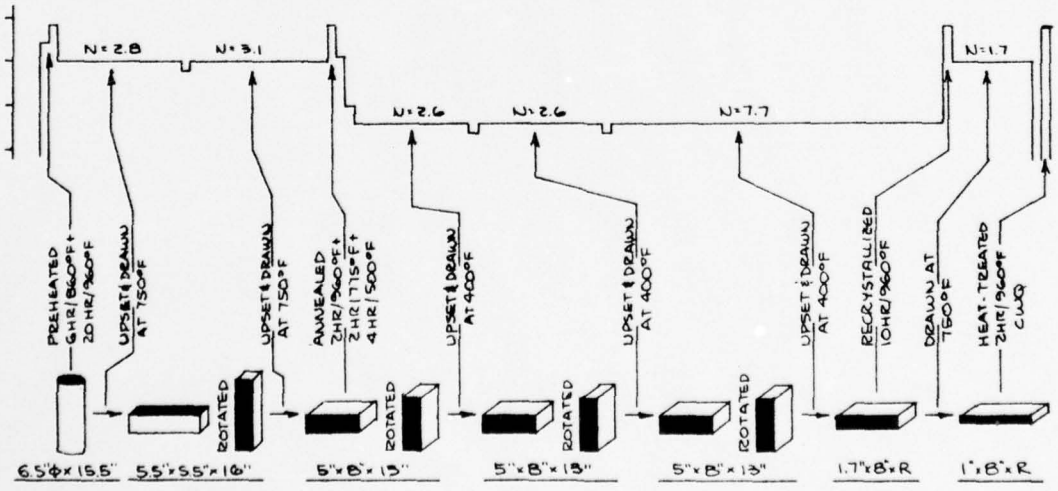
| 2ND STEP AGE | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T.S. KSI | Y.S. KSI | EL % | R/A % | U.T.S. KSI | U.T.S. Y.S. | T.S. KSI | Y.S. KSI | EL % | R/A % | U.T.S. KSI | U.T.S. Y.S. |
| 4 HR/350°F | 75.7 | 68.5 | 14.3 | 32 | 94.5 | 1.38 | 74.9 | 67.2 | 12.5 | 23 | 81.7 | 1.21 |
| 8 HR/350°F | 72.1 | 63.9 | 14.3 | 27 | 94.0 | 1.47 | 71.5 | 62.7 | 10.9 | 25 | 86.8 | 1.39 |

Figure 31. Microstructure, Properties, and Forging Practice for 2.25-Inch-Thick 7475-T7X Hand Forging S-437666-27E.




MAG 100X KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING



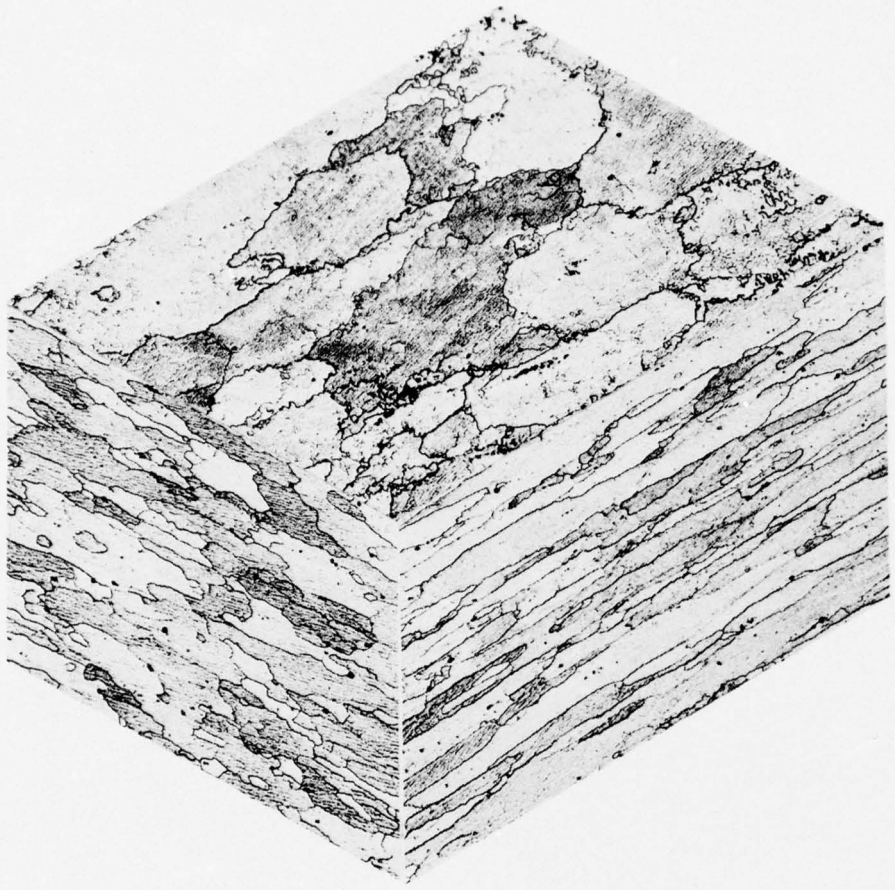

GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | X Y Z |
| 12 | 2 | 57 | 1,368 |

PROPERTIES LONGITUDINAL

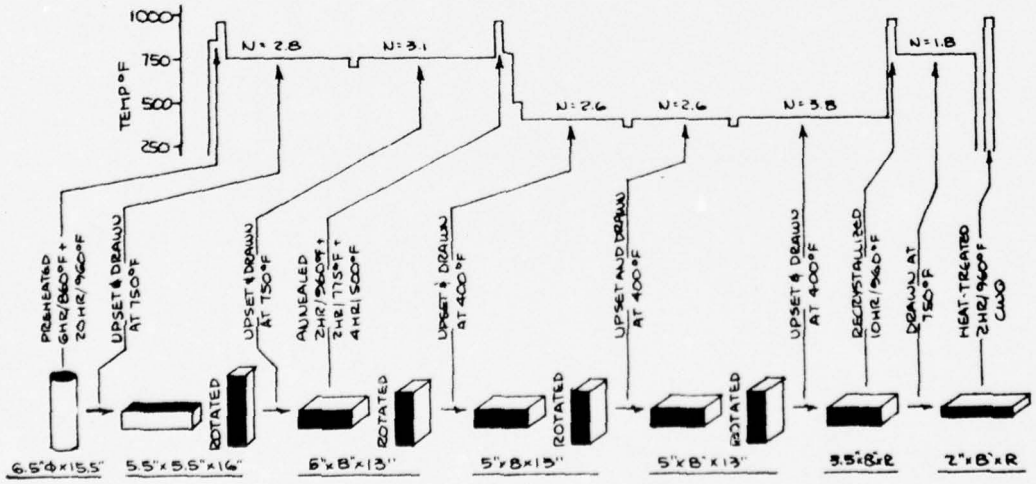
| 2ND STEP AGE | T.S. KSI | Y.S. KSI | EL % | RA % | N.T.S. KSI | N.Y.S. KSI |
|---|---|---|---|---|---|---|
| 4HR/350°F | 76.9 | 68.7 | 15.7 | 41 | 108.3 | 1.58 |
| 6HR/350°F | 75.9 | 67.4 | 17.1 | 48 | 104.7 | 1.55 |
| 8HR/350°F | 73.3 | 63.9 | 17.1 | 47 | 101.6 | 1.59 |

Figure 32. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-437666-28A.




MAG 100X KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING




GRAIN COUNT

| GRAINS/MM | | | GRAINS/MM³ |
|---|---|---|---|
| X | Y | Z | XYZ |
| 10 | 4 | 33 | 1,320 |

PROPERTIES

| 2ND STEP AGE | LONGITUDINAL | | | | | | SHORT-TRANSVERSE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T.S. (KSI) | Y.S. (KSI) | El. % | R/A % | N.T.S (KSI) | N.T.S Y.S. | T.S. (KSI) | Y.S. (KSI) | El. % | R/A % | N.T.S (KSI) | N.T.S Y.S. |
| 4HR/350°F | 76.5 | 69.8 | 15.7 | 45 | 101.1 | 1.45 | 75.6 | 68.6 | 9.5 | 22 | 91.9 | 1.34 |
| 6HR/350°F | 72.3 | 64.9 | 17.1 | 49 | 99.6 | 1.53 | 74.5 | 65.7 | 6.3 | 9 | 93.5 | 1.42 |
| 8HR/350°F | 72.5 | 62.4 | 17.1 | 42 | 96.5 | 1.55 | 73.0 | 64.2 | 9.3 | 11 | 89.9 | 1.40 |

Figure 33. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-437666-28B.

## TABLE 6. FORGING PRACTICES USED TO FABRICATE 1- TO 1.75-INCH-THICK 7475-T7X HAND FORGINGS IN PHASE III

| Final Forging | | | | | 6.5 $\phi$ 15.5-In. Ingot Section | | | | Forged Billet | | | | | Recrystallization | | Forging by Drawing at 750°F, Reduction, N | Solution-Heat-Treat Temperature (°F) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S-No. | Size (in.) | Grain Count, G/mm | | | Thermal Treatment | Forging Operation | | | Size (in.) | Thermal Treatment | Forging Operation | | | Size (in. | Thermal Treatment | | |
| | | X | Y | Z | | Temp (°F) | Type | Reduction, N | | | Temp (°F) | Type | Reduction, N | | | | |
| 437666-26A | 1x8xR | Unrecry | | | D | 550 | Upset & draw | 9.1 | → | | | Upset & draw | 7.4 | 1.7x8xR | 48 hr/860°F | 1.7 | 2 hr/860 |
| 437666-27C | 1.75x8xR | 14 | 10 | 41 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 3.1 | 5x8x13 | A | 400 | Upset & draw | 8.7 | 1.75x8xR | 10 hr/960°F | None | 2 hr/960 |
| 437666-27D | 1.5x8xR | 23 | 14 | 44 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 3.1 | 5x8x13 | A | 400 | Upset & draw | 13 | 1.5x8xR | 10 hr/960°F | None | 2 hr/960 |
| 437666-27E | 1x8xR | 26 | 16 | 53 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 3.1 | 5x8x13 | A | 400 | Upset & draw | 2.6 | 1x8xR | 10 hr/960°F | None | 2 hr/960 |
| 437666-28A | 1x8xR | 12 | 2 | 57 | A | 750 | Upset & draw | 2.8 | | | | Upset & draw | 2.6 | | | | |
| | | | | | | 750 | Upset & draw | 3.1 | 5x8x13 | A | 400 | Upset & draw | 7.7 | 1.7x8xR | 10 hr/960°F | None | 2 hr/960 |

NOTES:
1. Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; D heated 16 hours at 750°F.
2. Forged-billet thermal treatments: A heated 2 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
3. All thermal treatments carried out in circulating-air furnaces.

## TABLE 7. FORGING PRACTICES USED TO FABRICATE 2- TO 2.25-INCH-THICK 7475-T7X HAND FORGINGS IN PHASE III

| Final Forging | | | | | 6.5 ϕ x 15.5-In. Ingot Section | | | | Forged Billet | | | | | Recrystallization | | Forging by Drawing at 750°F, Reduction, N | Solution-Heat-Treat Temperature (°F) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grain Count, G/mm | | | | Forging Operation | | | | | Forging Operation | | | | | | |
| S-No. | Size (in.) | X | Y | Z | Thermal Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Treatment | Temp (°F) | Type | Reduction, N | Size (in.) | Thermal Treatment | | |
| 437666-26B | 2x8xR | Unrecry | | | D | 550 | Upset & draw | 4.4 | → | | | | | 3.5x8xR | 48 hr/860°F | 1.8 | 2 hr/860 |
| 437666-27E | 2.25x8xR | 17 | 10 | 29 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 3.1 | 5x8x13 | A | 400 | Upset & draw | 5.8 | 2.25x8xR | 10 hr/960°F | None | 2 hr/960 |
| 437666-27D | 2x8xR | 10 | 5 | 25 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 3.1 | 5x8x13 | A | 400 | Upset & draw | 6.5 | 2x8xR | 10 hr/960°F | None | 2 hr/960 |
| 437666-28B | 2x8xR | 10 | 4 | 33 | A | 750 | Upset & draw | 2.8 | | | | | | | | | |
| | | | | | | 750 | Upset & draw | 3.1 | 5x8x13 | A | 400 | Upset & draw | 2.6 | | | | |
| | | | | | | | | | | | | Upset & draw | 2.6 | | | | |
| | | | | | | | | | | | | Upset & draw | 3.8 | 3.5x8xR | 10 hr/960°F | 1.8 | 2 hr/960 |

NOTES:
1. Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; D heated 16 hours at 750°F.
2. Forged-billet thermal treatments: A heated 2 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
3. All thermal treatments carried out in circulating-air furnaces.

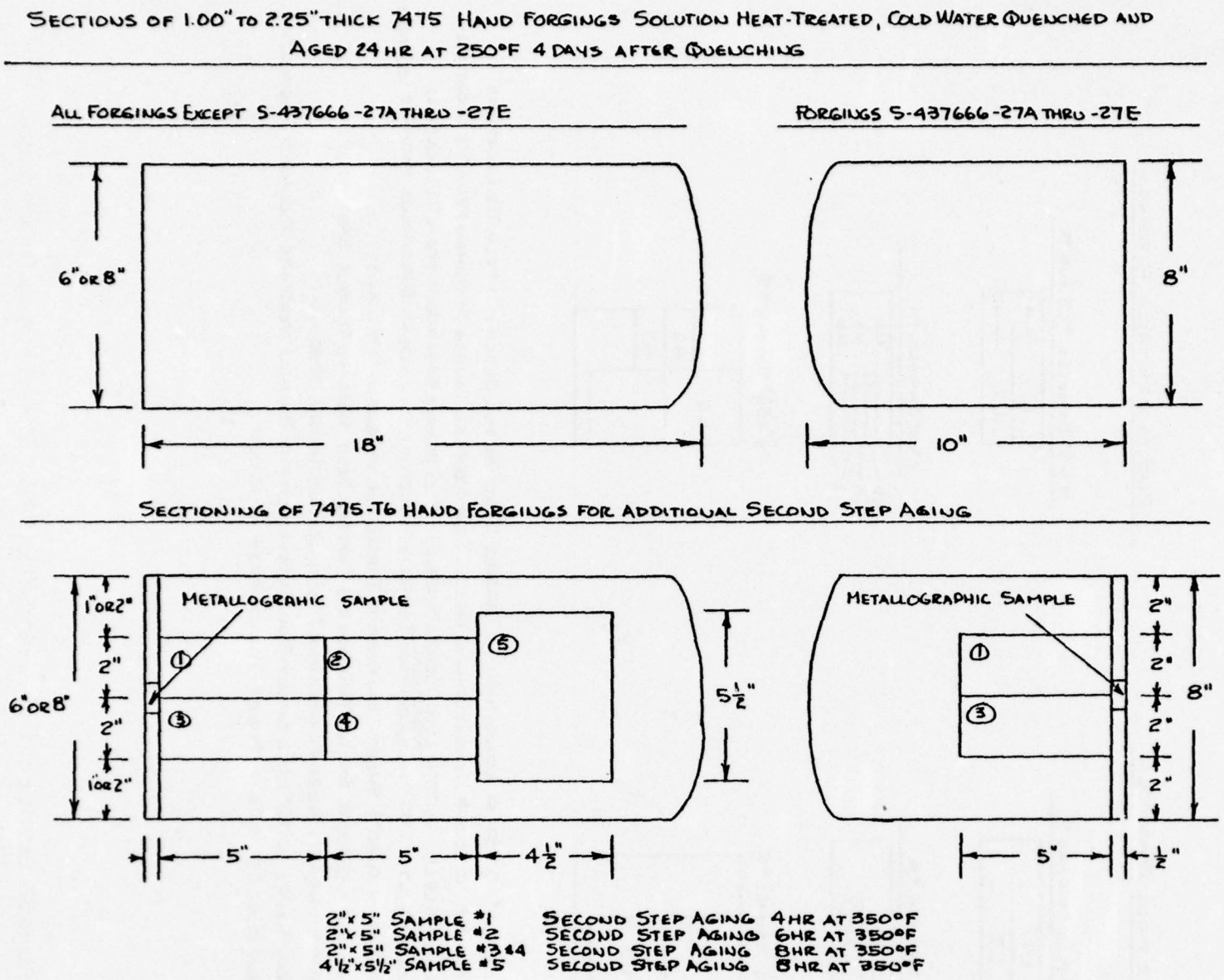
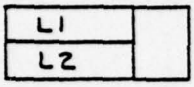


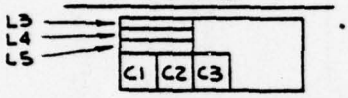

Figure 34. Solution Heat-Treatment, Quenching, and Artificial Aging of 1- to 2.25-Inch-Thick 7475 Hand Forging.

1.00" TO 1.75" THICK FORGINGS

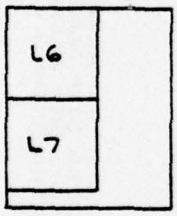
2" x 5" SAMPLES #1, 2 AND 3




2" x 5" SAMPLE #4

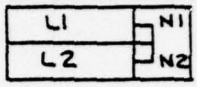



$4\frac{1}{2}$" x $5\frac{1}{2}$" SAMPLE #5

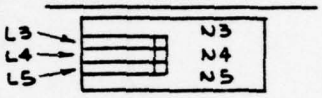



2.00" TO 2.25" THICK FORGINGS

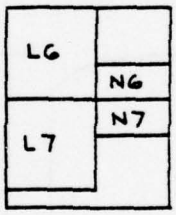
2" x 5" SAMPLES #1, 2 AND 3




2" x 5" SAMPLE #4




$4\frac{1}{2}$" x $5\frac{1}{2}$" SAMPLE #5




SPECIMEN L1 0.357" ϕ LONGITUDINAL TAPERED SEAT TENSILE SPECIMEN FROM T/2 LOCATION
SPECIMEN L2 0.500" ϕ LONGITUDINAL TAPERED SEAT NOTCHED TENSILE SPECIMEN FROM T/2 LOCATION
SPECIMENS L3, L4, L5 0.125" ϕ LONGITUDINAL THREADED END TENSILE SPECIMENS FROM T/2 LOCATION
SPECIMENS L6, L7 1.00" THICK, LONGITUDINAL COMPACT TENSION FRACTURE TOUGHNESS SPECIMENS FROM T/2 LOCATION
SPECIMEN N1 0.160" ϕ SHORT-TRANSVERSE TAPERED SEAT TENSILE SPECIMEN
SPECIMEN N2 0.500" ϕ SHORT-TRANSVERSE TAPERED SEAT NOTCHED TENSILE SPECIMEN
SPECIMENS N3, N4, N5 SHORT-TRANSVERSE THREADED END TENSILE SPECIMENS
SPECIMENS N6, N7 0.75" THICK SHORT-TRANSVERSE COMPACT TENSION FRACTURE TOUGHNESS SPECIMENS
SPECIMENS C1, C2, C3 0.75" ϕ SHORT-TRANSVERSE C-RINGS.

Figure 35. Sampling of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings for Mechanical-Property and Corrosion Tests.

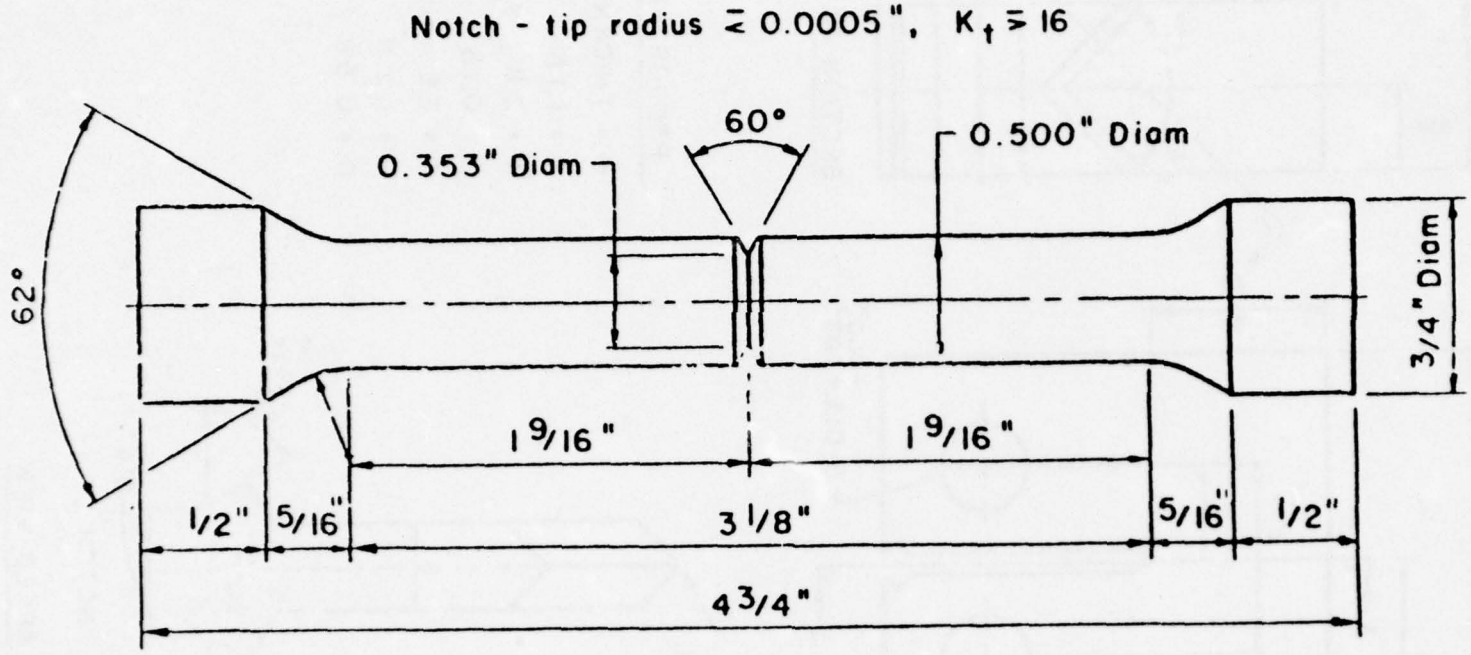
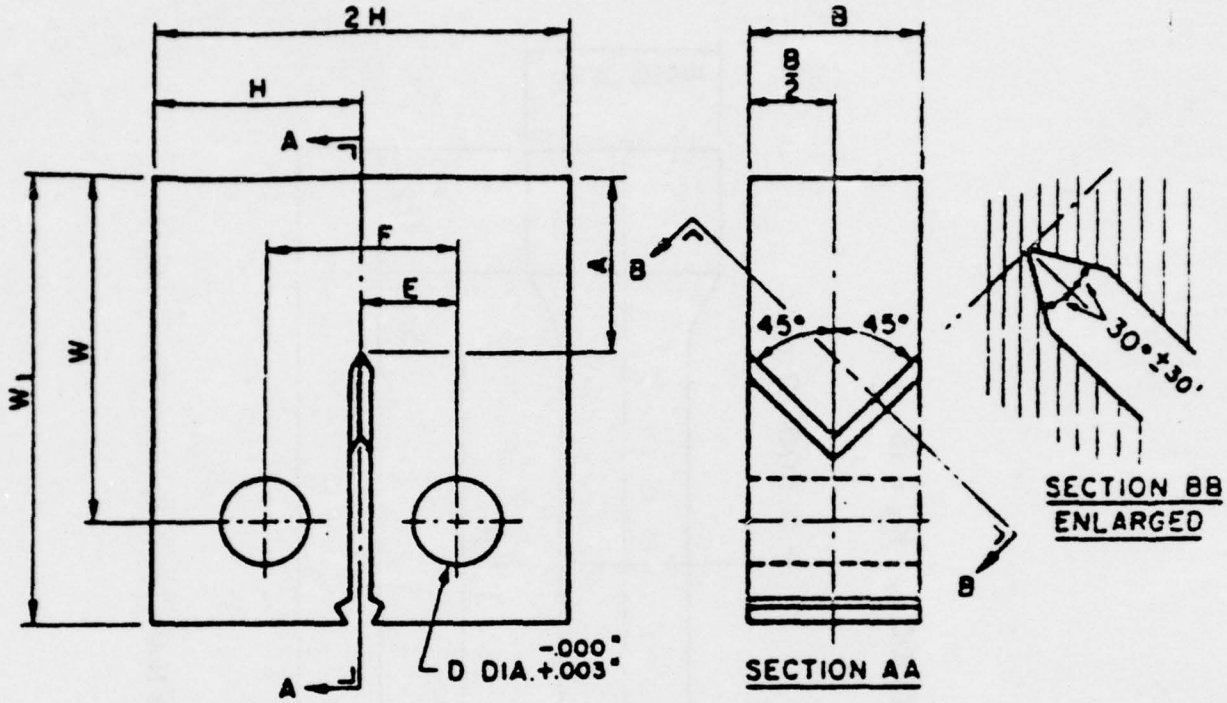
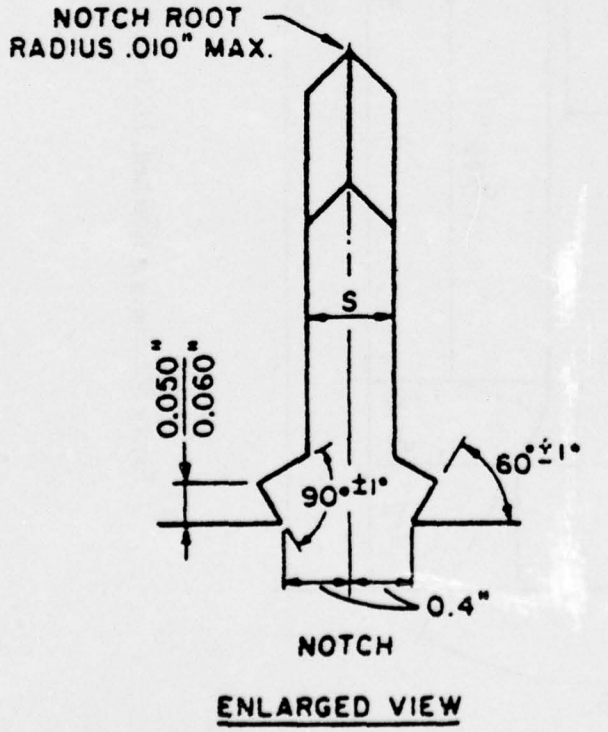



Figure 36. Sharply Notched, 1/2-Inch-Diameter Notch-Tensile Specimen (Tapered Seat).




**PROPORTIONS**

B = THICKNESS

A = 1.1B

W = 2B ; $W_1$ = 2.5B

S = 0.1B

F = 2E = 1.10B

H = 1.2B

D = 0.5B

Figure 37. Compact-Tension Fracture-Toughness Specimen.

## TABLE 8. PROPERTIES OF 1-INCH-THICK RECRYSTALLIZED PLUS HOT-WORKED 7475-T7X HAND FORGINGS

| S-No. | Thickness (in.) | Solution-Heat-Treat Temperature ($^{O}$F) | 2nd-Step Aging | Longitudinal Mechanical Properties | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UTS[1] (ksi) | YS (ksi) | El (%) | Reduction in Area (%) | NTS[2] (ksi) | NTS/YS | $K_Q$[3] (ksi$\sqrt{in.}$) |
| 426669-11 | 1.00 | 960 | 4 hr/350$^{O}$F | 78.7 | 72.7 | 17.1 | 47 | 109.3 | 1.50 | |
| | | | 6 hr/350$^{O}$F | 74.3 | 66.9 | 17.9 | 57 | 108.3 | 1.62 | |
| | | | 8 hr/350$^{O}$F | 75.1 | 66.4 | 16.4 | 46 | 103.7 | 1.56 | 54.0 |
| | | | Avg | | | 17.1 | 50 | | 1.56 | |
| 426669-12 | 1.00 | 960 | 4 hr/350$^{O}$F | 78.5 | 71.9 | 16.4 | 51 | 107.3 | 1.49 | |
| | | | 6 hr/350$^{O}$F | 76.7 | 68.7 | 17.9 | 51 | 107.8 | 1.57 | |
| | | | 8 hr/350$^{O}$F | 77.7 | 69.7 | 17.9 | 53 | 107.3 | 1.54 | 42.6 |
| | | | Avg | | | 17.4 | 52 | | 1.53 | |
| 426669-13 | 1.00 | 860 | 4 hr/350$^{O}$F | 76.1 | 67.7 | 15.0 | 42 | 103.2 | 1.52 | |
| | | | 6 hr/350$^{O}$F | 73.9 | 63.7 | 15.7 | 42 | 100.6 | 1.58 | |
| | | | 8 hr/350$^{O}$F | 73.1 | 62.4 | 15.7 | 41 | 100.6 | 1.52 | |
| | | | Avg | | | 15.5 | 42 | | 1.54 | |
| 426669-19 | 1.00 | 960 | 4 hr/350$^{O}$F | 78.9 | 72.3 | 15.0 | 41 | 109.8 | 1.52 | |
| | | | 6 hr/350$^{O}$F | 77.5 | 69.4 | 15.7 | 45 | 106.7 | 1.54 | |
| | | | 8 hr/350$^{O}$F | 76.1 | 66.9 | 17.1 | 51 | 102.7 | 1.54 | 49.8 |
| | | | Avg | | | 15.9 | 46 | | 1.53 | |
| 426669-22 | 1.00 | 960 | 4 hr/350$^{O}$F | 77.9 | 69.2 | 15.7 | 39 | 102.1 | 1.48 | |
| | | | 6 hr/350$^{O}$F | 75.9 | 66.2 | 15.7 | 44 | 100.6 | 1.52 | |
| | | | 8 hr/350$^{O}$F | 73.7 | 63.4 | 15.0 | 47 | 99.1 | 1.56 | 50.4 |
| | | | Avg | | | 15.5 | 43 | | 1.52 | |
| 437666-28A | 1.00 | 960 | 4 hr/350$^{O}$F | 76.9 | 68.7 | 15.7 | 41 | 108.3 | 1.58 | |
| | | | 6 hr/350$^{O}$F | 75.9 | 67.4 | 17.1 | 48 | 104.7 | 1.55 | |
| | | | 8 hr/350$^{O}$F | 73.3 | 63.9 | 17.1 | 47 | 101.6 | 1.59 | 51.4 |
| | | | Avg | | | 16.6 | 45 | | 1.57 | |

NOTES:
1. Single 0.357-inch $\phi$ tapered-seat longitudinal tensile specimens and 0.160-inch $\phi$ tapered-seat short-transverse tensile specimens.
2. Single 0.500-inch $\phi$ tapered-seat longitudinal and short-transverse notched tensile specimens.
3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.
4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250$^{O}$F plus indicated 2nd-step aging at least 4 days after quenching.

TABLE 9. PROPERTIES OF 1- TO 1.75-INCH-THICK RECRYSTALLIZED 7475-T7X HAND FORGINGS

| S-No. | Thickness (in.) | Solution-Heat-Treat Temperature ($^{O}$F) | 2nd-Step Aging | Longitudinal Mechanical Properties | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UTS[1] (ksi) | YS (ksi) | El (%) | Reduction in Area (%) | NTS[2] (ksi) | NTS/YS | $K_Q$[3] (ksi$\sqrt{in.}$) |
| 426669-8 | 1.00 | 960 | 4 hr/350$^{O}$F | 77.1 | 70.2 | 15.7 | 42 | 107.8 | 1.54 | – |
| | | | 6 hr/350$^{O}$F | 74.7 | 68.4 | 16.4 | 43 | 105.2 | 1.54 | – |
| | | | 8 hr/350$^{O}$F | 75.9 | 64.9 | 15.0 | 37 | 105.2 | 1.62 | – |
| | | | Avg | | | 15.7 | 41 | | 1.57 | |
| 426669-9 | 1.00 | 960 | 4 hr/350$^{O}$F | 79.3 | 72.4 | 14.3 | 36 | 107.3 | 1.48 | – |
| | | | 6 hr/350$^{O}$F | 76.7 | 69.2 | 16.4 | 31 | 106.7 | 1.54 | – |
| | | | 8 hr/350$^{O}$F | 75.3 | 66.7 | 15.0 | 39 | 105.7 | 1.58 | – |
| | | | Avg | | | 15.2 | 35 | | 1.53 | |
| 426669-10 | 1.00 | 960 | 4 hr/350$^{O}$F | 76.5 | 70.2 | 15.7 | 43 | 106.2 | 1.51 | – |
| | | | 6 hr/350$^{O}$F | 74.3 | 68.2 | 15.0 | 47 | 103.7 | 1.52 | – |
| | | | 8 hr/350$^{O}$F | 74.5 | 65.9 | 15.0 | 38 | 104.2 | 1.58 | – |
| | | | Avg | | | 15.2 | 43 | | 1.54 | |
| 426669-17 | 1.00 | 860 | 4 hr/350$^{O}$F | 76.1 | 67.4 | 14.3 | 38 | 102.7 | 1.52 | – |
| | | | 6 hr/350$^{O}$F | 75.9 | 65.2 | 17.1 | 43 | 99.6 | 1.53 | – |
| | | | 8 hr/350$^{O}$F | 73.1 | 62.9 | 13.6 | 40 | 99.3 | 1.58 | – |
| | | | Avg | | | 15.0 | 40 | | 1.54 | |
| 426669-18 | 1.00 | 960 | 4 hr/350$^{O}$F | 77.9 | 71.2 | 15.7 | 38 | 104.7 | 1.47 | – |
| | | | 6 hr/350$^{O}$F | 76.1 | 68.4 | 15.7 | 38 | 103.2 | 1.51 | – |
| | | | 8 hr/350$^{O}$F | 73.5 | 65.4 | 15.7 | 45 | 102.7 | 1.57 | 50.1 |
| | | | Avg | | | 15.7 | 40 | | 1.52 | |
| 426669-20 | 1.00 | 960 | 4 hr/350$^{O}$F | 74.3 | 66.9 | 14.3 | 29 | 98.1 | 1.47 | – |
| | | | 6 hr/350$^{O}$F | 74.4 | 66.7 | 15.7 | 39 | 96.5 | 1.45 | – |
| | | | 8 hr/350$^{O}$F | 73.9 | 64.4 | 15.7 | 39 | 97.5 | 1.51 | – |
| | | | Avg | | | 15.2 | 36 | | 1.48 | |
| 426669-23 | 1.00 | 860 | 4 hr/350$^{O}$F | 73.3 | 64.9 | 15.7 | 38 | 97.5 | 1.50 | – |
| | | | 6 hr/350$^{O}$F | 74.1 | 64.1 | 15.7 | 41 | 102.1 | 1.59 | – |
| | | | 8 hr/350$^{O}$F | 71.1 | 60.4 | 15.7 | 44 | 98.6 | 1.63 | – |
| | | | Avg | | | 15.7 | 41 | | 1.57 | |
| 437666-27A | 1.00 | 960 | 4 hr/350$^{O}$F | 75.1 | 68.1 | 16.4 | 48 | 100.6 | 1.48 | – |
| | | | 8 hr/350$^{O}$F | 72.3 | 64.2 | 16.4 | 50 | 97.5 | 1.52 | – |
| | | | Avg | | | 16.4 | 49 | | 1.50 | |
| 437666-27B | 1.50 | 960 | 4 hr/350$^{O}$F | 75.5 | 68.7 | 14.3 | 34 | 100.6 | 1.46 | – |
| | | | 8 hr/350$^{O}$F | 72.5 | 64.0 | 15.0 | 35 | 95.5 | 1.49 | – |
| | | | Avg | | | 14.6 | 35 | | 1.48 | |
| 437666-27C | 1.75 | 960 | 4 hr/350$^{O}$F | 75.3 | 67.7 | 14.3 | 34 | 99.1 | 1.46 | – |
| | | | 8 hr/350$^{O}$F | 72.5 | 63.4 | 15.7 | 36 | 97.5 | 1.54 | – |
| | | | Avg | | | 15.0 | 35 | | 1.50 | |

NOTES:
1. Single 0.357-inch $\phi$ tapered-seat longitudinal tensile specimens and 0.160-inch $\phi$ tapered-seat short-transverse tensile specimens.
2. Single 0.500-inch $\phi$ tapered-seat longitudinal and short-transverse notched tensile specimens.
3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.
4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250$^{O}$F plus indicated 2nd-step aging at least 4 days after quenching.

TABLE 10. PROPERTIES OF 1-INCH-THICK UNRECRYSTALLIZED 7475-T7X HAND FORGINGS

| S-No. | Thickness (in.) | Solution-Heat-Treat Temperature ($^{O}$F) | 2nd-Step Aging | Longitudinal Mechanical Properties | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | UTS[1] (ksi) | YS (ksi) | El (%) | Reduction in Area (%) | NTS[2] (ksi) | NTS/YS |
| 426669-14 | 1.00 | 960 | 4 hr/350$^{O}$F | 78.9 | 72.4 | 15.7 | 48 | 106.7 | 1.47 |
| | | | 6 hr/350$^{O}$F | 75.7 | 67.9 | 16.4 | 50 | 103.2 | 1.52 |
| | | | 8 hr/350$^{O}$F | 74.7 | 67.2 | 17.9 | 50 | 104.2 | 1.55 |
| 437666-26A | 1.00 | 860 | 4 hr/350$^{O}$F | 73.7 | 66.9 | 15.7 | 46 | 95.0 | 1.42 |
| | | | 6 hr/350$^{O}$F | 71.9 | 64.9 | 15.7 | 45 | 99.6 | 1.53 |
| | | | 8 hr/350$^{O}$F | 72.1 | 61.9 | 15.7 | 44 | 101.6 | 1.64 |

NOTES:
1. Single 0.357-inch $\phi$ tapered-seat longitudinal tensile specimens and 0.160-inch $\phi$ tapered-seat short-transverse tensile specimens.
2. Single 0.500-inch $\phi$ tapered-seat longitudinal and short-transverse notched tensile specimens.
3. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250$^{O}$F plus indicated 2nd-step aging at least 4 days after quenching.

## TABLE 11. PROPERTIES OF 2-INCH-THICK RECRYSTALLIZED PLUS HOT-WORKED 7475-T7X HAND FORGINGS

| S-No. | Thickness (in.) | Solution – Heat-Treat Temperature (°F) | 2nd-Step Aging | Mechanical Properties | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Longitudinal | | | | | | Short-Transverse | | | | | | |
| | | | | UTS[1] (ksi) | YS (ksi) | El (%) | RA (%) | NTS[2] (ksi) | NTS/YS | $K_Q$[3] (ksi$\sqrt{in.}$) | UTS[1] (ksi) | YS (ksi) | El (%) | RA (%) | NTS[2] (ksi) | NTS/YS | $K_Q$[3] (ksi$\sqrt{in.}$) |
| 426669-1 | 2.00 | 960 | 4 hr/350°F | 77.3 | 70.7 | 15.7 | 43 | 102.1 | 1.44 | – | 77.4 | 70.1 | 10.9 | 18 | 101.1 | 1.44 | – |
| | | | 6 hr/350°F | 74.5 | 66.4 | 17.1 | 45 | 101.1 | 1.52 | – | 75.1 | 63.8 | 9.4 | 18 | 99.1 | 1.55 | – |
| | | | 8 hr/350°F | 72.9 | 64.2 | 18.6 | 46 | 102.7 | 1.60 | 55.4 | 72.1 | 60.8 | 7.8 | 11 | 91.9 | 1.51 | 44.2 |
| | | | Avg | | | 17.1 | 45 | | 1.52 | | | | 9.4 | 16 | | 1.50 | |
| 426669-5 | 2.00 | 960 | 4 hr/350°F | 77.3 | 70.9 | 13.6 | 29 | 100.6 | 1.42 | – | 76.4 | 67.9 | 9.4 | 19 | 96.5 | 1.42 | – |
| | | | 6 hr/350°F | 74.3 | 66.9 | 17.9 | 47 | 101.1 | 1.51 | – | 74.9 | 64.9 | 10.9 | 19 | 100.6 | 1.55 | – |
| | | | 8 hr/350°F | 72.5 | 64.7 | 17.9 | 47 | 100.6 | 1.55 | 54.8 | 73.6 | 61.9 | 7.8 | 10 | 80.7 | 1.30 | 41.1 |
| | | | Avg | | | 16.5 | 41 | | 1.49 | | | | 9.4 | 16 | | 1.42 | |
| 426669-6 | 2.00 | 960 | 4 hr/350°F | 78.5 | 72.2 | 15.0 | 35 | 102.1 | 1.41 | – | 77.1 | 69.0 | 6.2 | 7 | 94.5 | 1.37 | – |
| | | | 6 hr/350°F | 76.7 | 68.7 | 17.1 | 44 | 101.6 | 1.48 | – | 75.9 | 64.9 | 9.4 | 14 | 96.5 | 1.49 | – |
| | | | 8 hr/350°F | 74.5 | 66.4 | 15.7 | 47 | 96.0 | 1.45 | 55.4 | 73.9 | 62.3 | 7.8 | 15 | 96.0 | 1.54 | 45.2 |
| | | | Avg | | | 15.9 | 42 | | 1.45 | | | | 7.8 | 12 | | 1.47 | |
| 437666-28B | 2.00 | 960 | 4 hr/350°F | 76.5 | 69.8 | 15.7 | 45 | 101.1 | 1.45 | – | 75.6 | 68.6 | 9.3 | 22 | 91.9 | 1.34 | – |
| | | | 6 hr/350°F | 72.3 | 64.9 | 17.1 | 49 | 99.6 | 1.53 | – | 74.5 | 65.7 | 6.3 | 9 | 93.5 | 1.42 | – |
| | | | 8 hr/350°F | 72.5 | 62.4 | 17.1 | 42 | 96.5 | 1.55 | 46.4 | 73.0 | 64.2 | 9.3 | 11 | 89.9 | 1.40 | 37.4 |
| | | | Avg | | | 16.6 | 45 | | 1.51 | | | | 8.3 | 14 | | 1.39 | |

NOTES:
1. Single 0.357-inch ϕ tapered-seat longitudinal tensile specimens and 0.160-inch ϕ tapered-seat short-transverse tensile specimens.
2. Single 0.500-inch ϕ tapered-seat longitudinal and short-transverse notched tensile specimens.
3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.
4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours to 250°F plus indicated 2nd-step aging at least 4 days after quenching.

## TABLE 12. PROPERTIES OF 2- TO 2.25-INCH-THICK RECRYSTALLIZED 7475-T7X HAND FORGINGS

| S-No. | Thickness (in.) | Solution - Heat-Treat Temperature ($^{O}$F) | 2nd-Step Aging | Mechanical Properties | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Longitudinal | | | | | | | Short-Transverse | | | | | | |
| | | | | UTS[1] (ksi) | YS (ksi) | El (%) | RA (%) | NTS[2] (ksi) | NTS/YS | $K_Q$[3] (ksi $\sqrt{in.}$) | UTS[1] (ksi) | YS (ksi) | El (%) | RA (%) | NTS[2] (ksi) | NTS/YS | $K_Q$[3] (ksi $\sqrt{in.}$) |
| 426669-2 | 2.00 | 960 | 4 hr/350$^{O}$F | 78.3 | 70.7 | 14.3 | 19 | 103.2 | 1.46 | – | 79.1 | 68.7 | 6.2 | 6 | 89.9 | 1.31 | – |
| | | | 6 hr/350$^{O}$F | 76.9 | 67.9 | 12.9 | 24 | 98.6 | 1.45 | – | 78.4 | 66.4 | 9.4 | 11 | 91.9 | 1.38 | – |
| | | | 8 hr/350$^{O}$F | 74.9 | 65.4 | 13.6 | 30 | 99.1 | 1.51 | – | 73.1 | 65.7 | 4.7 | 6 | 93.0 | 1.42 | – |
| | | | Avg | | | 13.6 | 24 | | 1.47 | | | | 6.8 | 8 | | 1.37 | |
| 426669-3 | 2.00 | 960 | 4 hr/350$^{O}$F | 77.3 | 70.9 | 14.3 | 27 | 98.6 | 1.39 | – | 74.6 | 67.9 | 4.7 | 7 | 90.4 | 1.33 | – |
| | | | 6 hr/350$^{O}$F | 75.1 | 67.4 | 14.3 | 30 | 98.6 | 1.46 | – | 73.6 | 63.1 | 7.8 | 7 | 99.6 | 1.57 | – |
| | | | 8 hr/350$^{O}$F | 73.9 | 65.9 | 13.6 | 30 | 99.6 | 1.51 | – | 73.1 | 62.7 | 7.8 | 11 | 95.0 | 1.52 | – |
| | | | Avg | | | 14.1 | 29 | | 1.45 | | | | 6.8 | 8 | | 1.47 | |
| 426669-16 | 2.00 | 960 | 4 hr/350$^{O}$F | 76.1 | 68.7 | 12.6 | 24 | 100.6 | 1.46 | – | 75.1 | 66.4 | 7.8 | 10 | 84.8 | 1.28 | – |
| | | | 6 hr/350$^{O}$F | 74.9 | 65.9 | 12.1 | 23 | 99.6 | 1.51 | – | 73.6 | 61.9 | 9.4 | 10 | 85.8 | 1.38 | – |
| | | | 8 hr/350$^{O}$F | 72.7 | 63.2 | 12.1 | 25 | 92.4 | 1.46 | – | 73.9 | 62.3 | 10.9 | 7 | 94.0 | 1.51 | – |
| | | | Avg | | | 12.3 | 24 | | 1.48 | | | | 9.4 | 9 | | 1.39 | |
| 426669-21 | 2.00 | 960 | 4 hr/350$^{O}$F | 77.4 | 69.4 | 11.4 | 20 | 93.0 | 1.33 | – | 72.6 | 64.5 | 9.3 | 16 | 86.8 | 1.35 | – |
| | | | 6 hr/350$^{O}$F | 75.1 | 66.7 | 12.9 | 27 | 91.9 | 1.38 | – | 73.4 | 64.2 | 12.5 | 19 | 86.3 | 1.34 | – |
| | | | 8 hr/350$^{O}$F | 72.3 | 62.7 | 12.9 | 28 | 91.9 | 1.47 | 46.6 | 71.1 | 60.0 | 7.8 | 11 | 83.2 | 1.39 | 44.6 |
| | | | Avg | | | 12.4 | 25 | | 1.39 | | | | 9.9 | 15 | | 1.36 | |
| 437666-27D | 2.00 | 960 | 4 hr/350$^{O}$F | 74.3 | 66.7 | 15.7 | 35 | 101.1 | 1.52 | – | 74.1 | 66.0 | 12.5 | 24 | 90.4 | 1.37 | – |
| | | | 8 hr/350$^{O}$F | 72.5 | 62.9 | 15.7 | 36 | 93.7 | 1.49 | – | 73.9 | 65.7 | 12.5 | 22 | 91.9 | 1.40 | – |
| | | | Avg | | | 15.7 | 36 | | 1.50 | | | | 12.5 | 23 | | 1.38 | |
| 437666-27E | 2.25 | 960 | 4 hr/350$^{O}$F | 75.7 | 68.5 | 14.3 | 32 | 94.5 | 1.38 | – | 74.9 | 67.2 | 12.5 | 23 | 81.7 | 1.21 | – |
| | | | 8 hr/350$^{O}$F | 72.1 | 63.9 | 14.3 | 27 | 94.0 | 1.47 | – | 71.5 | 62.7 | 10.9 | 25 | 86.8 | 1.39 | – |
| | | | Avg | | | 14.3 | 30 | | 1.42 | | | | 11.7 | 24 | | 1.30 | |

NOTES:
1. Single 0.357-inch $\phi$ tapered-seat longitudinal tensile specimens and 0.160-inch $\phi$ tapered-seat short-transverse tensile specimens.
2. Single 0.500-inch $\phi$ tapered-seat longitudinal and short-transverse notched tensile specimens.
3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.
4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250$^{O}$F plus indicated 2nd-step aging at least 4 days after quenching.

## TABLE 13. PROPERTIES OF 2-INCH-THICK UNRECRYSTALLIZED 7475-T7X HAND FORGINGS

| S-No. | Thickness (in.) | Solution-Heat-Treat Temperature (°F) | 2nd-Step Aging | Mechanical Properties | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Longitudinal | | | | | | | Short-Transverse | | | | | | |
| | | | | UTS[1] (ksi) | YS (ksi) | El (%) | RA (%) | NTS[2] (ksi) | NTS/YS | $K_Q$[3] (ksi $\sqrt{in.}$) | UTS[1] (ksi) | YS (ksi) | El (%) | RA (%) | NTS[2] (ksi) | NTS/YS | $K_Q$[3] (ksi $\sqrt{in.}$) |
| 426669-7 | 2.00 | 860 | 4 hr/350°F | 73.3 | 64.9 | 14.3 | 33 | 95.0 | 1.46 | – | 74.1 | 65.3 | 7.8 | 6 | 91.9 | 1.41 | – |
| | | | 6 hr/350°F | 70.9 | 61.2 | 14.3 | 32 | 92.4 | 1.51 | – | 69.7 | 60.4 | 12.5 | 29 | 91.4 | 1.51 | – |
| | | | 8 hr/350°F | 70.7 | 60.4 | 15.0 | 29 | 95.0 | 1.57 | – | 70.6 | 57.8 | 10.9 | 20 | 85.8 | 1.48 | – |
| 426669-15 | 2.00 | 960 | 4 hr/350°F | 78.7 | 72.2 | 12.9 | 27 | 101.6 | 1.41 | – | 77.1 | 70.1 | 7.8 | 29 | 103.2 | 1.47 | – |
| | | | 6 hr/350°F | 76.7 | 69.2 | 15.0 | 41 | 103.7 | 1.50 | – | 75.9 | 67.9 | 4.7 | 2 | 103.7 | 1.53 | – |
| | | | 8 hr/350°F | 73.1 | 64.4 | 17.9 | 49 | 99.1 | 1.54 | – | 72.4 | 64.9 | 7.8 | 5 | 95.5 | 1.47 | – |
| 437666-26B | 2.00 | 860 | 4 hr/350°F | 74.5 | 67.4 | 15.7 | 48 | 98.6 | 1.46 | – | 71.8 | 67.0 | 3.1 | 6 | 93.0 | 1.39 | – |
| | | | 6 hr/350°F | 71.9 | 63.7 | 15.7 | 48 | 96.2 | 1.51 | – | 72.3 | 67.2 | 3.1 | 7 | 88.9 | 1.32 | – |
| | | | 8 hr/350°F | 70.3 | 61.1 | 17.1 | 50 | 95.5 | 1.56 | 45.5 | 72.0 | 62.5 | 6.3 | 10 | 88.4 | 1.41 | 35.5 |

NOTES:
1. Single 0.357-inch ϕ tapered-seat longitudinal tensile specimens and 0.160-inch ϕ tapered-seat short-transverse tensile specimens.
2. Single 0.500-inch ϕ tapered-seat longitudinal and short-transverse notched tensile specimens.
3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.
4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250°F plus indicated 2nd-step aging at least 4 days after quenching.

TABLE 14. RESULTS OF ACCELERATED STRESS-CORROSION TESTS ON 1- TO 2-INCH-THICK 7475-T7X HAND FORGINGS (LONGITUDINAL SPECIMENS)

| S-No. | Thickness (in.) | Grain Dimensions | | | | Tensile Properties | | | 1/8-In. $\phi$ Tensile Bars Stressed at 75% YS[1] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Thickness (mm) | Width (mm) | Length (mm) | Aspect Ratio | UTS (ksi) | YS (ksi) | El (%) | Spec L3 | Spec L4 | Spec L5 |
| **Recrystallized Plus Hot-Worked** | | | | | | | | | | | |
| 426669-1 | 2.00 | 0.028 | 1.000 | 1.000 | 35.7 | 74.5 | 66.4 | 17.0 | OK 84DA | OK 84DA | OK 84DA |
| 437666-28B | 2.00 | 0.030 | 0.250 | 0.100 | 3.3 | 72.5 | 62.4 | 17.0 | OK 84DA | OK 84DA | OK 84DA |
| 426669-5 | 2.00 | 0.036 | 1.000 | 1.000 | 27.7 | 74.3 | 66.9 | 18.0 | OK 84DA | OK 84DA | OK 84DA |
| 426669-6 | 2.00 | 0.042 | 0.500 | 0.250 | 6.0 | 76.7 | 68.7 | 17.0 | OK 84DA | OK 84DA | OK 84DA |
| 437666-28A | 1.00 | 0.018 | 0.500 | 0.083 | 4.6 | 75.8 | 68.0 | 16.0 | OK 84DA | OK 84DA | OK 84DA |
| 426669-19 | 1.00 | 0.020 | 0.333 | 0.167 | 8.4 | 77.9 | 70.1 | 14.0 | OK 84DA | OK 84DA | OK 84DA |
| 426669-12 | 1.00 | 0.023 | 0.500 | 0.200 | 8.7 | 76.6 | 66.0 | 13.0 | OK 84DA | OK 84DA | OK 84DA |
| 426669-11 | 1.00 | 0.025 | 0.500 | 0.333 | 13.2 | 78.7 | 68.6 | 13.0 | OK 84DA | OK 84DA | OK 84DA |
| 426669-22 | 1.00 | 0.046 | 1.000 | 0.500 | 10.9 | 76.0 | 64.9 | 17.0 | OK 84DA | OK 84DA | OK 84DA |
| **Recrystallized** | | | | | | | | | | | |
| 426669-21 | 2.00 | 0.031 | 0.143 | 0.067 | 2.2 | 75.1 | 66.7 | 13.0 | OK 84DA | OK 84DA | OK 84DA |
| 426669-18 | 1.00 | 0.040 | 0.333 | 0.200 | 5.0 | 77.0 | 67.1 | 16.0 | OK 84DA | OK 84DA | OK 84DA |
| **Unrecrystallized** | | | | | | | | | | | |
| 426669-15 | 2.00 | – | – | – | – | 73.1 | 64.4 | 18.0 | OK 84DA | OK 84DA | OK 84DA |
| 437666-26B | 2.00 | – | – | – | – | 71.9 | 63.7 | 16.0 | OK 84DA | OK 84DA | OK 84DA |
| 426669-14 | 1.00 | – | – | – | – | 77.8 | 69.2 | 13.0 | OK 84DA | OK 84DA | OK 84DA |

NOTES:
1. Specimens exposed stressed for 84 days by alternate immersion to 3.5% NaCl solution (Federal Test Method 823).
2. All forgings artificially aged 24 hours at 250°F plus 8 hours at 350°F.
3. Specimens from T/2 location.

## TABLE 15. RESULTS OF ACCELERATED STRESS-CORROSION TESTS ON 1- TO 2-INCH-THICK 7475-T7X HAND FORGINGS (SHORT-TRANSVERSE SPECIMENS)

| S-No. | Thickness (in.) | Grain Dimensions: Thickness (mm) | Width (mm) | Length (mm) | Aspect Ratio | Tensile Properties: UTS (ksi) | YS (ksi) | El (%) | 1/8-In. ϕ Tensile Bars Stressed at 42 ksi: N3 | N4 | N5 | 3/4-In. ϕ C-Rings Stressed at 42 ksi: C1 | C2 | C3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Recrystallized Plus Hot-Worked** | | | | | | | | | | | | | | |
| A26669-1 | 2.00 | 0.028 | 1.000 | 1.000 | 35.7 | 76.0 | 66.6 | 12.0 | OK 84DA | OK 84DA | OK 84DA | – | – | – |
| 437666-28B | 2.00 | 0.030 | 0.250 | 0.100 | 3.3 | 72.7 | 64.0 | 9.0 | OK 84DA | OK 84DA | OK 84DA | – | – | – |
| 426669-5 | 2.00 | 0.036 | 1.000 | 1.000 | 27.7 | 75.2 | 64.3 | 11.0 | OK 84DA | OK 84DA | OK 84DA | – | – | – |
| 426669-6 | 2.00 | 0.042 | 0.500 | 0.250 | 6.0 | 75.4 | 67.0 | 9.0 | F 68DA | F 84DA | OK 84DA | – | – | – |
| 437666-28A | 1.00 | 0.018 | 0.500 | 0.083 | 4.6 | – | – | – | – | – | – | OK 30DA[2] | OK 84DA[2] | OK 84DA[2] |
| 426669-19 | 1.00 | 0.020 | 0.333 | 0.167 | 8.4 | – | – | – | – | – | – | OK 84DA[3] | OK 30DA[3] | OK 84DA[3] |
| 426669-12 | 1.00 | 0.023 | 0.500 | 0.200 | 8.7 | – | – | – | – | – | – | OK 84DA | OK 84DA[4] | OK 84DA |
| 426669-11 | 1.00 | 0.025 | 0.500 | 0.333 | 13.2 | – | – | – | – | – | – | OK 84DA | OK 84DA | OK 84DA[4] |
| 426669-22 | 1.00 | 0.046 | 1.000 | 0.500 | 10.9 | – | – | – | – | – | – | OK 84DA[4] | OK 84DA | OK 84DA |
| **Recrystallized** | | | | | | | | | | | | | | |
| 426669-21 | 2.00 | 0.031 | 0.143 | 0.067 | 2.2 | 68.4 | 64.1 | 4.0 | OK 84DA | OK 84DA | OK 84DA | – | – | – |
| 426669-18 | 1.00 | 0.040 | 0.333 | 0.200 | 5.0 | – | – | – | – | – | – | OK 84DA[4] | OK 84DA | OK 84DA |
| **Unrecrystallized** | | | | | | | | | | | | | | |
| 426669-15 | 2.00 | – | – | – | – | 74.3 | 64.9 | 10.0 | Defective specimen | F 47DA | OK 84DA | – | | – |
| 437666-26B | 2.00 | – | – | – | – | 72.7 | 64.0 | 9.0 | OK 84DA | OK 84DA | OK 84DA | – | – | – |
| 426669-14 | 1.00 | – | – | – | – | – | – | – | – | – | – | OK 84DA[4] | OK 84DA | OK 84DA |

NOTES:
1. After 30-day and 84-day exposure, C-rings did not crack or show any visible evidence of lined-up pitting.
2. One specimen examined microscopically after 30 days and 2 specimens examined microscopically after 84 days. No evidence of stress-corrosion cracking noted after either 30- or 84-day exposure.
3. One specimen examined microscopically after 30 days and 2 specimens examined microscopically after 84 days. Slight evidence of stress-corrosion cracking after 30 days and no increase in the evidence of stress-corrosion cracking after 84 days.
4. Specimens examined microscopically after 84 days. No evidence of stress-corrosion cracking.
5. All specimens from T/2 location exposed stressed for 84 days by alternate immersion to 3.5% NaCl solution (Federal Test Method 823).
6. All forgings aged 24 hours at 250°F plus 8 hours at 350°F.

## TABLE 16. GRAIN COUNTS, GRAIN DIMENSIONS, AND FABRICATING VARIABLES FOR 7475-T7X HAND FORGINGS PRODUCED USING ITMT-TYPE PRACTICES

| Warm Forging | | Ingot Breakdown at 750°F, | Recry | Hot Forging at 750°F After Recry, | Grain Counts | | | | Calculated Grain Dimensions | | | | Forging | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | G/mm | | | $G/mm^3$ | Thickness $\frac{l}{Z}$ | Width $\frac{l}{Y}$ | Length $\frac{l}{X}$ | Aspect $\frac{Z}{X}$ | Thickness | |
| Reduction, N | Temperature (°F) | Reduction, N | Temperature (°F) | Reduction, N | Z | Y | X | XYZ | | | | | (in.) | S-No. |
| **1.00- to 1.50-In.-Thick Recrystallized** | | | | | | | | | | | | | | |
| 15.5 | 350 | None | 860 | None | 30 | 2 | 3 | 180 | 0.033 | 0.500 | 0.333 | 10.0 | 1.00 | 426669-23 |
| 15.5 | 400 | None | 860 | None | 24 | 2 | 2 | 96 | 0.042 | 0.500 | 0.500 | 11.9 | 1.00 | 426669-17 |
| 15.5 | 400 | None | 960 | None | 25 | 3 | 5 | 375 | 0.040 | 0.333 | 0.200 | 5.0 | 1.00 | 426669-18 |
| 13.0 | 400 | 2.8 + 3.1 | 960 | None | 53 | 16 | 26 | 22,048 | 0.019 | 0.062 | 0.038 | 2.0 | 1.00 | 437666-27A |
| 13.0 | 400 | 2.8 + 3.1 | 960 | None | 16 | 3 | 6 | 288 | 0.062 | 0.333 | 0.167 | 2.7 | 1.00 | 426669-20 |
| 8.7 | 400 | 2.8 + 3.1 | 960 | None | 44 | 14 | 23 | 14,168 | 0.023 | 0.071 | 0.044 | 1.9 | 1.50 | 437666-27B |
| 7.0 | 500 | 2.8 + 2.3 | 960 | None | 22 | 2 | 4 | 176 | 0.046 | 0.500 | 0.250 | 5.4 | 1.00 | 426669-8 |
| 4.0 | 500 | 2.8 + 4.0 | 960 | None | 24 | 3 | 8 | 576 | 0.042 | 0.333 | 0.125 | 3.0 | 1.00 | 426669-9 |
| 2.0 | 500 | 2.8 + 8.0 | 960 | None | 20 | 5 | 3 | 300 | 0.050 | 0.200 | 0.333 | 6.6 | 1.00 | 426669-10 |
| **1.75- to 2.25-Thick Recrystallized** | | | | | | | | | | | | | | |
| 7.4 | 400 | 2.8 + 3.1 | 960 | None | 41 | 10 | 14 | 5,740 | 0.024 | 0.100 | 0.071 | 3.0 | 1.75 | 437666-27C |
| 6.5 | 400 | 2.8 + 3.1 | 960 | None | 32 | 7 | 15 | 3,360 | 0.031 | 0.143 | 0.067 | 2.2 | 2.00 | 426669-21 |
| 6.5 | 400 | 2.8 + 3.1 | 960 | None | 25 | 5 | 10 | 1,250 | 0.040 | 0.200 | 0.100 | 2.5 | 2.00 | 437666-27D |
| 5.8 | 400 | 2.8 + 3.1 | 960 | None | 29 | 10 | 17 | 4,930 | 0.034 | 0.100 | 0.059 | 1.7 | 2.25 | 437666-27E |
| 1.8 + 4.0 | 500 | 2.8 + 2.3 | 960 | None | 17 | 2 | 3 | 102 | 0.059 | 0.500 | 0.333 | 5.6 | 2.00 | 426669-16 |
| 4.0 | 500 | 2.8 + 2.0 | 960 | None | 6 | 1 | 1 | 6 | 0.167 | 1.000 | 1.000 | 5.9 | 2.00 | 426669-3 |
| 2.0 | 500 | 2.8 + 4.0 | 960 | None | 19 | 2 | 7 | 266 | 0.053 | 0.500 | 0.143 | 2.7 | 2.00 | 426669-2 |
| **1.00-In.-Thick Recrystallized Plus Hot-Forged** | | | | | | | | | | | | | | |
| 2.6 + 2.6 + 7.7 | 400 | 2.8 + 3.1 | 960 | 1.7 | 57 | 2 | 12 | 1,368 | 0.018 | 0.500 | 0.083 | 4.6 | 1.00 | 437666-28A |
| 9.1 | 400 | None | 860 | 1.7 | 22 | 1 | 2 | 44 | 0.046 | 1.000 | 0.500 | 10.9 | 1.00 | 426669-22 |
| 9.1 | 500 | None | 860 | 1.7 | 19 | 1 | 1 | 19 | 0.053 | 1.000 | 1.000 | 18.9 | 1.00 | 426669-13 |
| 9.1 | 550 | None | 860 | 1.7 | Unrecrystallized | | | | – | – | – | – | 1.00 | 437666-26A |
| 7.7 | 400 | 2.8 + 3.1 | 960 | 1.7 | 50 | 3 | 6 | 900 | 0.020 | 0.333 | 0.167 | 8.4 | 1.00 | 426669-19 |
| 4.1 | 500 | 2.8 + 2.3 | 960 | 1.7 | 40 | 2 | 3 | 240 | 0.025 | 0.500 | 0.33 | 13.2 | 1.00 | 426669-11 |
| 2.1 | 500 | 2.8 + 4.6 | 960 | 1.7 | 43 | 2 | 5 | 430 | 0.023 | 0.500 | 0.200 | 8.7 | 1.00 | 426669-12 |
| **2.00-In.-Thick Recrystallized Plus Hot-Forged** | | | | | | | | | | | | | | |
| 2.6 + 2.6 + 3.8 | 400 | 2.8 + 3.1 | 960 | 1.8 | 33 | 4 | 10 | 1,320 | 0.030 | 0.250 | 0.100 | 3.3 | 2.00 | 437666-28B |
| 2.0 + 2.3 + 2.7 | 500 | 2.8 + 2.0 | 960 | 1.5 | 24 | 2 | 4 | 192 | 0.042 | 0.500 | 0.250 | 6.0 | 2.00 | 426669-6 |
| 4.4 | 500 | None | 860 | 1.8 | Unrecrystallized | | | | – | – | – | – | 2.00 | 426669-7 |
| 4.4 | 550 | None | 860 | 1.8 | Unrecrystallized | | | | – | – | – | – | 2.00 | 437666-26B |
| 2.0 + 2.3 | 500 | 2.8 + 2.3 | 960 | 1.8 | 28 | 1 | 1 | 28 | 0.036 | 1.000 | 1.000 | 27.7 | 2.00 | 426669-5 |
| 2.0 | 500 | 2.8 + 2.3 | 960 | 1.8 | 36 | 1 | 1 | 36 | 0.028 | 1.000 | 1.000 | 35.7 | 2.00 | 426669-1 |

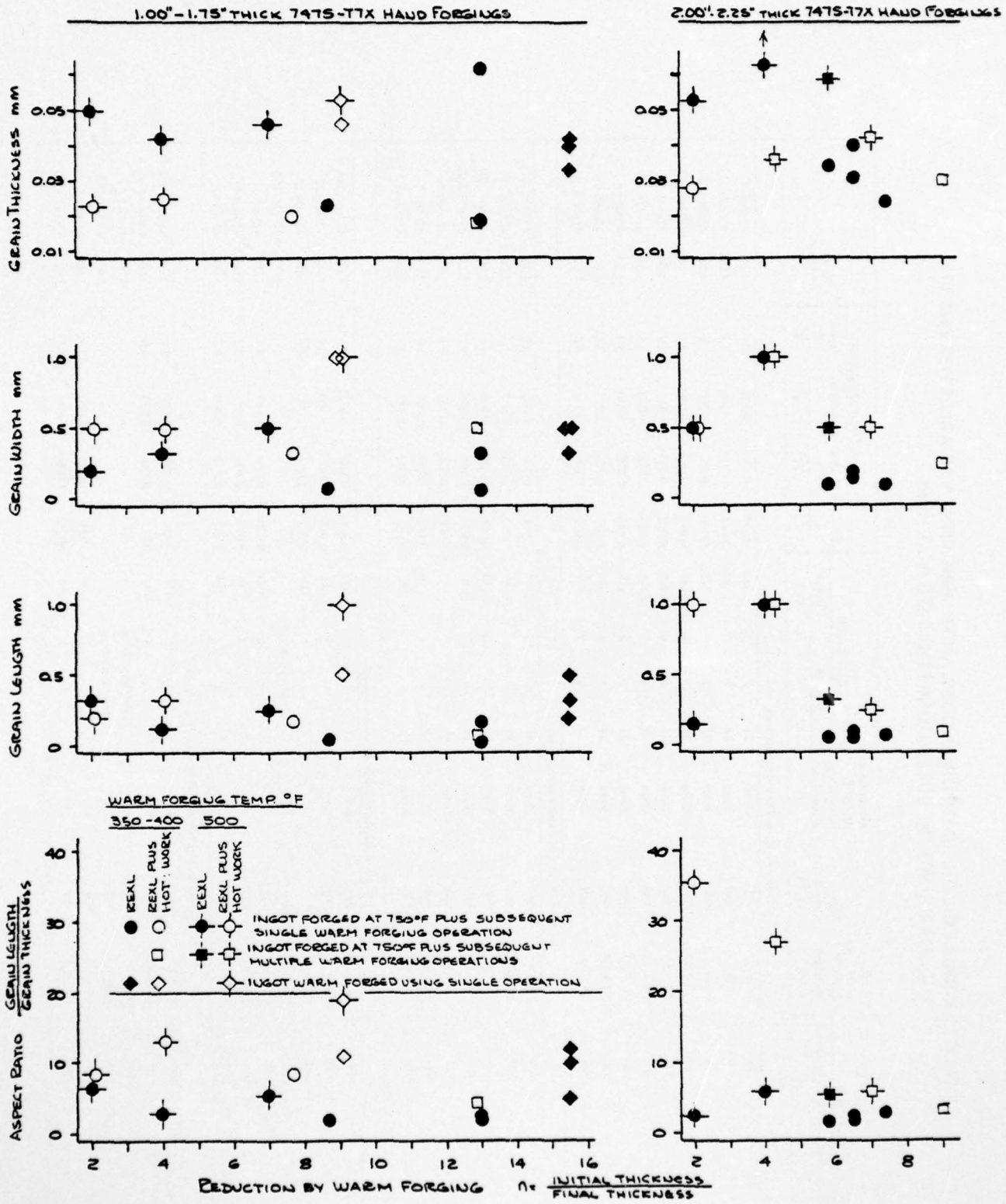



Figure 38. Relationship Between Grain Dimensions and Amount of Warm Forging for 1- to 2.25-Inch-Thick 7475-T7X ITMT Hand Forgings.

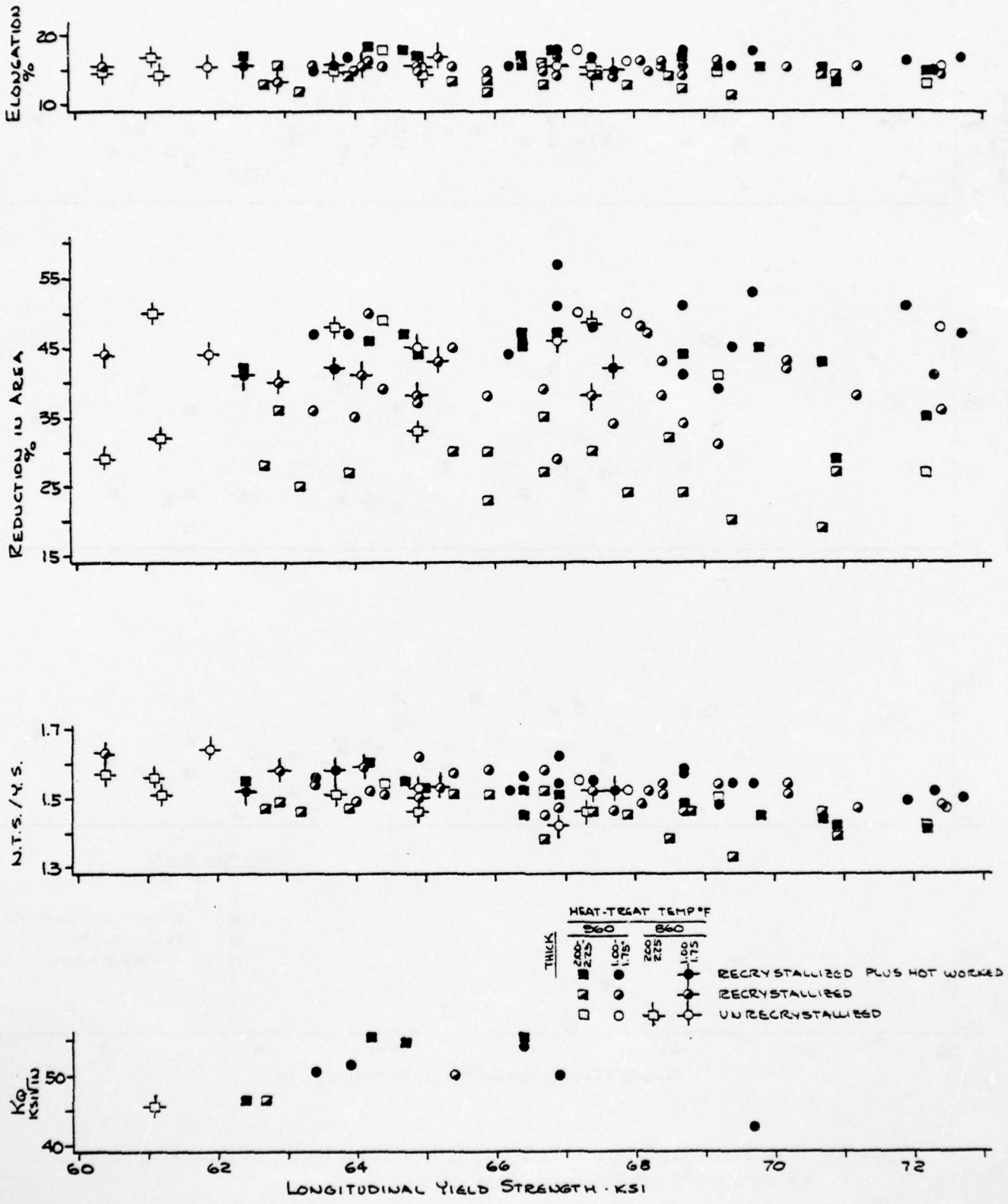



Figure 39. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of Yield Strength.

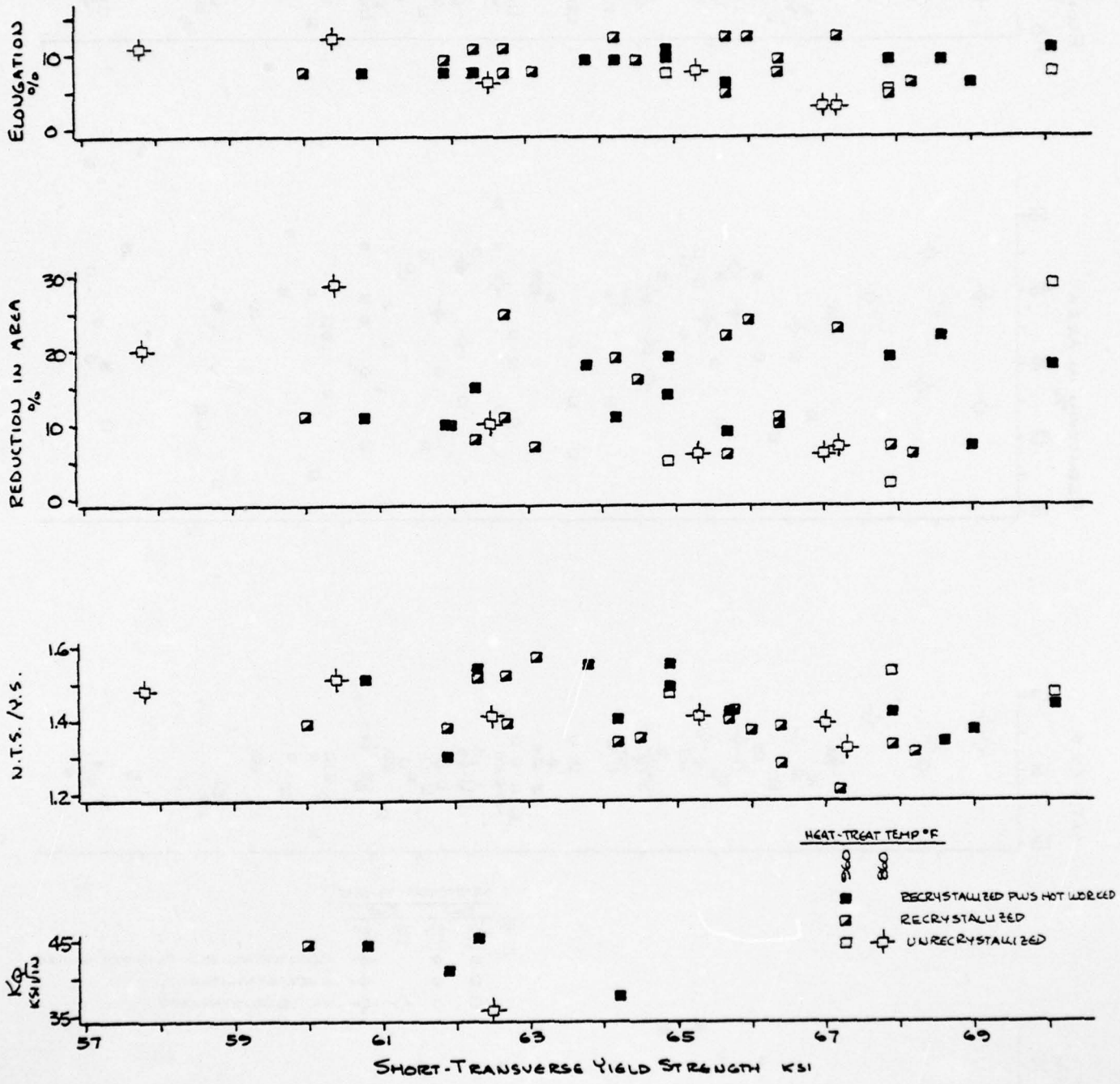



Figure 40. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of Short-Transverse Yield Strength.

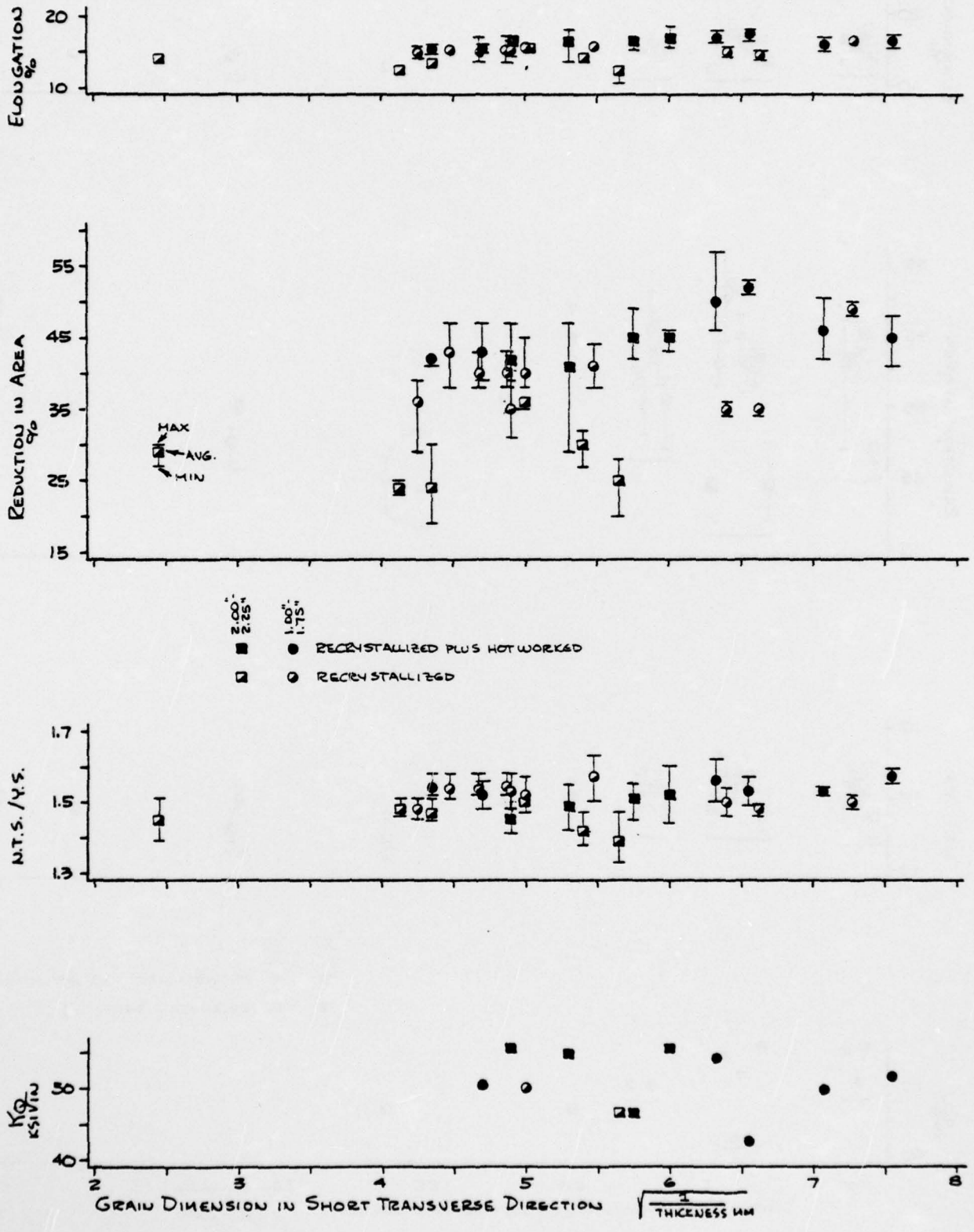



Figure 41. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Grain Dimension in the Short-Transverse Direction.

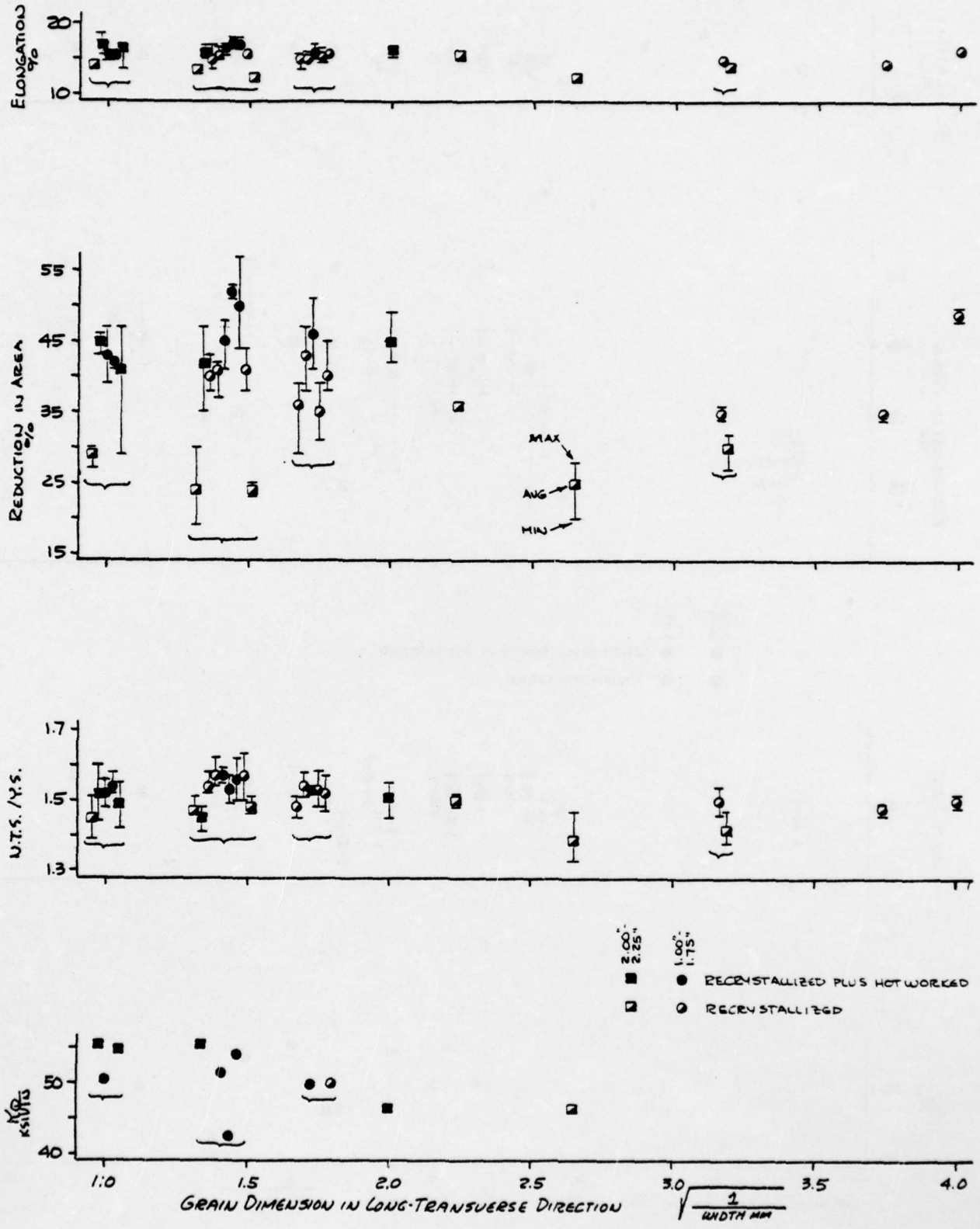



Figure 42. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Grain Dimension in the Long-Transverse Direction.

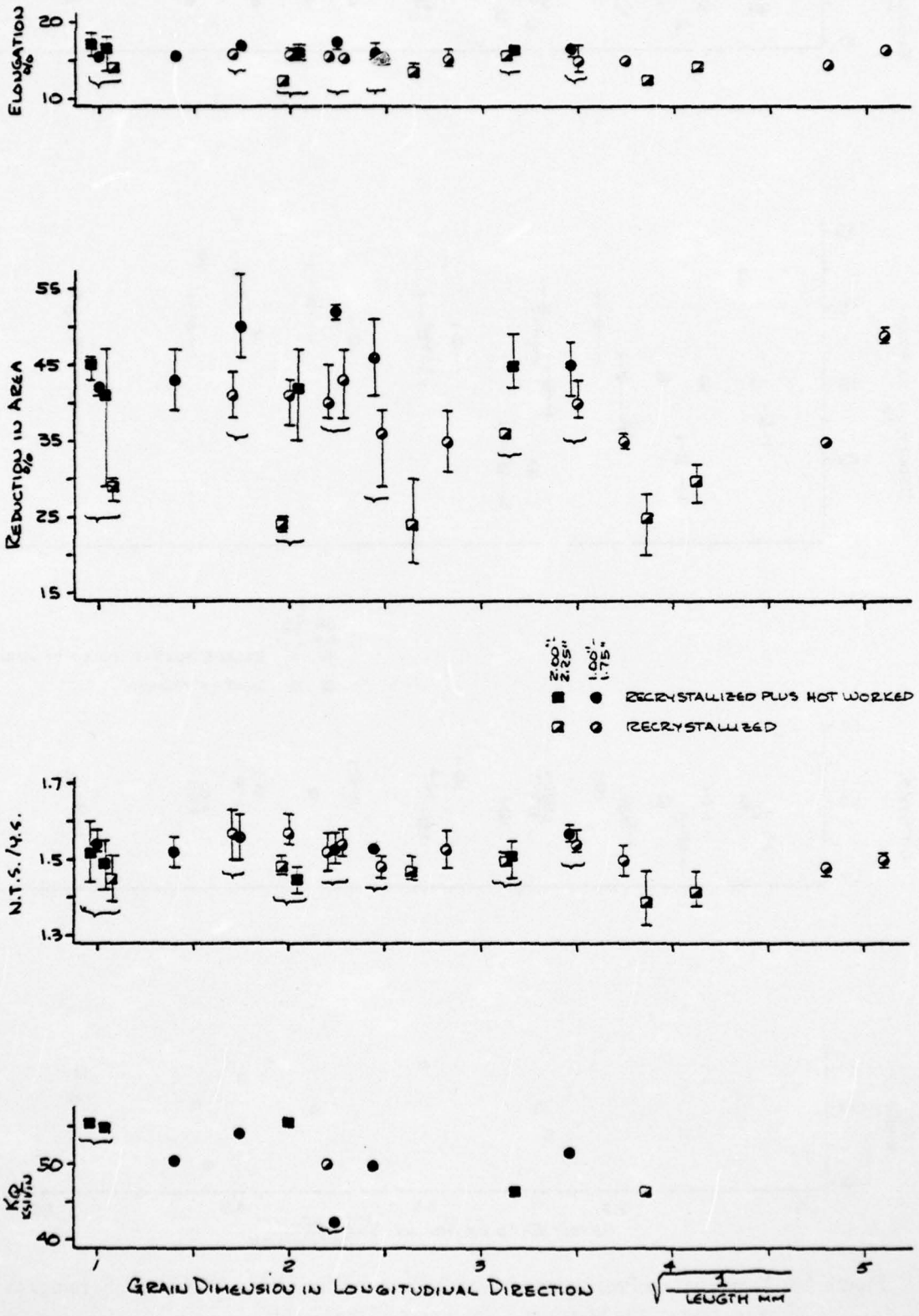



Figure 43. Longitudinal Properties of 1- to 2.25-Inch- Thick 7475-T7X Hand Forgings as a Function of the Grain Dimension in the Longitudinal Direction.

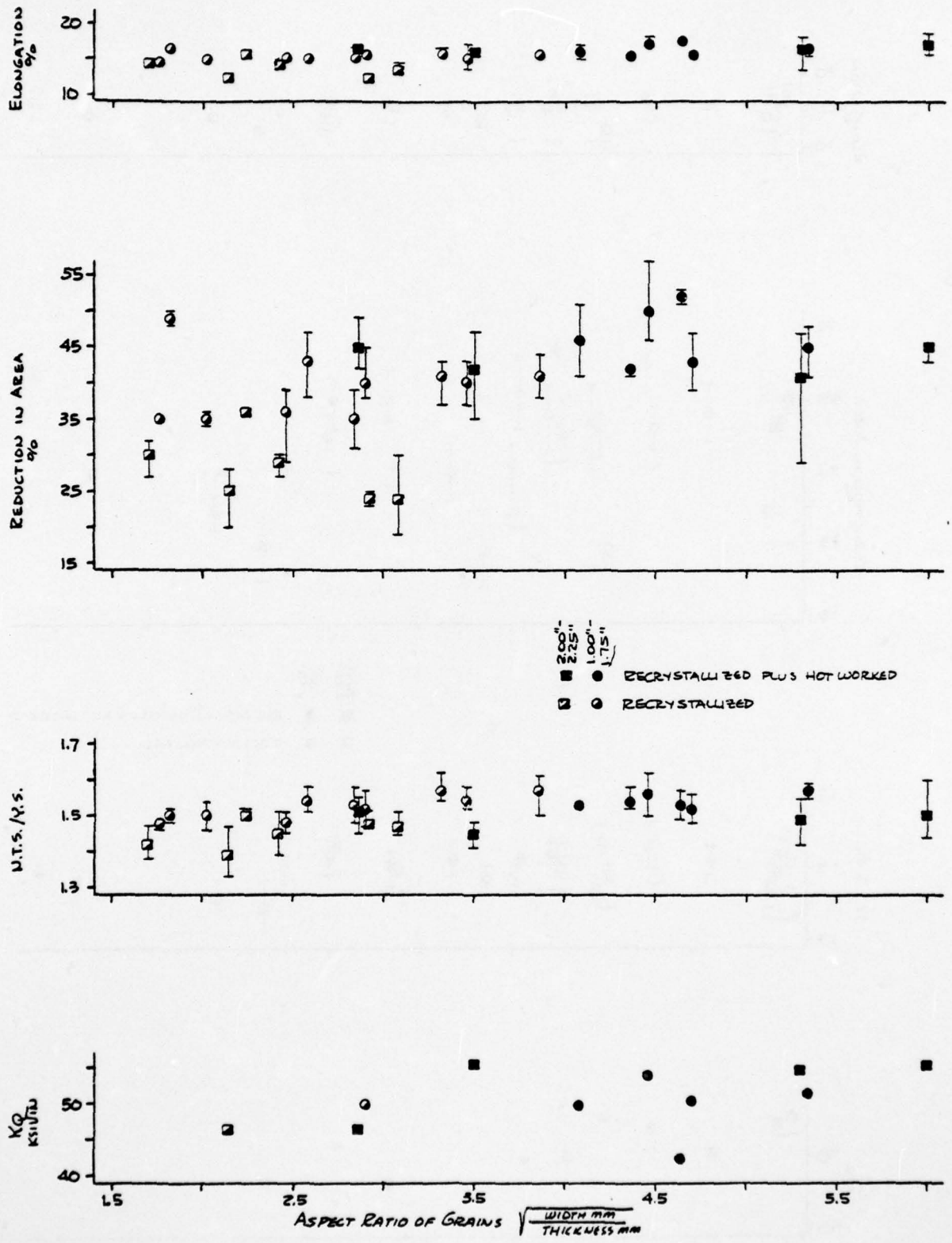



Figure 44. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Width and Thickness of the Grains.

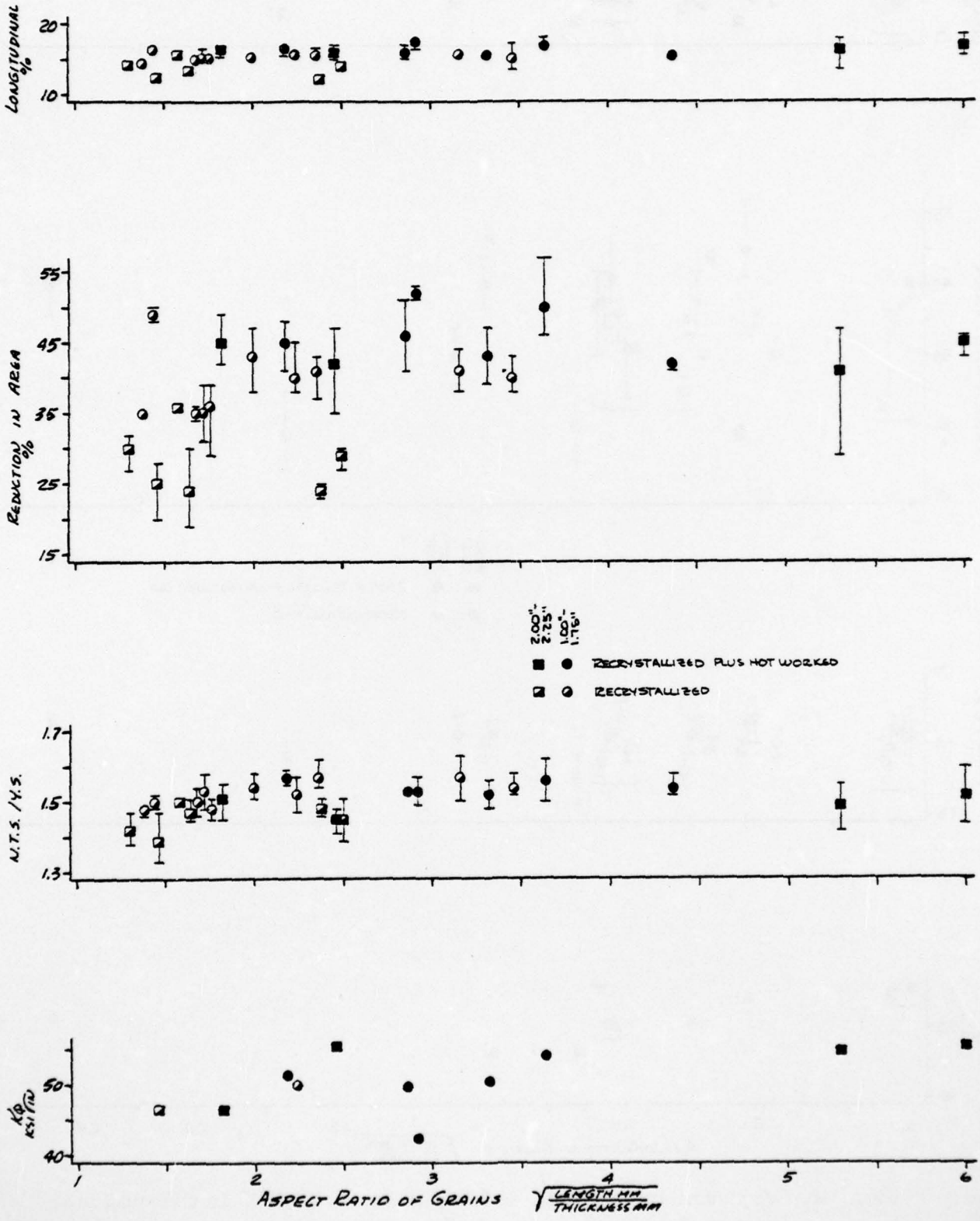



Figure 45. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Length and the Thickness of the Grains.

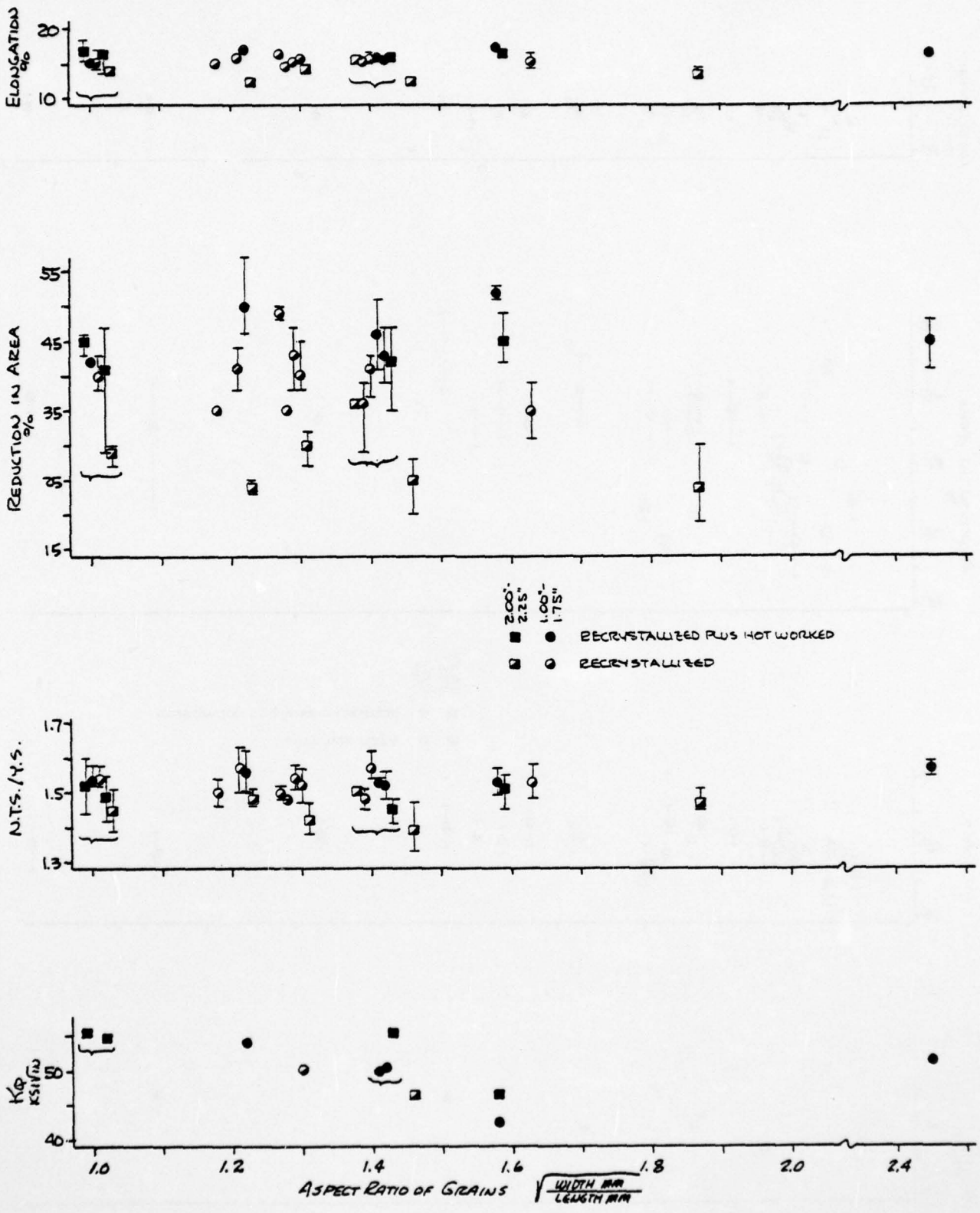



Figure 46. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Width and Length of the Grains.

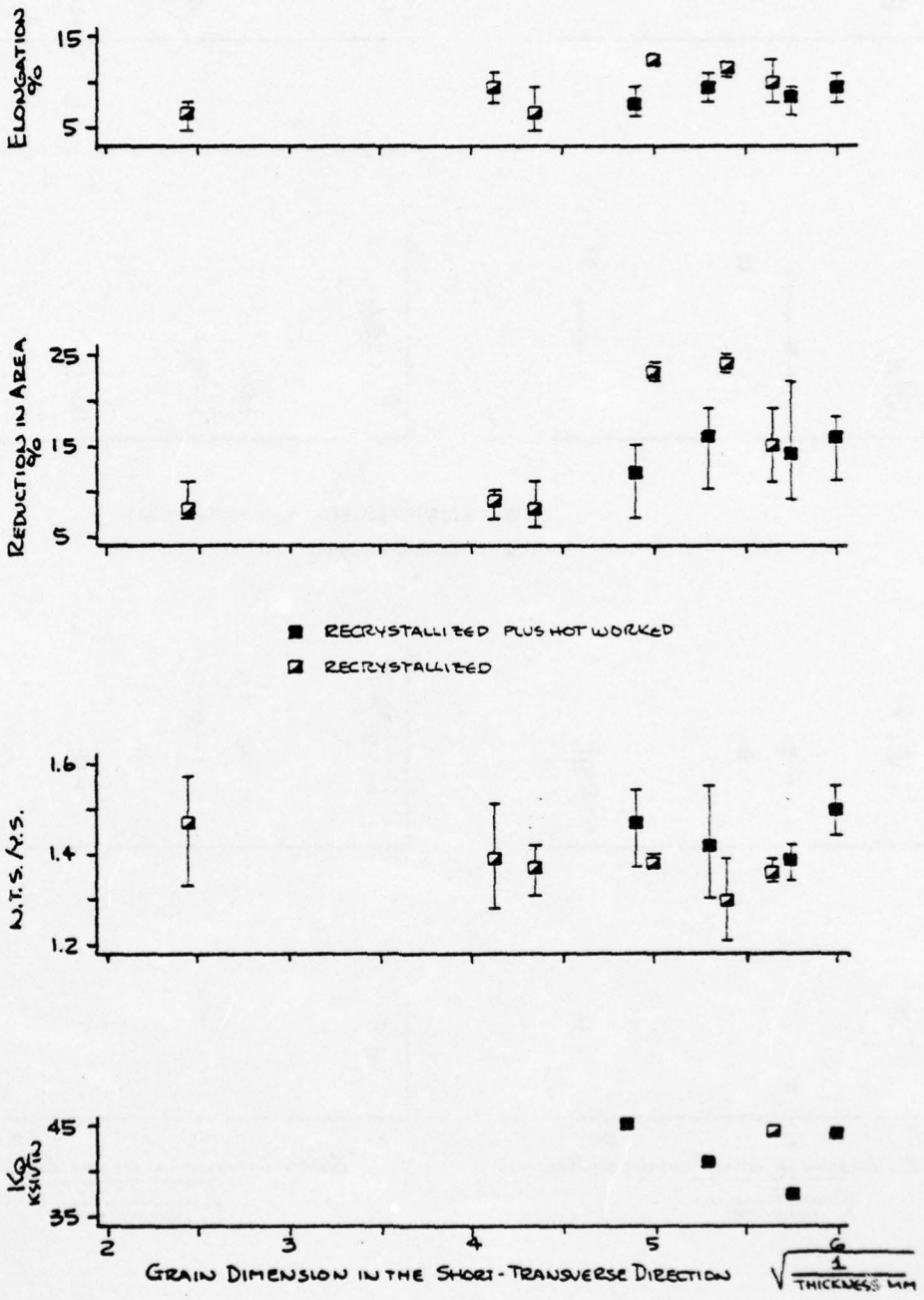



Figure 47. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Grain Dimension in the Longitudinal Direction.

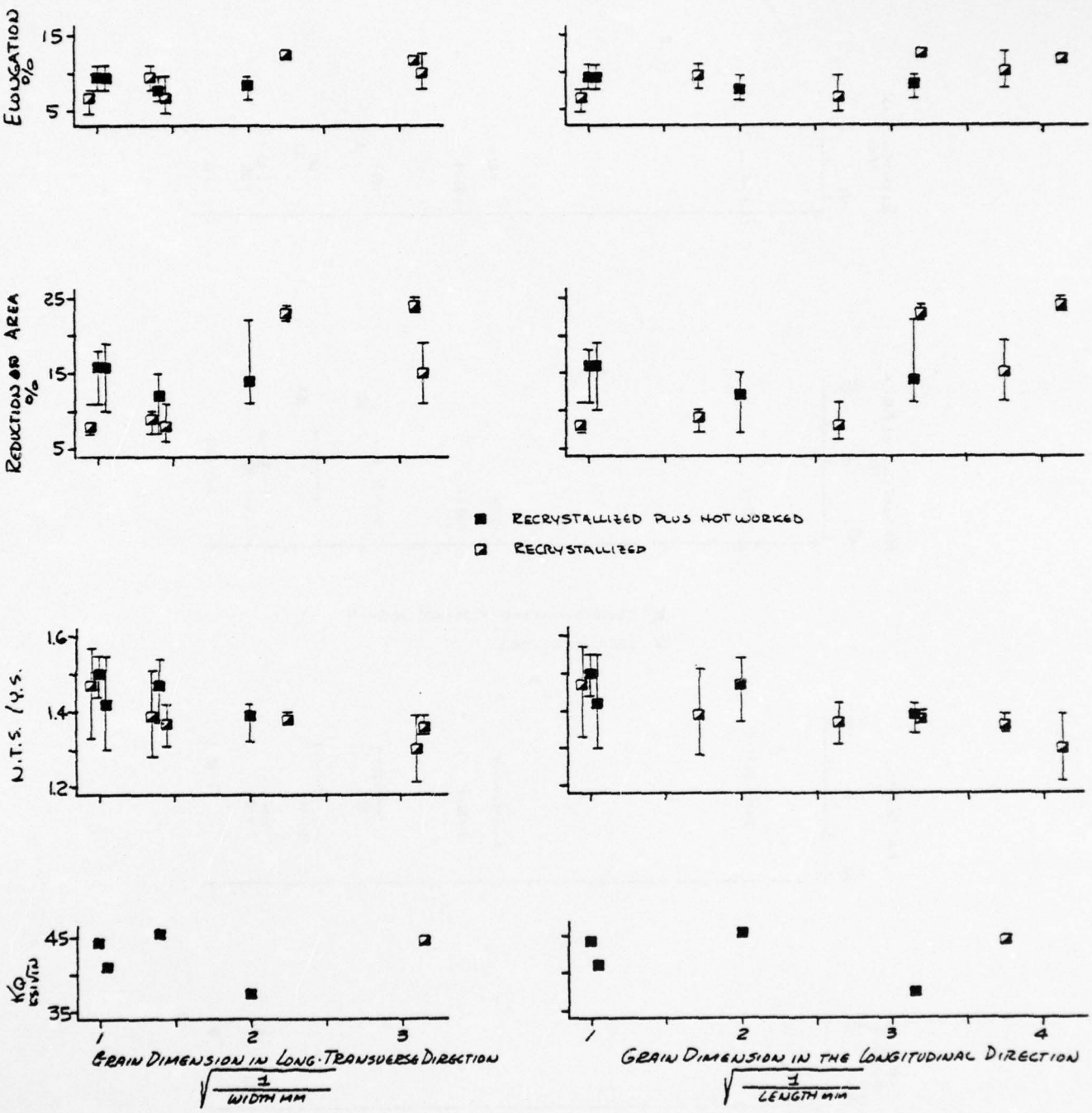
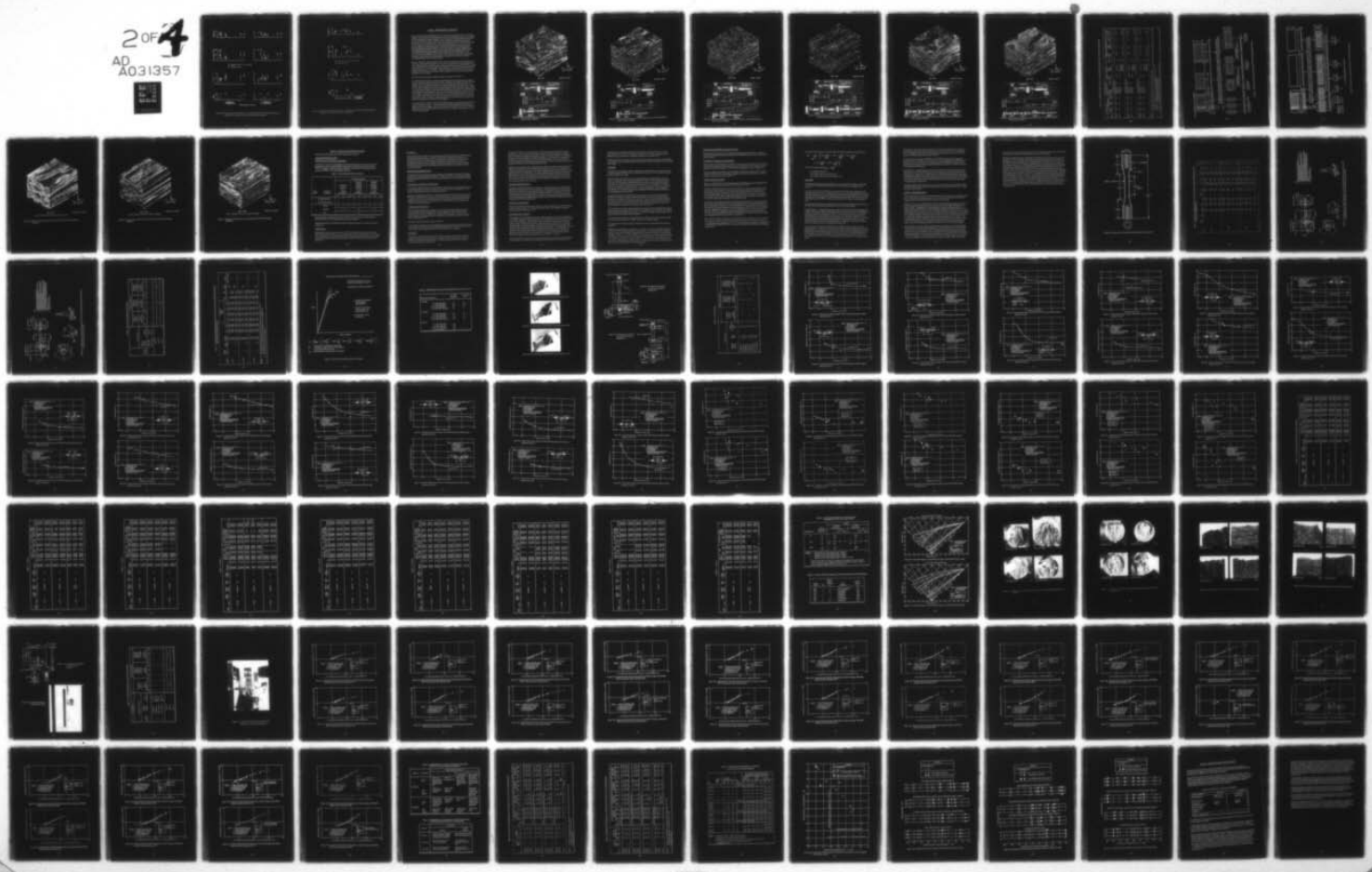



Figure 48. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Grain Dimensions in the Longitudinal and Long-Transverse Directions.

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IMPROVEMENT OF HELICOPTER FORGINGS BY CONTROLLED SOLIDIFICATION--ETC(U)
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UNCLASSIFIED D210-11022-1 USAAVSCOM-76-41 NL

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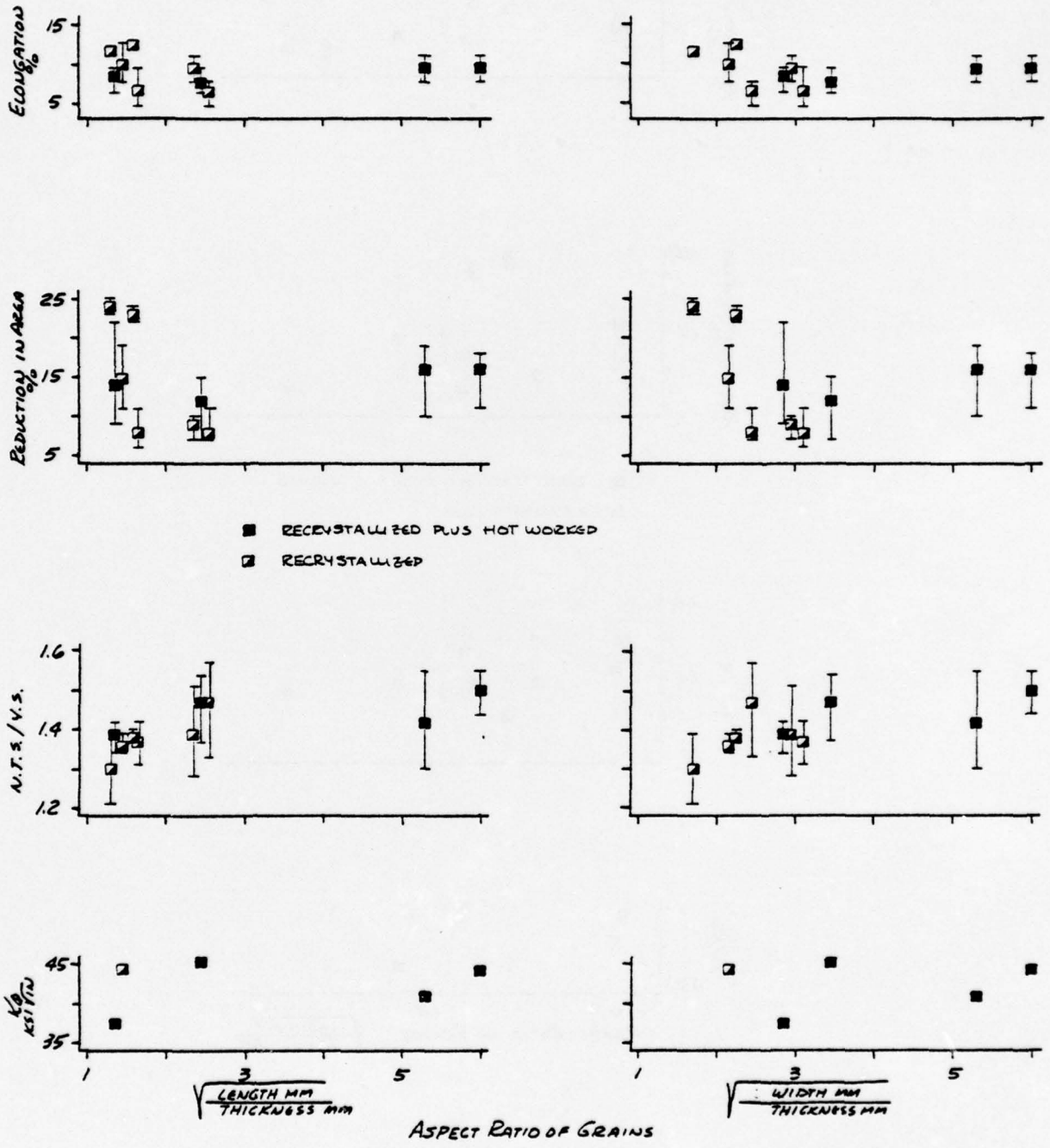



Figure 49. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Length, Width, and Thickness of the Grains.

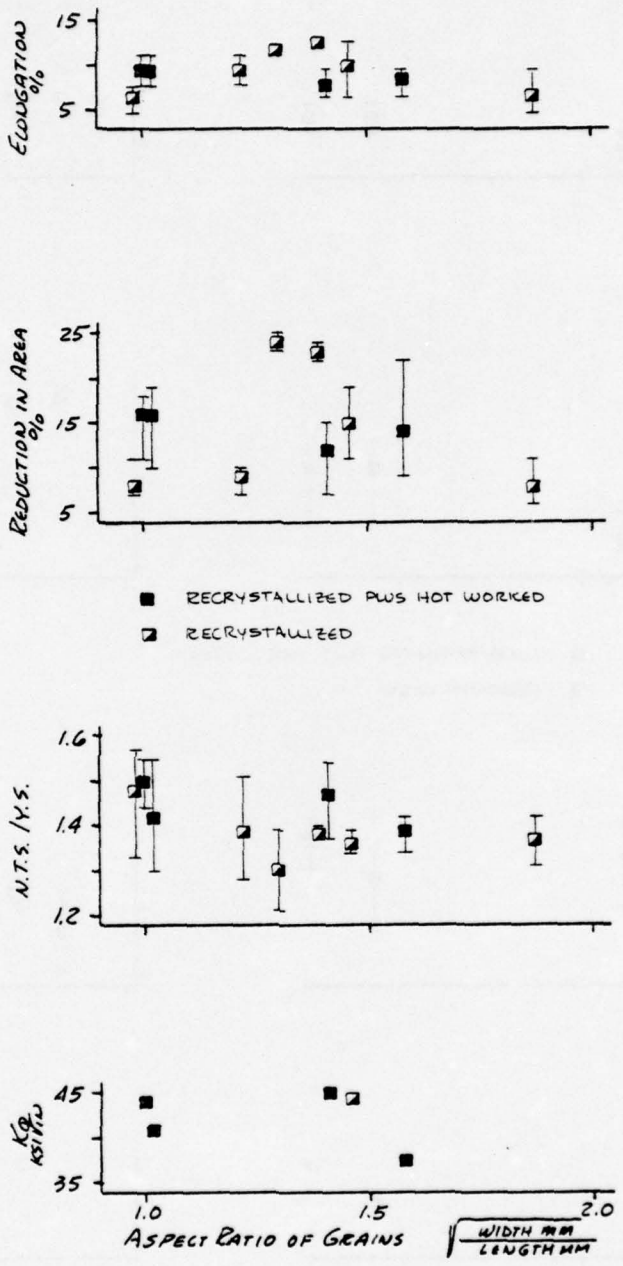



Figure 50. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Length and Width of the Grains.

## TASK II – PRODUCTION OF FORGINGS

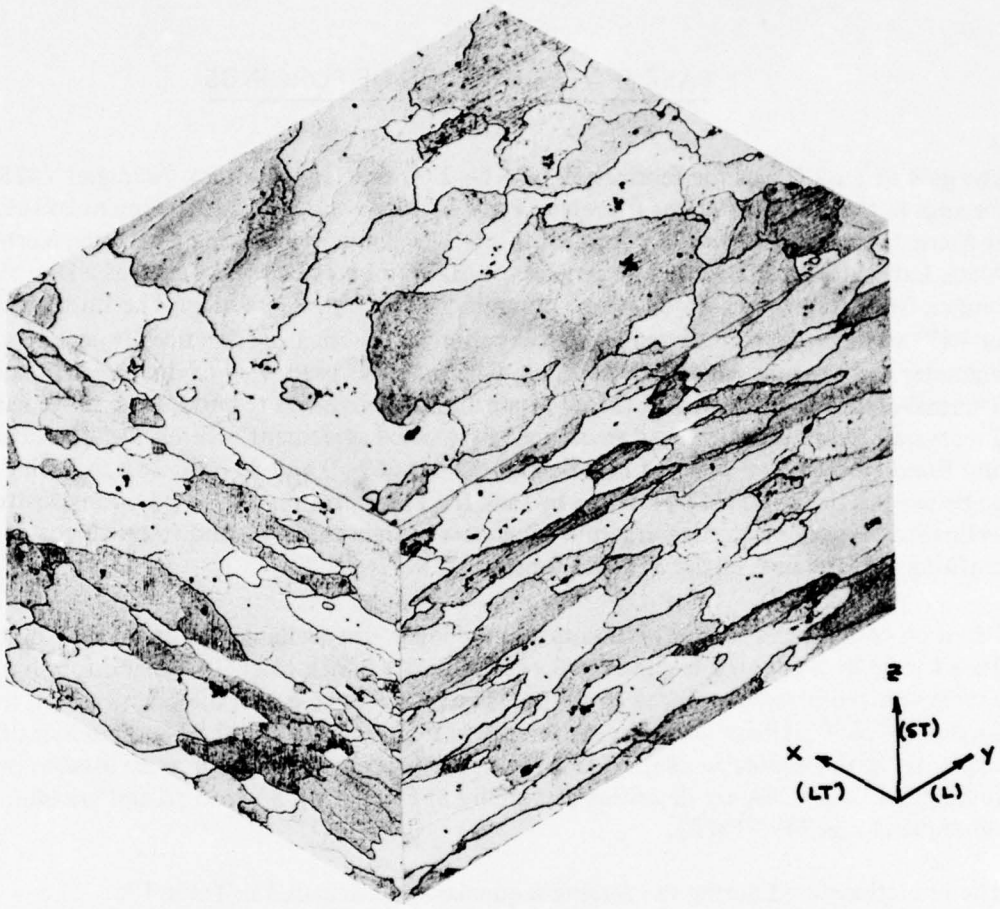
The goal of Task II was the fabrication of 6.7-, 2.0-, and 1.0-inch-thick 7075 and 7475 hand forgings in the F temper at the Cleveland Plant of Alcoa and the heat treatment of the forgings at Alcoa Laboratories to supply forgings in the T73 temper for testing by Boeing Vertol and Alcoa Laboratories. The three thicknesses of 7075 forgings were produced as a stepped forging from commercial ingot using a commercial fabricating practice. The three thicknesses of 7475 forgings were produced by two experimental fabricating practices from 17-inch-diameter ingot cast at Alcoa Laboratories. The practices used were of the Intermediate-Thermal-Mechanical-Treatment (ITMT) type and were selected to produce forgings having a recrystallized-plus-hot-worked structure. By mutual agreement, Boeing Vertol, Alcoa, and Frankford Arsenal selected ITMT practices 426669-19 and 437666-28A in Task I to be used as the two ITMT practices in Task II. This selection was based on microstructure evaluation, tensile properties, fracture-toughness characterization, and stress-corrosion-cracking performance of the 31 hand forgings.

Based on commercial forging restraints and the ingot size available, the two ITMT practices in Task I were then equated to produce 6.7-, 2.0-, and 1.0-inch-thick 7475 hand forgings having a recrystallized-plus-hot-worked structure. The practices based on the practice used to produce forging S-426669-19 are described pictorially in Figures 51, 52, and 53 and are identified subsequently in this report as 7475-TMT1. The practices based on the practice used to produce forging S-437666-28A are described pictorially in Figures 54, 55, and 56 and are identified subsequently as 7475-TMT2.

The reductions used during the forging sequences are compared in Table 17.

The solution-heat treatment, quenching, and artificial aging of the forgings at Alcoa Laboratories are described in Figure 57 for the 7075-T73 forgings and in Figure 58 for the 7475-T73 forgings. The 6.7-inch-thick forgings were fabricated so that short-transverse fatigue tests could be made by Boeing Vertol. However, to minimize the effect of quench rate in comparing the properties obtained on the 6.7-inch-thick forgings with the properties obtained on the 2- and 1-inch-thick forgings, 2-inch-thick sections were sawed from the 6.7-inch-thick forgings and thermally treated as indicated. The time of the second-step aging practice used for the 7475 forgings was longer than that used for 7075-T73 because the results of the accelerated stress-corrosion tests carried out in Task I indicated that the standard 7075-T73 second-step aging practice might not produce a satisfactory resistance to stress-corrosion cracking in the short-transverse direction in 7475-T73 hand forgings.

The grain dimensions of the 7475-T73 hand forgings having a recrystallized-plus-hot-worked structure are given in Table 17. Three-dimensional photomicrographs of the structures of samples of the hand forgings are presented in Figures 51 through 56 for the 7475-T73 hand forgings having a recrystallized-plus-hot-worked structure, in Figures 59 through 61 for the 7075-T73 hand forgings.




Mag 100X Keller's Etch

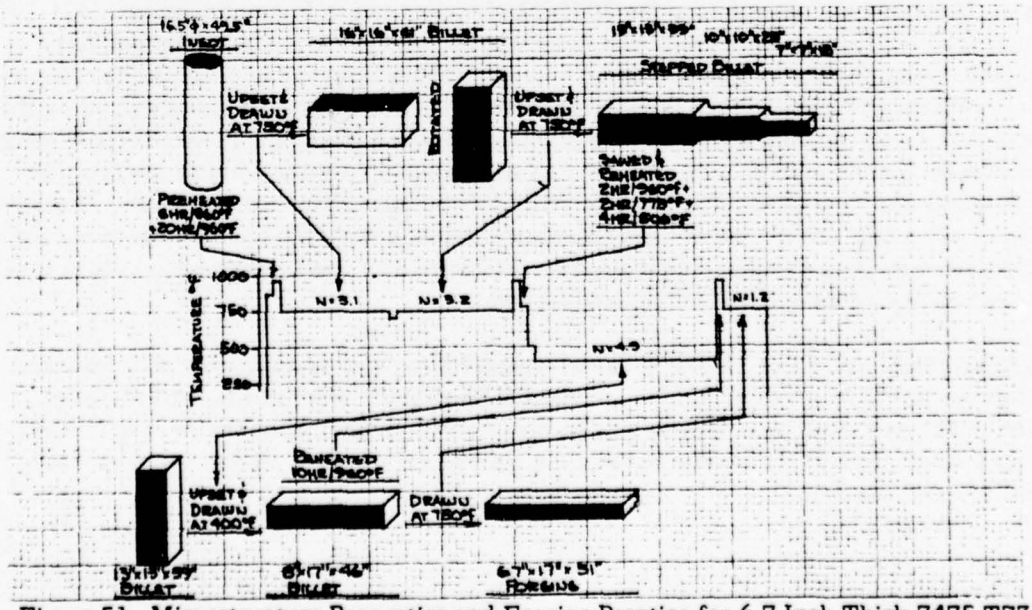
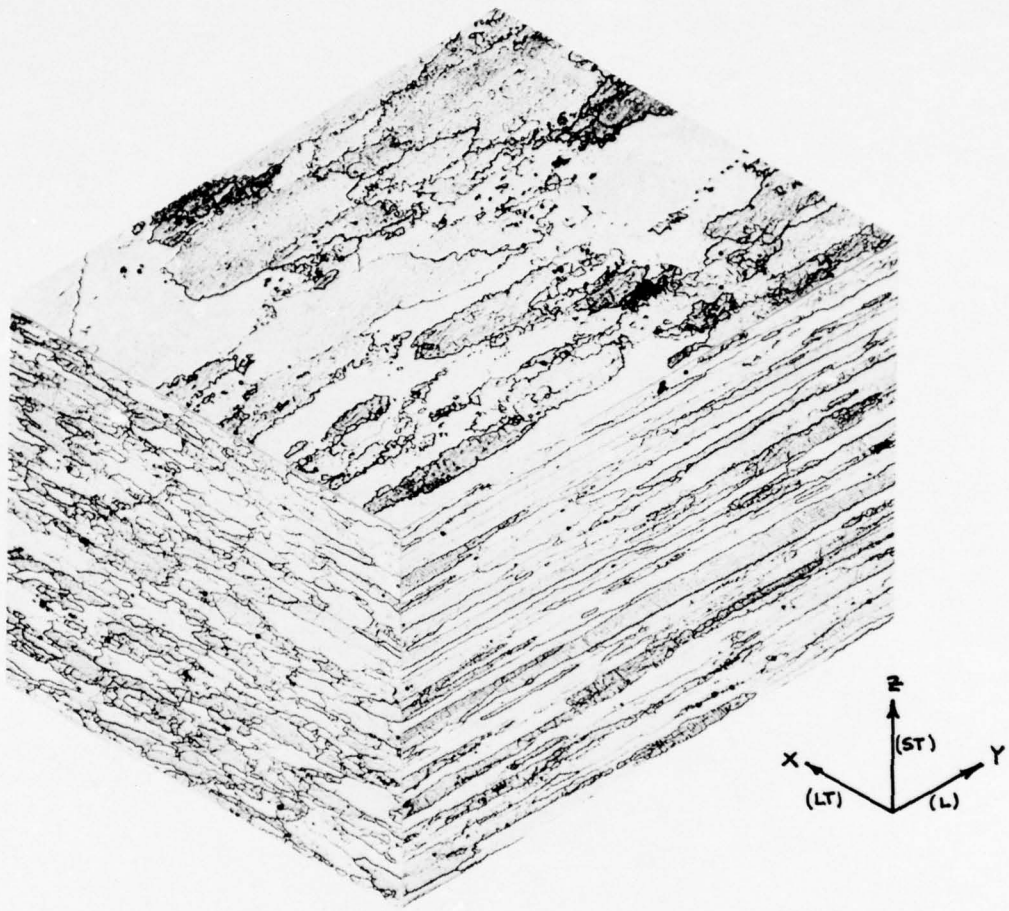



Figure 51. Microstructure Properties and Forging Practice for 6.7-Inch-Thick 7475-T73 Task II Forging, S-438170.




Mag 100X Keller's Etch

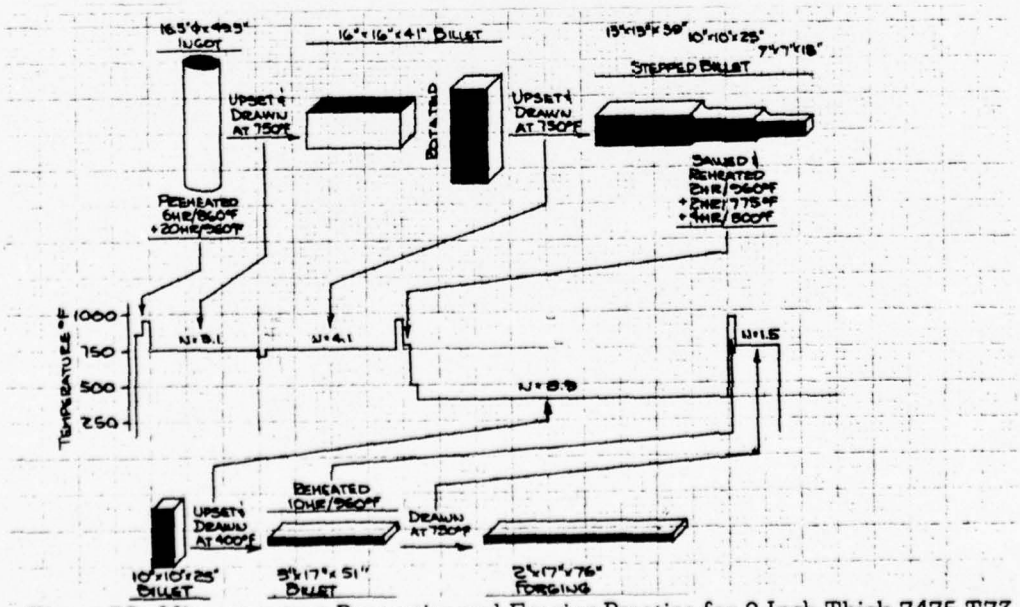
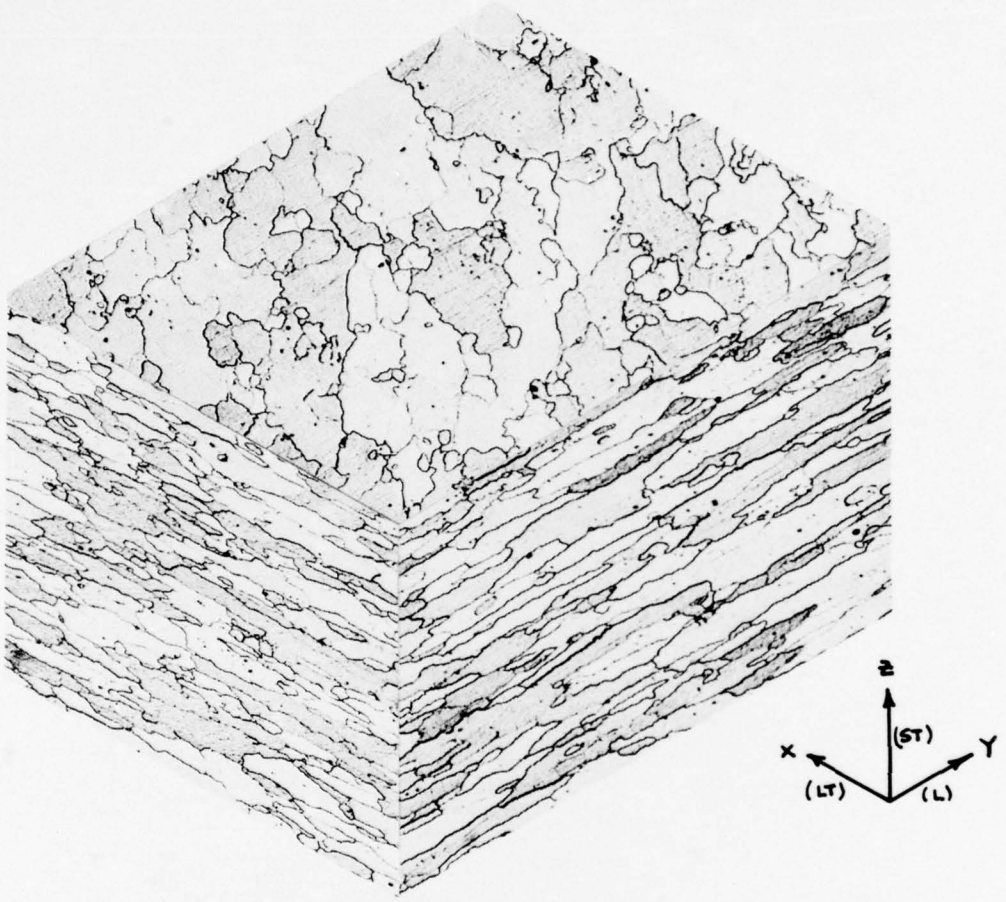



Figure 52. Microstructure Properties and Forging Practice for 2-Inch-Thick 7475-T73 Task II Forging, S-438169.




Mag 100X Keller' Etch

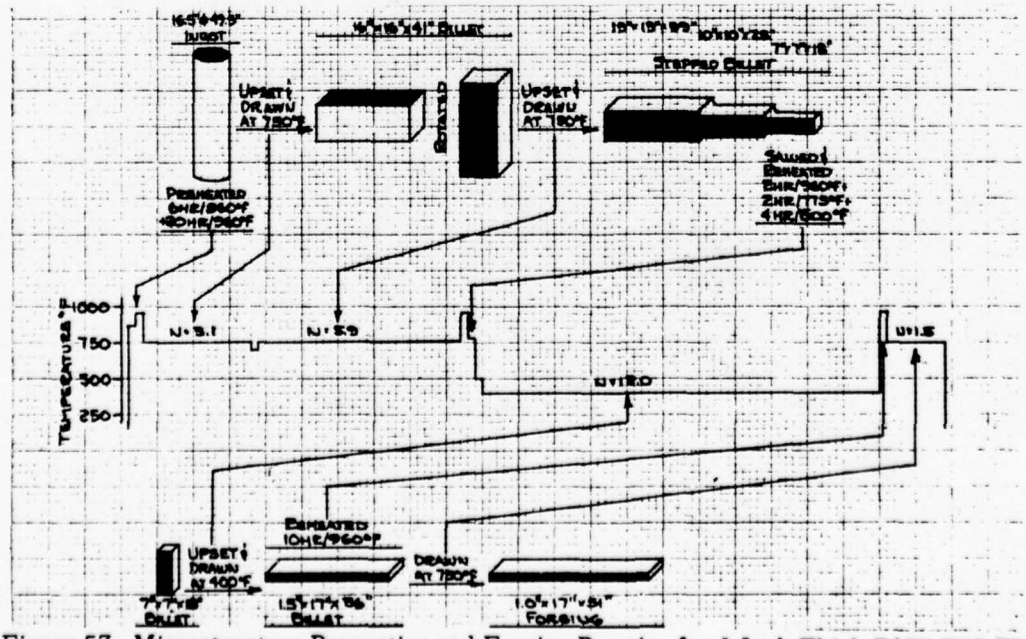
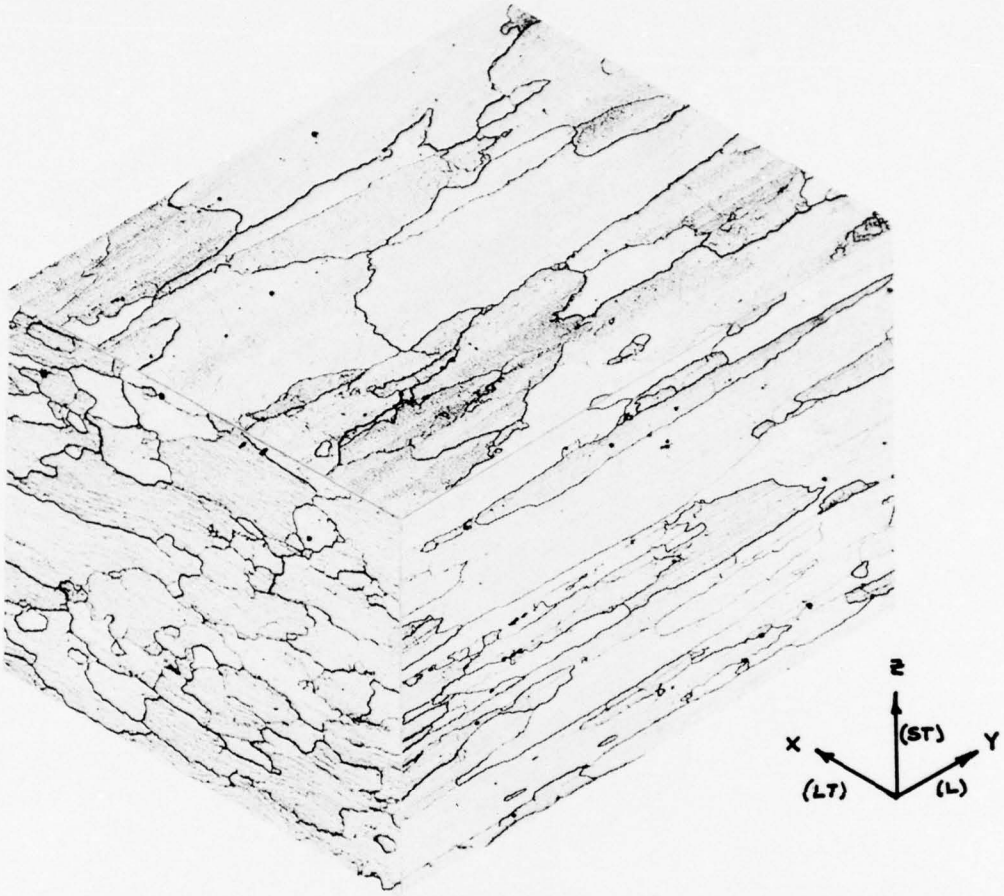



Figure 53. Microstructure Properties and Forging Practice for 1-Inch-Thick 7475-T73 — Task II Forging, S-438168.




Mag 100X Keller's Etch

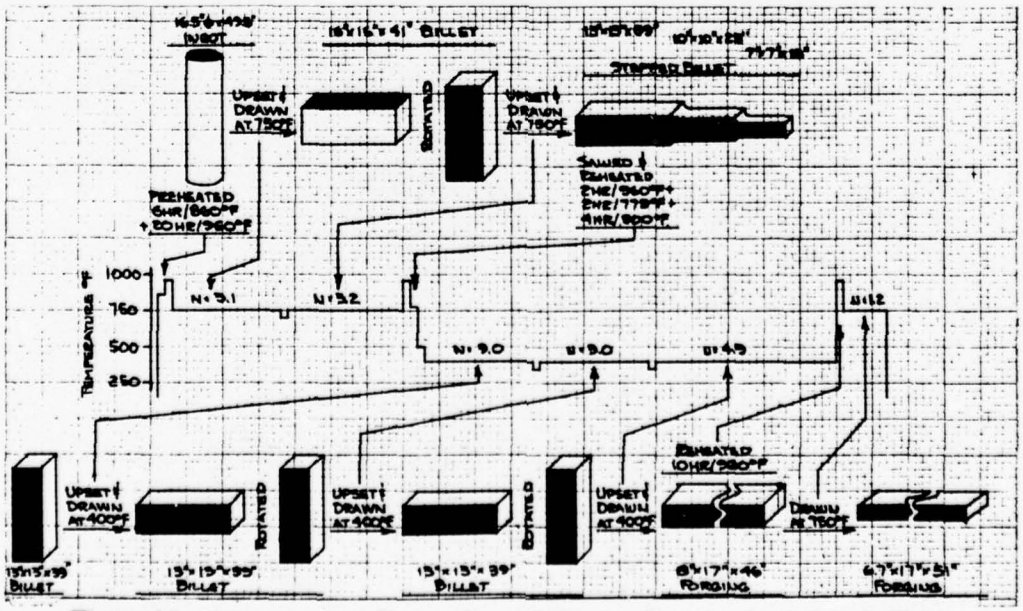
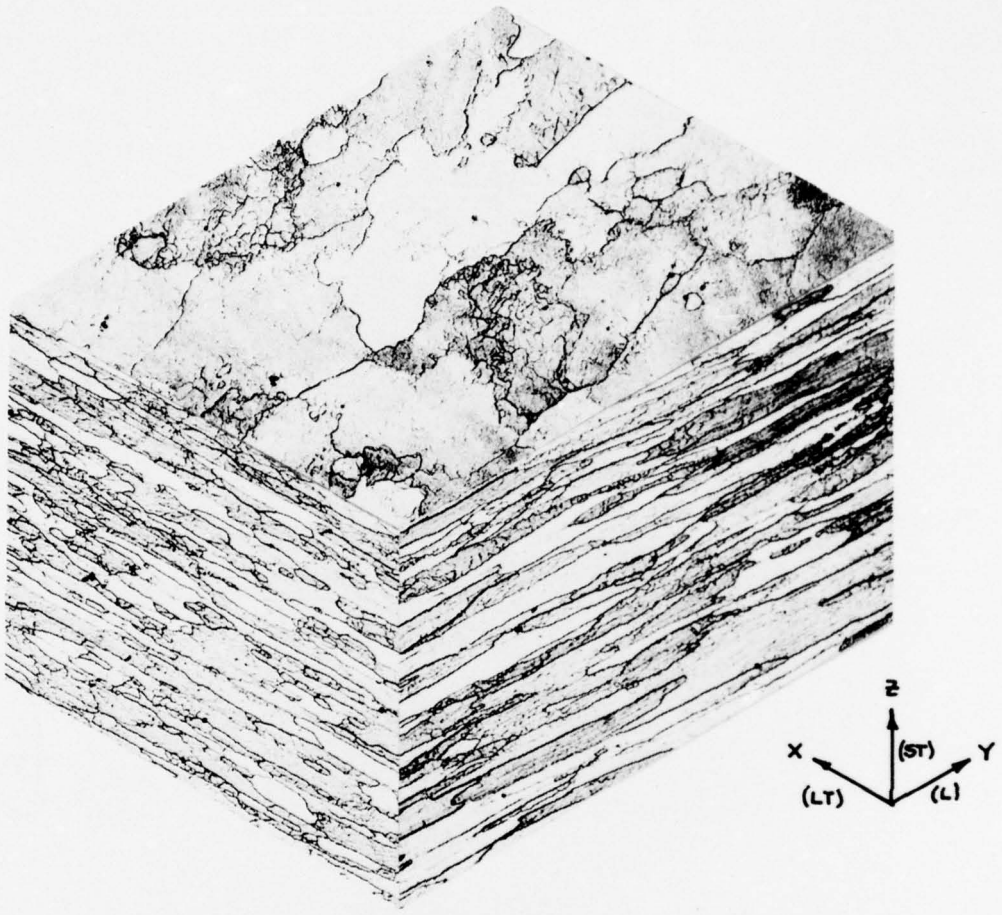



Figure 54. Microstructure Properties and Forging Practice for 6.7-Inch-Thick 7475-T73 Task II Forging, S-438173.




Mag 100X Keller's Etch

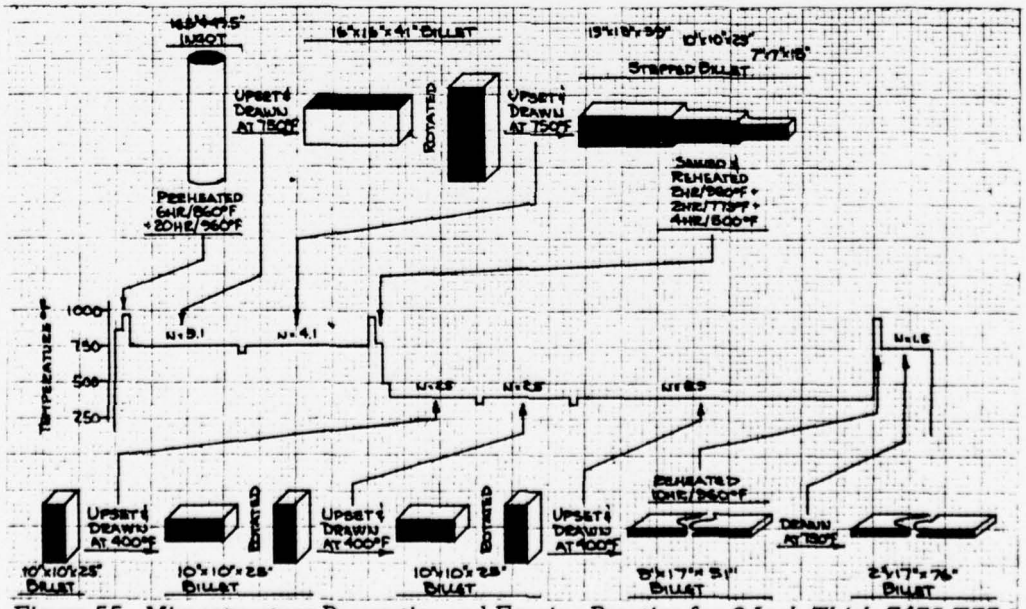
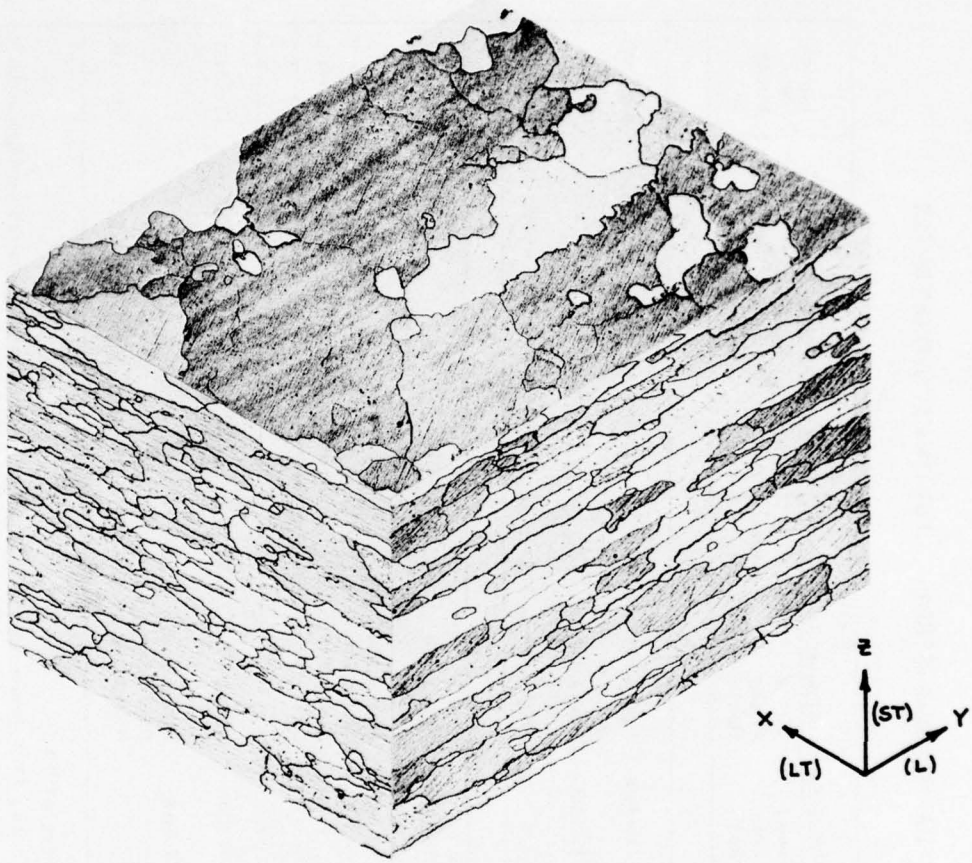



Figure 55. Microstructure Properties and Forging Practice for 2-Inch-Thick 7475-T73 Task II Forging, S-438172.




Mag 100X Keller's Etch

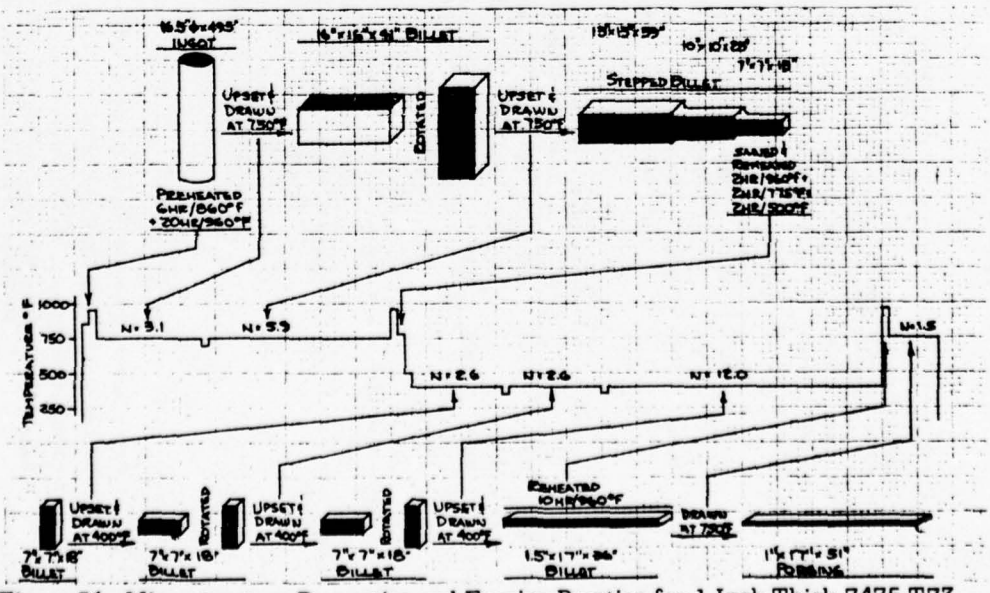



Figure 56. Microstructure Properties and Forging Practice for 1-Inch-Thick 7475-T73 Task II Forging, S-438171.

## TABLE 17. FABRICATING DETAILS FOR 7475 HAND FORGINGS PRODUCED BY ITMT-TYPE PROCEDURES

| Finished Hand Forging | | | | Initial Forging of 16.5 $\phi$ x 49-In. Ingot at 750°F[1] | | Warm Forging of Billet at 400°F[2] | | | Forging of Recrystallized Billet at 750°F[3] | | | Finished Size of Forging (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grain Dimensions | | | | | | | | | | | |
| S-No. | Thickness (mm) | Width (mm) | Length (mm) | Type of Forging Operation | Reduction, N | Initial Size (in.) | Type of Forging Operation | Reduction, N | Initial Size (in.) | Type of Forging Operation | Reduction, N | |
| | | | | 6.7-In.-Thick Hand Forgings | | | | | | | | |
| 438170 | 0.042 | 0.083 | 0.125 | Upset & draw | 3.1 | | | | | | | |
| | | | | Upset & draw | 3.2 | 13x13x39 | Upset & draw | 4.9 | 8x17x46 | Draw | 1.2 | 6.7x17x51 |
| 438173 | 0.036 | 0.083 | 0.200 | Upset & draw | 3.1 | | | | | | | |
| | | | | Upset & draw | 3.2 | 13x13x39 | Upset & draw | 3.0 | | | | |
| | | | | | | | Upset & draw | 3.0 | | | | |
| | | | | | | | Upset & draw | 4.9 | 8x17x46 | Draw | 1.2 | 6.7x17x51 |
| | | | | 2.0-Inch-Thick Hand Forgings | | | | | | | | |
| 438169 | 0.010 | 0.029 | 0.067 | Upset & draw | 3.1 | | | | | | | |
| | | | | Upset & draw | 4.1 | 10x10x25 | Upset & draw | 8.3 | 3x17x51 | Draw | 1.5 | 2.0x17x76 |
| 438172 | 0.015 | 0.071 | 0.250 | Upset & draw | 3.1 | | | | | | | |
| | | | | Upset & draw | 4.1 | 10x10x25 | Upset & draw | 2.5 | | | | |
| | | | | | | | Upset & draw | 2.5 | | | | |
| | | | | | | | Upset & draw | 8.3 | 3x17x51 | Draw | 1.5 | 2.0x17x76 |
| | | | | 1.0-Inch-Thick Hand Forging | | | | | | | | |
| 438168 | 0.013 | 0.062 | 0.091 | Upset & draw | 3.1 | | | | | | | |
| | | | | Upset & draw | 5.9 | 7x7x18 | Upset & draw | 12.0 | 1.5x17x36 | Draw | 1.5 | 1.0x17x51 |
| 438171 | 0.020 | 0.091 | 0.143 | Upset & draw | 3.1 | | | | | | | |
| | | | | Upset & draw | 5.9 | 7x7x18 | Upset & draw | 2.6 | | | | |
| | | | | | | | Upset & draw | 2.6 | | | | |
| | | | | | | | Upset & draw | 12.0 | 1.5x17x36 | Draw | 1.5 | 1.0x17x51 |

NOTES:
1. Ingot preheated 6 hours at 860°F plus 20 hours at 960°F prior to forging at 750°F.
2. Billet reheated 2 hours at 960°F, furnace cooled to 775°F, soaked 2 hours at 775°F, furnace cooled to 500°F, and soaked 4 hours at 500°F prior to warm-forging at 400°F.
3. Forging reheated 10 hours at 960°F after warm-forging at 400°F and prior to forging at 750°F.
4. Reduction, $N = \frac{\text{original thickness in direction of greatest reduction}}{\text{final thickness in direction of greatest reduction}}$
5. Composition of ingot: Cu, 1.55; Mg, 2.37; Zn, 5.73; Fe, 0.06; Si, 0.04; Cr, 0.20; Ti, 0.02; Be, 0.002.

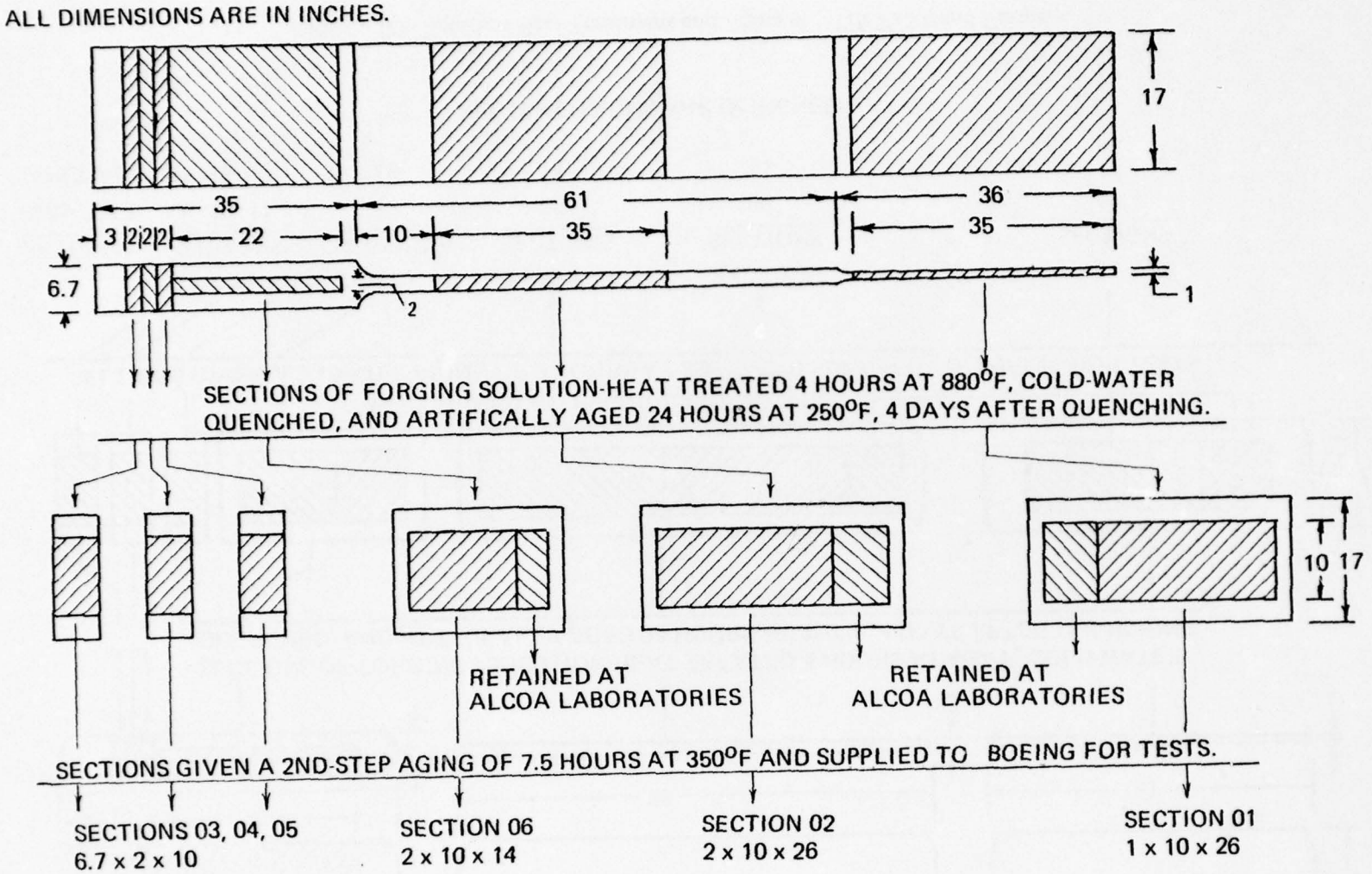
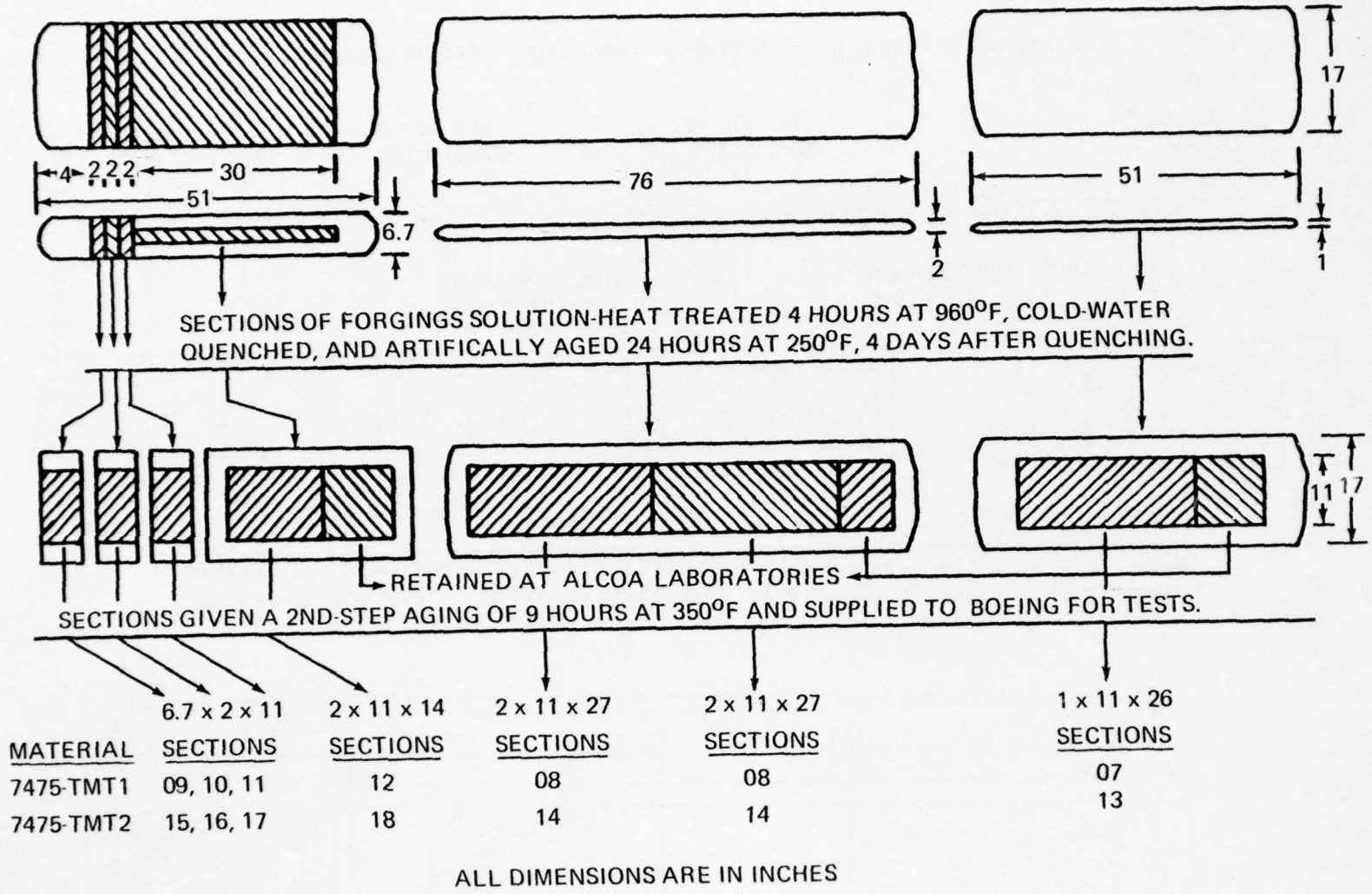


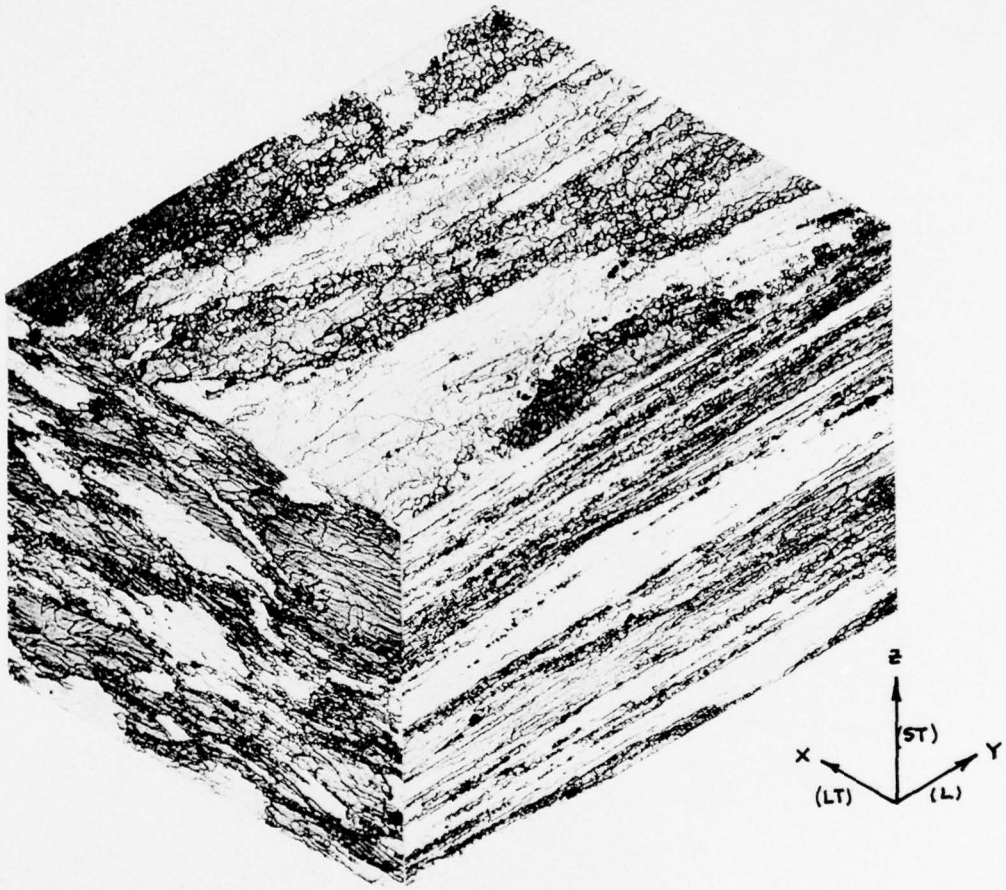

Figure 57. Solution Heat Treatment and Aging of 7075-T73 Stepped Hand Forging.




| MATERIAL | 6.7 x 2 x 11 SECTIONS | 2 x 11 x 14 SECTIONS | 2 x 11 x 27 SECTIONS | 2 x 11 x 27 SECTIONS | 1 x 11 x 26 SECTIONS |
|---|---|---|---|---|---|
| 7475-TMT1 | 09, 10, 11 | 12 | 08 | 08 | 07 |
| 7475-TMT2 | 15, 16, 17 | 18 | 14 | 14 | 13 |

ALL DIMENSIONS ARE IN INCHES

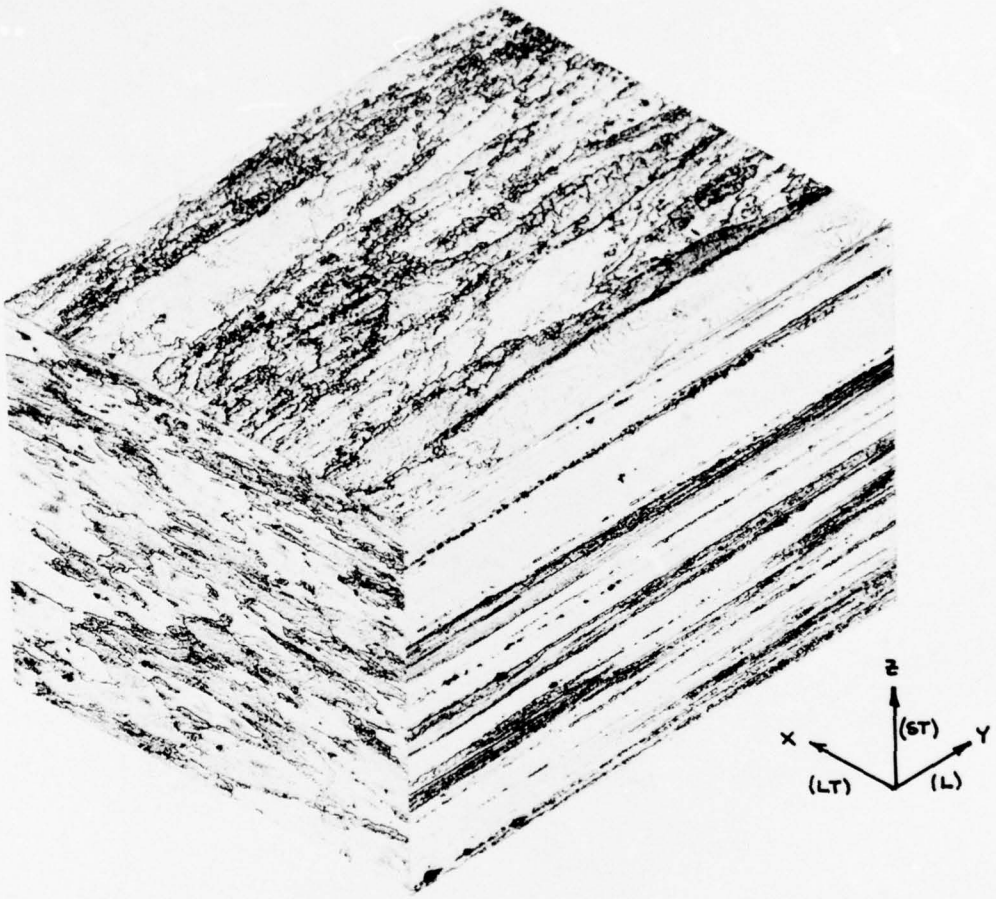
Figure 58. Solution Heat Treatment and Aging of 7475-T73 Hand Forgings.




Mag 100X Keller's Etch

6.70" Thick 7075-T73 Hand Forging

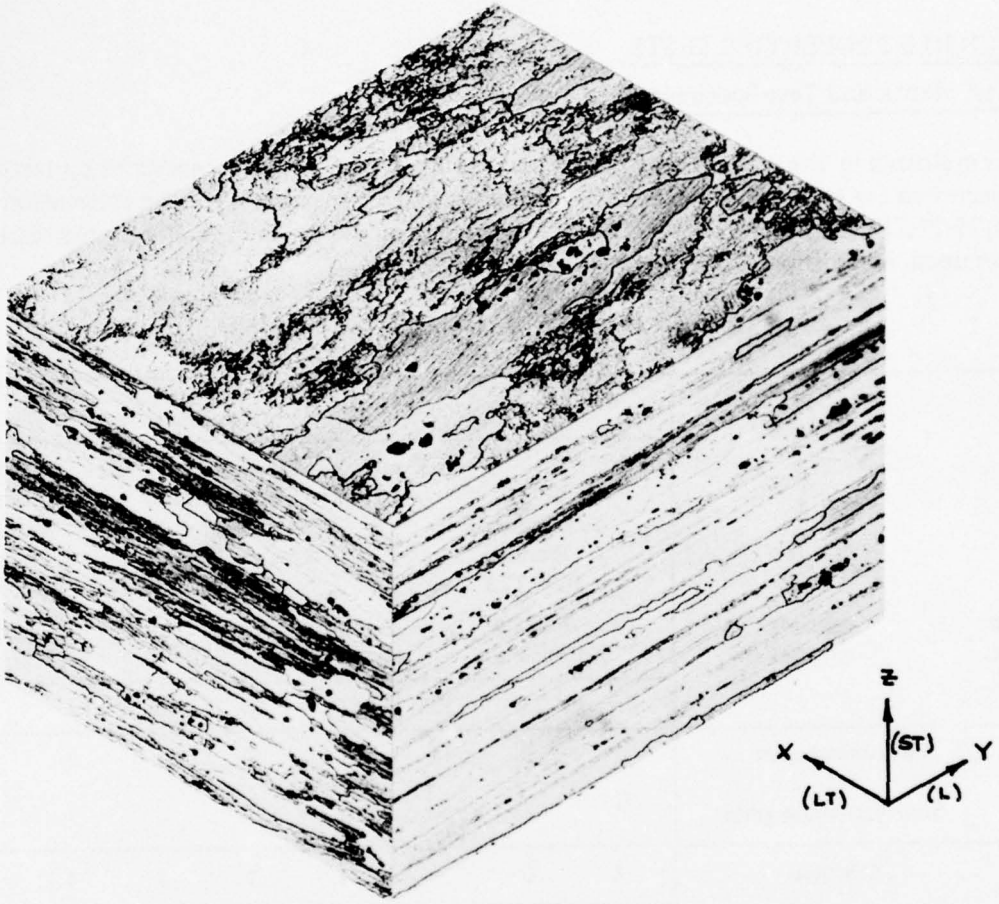
Figure 59. Microstructure Properties for 6.7-Inch-Thick 7075-T73 Task II Forging, S-437701-3.




Mag 100X Keller's Etch

2.00" Thick 7075-T73 Hand Forging

Figure 60. Microstructure Properties for 2-Inch-Thick 7075-T73 Task II Forging, S-437701-2.




Mag 100X Keller's Etch

1.00" Thick 7075-T73 Hand Forging

Figure 61. Microstructure Properties for 1-Inch-Thick 7075-T73 Task II Forging, S-437701-1.

## TASK III – MECHANICAL-PROPERTIES TESTS

The mechanical properties of all Task II forgings were measured.

### TENSILE-PROPERTIES TESTS

#### Test Matrix and Test-Specimen Configuration

As indicated in Table 18, tensile properties of Task II forgings were measured by testing 10 specimens for each of the selected TMT forgings and 10 specimens for the conventional 7075-T73 forgings. The short-transverse properties of the 6.7-inch-thick forgings were determined, in addition to the longitudinal properties.

TABLE 18. TENSILE-PROPERTIES TEST MATRIX

| Group Number | Specimen Configuration | Number of Specimens | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conventional Process 7075-T73 Forging Thickness (in.) | | | Advanced Thermal/ Mechanical Treatment 7474-TMT1 Forging Thickness (in.) | | | Advanced Thermal/ Mechanical Treatment 7475-TMT2 Forging Thickness (in.) | | |
| | | 6.7 | 2.0 | 1.0 | 6.7 | 2.0 | 1.0 | 6.7 | 2.0 | 1.0 |
| 1 | Longitudinal grain | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 |
| 2 | Short-transverse grain | 2 | – | – | 2 | – | – | 2 | – | – |
| | Subtotal | 4 | 3 | 3 | 4 | 3 | 3 | 4 | 3 | 3 |
| | Subtotal | 10 | | | 10 | | | 10 | | |
| | Total | 30 | | | | | | | | |

The test-specimen configuration is shown in Figure 62 and conforms to ASTM Standard E8-61T, Reference 9, for standard tension-test round specimens.

Selected locations in each forging from which the tensile specimens were taken are shown in Appendix A.

#### Test Procedure

Specimens were tested using a strain rate of 0.005 inch/inch/minute up to the 0.2-percent yield offset and then straining at a rate causing failure within one minute after offset. Testing was accomplished by using a Baldwin-Wiedeman universal tensile-testing machine; stress-strain plots were recorded on a Hewlett Packard Model 7590C X-Y recorder and are presented in Appendix B.

### Test Results

Test results are shown in Table 19. The data show that TMT may improve the ultimate tensile strength and the yield strength in addition to significantly increasing the ductility of the material. One 7075-T73 specimen, 0101, demonstrated a slant fracture and resulted in the low values measured for percent elongation and reduction in area shown in the table. A metallurgical examination of the specimen confirmed the suspicion that due to the location of the specimen near a corner of the forging, the grain orientation is not parallel to the long axis of the specimen.

## FRACTURE-TOUGHNESS TESTS

The objective of these tests was to develop valid fracture-toughness values ($K_{IC}$) for thermal-mechanically treated aluminum-alloy forgings. Testing was conducted according to the guidelines of ASTM specification E399-72T[10] in room-temperature air by testing standard-compact specimens.

### Test-Specimen Configuration and Preparation

The fracture-toughness specimens were manufactured from blanks cut from selected locations in each forging. These locations, including serial numbers, are shown in Appendix A. The specimen configurations are shown in Figures 63 and 64.

Specimens were fatigue precracked on a universal Sonntag Model SF-1U fatigue-test machine fitted with a clevis fixture to accommodate compact specimens. All fatigue precracking was conducted at 10 Hz in air at room temperature using constant-amplitude loading within the guidelines of the specification. The specimens were observed under a 3-power microscope to assure the desired crack length.

### *Test Procedure and Test Setup*

Fracture-toughness testing was conducted on a Vertol servocontrolled hydraulic tension-tension machine capable of ramp loading. The ramp-loading rate used corresponded to a stress-intensity rate between 30,000 and 150,000 psi $\sqrt{\text{in.}}$ per minute. Clevis fixtures required for each size compact specimen were designed and fabricated according to the guidelines of ASTM E399-72T.[10]

The matrix of specimens tested is shown in Table 20.

Crack opening was measured by a strain-gage-instrumented clip gage. The test data, load, and crack opening were plotted directly by a Hewlett Packard Model 7590C X-Y recorder. From each recording, the load $P_Q$ was obtained for determining fracture toughness.

### Test Results

The results of the testing are summarized in Table 21 along with pertinent data used in the analysis. The method of reducing data is in accordance with the requirements of ASTM E399-72T and is demonstrated in Figure 65. Individual load-displacement recordings for each specimen are given in Appendix C.

As indicated in Table 21, five tests resulted in valid measurements of plane-strain fracture toughness, $K_{IC}$. For each of the invalid measurements, the conditional fracture toughness, $K_Q$, and the reason for invalidity is indicated. As seen in the notes of Table 21, all specimens except one were invalid because of specimen dimensions. This indicates that a plane-strain condition cannot be achieved in the 1- and 2-inch-thick forgings. In the case of the thick (6.7-inch) forgings, the specimens must be larger in order to obtain a valid plane-strain fracture-toughness value, $K_{IC}$, for the longitudinal grain direction.

Significant improvements in the conditional fracture toughness of TMT aluminum-alloy forgings have been achieved for all three thicknesses investigated. Table 22 is a comparison of average results for each forging and shows the percentage improvement when compared to the commercial 7075-T73 measurements. The high conditional fracture-toughness values of the TMT forgings are further substantiated by the fact that each TMT specimen fracture shows shear lips. In particular, the longitudinal grain direction shows very large shear lips covering 20 to 50 percent of the fracture surface. Typical examples of the difference in fracture surface are shown in Figures 66, 67, and 68.

## FATIGUE-STRENGTH TESTS

The fatigue-strength characteristics of a metal are of primary importance in considering the application of that material to helicopter structure. A thorough evaluation must include an analysis of the influences of stress ratio (minimum stress/maximum stress), stress concentration, grain direction, and forging thickness on fatigue properties. The testing conducted on axially loaded specimens provides the data necessary for evaluating the thermal-mechanical-treatment aluminum-alloy forgings when compared to data for similar forgings fabricated from conventional 7075-T73 aluminum alloy.

### Test-Specimen Configuration

Two types of specimens, smooth and notched, were used for fatigue tests. Smooth-specimen details are shown in Figure 69. The notced specimen, Figure 70, is designed to produce a stress-concentration factor, $K_T$, of 3.0.

### Test Procedure and Test Setup

All specimens were axially loaded using either a Wiedeman fatigue-test machine Model SF-1-U or an Amsler Vibraphore fatigue-test machine. Load frequency was 30 Hz on the SF-1-U and 70 Hz on the Vibraphore. No difference in fatigue strength was noted between specimens tested at 30 Hz and those tested at 70 Hz. Axial test loads were measured by a calibrated strain-gage link. The adapter assembly which fixed the test specimen in the machine also contains calibrated strain-gaged links to determine bending loads. The bending gages were used during specimen installation to produce an alignment which results in no bending in the specimen. During testing, all links were monitored to verify the axial load and to verify alignment of the test specimen. Strain gages were coupled to an Ellis Associates BA-12 or BA-13 bridge amplifier and total system accuracy was within ± 2 percent.

All fatigue testing was conducted in air at room temperature and at constant-amplitude load levels in groups of a minimum of eight specimens to develop the S-N curve for each of 26

combinations of test-program variables, with the objective of acquiring data over the life range from $10^4$ to 5 x $10^7$ cycles. Program variables, shown in Table 23, include material, forging thickness, grain direction, stress ratio, and stress-concentration factor.

Testing emphasized the specially treated forgings, and in particular the two-inch-thick forging, to develop the steady-stress/alternating-stress relationship (Goodman diagram) for the 7475-TMT alloy forgings.

Test Results

The objective of the fatigue testing is to demonstrate the achievement of a 20-percent increase in fatigue strength of TMT alloys when compared to 7075-T73. In many instances, that goal has been achieved or exceeded.

The results of the tests are shown in terms of fatigue-stress level and number of cycles in Figure 71 through 96. Where possible, comparisons of data for 7075-T73 groups have been made with 7475-TMT results obtained from this series of tests and are presented in Figures 97 through 108. Detailed test results are provided in Table 24. A summary of the results based on a comparison of endurance limits at 5 x $10^7$ cycles is given in Table 25 by using test data and other sources of data for 7075-T73. Goodman diagrams for the two-inch-thick 7475-TMT1 and 7475-TMT2 aluminum-alloy forgings are presented in Figures 109 and 110 for the longitudinal grain orientation.

All specimens except two exhibited typical failure modes for smooth and notched fatigue specimens. The smooth specimens failed at the minimum section at the midlength of the specimen; the notched specimens failed at the notch. The two smooth specimens which did not follow trends failed in the threads provided for gripping the specimen in the test fixture. Because of the flat curve defined by the seven other specimens from this group, these two atypical failures are included in the statistical analysis of the data.

As demonstrated by the data, TMT1 achieved or exceeded the goal of a 20-percent increase in fatigue strength when compared to 7075-T73 for the majority of test conditions. The improvements ranged approximately from 5 percent to 75 percent and suggest that advantages can be achieved with this thermal-mechanical treatment.

The TMT2 practice achieved or exceeded the goal of a 20-percent increase in fatigue strength in two cases and is rated second to TMT1 on the basis of fatigue properties.

The impact of these results on design of helicopter structure is demonstrated by example in Appendix E.

Metallurgical examinations were conducted on a number of specimens to identify the origin of failure, the extent of fatigue damage prior to separation of the fracture surfaces, and microstructure characteristics. Hardness measurements are summarized in Table 26. As indicated in Figures 111 and 112, the origin of failure for the smooth and notched specimens selected is at the surface of the specimen. Grain orientation and grain size are shown in Figures 113 and 114. Two test specimens, 0716 shown in Figure 111 and 0714, have a slanted grain orientation which is neither longitudinal nor transverse. This is attributed to the fact that these specimens came from the edge of the one-inch-thick forging.

## FATIGUE-CRACK PROPAGATION-RATE TESTS

The objective of these tests is to obtain fatigue-crack propagation-rate data over a range of stress and environmental conditions representative of those expected in the service life of helicopter hardware.

### Test-Specimen Configuration and Preparation

Thirty fatigue-crack propagation-rate specimens were fabricated from blanks cut from selected locations in each forging. These locations are centered with respect to the thickness of each blank and are shown in Appendix A. The specimen configuration is shown in Figure 115.

In order to measure crack growth, a grid consisting of approximately 40 lines with a nominal spacing of 0.040 inch was photographically applied to one side of each specimen. A typical specimen with the grid is shown in Figure 116.

### Test Procedure and Test Setup

Table 27 contains the matrix of test parameters for the 30 fatigue-crack and propagation-rate specimens. All testing was conducted at a load frequency of 5 Hz.

Loads were applied to the specimen as shown in Figure 116. The test setup included a load cell in series with the specimen. Load control was provided to permit no greater than ± 1.5-percent variation of the cyclic range of load for the duration of each test. In cases where precracking loads higher than the test crack-propagation loads were required, care was taken to step down to the test loads in small increments and to let the crack grow to a length such that the prior load would not influence the crack-growth data.

Crack growth was monitored visually by observing the intersection of the crack front with the grid lines previously described. Dye penetrant (Type MIL-I-25135, spotcheck SKL-HF penetrant by Magnaflux Corporation) and optical magnification of various power (15X and 45X) were used as aids in following the crack in those specimens tested in a 3.5-percent salt solution; the optical magnification was used as an aid in following the crack. In this case, the salt solution is contained in a transparent container surrounding the crack as shown in Figure 117 The crack is viewed through the container. Periodic checks were made to insure that cracking was progressing uniformly on both sides of the specimen.

Basic crack-growth data, consisting of crack length and number of fatigue cycles, was reduced by computer to determine the fracture-mechanics parameters of stress-intensity-range factor, $\Delta K$, and fatigue crack propagation rate, $\Delta a/\Delta N$. Data is presented in Figures 118 through 147 and tabulations including basic data can be found in Appendix D with a listing of the computer program used.

The stress-intensity range was calculated using the following expression from Reference 8:

$$\Delta K = \frac{\Delta P}{BW^{1/2}} \left[ 29.6 \left(\frac{a}{W}\right)^{1/2} - 185.5 \left(\frac{a}{W}\right)^{3/2} + 655.7 \left(\frac{a}{W}\right)^{5/2} - 1017.0 \left(\frac{a}{W}\right)^{7/2} + 638.9 \left(\frac{a}{W}\right)^{9/2} \right] ,$$

where $\Delta P$ is the load range, $P_{MAX} - P_{MIN}$,

a is average crack length,

B is average thickness of specimen, and

W is average width of specimen per Reference 8.

Test Results

The results of the fatigue-crack propagation-rate tests are presented in Figures 118 through 147 as plots of stress-intensity-factor range, $\Delta K$, versus fatigue-crack-propagation rate, $\Delta a/\Delta N$.

In general, both TMT1 and TMT2 alloys demonstrated more favorable crack-growth rates when compared to 7075-T73. In some instances this is due to the fact that TMT alloys maintain stable crack-growth rates at the higher values of stress-intensity-range factor, $\Delta K$; in other instances, the crack-propagation rates of TMT alloys are slower than 7075-T73 rates. Of the two TMT alloys tested, TMT2 is rated better than TMT1 on the basis of crack-propagation rates.

The results of the short-transverse grain direction are particularly significant and demonstrate that TMT alloys are superior in performance to 7075-T73 in thick forgings.

Forging Thickness – Forging thickness may or may not influence the crack-propagation rates in TMT aluminum-alloy forgings. Referring to Table 28, one can see that the 7475-TMT2 performance is equal to or better than the 7075-T73, and is greater for the one- and two-inch-thick forgings in room-temperature air, than it is for the 6.7-inch-thick forging. The 7475-TMT1 alloy does not show room-air crack-propagation rates superior to 7075-T73 for one- and two-inch forgings, but demonstrates the advantage of stable growth rates in the 6.7-inch forging for both grain directions, something which is not possible in conventional 7075-T73 alloy at the higher values of stress-intensity-range factor, $\Delta K$.

In a 3.5-percent salt solution, 7475-TMT1 and 7475-TMT2 demonstrate the same crack-propagation rates. As shown in Table 28, the short-transverse crack-propagation rates of TMT aluminum alloys are equivalent to 7075-T73 rates in the thick (6.7-inch) forging, and remain stable at higher values of stress-intensity-factor range, $\Delta K$. A thickness effect is apparent in the longitudinal direction in TMT alloys; the crack-propagation rates of TMT alloys are 33 percent faster than 7075-T73 in one-inch forging and 100 percent faster in two- and 6.7-inch forging.

Environment – For each of the three materials, a 3.5-percent salt solution was found to increase the crack-growth rates above those obtained in an air environment. The crack-growth rate of 7475-TMT1 in salt solution is approximately three times the rate in air. This is also true for 7475-TMT2 and for conventional 7075-T73.

In a 3.5-percent salt solution, 7475-TMT1 and 7475-TMT2 demonstrate the same crack-propagation rates. In comparison to 7075-T73, the crack-propagation rates of TMT alloys are faster, but this is offset by the fact that TMT alloys have the capability to maintain stable crack-growth rates at high values of stress-intensity-factor range, $\Delta K$. This cannot be achieved in conventional 7075-T73 alloy.

Grain Direction – Longitudinal and short-transverse specimens were tested from the 6.7-inch-thick forgings. In both environments, room air and 3.5-percent salt solution, no significant differences were found in the crack-growth rates of TMT material loaded parallel to the grain (longitudinal) and TMT material loaded transverse to the grain (short-transverse). This applies to both TMT1 and TMT2, and is a distinct advantage over the conventional 7075-T73 material which demonstrates short-transverse crack-growth rates 33 percent faster than longitudinal crack-growth rates (see Table 29).

Another advantage clearly identified in the results is the fact that crack-growth rates in TMT1 and TMT2 remain stable at values of stress-intensity-factor range, $\Delta K$, where 7075-T73 crack-growth rates were unstable.

## STRESS – CORROSION TESTS

Alcoa's participation in Task III of the Boeing Vertol contract consisted of evaluating the resistance to stress-corrosion cracking of the 6.7-, 2.0-, and 1.0-inch-thick 7075 and 7475 hand forgings produced at the Cleveland Plant in Task II of this contract.

Samples of 6.7-, 2.0-, and 1.00-inch-thick 7075 and 7475 hand forgings solution-heat-treated, quenched, and artificially aged 24 hours at 250°F in Task II were aged additionally 2 to 9 hours at 350°F. Longitudinal 0.125-inch-diameter threaded-end tensile specimens were machined from the T/2 location of all of the samples of forgings. Short-transverse 0.125-inch-diameter threaded-end tensile specimens were machined from the samples of 6.7- and 2.0-inch-thick forgings, and short-transverse 0.75-inch-diameter C-rings were machined from the samples of 1.0-inch-thick forgings. The specimens were stressed at 25, 35, or 45 ksi and exposed to a 3.5-percent NaCl solution by alternate immersion, Federal Method 823, for 84 days. The second-step aging times at 350°F, the stresses at which the specimens were exposed, and the results of the corrosion test are summarized in Table 30 for the 6.7-inch-thick forgings, in Table 31 for the 2.0-inch-thick forgings, and in Table 32 for the 1.00-inch-thick forgings.

Stress-corrosion acceptance criteria and minimum tensile properties are well-established for 7075-T73 products. Figure 148 demonstrated that a second-step aging of 8 hours at 350°F resulted in the 1- and 2-inch-thick 7075-T73 forgings being aged to electrical conductivities well above the specified minimum of 38 percent IACS and to yield strengths well above the guaranteed minimum of 56 ksi specified for forgings up to 3 inches thick. The 6.7-inch-thick 7075-T73 forging given a second-step aging of 8 hours at 350°F also displayed an electrical conductivity well above the specified minimum of 38 percent IACS. Figure 148 provides

some evidence that the nominal aging practice provides sufficient latitude within the specification limits for successful commercial production of 7075-T73 forgings.

Although a minimum electrical conductivity and minimum tensile properties have not been specified for 7475-T73 forgings, the multiple second-step aging times that were used in the investigation permit a comparison of the tensile properties and electrical conductivity of the 7075-T73 and the 7475-T73 forgings at comparable levels of resistance to stress corrosion. From Figures 149 and 150, it is evident that the fabrication procedures used in this investigation produced longitudinal yield strengths in the 7475-T73 forgings that were above the minimum value of 56.0 ksi specified for 7075-T73 hand forgings of thicknesses less than 3.0 inches, but that for an equivalent resistance to stress-corrosion cracking the 7475-T73 forgings had strengths lower than those of the 7075-T73 forgings included for comparison. Based on this limited data for 7475-T73 forgings, it would appear that minimum tensile properties for 7475-T73 forgings would have to be lower than those that have been specified for 7075-T73 forgings. Furthermore, Figure 151 shows that the minimum electrical conductivity of 38 percent IACS will not be applicable to 7475-T73 forgings fabricated by the studied procedures. The 7475-T73 forgings require aging to higher electrical conductivities to obtain the same resistance to stress corrosion that 7075-T73 forgings display at an electrical conductivity of 38 percent IACS.

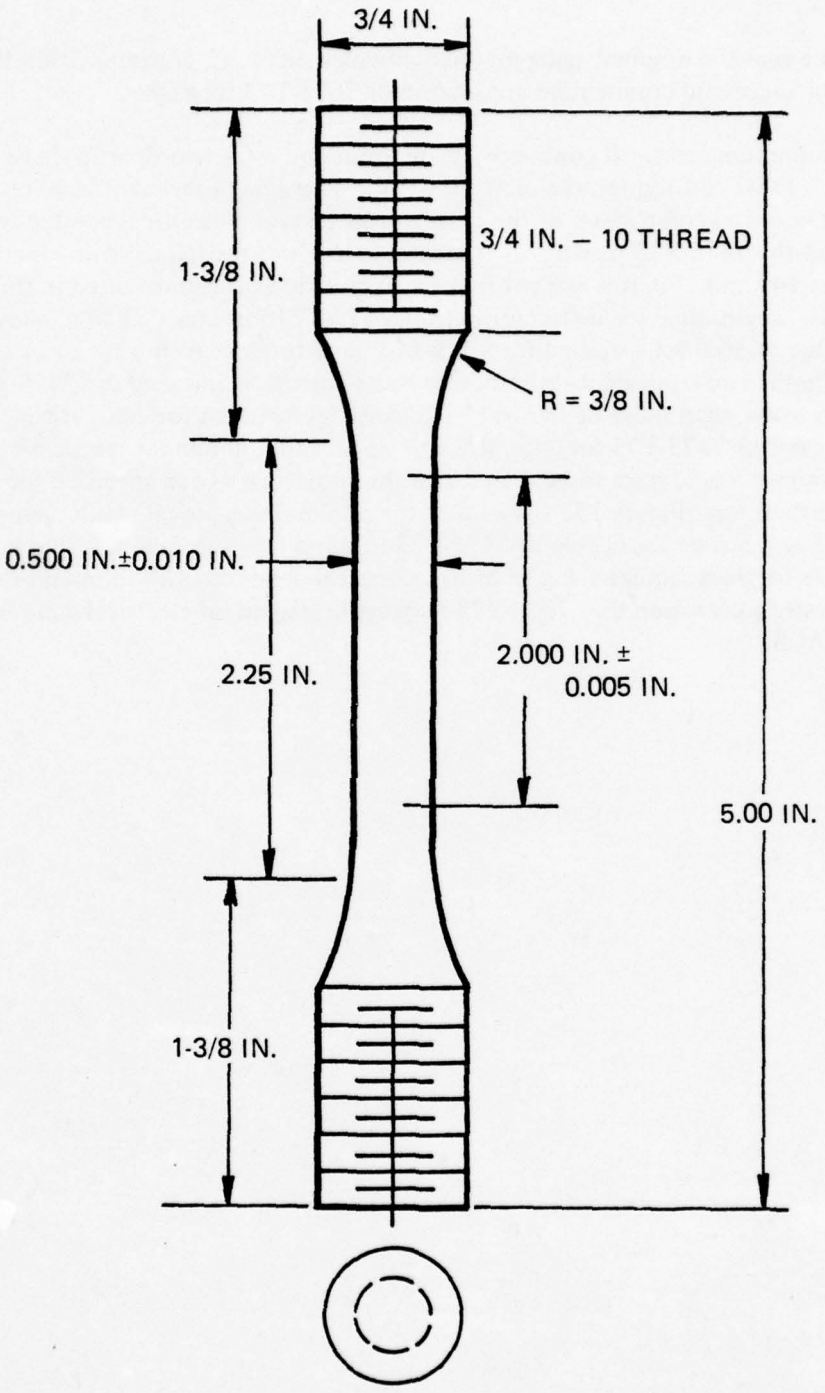
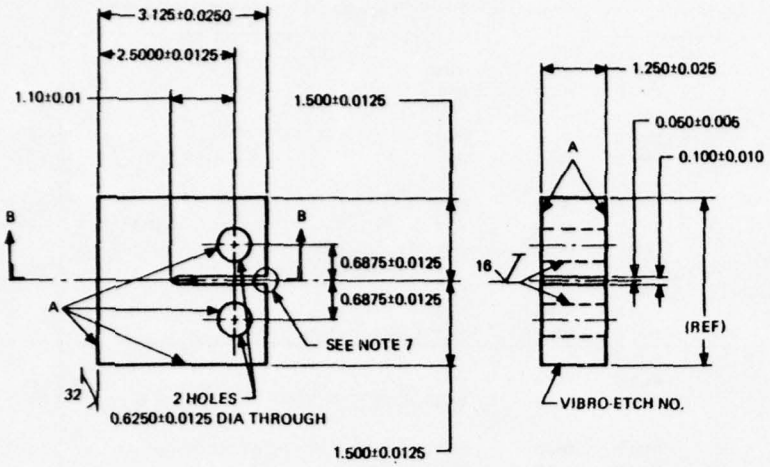



Figure 62. Configuration of Standard Round Specimen for Tension Test.

## TABLE 19. MECHANICAL PROPERTIES FOR TASK II FORGINGS, THERMAL/MECHANICAL HEAT-TREATED ALUMINUM ALLOY

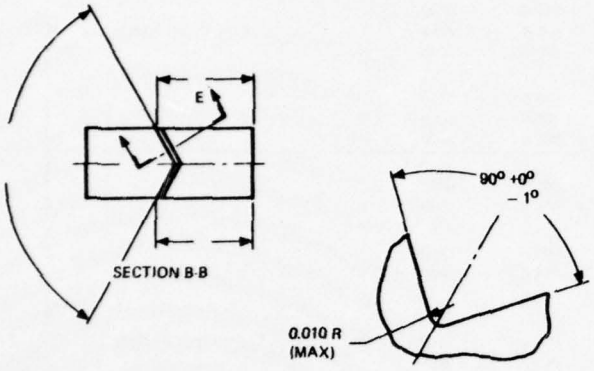
| Material | Forging Thickness (in.) | Grain Orientation | Specimen Number | Diameter (in.) | Area (sq in.) | Gage Length (in.) | Yield Load (lb) | Yield Stress (psi) | Ultimate Load (lb) | Ultimate Stress (psi) | Elongation (%) | Reduction in Area (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0101* | 0.500 | 0.1964 | 2 | 12,750* | 64,918* | 14,650* | 74,592* | 6* | 9* |
| | 1 | L | 0102 | 0.500 | 0.1964 | 2 | 12,625 | 64,282 | 14,650 | 74,592 | 13 | 23 |
| | | | 0111 | 0.499 | 0.1956 | 2 | 12,500 | 63,905 | 14,700 | 75,153 | 14 | 36 |
| | | | | | | | | av = 64,090 | | av = 74,870 | av = 13.5 | av = 30 |
| | | | 0201 | 0.500 | 0.1964 | 2 | 11,800 | 60,081 | 14,500 | 73,828 | 13 | 34 |
| 7075-T73 | 2 | L | 0202 | 0.500 | 0.1964 | 2 | 11,875 | 60,463 | 14,400 | 73,319 | 13 | 29 |
| | | | 0211 | 0.500 | 0.1964 | 2 | 11,800 | 60,081 | 14,300 | 72,810 | 13 | 34 |
| | | | | | | | | av = 60,130 | | av = 73,300 | av = 13 | av = 32 |
| | 6.7 | S-T | 0402 | 0.500 | 0.1964 | 2 | 11,700 | 59,572 | 13,400 | 68,228 | 4 | 5 |
| | | | 0403 | 0.500 | 0.1964 | 2 | 11,800 | 60,081 | 13,800 | 70,264 | 5 | 5 |
| | | | | | | | | av = 59,750 | | av = 69,200 | av = 4.5 | av = 5 |
| | | L | 0601 | 0.500 | 0.1964 | 2 | 11,625 | 59,190 | 13,800 | 70,264 | 13 | 33 |
| | | | 0609 | 0.500 | 0.1964 | 2 | 11,475 | 58,426 | 13,600 | 69,246 | 14 | 34 |
| | | | | | | | | av = 58,750 | | av = 69,700 | av = 13.5 | av = 34 |
| | | | 0701 | 0.500 | 0.1964 | 2 | 12,200 | 62,118 | 14,200 | 72,301 | 19 | 54 |
| | 1 | L | 0702 | 0.500 | 0.1964 | 2 | 12,200 | 62,118 | 14,300 | 72,810 | 16 | 44 |
| | | | 0711 | 0.498 | 0.1948 | 2 | 12,125 | 62,243 | 14,150 | 72,638 | 18 | 54 |
| | | | | | | | | av = 62,160 | | av = 72,580 | av = 17.7 | av = 50 |
| | | | 0827 | 0.498 | 0.1948 | 2 | 12,000 | 61,601 | 14,250 | 73,151 | 15 | 46 |
| 7475-T MT1 | 2 | L | 0828 | 0.499 | 0.1956 | 2 | 11,500 | 58,793 | 13,750 | 70,296 | 17 | 44 |
| | | | 0829 | 0.499 | 0.1956 | 2 | 11,875 | 60,710 | 14,100 | 72,085 | 17 | 40 |
| | | | | | | | | av = 60,370 | | av = 71,840 | av = 16.3 | av = 43 |
| | 6.7 | S-T | 1002 | 0.499 | 0.1956 | 2 | 12,250 | 62,627 | 14,000 | 71,574 | 5 | 7 |
| | | | 1003 | 0.500 | 0.1964 | 2 | 11,700 | 59,572 | 13,700 | 69,755 | 11 | 23 |
| | | | | | | | | av = 61,100 | | av = 70,665 | av = 11 | av = 23 |
| | | L | 1201 | 0.499 | 0.1956 | 2 | 12,375 | 63,266 | 14,400 | 73,619 | 17 | 47 |
| | | | 1209 | 0.499 | 0.1956 | 2 | 12,300 | 62,883 | 14,300 | 73,108 | 17 | 45 |
| | | | | | | | | av = 63,075 | | av = 73,360 | av = 17 | av = 46 |
| | | | 1301 | 0.500 | 0.1964 | 2 | 12,000 | 61,099 | 14,150 | 72,046 | 15 | 55 |
| | 1 | L | 1302 | 0.499 | 0.1956 | 2 | 11,750 | 60,071 | 14,050 | 71,830 | 17 | 52 |
| | | | 1311 | 0.500 | 0.1964 | 2 | 11,925 | 60,717 | 14,050 | 71,537 | 17 | 55 |
| | | | | | | | | av = 60,630 | | av = 71,800 | av = 16.3 | av = 54 |
| | | | 1427 | 0.500 | 0.1964 | 2 | 11,425 | 58,172 | 13,800 | 70,264 | 15 | 51 |
| 7475-T MT2 | 2 | L | 1428 | 0.499 | 0.1956 | 2 | 12,000 | 61,349 | 14,000 | 71,574 | 17 | 47 |
| | | | 1429 | 0.500 | 0.1964 | 2 | 11,375 | 51,917 | 13,650 | 69,501 | 17 | 48 |
| | | | | | | | | av = 59,150 | | av = 70,445 | av = 16.3 | av = 49 |
| | 6.7 | S-T | 1602 | 0.500 | 0.1964 | 2 | 12,100 | 61,608 | 14,050 | 71,537 | 14 | 25 |
| | | | 1603 | 0.500 | 0.1964 | 2 | 12,250 | 62,372 | 14,350 | 73,065 | 14 | 15 |
| | | | | | | | | av = 61,990 | | av = 72,300 | av = 14 | av = 20 |
| | | L | 1801 | 0.500 | 0.1964 | 2 | 12,400 | 63,136 | 14,400 | 73,319 | 17 | 44 |
| | | | 1809 | 0.500 | 0.1964 | 2 | 12,250 | 62,372 | 14,300 | 72,810 | 17 | 47 |
| | | | | | | | | av = 62,750 | | av = 73,065 | av = 17 | av = 46 |

*Metallurgical examination of specimen revealed grain direction not parallel to axis of specimen.




NOTES

1. 32 FINISH ON ALL SURFACES EXCEPT AS NOTED.
2. SURFACES MARKED "A" TO BE PERPENDICULAR AND PARALLEL AS APPLICABLE TO WITHIN 0.005 IN. TIR.
3. POINTS OF INTERSECTION OF THE CRACK-STARTER TIPS WITH THE TWO SPECIMEN FACES SHALL BE EQUAL DISTANCE FROM EITHER PIN-HOLE CENTER TO WITHIN 0.0125 IN.
4. DIMENSIONS "C" AND "D" MUST BE WITHIN 0.0250 IN. OF EACH OTHER.
5. EACH OF THE TWO PARALLEL NOTCH SURFACES MUST LIE IN ONE PLANE TO WITHIN 0.0125 IN. AND MUST BE PERPENDICULAR OR PARALLEL AS APPLICABLE TO THE SPECIMEN FACES TO WITHIN 0.0125 IN.
6. ALL DIMENSIONS IN INCHES.
7. INTEGRAL KNIFE-EDGE DETAILS.



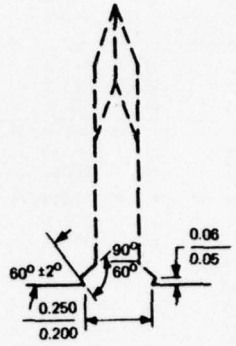




Figure 63. Configuration of Compact Specimen for Fracture-Toughness Testing, Specimens 0223, 0224, 0823, 0824, 1423, 1424, 0401, 1001, 1601, 0606, 1206, and 1806.

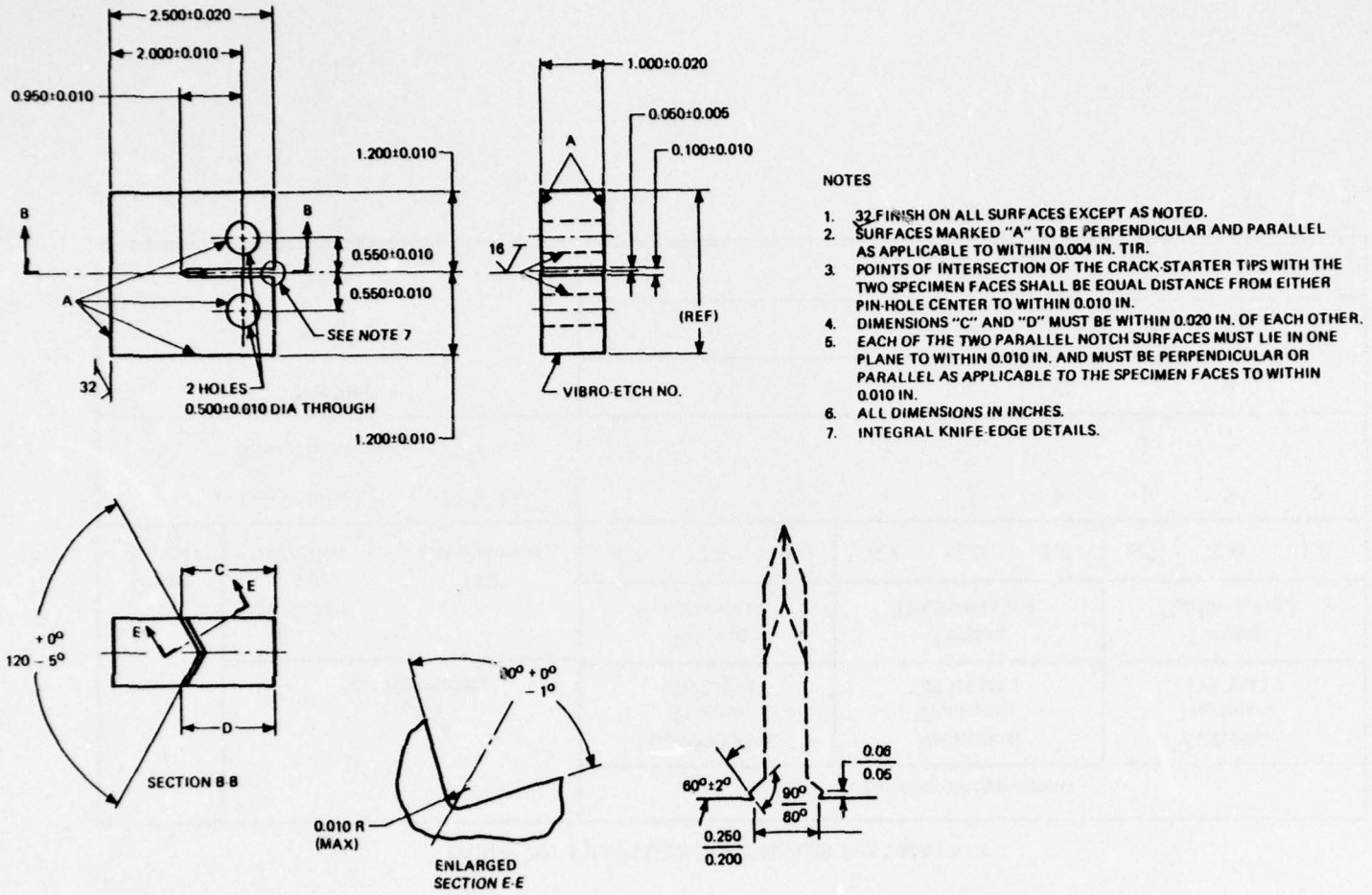



Figure 64. Configuration of Compact Specimen for Fracture-Toughness Testing, Specimens 0123, 0124, 0723, 0724, 1323, and 1324.

TABLE 20. FRACTURE-TOUGHNESS TEST MATRIX

| Group Number | Test Parameters: Specimen Grain Direction | Test Parameters: Test Environment | Number of Specimens: Conventional Process 7075-T73 | | | Mechanical Treatment 7475-TMT1 | | | Mechanical Treatment 7475-TMT2 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Forging Thickness (in.) | | | Forging Thickness (in.) | | | Forging Thickness (in.) | | |
| | | | 6.7 | 2.0 | 1.0 | 6.7 | 2.0 | 1.0 | 6.7 | 2.0 | 1.0 |
| 1 | Longitudinal | 70°F Air | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 2 |
| 2 | Short transverse | 70°F Air | 1 | – | – | 1 | – | – | 1 | – | – |
| | Subtotal | | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Subtotal | | | 6 | | | 6 | | | 6 | |
| | Total | | | | | | 18 | | | | |

TABLE 21. FRACTURE-TOUGHNESS-TEST RESULTS FOR TASK II FORGINGS, THERMAL/MECHANICAL HEAT-TREATED ALUMINUM ALLOY

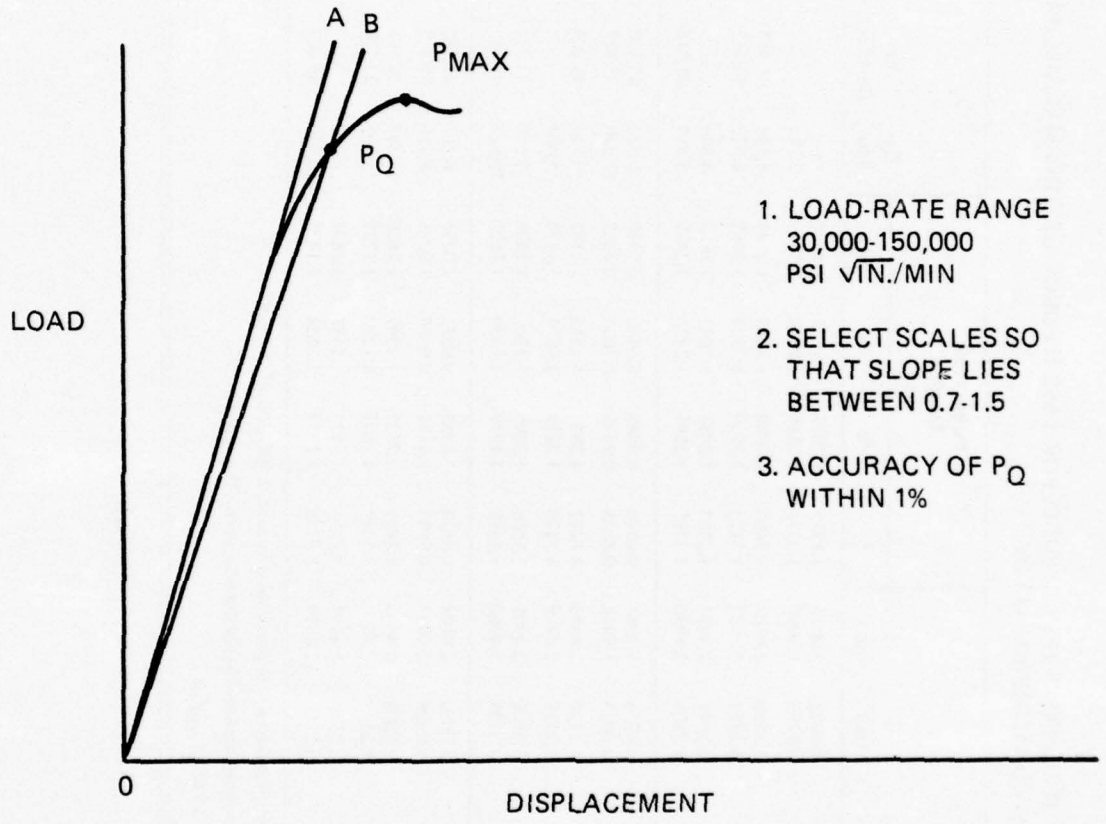
| Material | Forging Thickness (in.) | Grain Orientation | Specimen Number | B (in.) | W (in.) | Fatigue Crack Length, a (in.) $a_1$ | $a_2$ | $a_3$ | $a_{av}$ | $P_Q$ (lb) | $K_Q$ (ksi $\sqrt{in.}$) | $K_{IC}$ (ksi $\sqrt{in.}$) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | L | 0123 | 1.0023 | 2.0015 | 1.1315 | 1.2015 | 1.1615 | 1.1648 | – | – | – | Failed in precracking |
| | | | 0124 | 0.9753 | 2.0096 | 1.2276 | 1.2346 | 1.2096 | 1.2239 | 3,151 | – | 31.838 | |
| 7075-T73 | 2 | L | 0223 | 1.25006 | 2.4900 | 1.3400 | 1.3800 | 1.3700 | 1.3633 | 8,531 | 48.454 | – | 1 |
| | | | 0224 | 1.2512 | 2.5029 | 1.3129 | 1.3129 | 1.2929 | 1.3062 | 8,582 | 44.612 | – | 1 |
| | 6.7 | S-T | 0401 | 1.2511 | 2.4983 | 1.2783 | 1.2983 | 1.2683 | 1.2816 | 4,884 | – | 24.688 | |
| | | L | 0606 | 1.2505 | 2.5030 | 1.2385 | 1.2585 | 1.2485 | 1.2485 | 8,614 | 41.816 | – | 1 |
| | 1 | L | 0723 | 1.0026 | 1.9981 | 0.6540 | 0.9040 | 0.6440 | 0.7340 | 9,922 | 47.760 | – | 2 |
| | | | 0724 | 1.0023 | 1.9952 | 0.6835 | 0.9035 | 0.7035 | 0.7635 | 12,330 | 55.327 | – | 1 |
| 7475-TMT1 | 2 | L | 0853 | 1.2520 | 2.4942 | 1.1242 | 1.3842 | 1.1342 | 1.2142 | 9,137 | 42.604 | – | 3 |
| | | | 0854 | 1.2519 | 2.4779 | 1.1179 | 1.3279 | 1.0879 | 1.1779 | 8,684 | – | 39.178 | |
| | 6.7 | S-T | 1001 | 1.2506 | 2.4905 | 1.1005 | 1.3005 | 1.1305 | 1.1805 | 7,299 | 33.194 | – | |
| | | L | 1206 | 1.2525 | 2.4960 | 1.1589 | 1.1939 | 1.1339 | 1.1622 | 10,873 | 47.686 | – | 1 |
| | 1 | L | 1323 | 1.0030 | 2.0104 | 0.9635 | 1.1335 | 0.9835 | 1.0235 | 6,167 | 42.962 | – | 1 |
| | | | 1324 | 1.0028 | 2.0002 | 0.9695 | 1.1195 | 0.9895 | 1.0295 | 8,356 | 59.415 | – | 1 |
| 7475-TMT2 | 2 | L | 1453 | 1.2503 | 2.4843 | 1.1495 | 1.2525 | 1.1395 | 1.1828 | 10,697 | 48.598 | – | 1 |
| | | | 1454 | 1.2512 | 2.4897 | 1.1287 | 1.2637 | 1.1287 | 1.1737 | 11,905 | 53.522 | – | 1 |
| | 6-7 | S-T | 1601 | 1.2518 | 2.4995 | 1.1275 | 1.3175 | 1.1175 | 1.1875 | 8,080 | – | 36.535 | |
| | | L | 1806 | 1.2506 | 2.4970 | 1.0738 | 1.2538 | 1.1138 | 1.1471 | 10,420 | 45.003 | – | 1 |

NOTES:
1. Specimen dimensions too small for plane-strain fracture-toughness measurement, $2.5(K_Q/\sigma_{YS})^2 > B$ and $> a$.
2. Specimen dimensions too small for plane-strain fracture-toughness measurement, $P_{MAX}/P_Q > 1.10$.
3. Specimen crack too short for valid test, $2.5\ (K_Q/\sigma_{YS})^2 > a$.

FRACTURE TOUGHNESS TEST SPECIMEN NO. _____

LINE 0A TANGENT TO INITIAL
LOAD-DISPLACEMENT CURVE

TANGENT 0B = 0.95 TANGENT 0A




1. LOAD-RATE RANGE
   30,000-150,000
   PSI $\sqrt{IN.}$/MIN

2. SELECT SCALES SO
   THAT SLOPE LIES
   BETWEEN 0.7-1.5

3. ACCURACY OF $P_Q$
   WITHIN 1%

$$K_Q = \frac{P_Q}{B\sqrt{W}} \left[ 29.6\left(\frac{a}{W}\right)^{1/2} - 185.5\left(\frac{a}{W}\right)^{3/2} + 655.7\left(\frac{a}{W}\right)^{5/2} - 1017\left(\frac{a}{W}\right)^{7/2} + 638.9\left(\frac{a}{W}\right)^{9/2} \right]$$

B = AVERAGE THICKNESS OF SPECIMEN
W = AVERAGE DIMENSION PER ASTM 399-72
a = AVERAGE CRACK LENGTH
$K_Q$ = CONDITIONAL FRACTURE TOUGHNESS

Figure 65. Method for Determining Fracture Toughness.

TABLE 22. IMPROVEMENT IN FRACTURE TOUGHNESS RELATIVE TO 7075-T73

| Material and Configuration | | $K_Q$ or $K_{IC}$ (ksi$\sqrt{\text{in.}}$) | Improvement (%) |
|---|---|---|---|
| 7475-TMT1 | | | |
| | 1 in. thick longitudinal | 51.5 | 62 |
| | 2 in. thick longitudinal | 39.2 | None |
| | 6.7 in. thick longitudinal | 47.7 | 11 |
| | 6.7 in. thick short transverse | 33.2 | 34 |
| 7475-TMT2 | | | |
| | 1 in. thick longitudinal | 51.2 | 61 |
| | 2 in. thick longitudinal | 51.1 | 10 |
| | 6.7 in. thick longitudinal | 45.0 | 8 |
| | 6.7 in. thick short transverse | 36.5 | 48 |
| 7075-T73 | | | |
| | 1 in. thick longitudinal | 31.8 | – |
| | 2 in. thick longitudinal | 46.5 | – |
| | 6.7 in. thick longitudinal | 41.8 | – |
| | 6.7 in. short transverse | 24.7 | – |

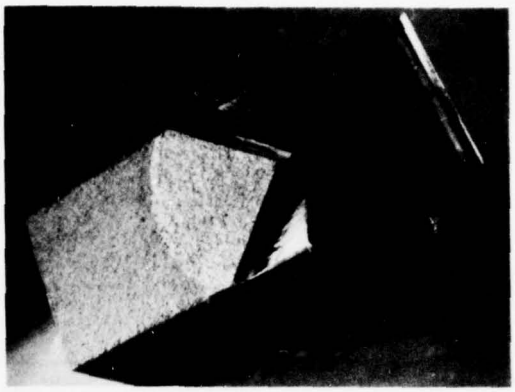


Figure 66. Fracture Surface of 7075-T73 Toughness Specimen 0124.

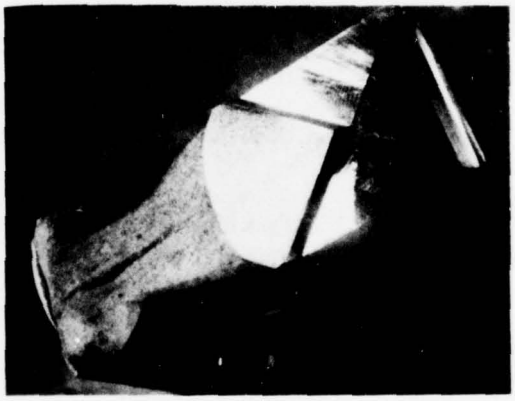


Figure 67. Fracture Surface of 7475-TMT1 Toughness Specimen 0724.

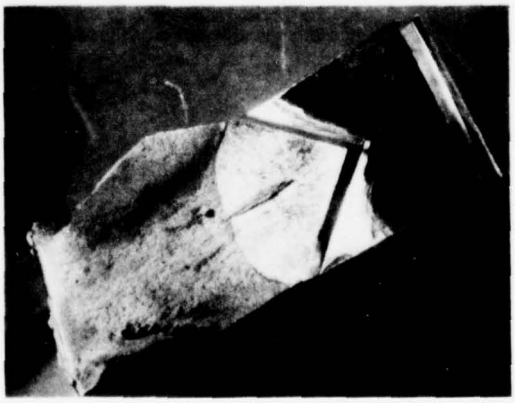


Figure 68. Fracture Surface of 7475-TMT2 Toughness Specimen 1324.

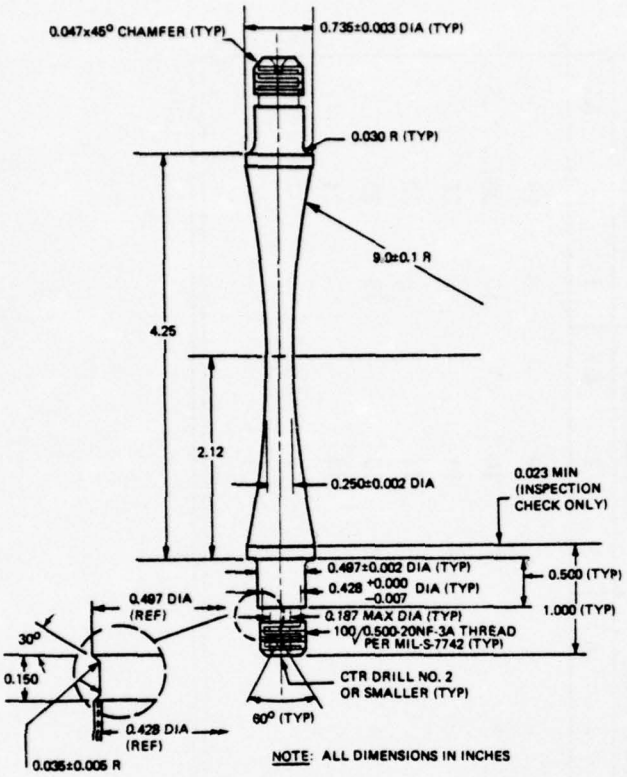



Figure 69. Configuration of Smooth Specimen for Goodman Fatigue Test.

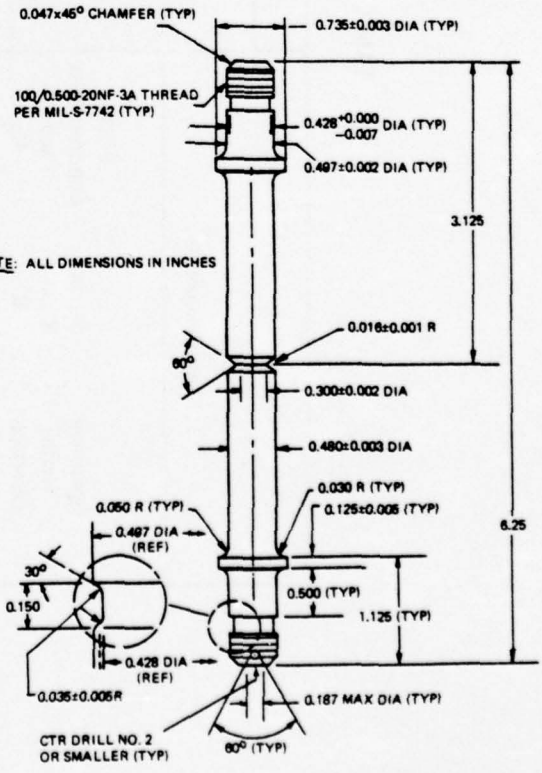



Figure 70. Configuration of Notched Specimen for Goodman Fatigue Test.

TABLE 23. FATIGUE TESTS

| Test Parameters | | | Specimen Group Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Conventional Process 7075-T73 | | | Advanced Thermal/ Mechanical Treatment 7475-TMT1 | | | Advanced Thermal/ Mechanical Treatment 7475-TMT2 | | |
| Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor, $K_T$ | Forging Thickness (in.) | | | Forging Thickness (in.) | | | Forging Thickness (in.) | | |
| | | | 1 | 2 | 6.7 | 1 | 2 | 6.7 | 1 | 2 | 6.7 |
| Longitudinal | – 1.0 | 1.0 | – | – | – | – | 9 | – | – | 19 | – |
| Longitudinal | + 0.05 | 1.0 | 1 | 3 | 5 | 7 | 10 | 15 | 17 | 20 | 25 |
| Longitudinal | + 0.50 | 1.0 | – | – | – | – | 11 | – | – | 21 | – |
| Longitudinal | – 1.0 | 3.0 | – | – | – | – | 12 | – | – | 22 | – |
| Longitudinal | + 0.05 | 3.0 | 2 | 4 | – | 8 | 13 | – | 18 | 23 | – |
| Longitudinal | + 0.50 | 3.0 | – | – | – | – | 14 | – | – | 24 | – |
| Short transverse | + 0.05 | 1.0 | – | – | 6 | – | – | 16 | – | – | 26 |
| Short transverse | + 0.05 | 3.0 | – | – | – | – | – | – | – | – | – |

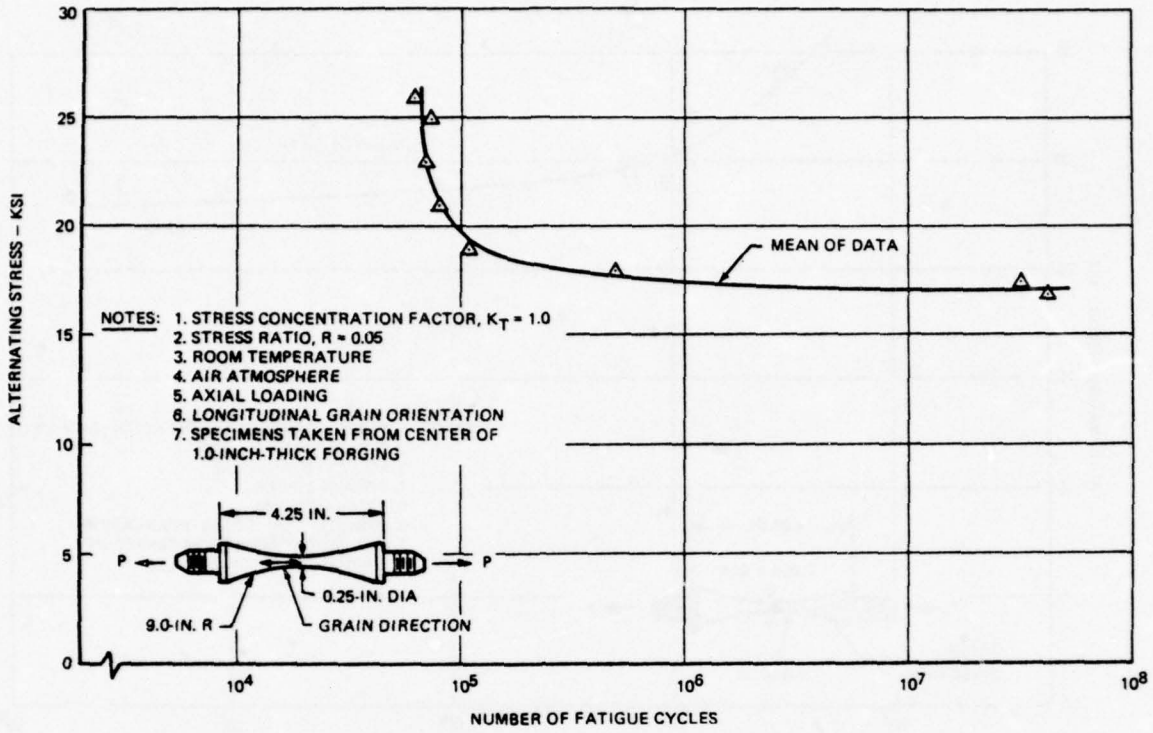



Figure 71. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 1.

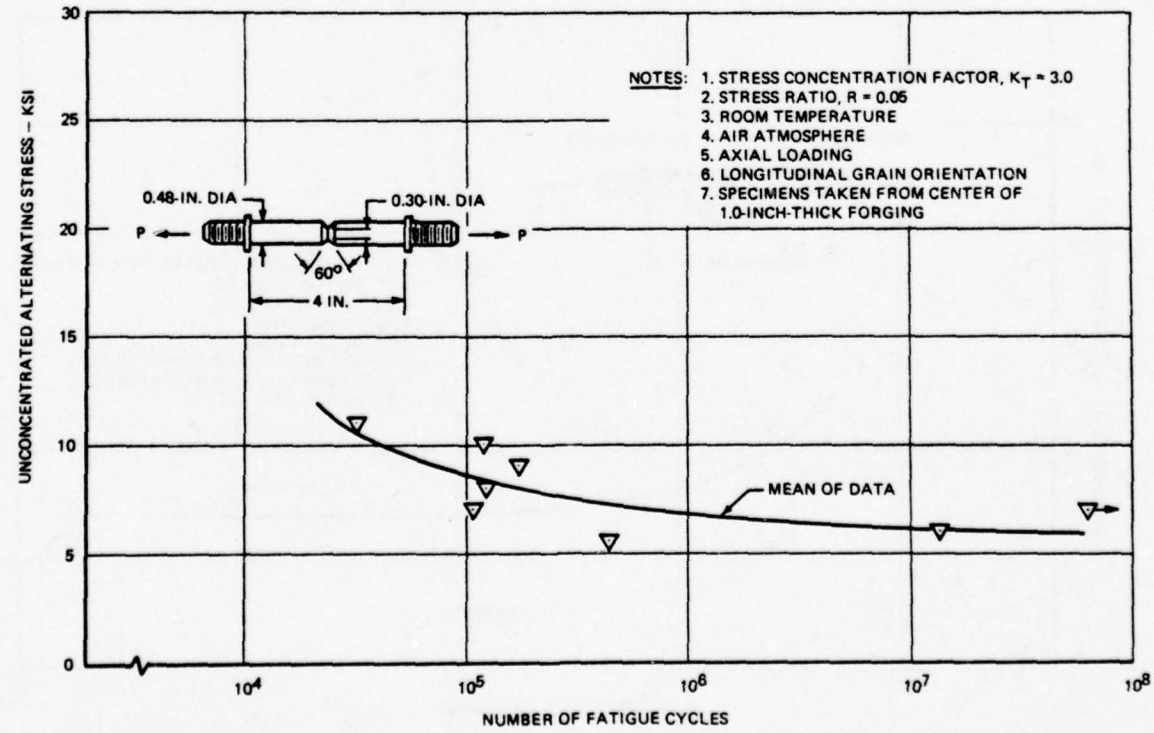



Figure 72. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 2.

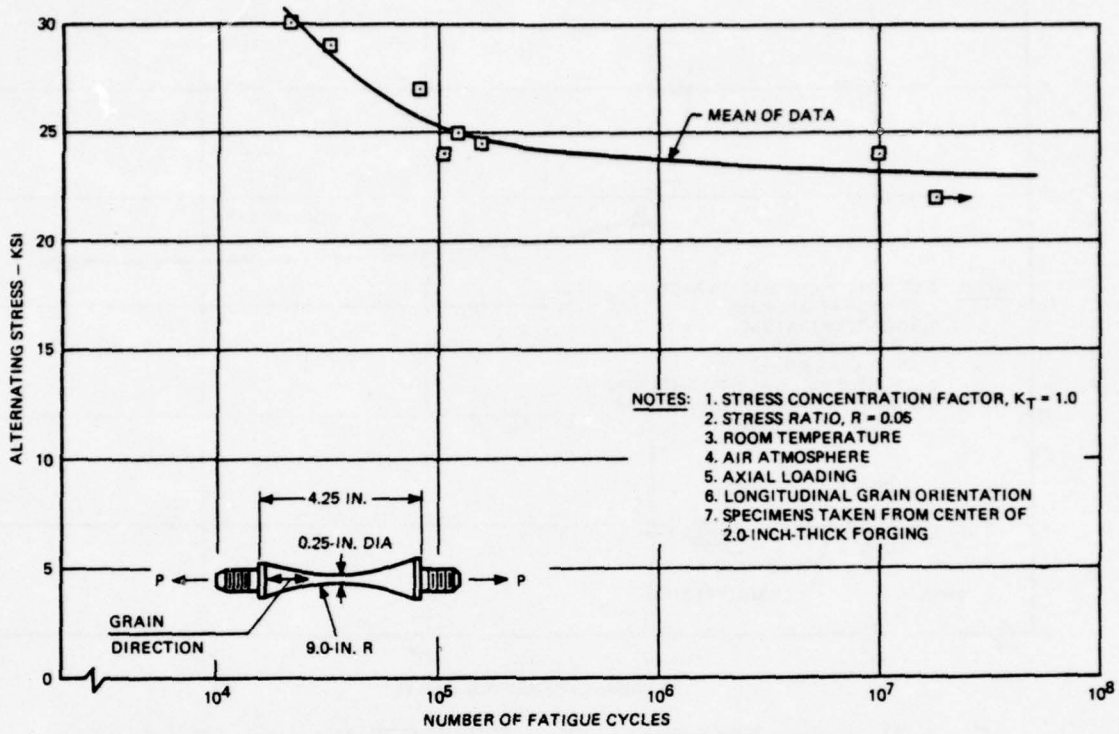



*Figure 73.* Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 3.

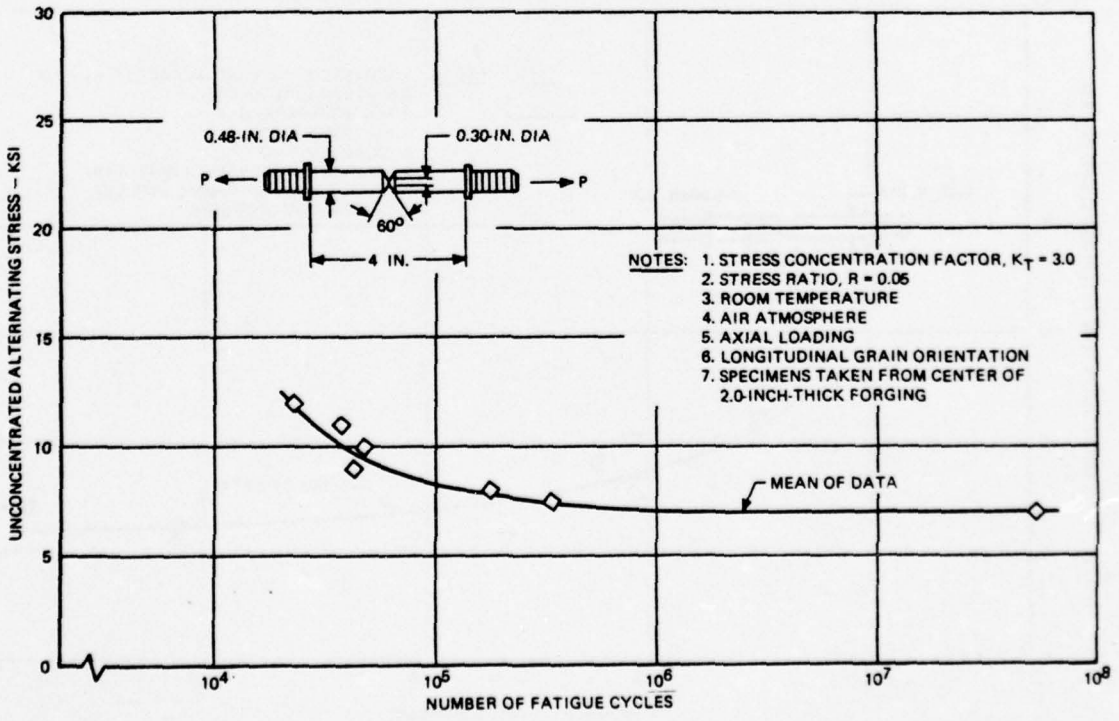



*Figure 74.* Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 4.

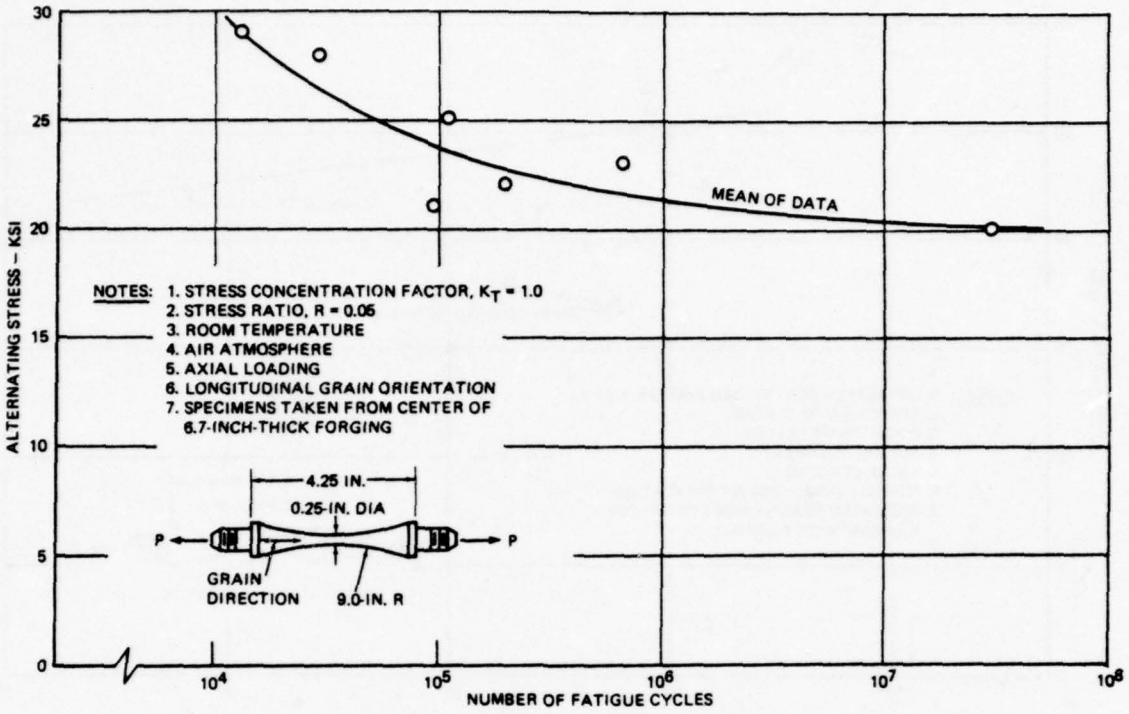



Figure 75. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 5.

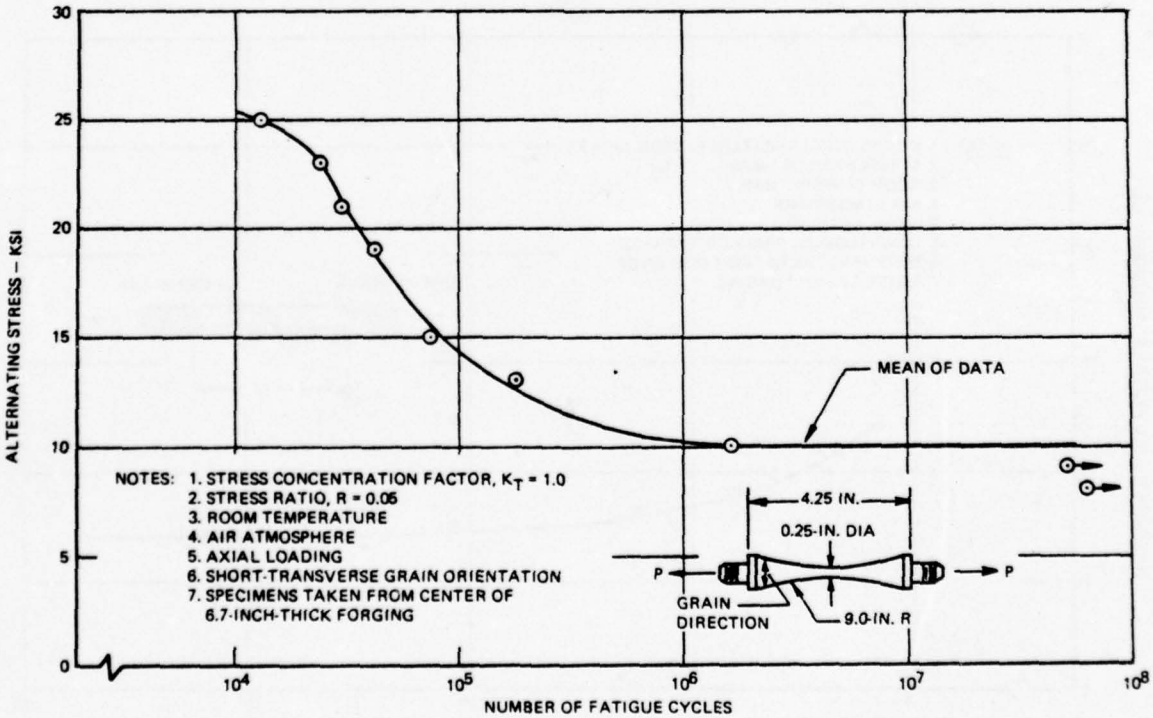



Figure 76. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 6.

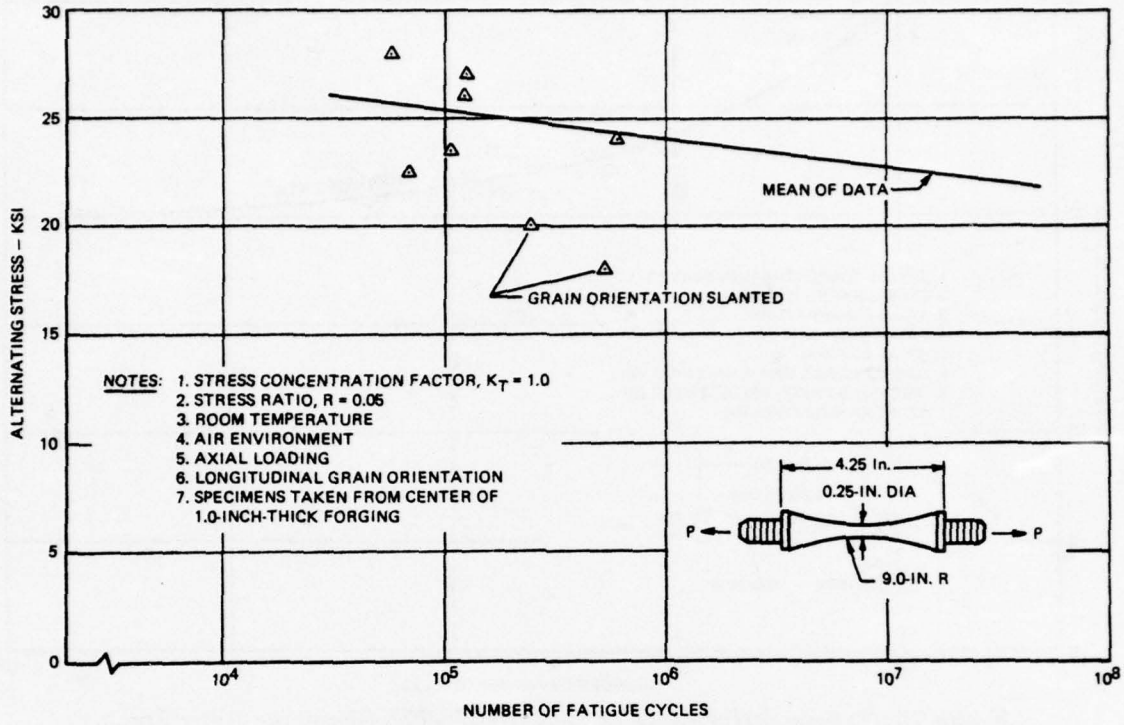



Figure 77. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 7.

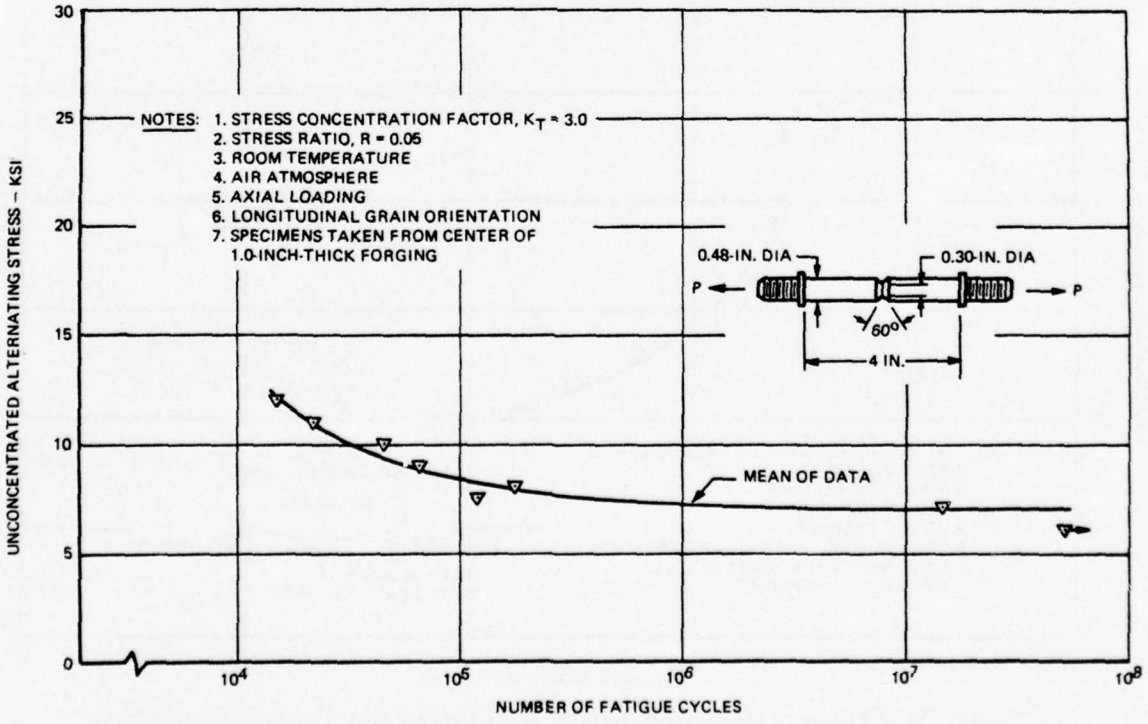



Figure 78. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 8.

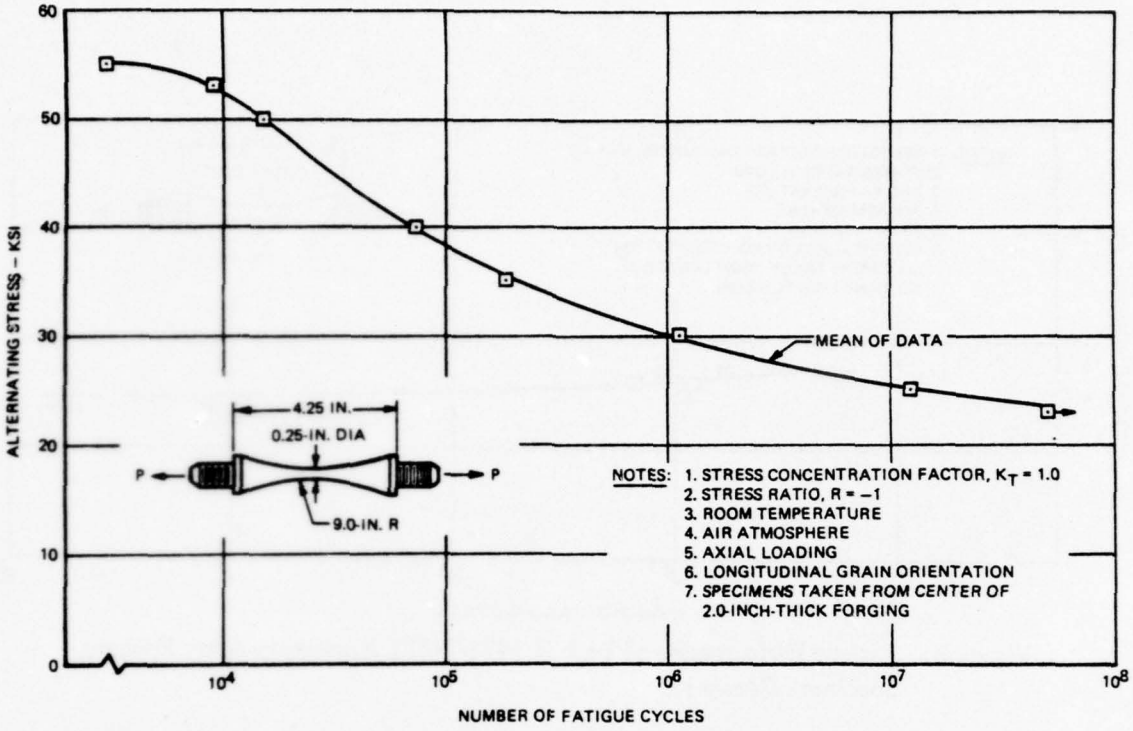



Figure 79. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, *Specimen Group 9.*

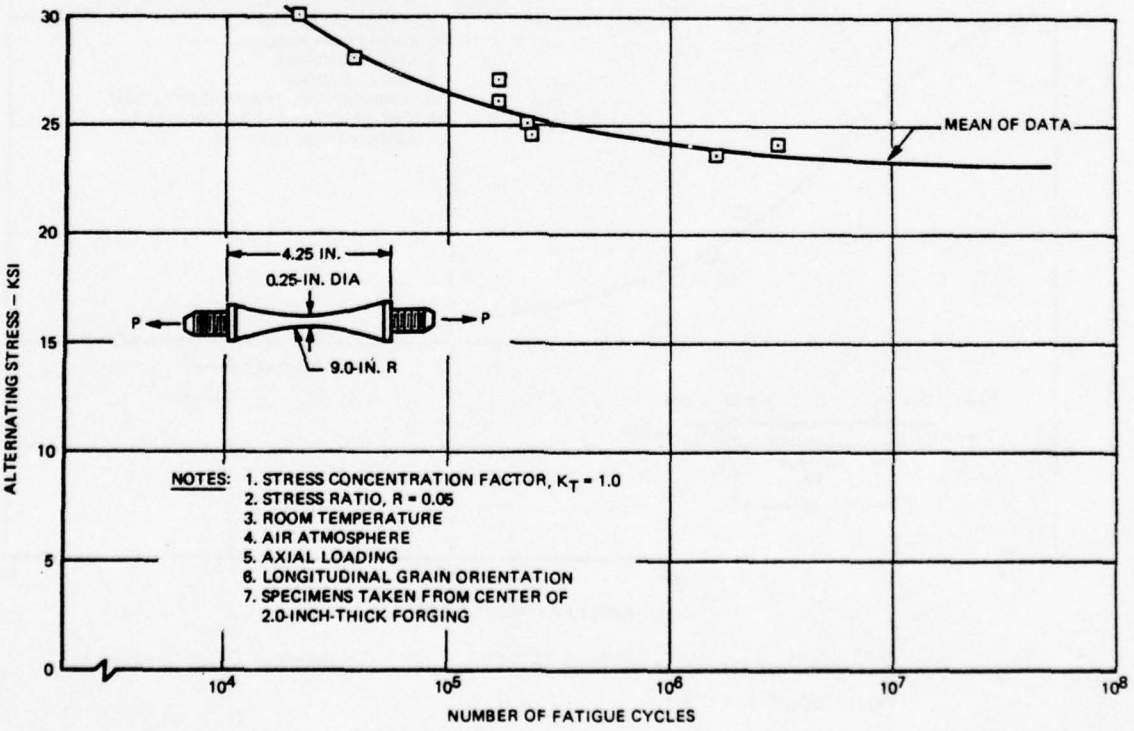



Figure 80. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 10.

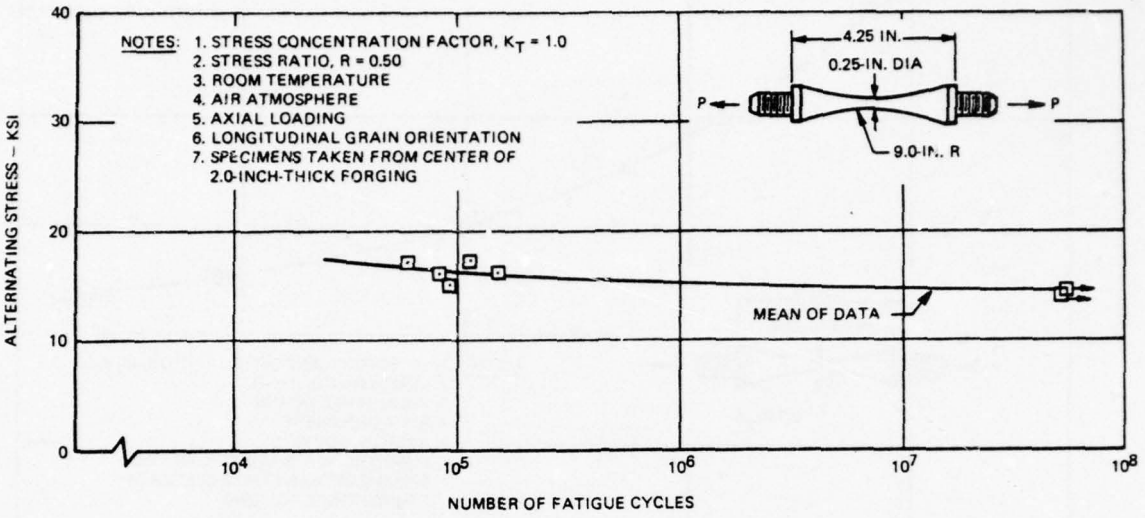



Figure 81. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 11.

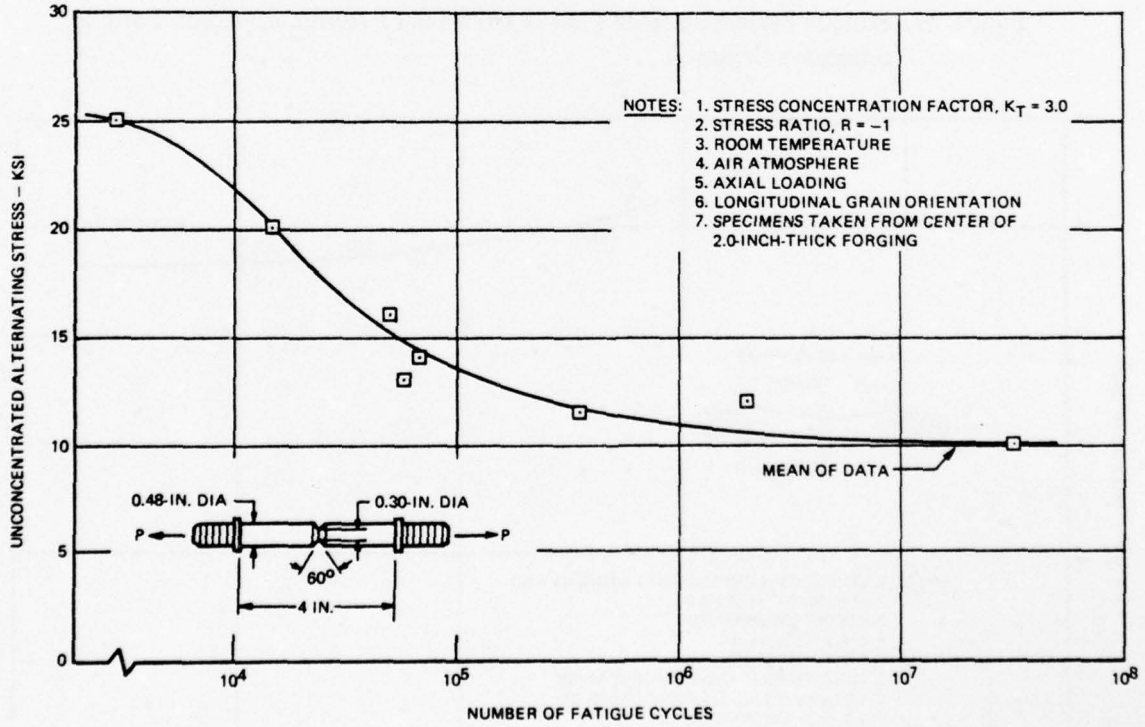



Figure 82. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 12.

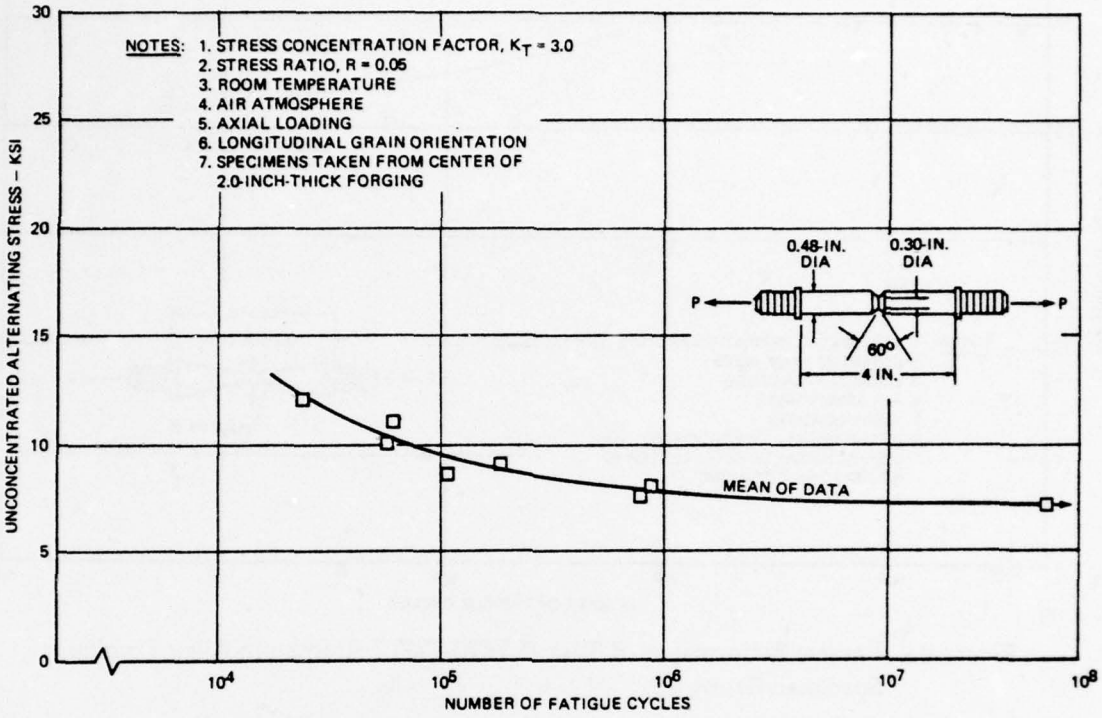



Figure 83. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 13.

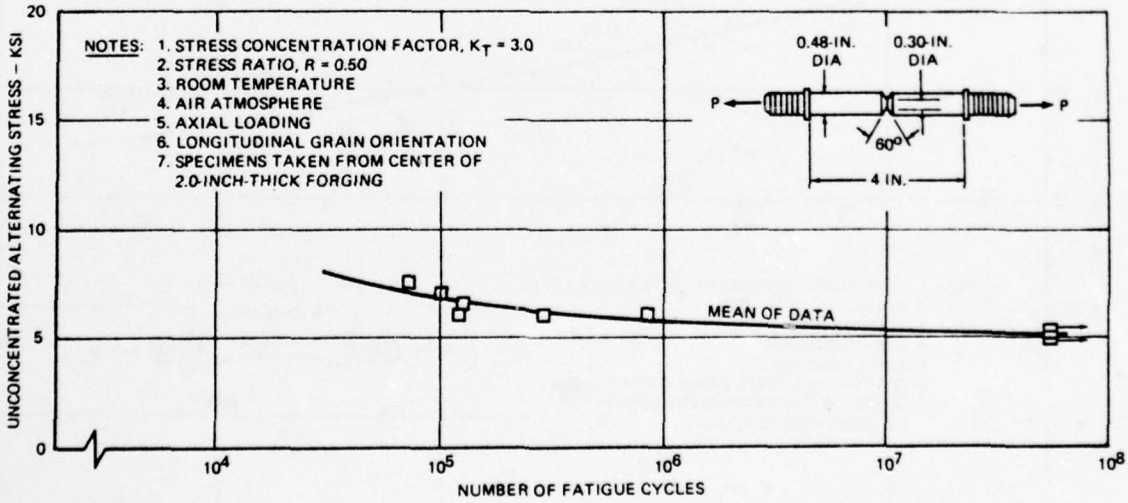



Figure 84. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 14.

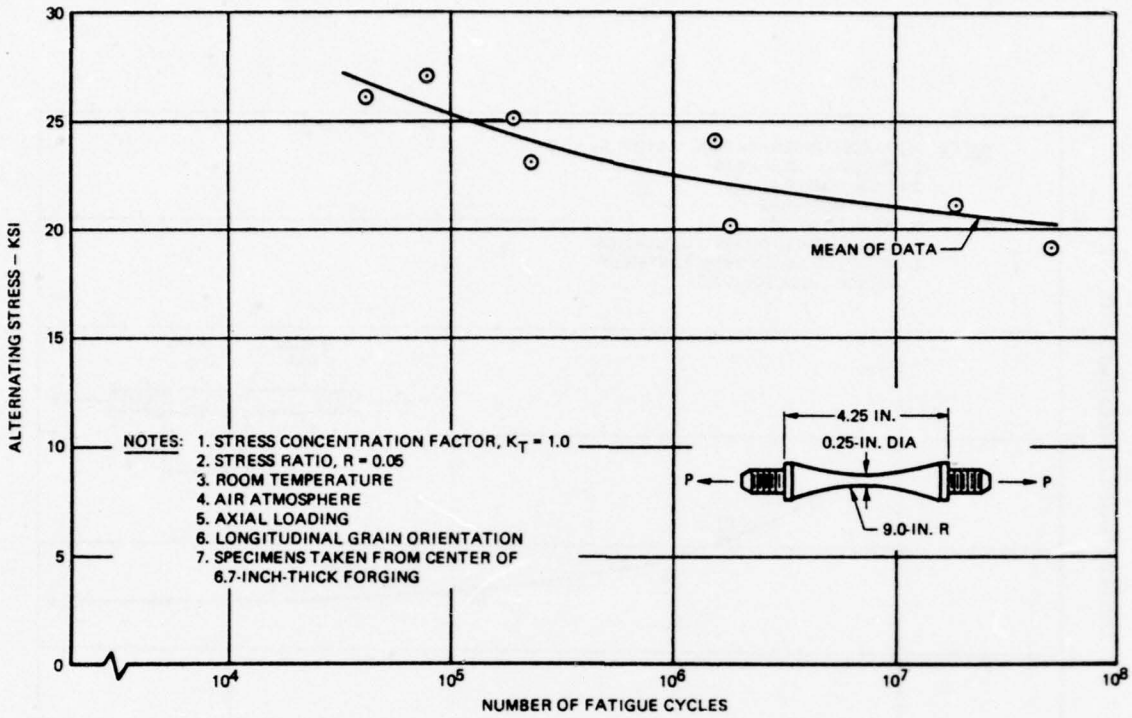



Figure 85. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 15.

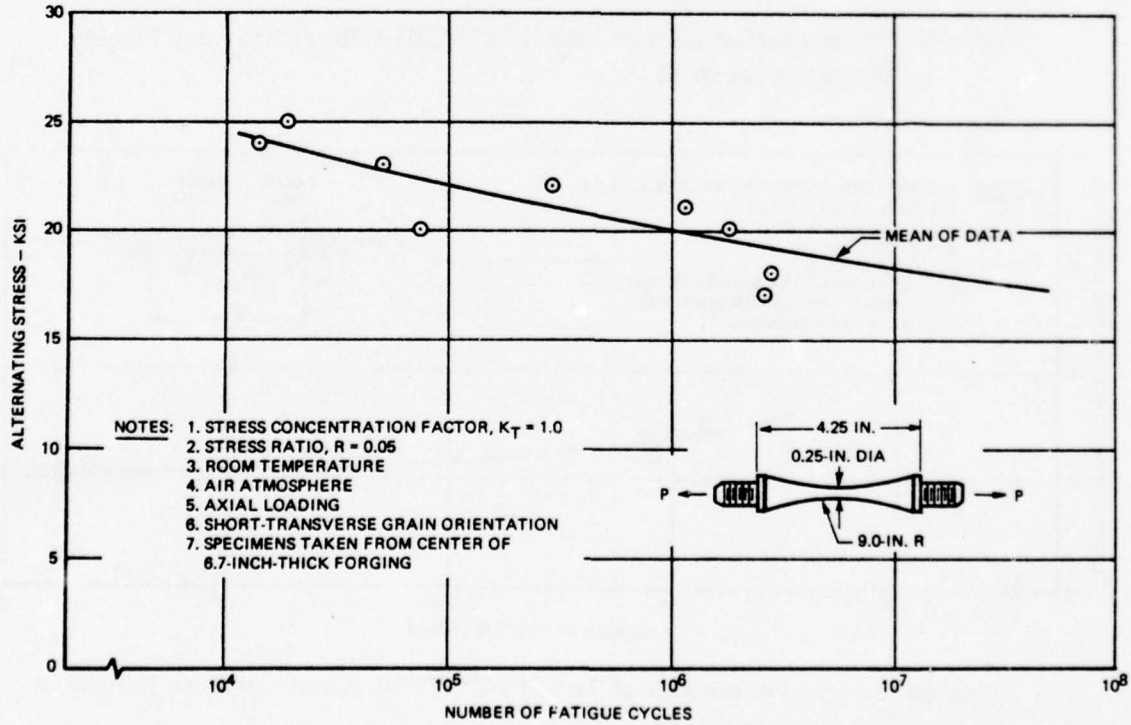



Figure 86. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 16.

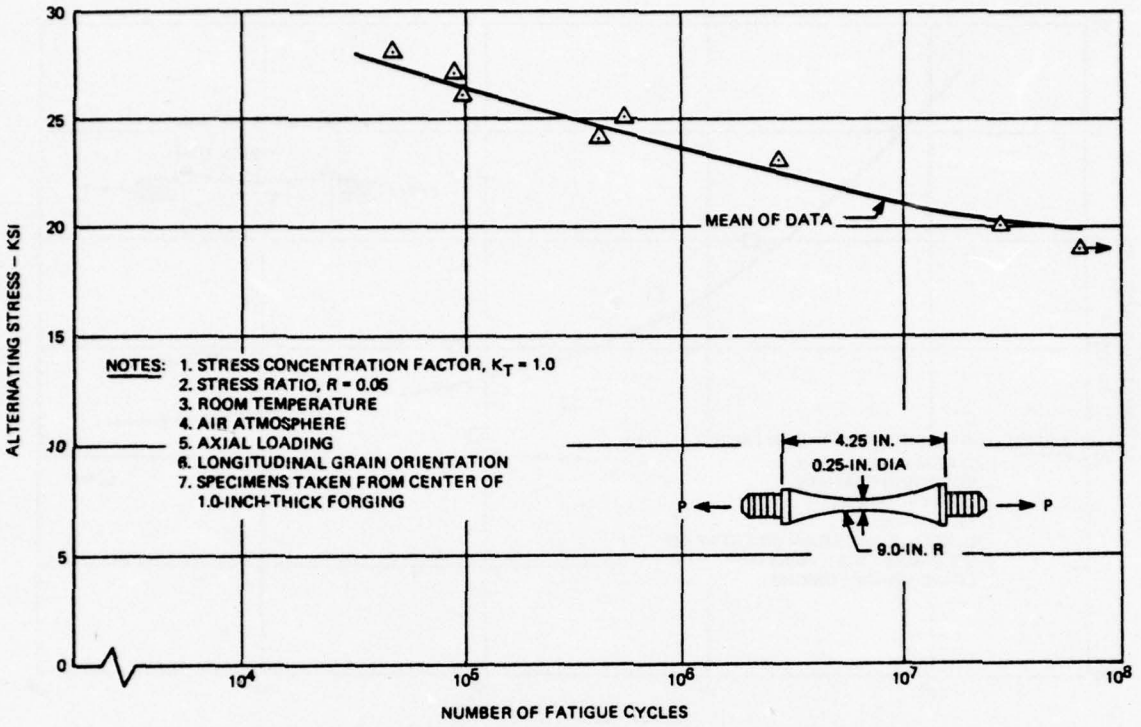



Figure 87. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 17.

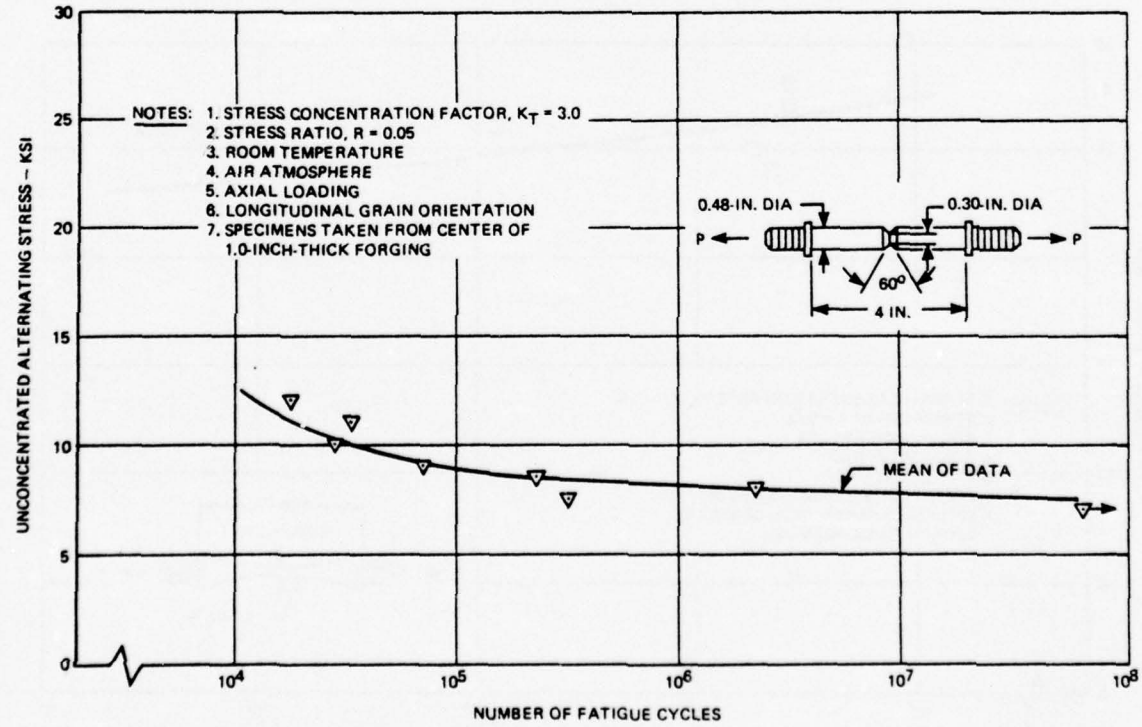



Figure 88. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 18.

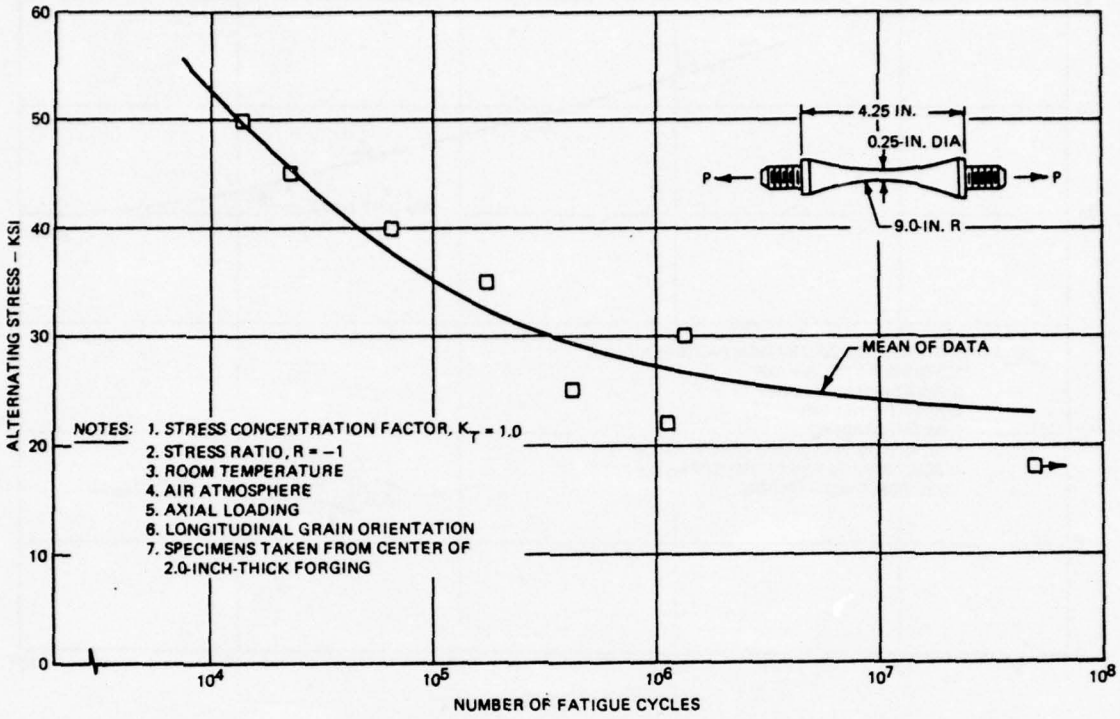



Figure 89. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 19.

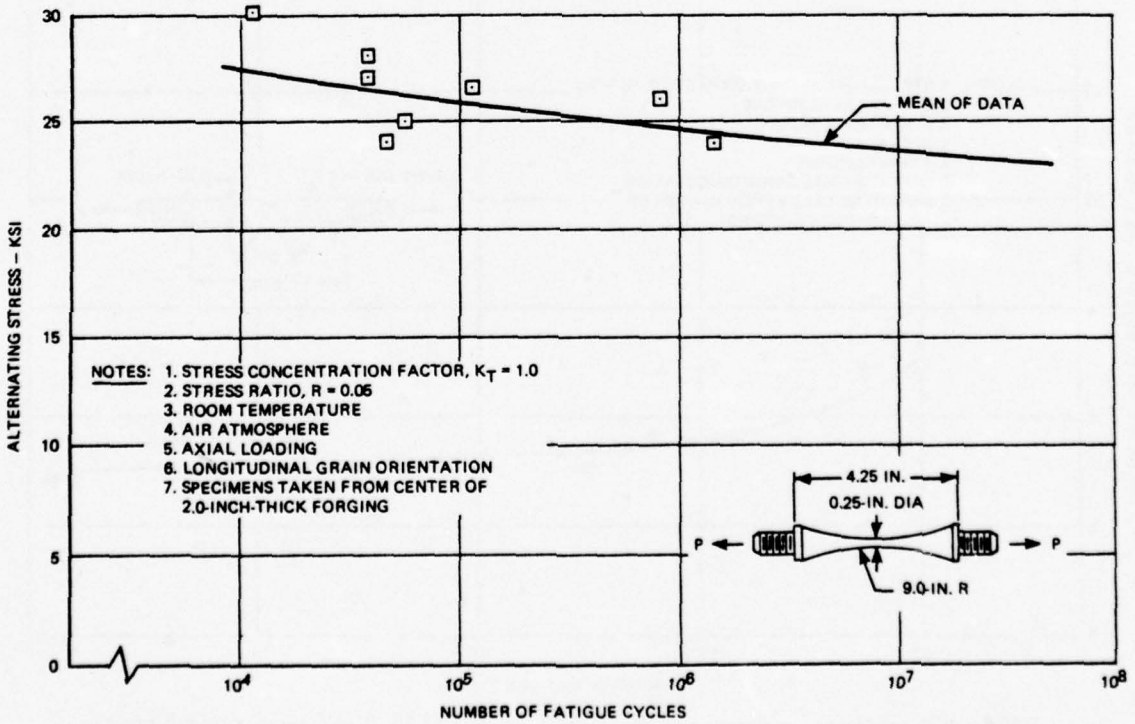



Figure 90. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 20.

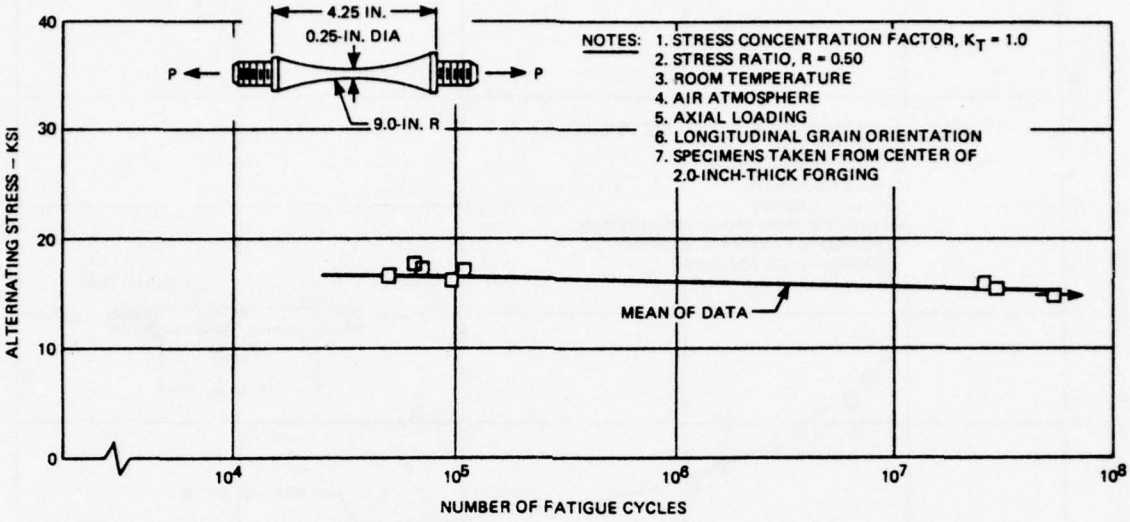



Figure 91. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 21.

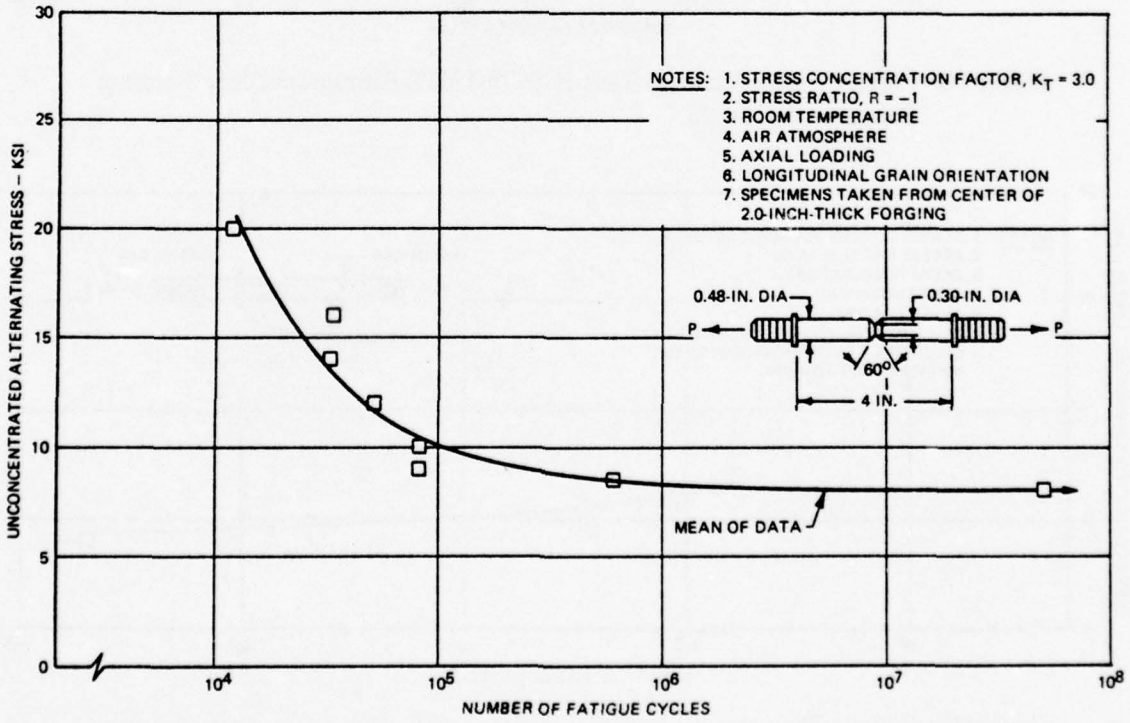



Figure 92. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 22.

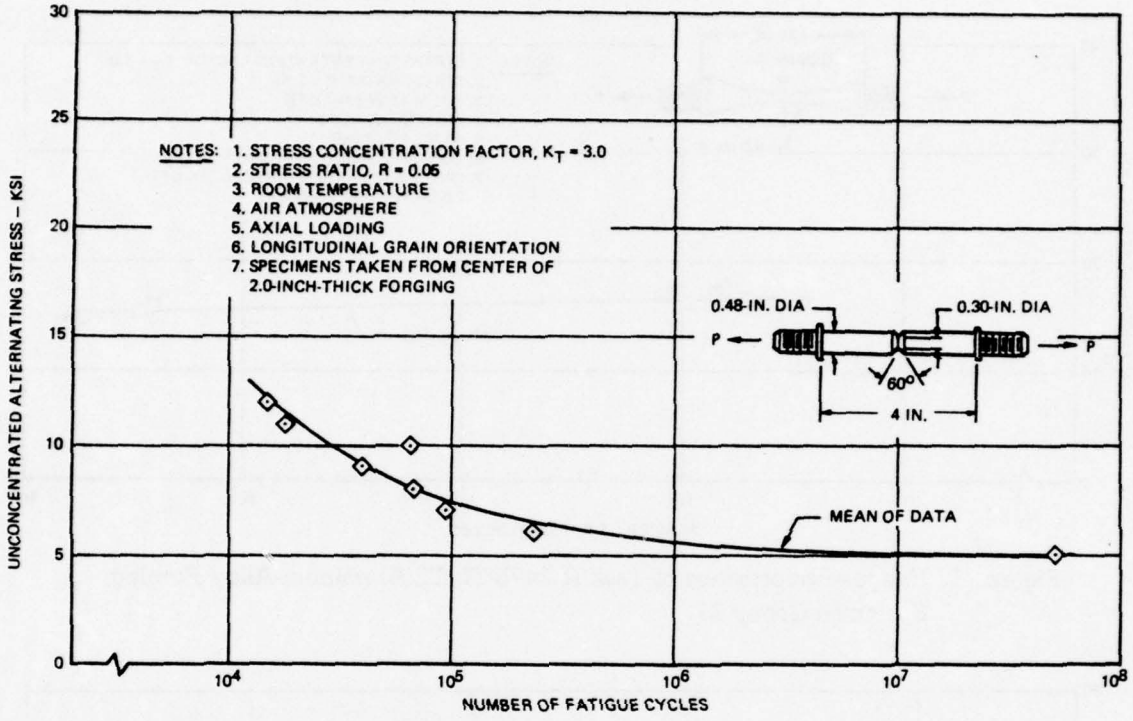



Figure 93. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 23.

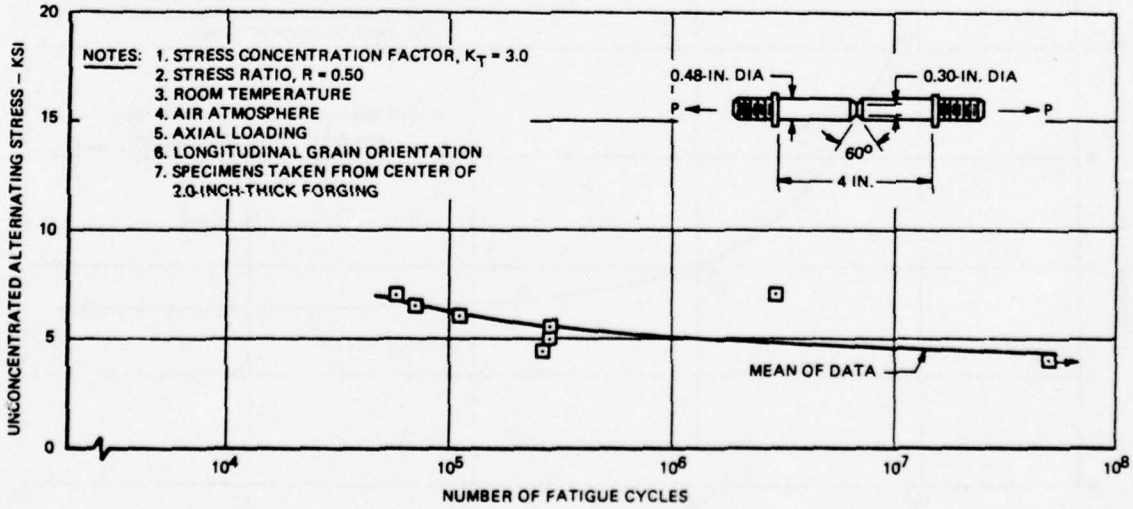



Figure 94. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 24.

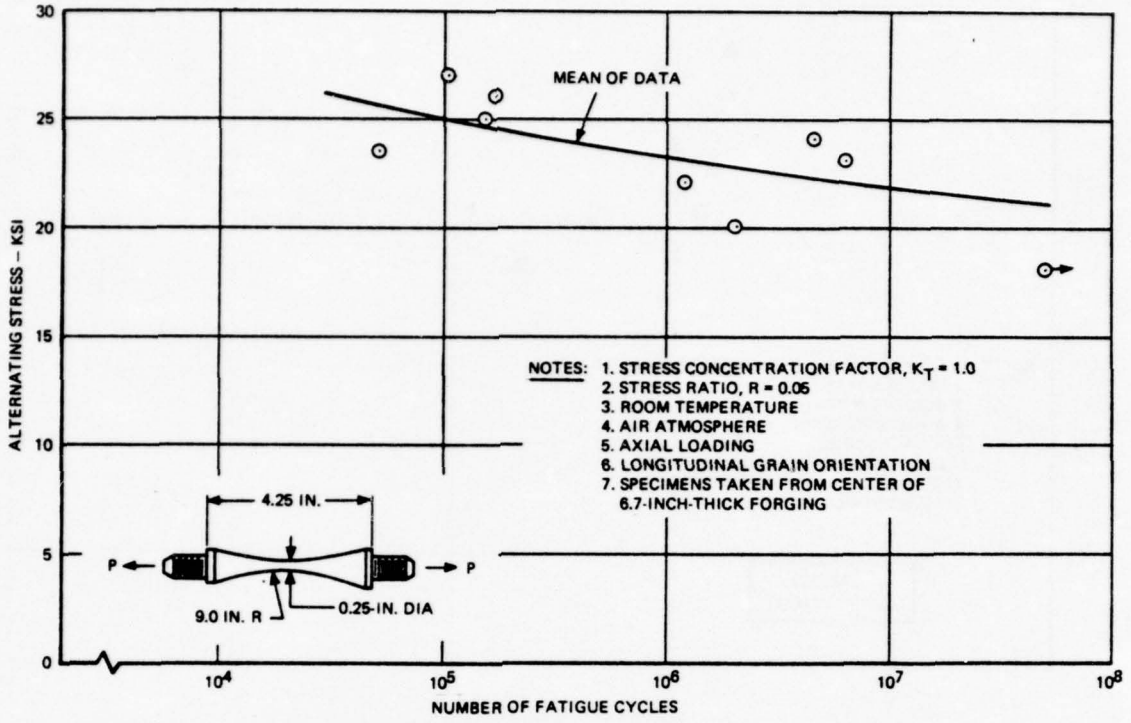



Figure 95. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 25.

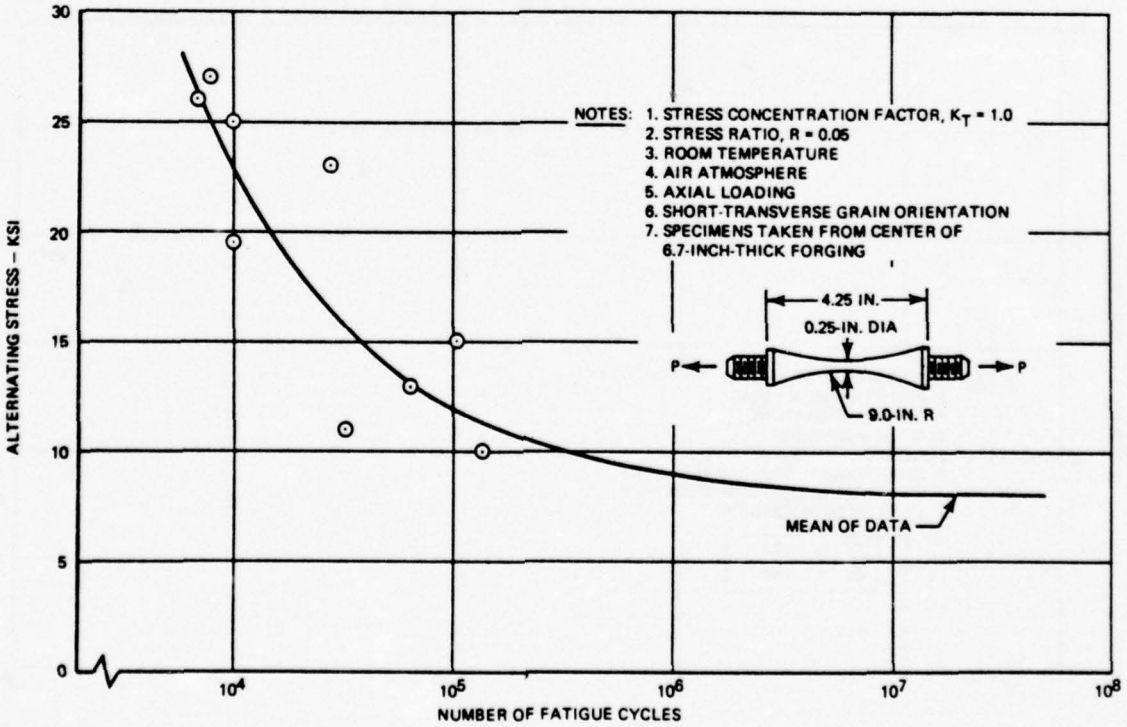



Figure 96. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 26.

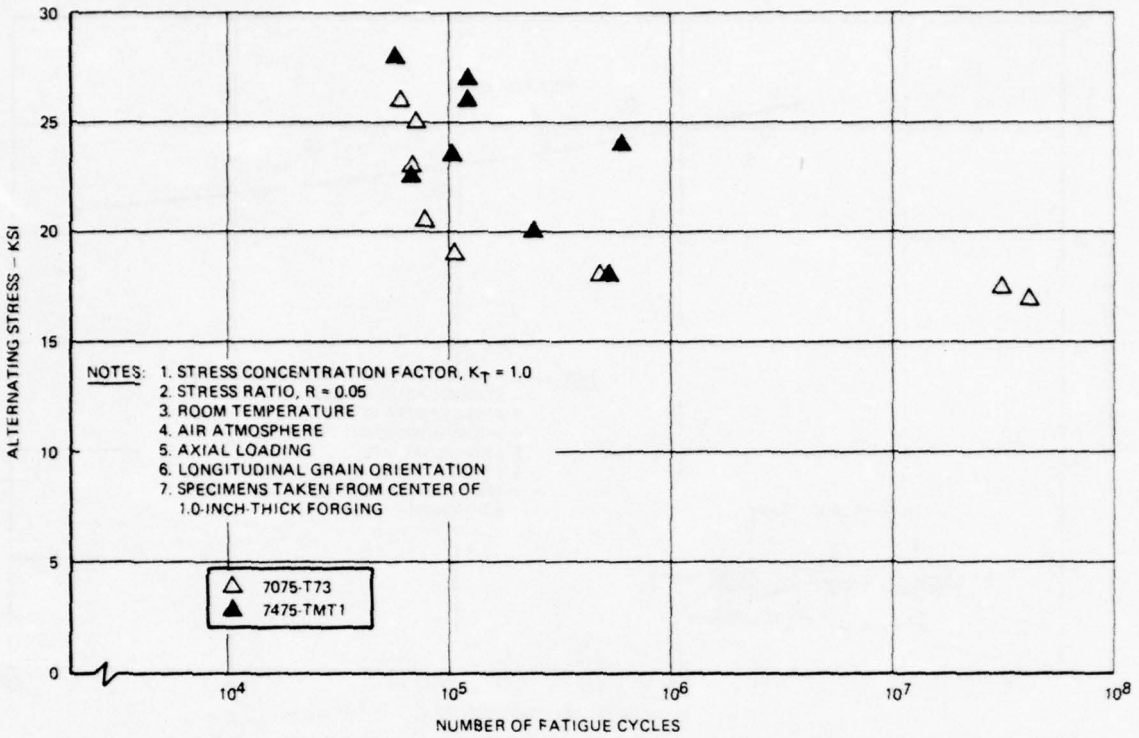



Figure 97. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 1 and 7.

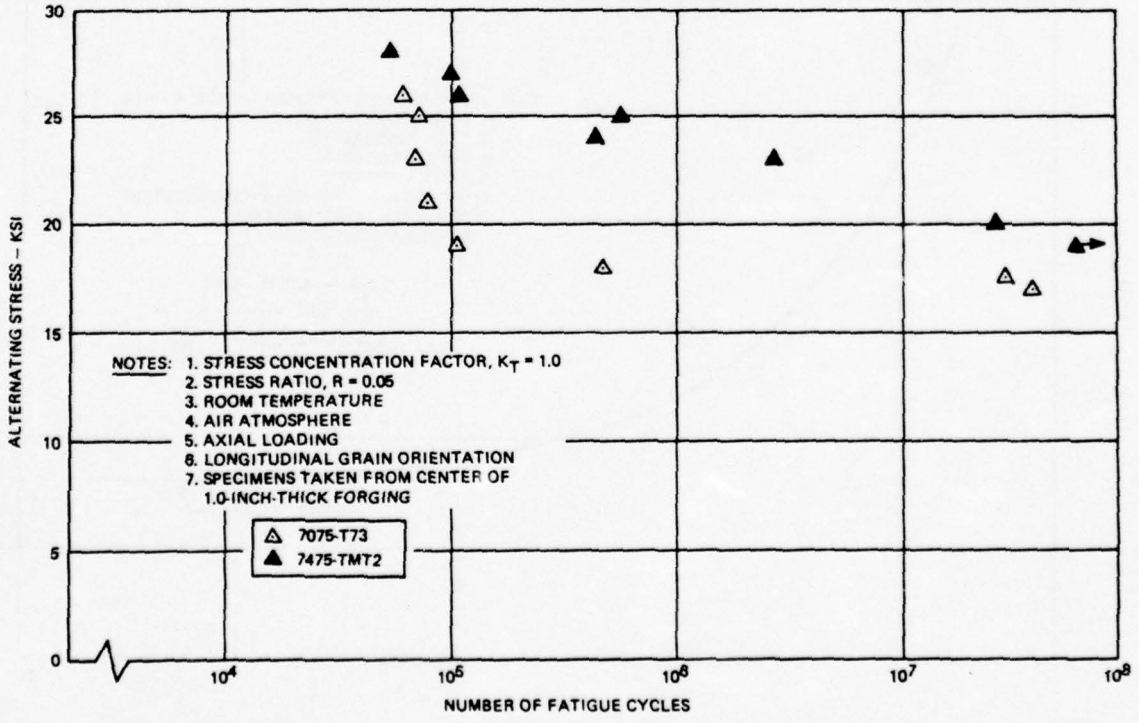



Figure 98. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 1 and 17.

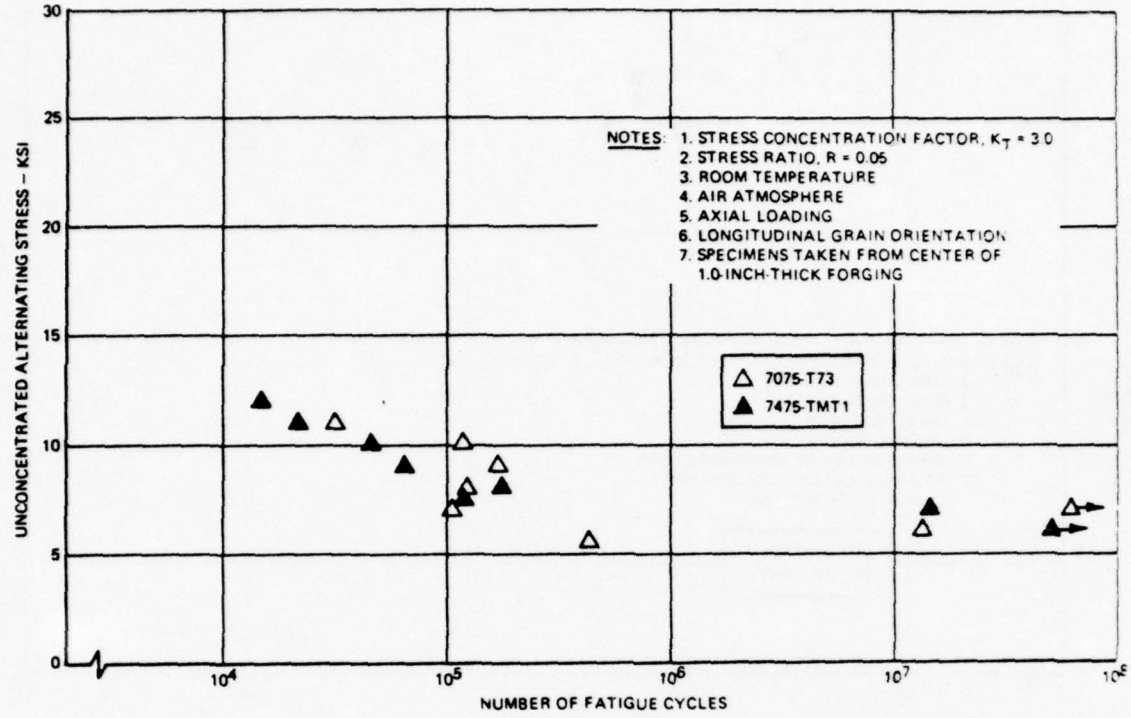



Figure 99. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 2 and 8.

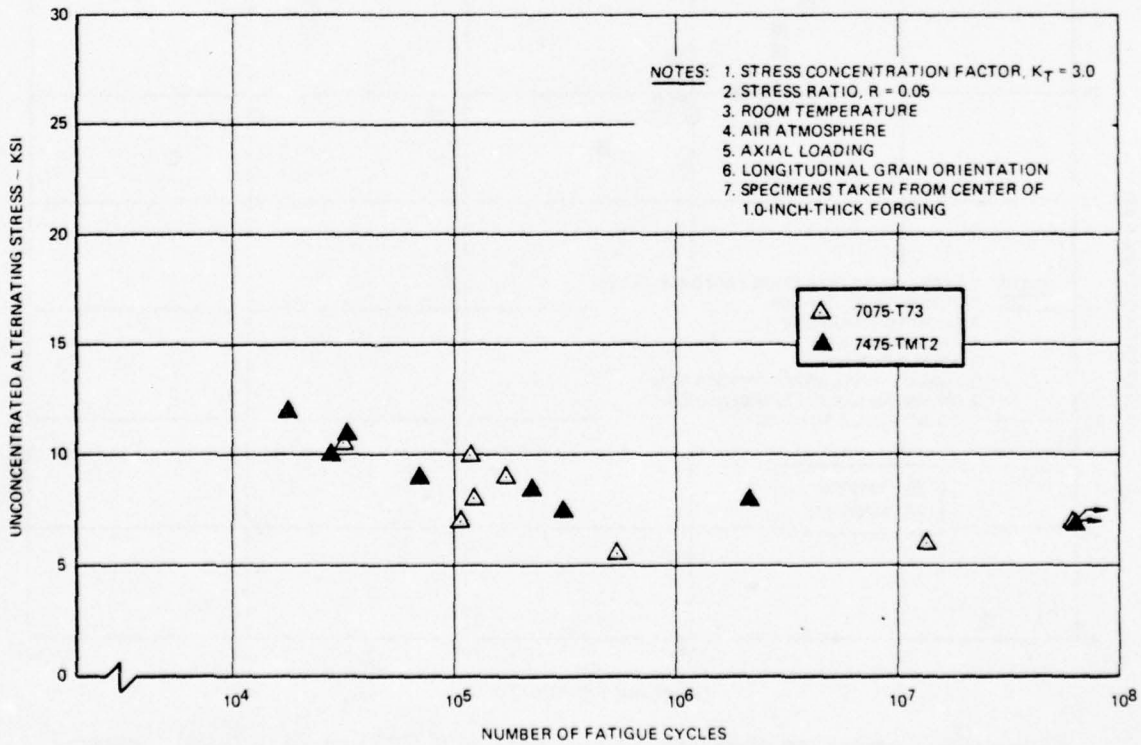



Figure 100. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 2 and 18.

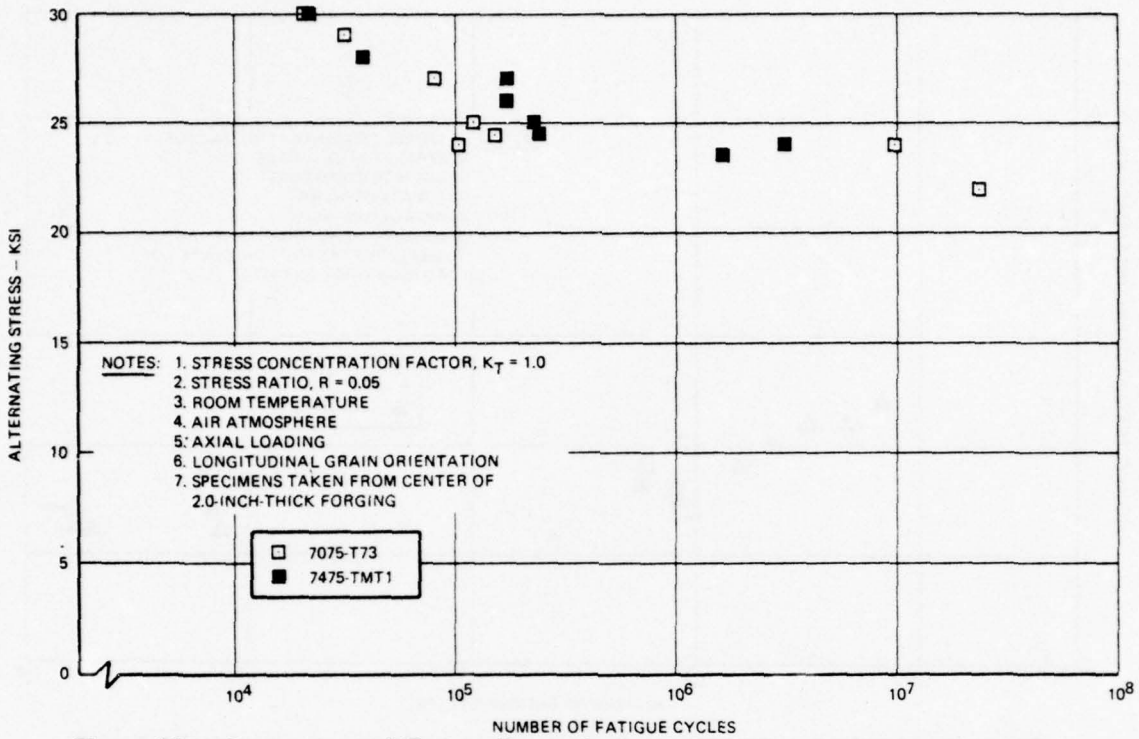



Figure 101. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, *Groups 3 and 10.*

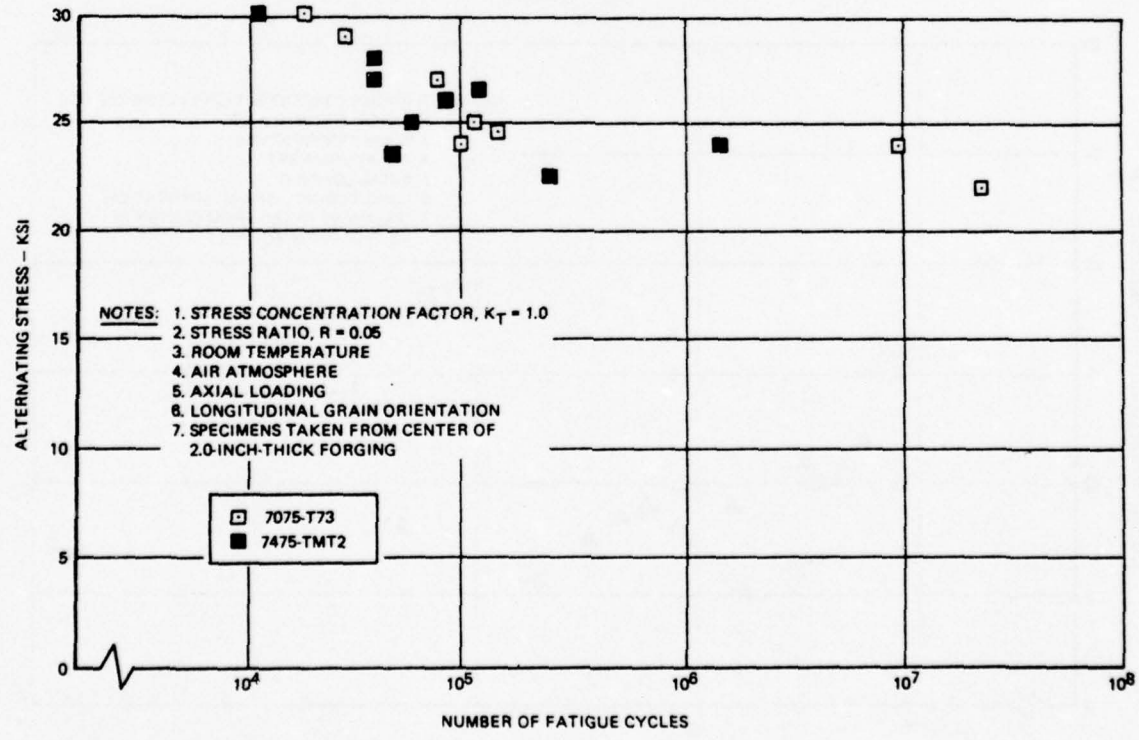



Figure 102. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 3 and 20.

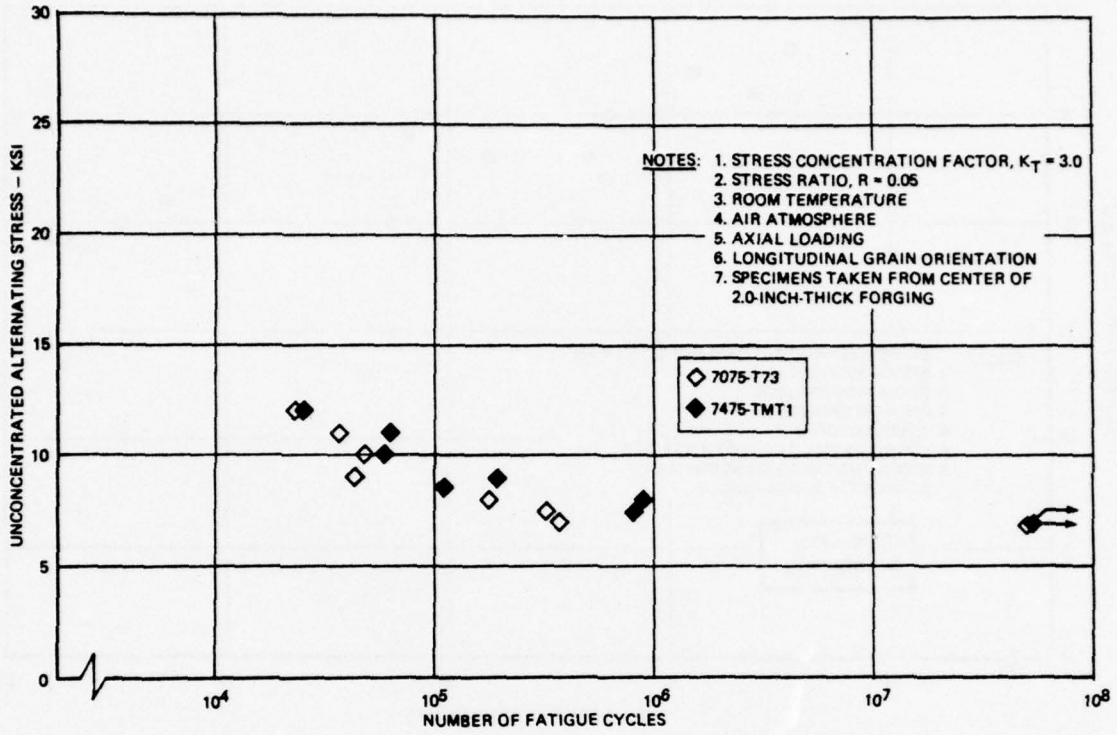



Figure 103. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 4 and 13.

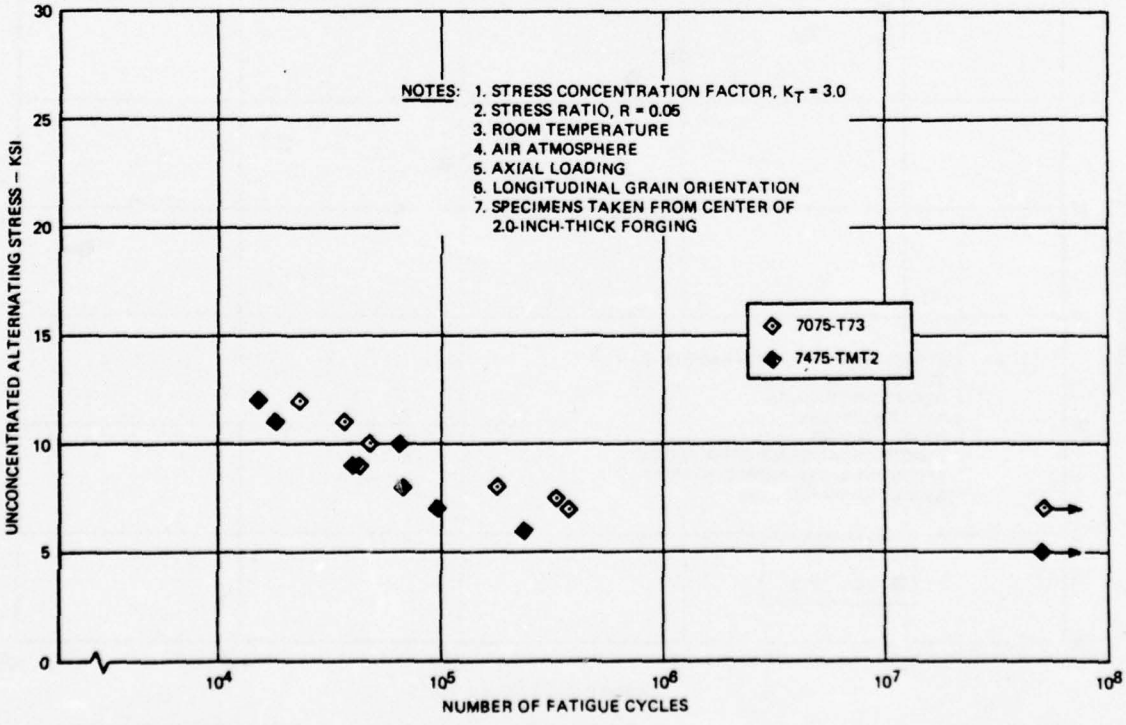



Figure 104. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 4 and 23.

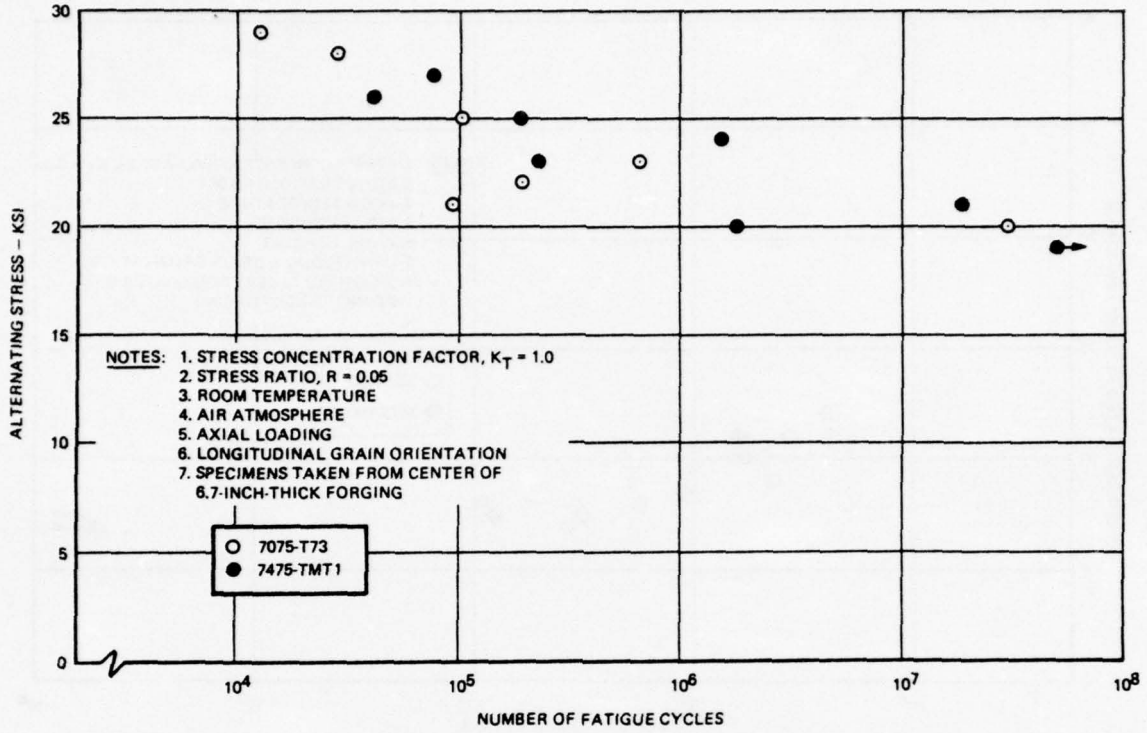



Figure 105. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 5 and 15.

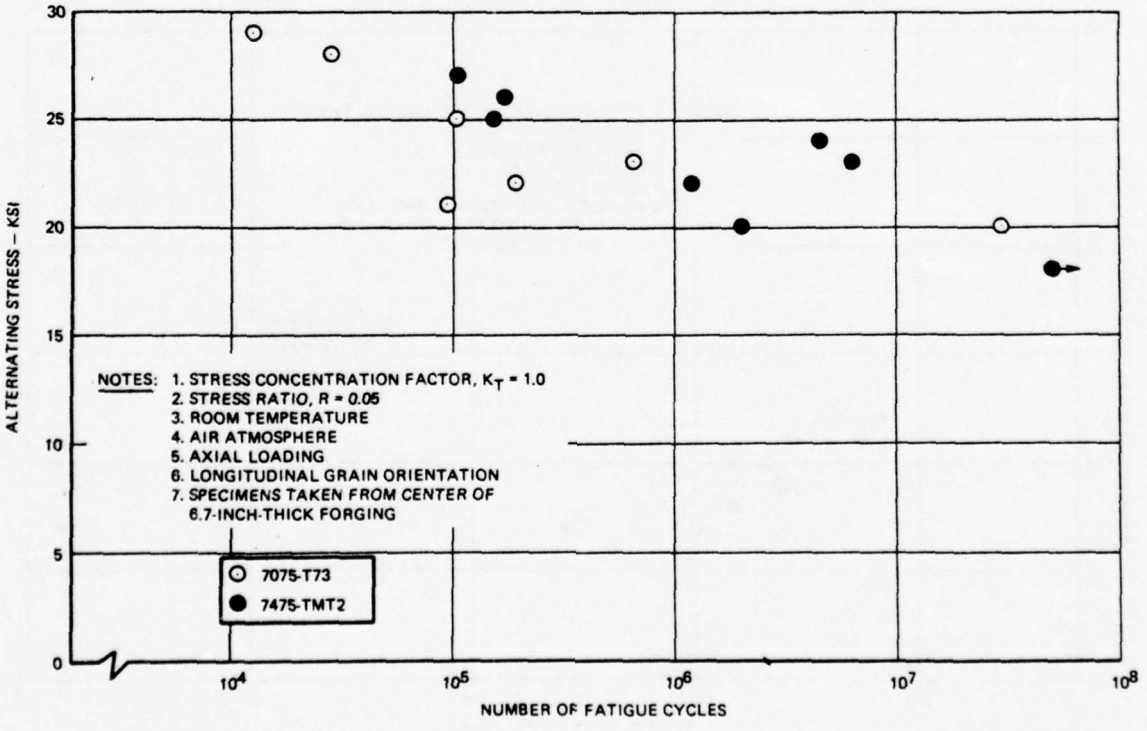



Figure 106. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 5 and 25.

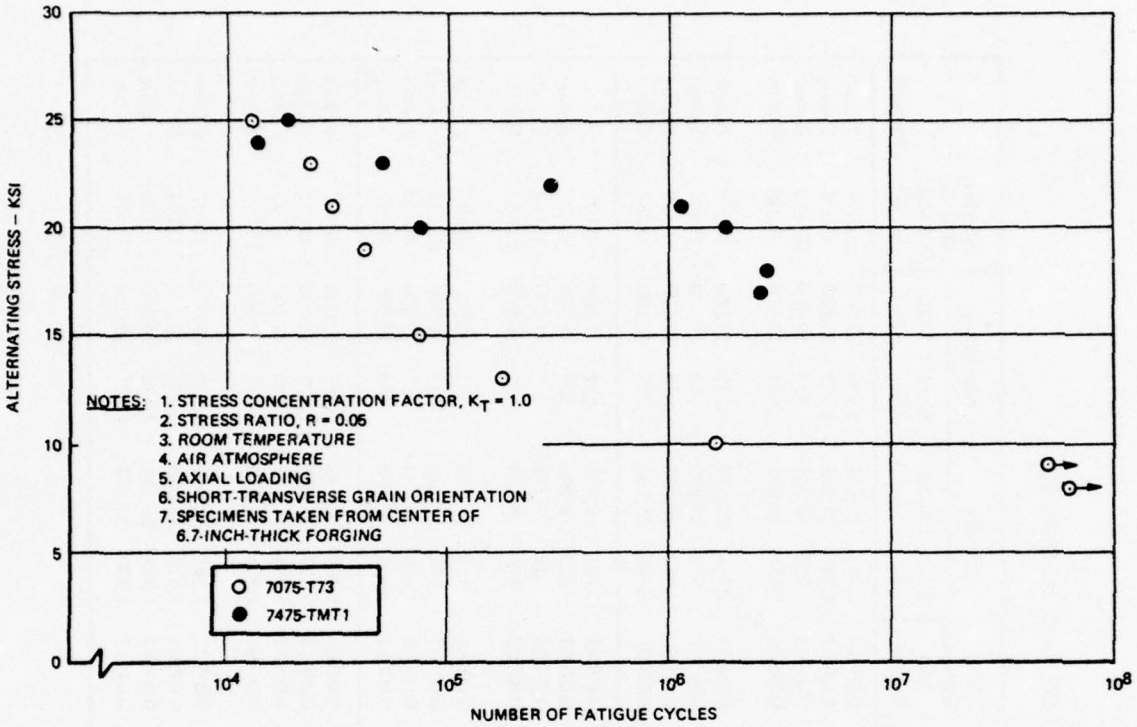



Figure 107. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 6 and 16.

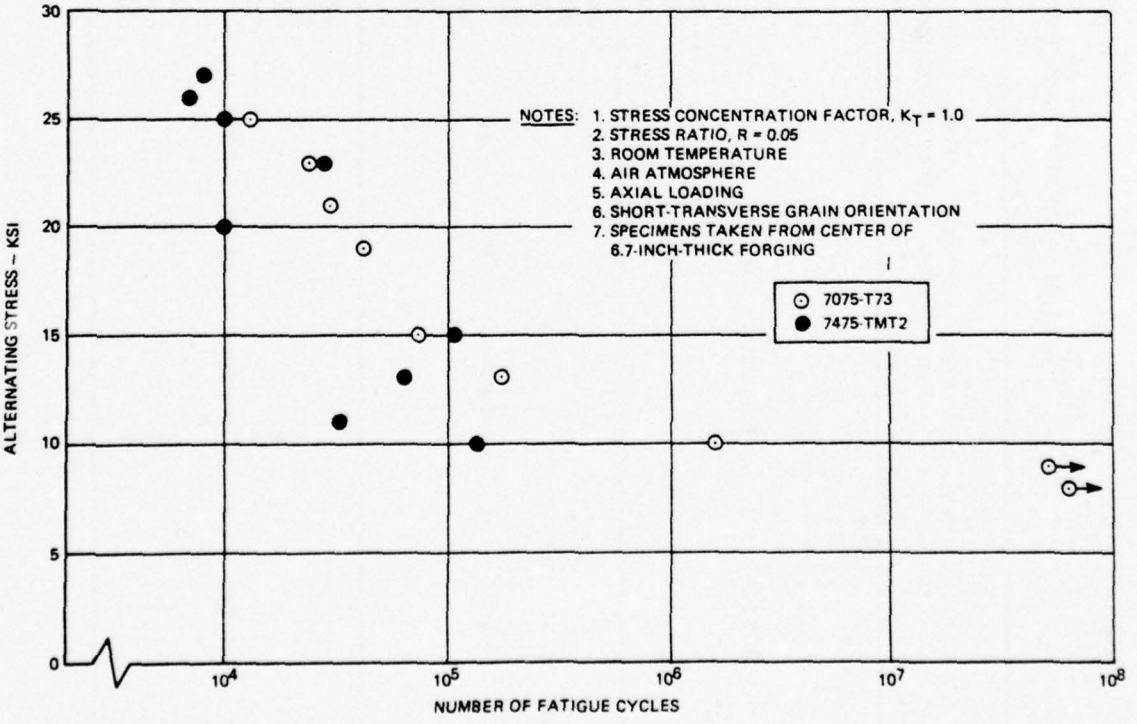



Figure 108. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 6 and 26.

TABLE 24. AXIAL-FATIGUE-TEST RESULTS FOR TASK II FORGINGS

| Group Number | Material | Forging Thickness (in.) | Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor | Specimen Number | Hz | Cross-Sectional Area (sq in.) | Steady | | Alternating | | Number of Cycles to Failure, X $10^6$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Load (lb) | Stress (psi) | Load (lb) | Stress (psi) | | |
| | | | | | | 0103 | 30 | 0.04913 | 1,249 | 25,415 | 1,130 | 23,000 | 0.069 | Failure |
| | | | | | | 0105 | 30 | 0.04917 | 1,141 | 23,205 | 1,032 | 21,000 | 0.079 | Failure |
| | | | | | | 0107 | 30 | 0.04913 | 922 | 18,785 | 835 | 17,000 | 41.410 | Failure |
| | | | | | | 0109 | 70 | 0.04921 | 1,033 | 20,995 | 935 | 19,000 | 0.108 | Failure |
| 1 | 7075-T73 | 1 | Longitudinal | 0.05 | 1.0 | | | | | | | | | |
| | | | | | | 0112 | 70 | 0.04917 | 1,359 | 27,630 | 1,229 | 25,000 | 0.072 | Failure |
| | | | | | | 0114 | 70 | 0.04917 | 978 | 19,890 | 885 | 18,000 | 0.484 | Failure |
| | | | | | | 0116 | 70 | 0.04909 | 949 | 19,340 | 859 | 17,500 | 31.520 | Failure |
| | | | | | | 0118 | 30 | 0.04901 | 1,408 | 28,730 | 1,274 | 26,000 | 0.061 | Failure |
| | | | | | | 0104 | 70 | 0.07045 | 701 | 9,945 | 634 | 9,000 | 0.171 | Failure |
| | | | | | | 0106 | 30 | 0.07097 | 627 | 8,840 | 568 | 8,000 | 0.123 | Failure |
| | | | | | | 0108 | 30 | 0.07036 | 544 | 7,735 | 492 | 7,000 | 0.108 | Failure |
| | | | | | | 0110 | 30 | 0.07092 | 470 | 6,630 | 426 | 6,000 | 13.642 | Failure |
| 2 | 7075-T73 | 1 | Longitudinal | 0.05 | 3.0 | | | | | | | | | |
| | | | | | | 0113 | 30 | 0.07059 | 780 | 11,050 | 706 | 10,000 | 0.120 | Failure |
| | | | | | | 0115 | 30 | 0.07097 | 549 | 7,735 | 497 | 7,000 | 62.132 | Runout |
| | | | | | | 0117 | 30 | 0.07078 | 430 | 6,080 | 389 | 5,500 | 0.440 | Failure |
| | | | | | | 0119 | 30 | 0.07087 | 862 | 12,160 | 780 | 11,000 | 0.032 | Failure |
| | | | | | | 0203 | 30 | 0.04909 | 1,465 | 29,835 | 1,325 | 27,000 | 0.082 | Failure |
| | | | | | | 0205 | 30 | 0.04913 | 1,357 | 27,632 | 1,228 | 25,000 | 0.122 | Failure |
| | | | | | | 0207 | 70 | 0.04917 | 1,304 | 26,520 | 1,180 | 24,000 | 9.995 | Failure |
| | | | | | | 0209 | 30 | 0.04901 | 1,191 | 24,310 | 1,078 | 22,000 | 23.812 | Failure |
| 3 | 7075-T73 | 2 | Longitudinal | 0.05 | 1.0 | | | | | | | | | |
| | | | | | | 0212 | 30 | 0.04932 | 1,581 | 32,045 | 1,430 | 29,000 | 0.032 | Failure |
| | | | | | | 0214 | 30 | 0.04905 | 1,328 | 27,070 | 1,202 | 24,500 | 0.154 | Failure |
| | | | | | | 0216 | 30 | 0.04917 | 1,304 | 26,520 | 1,180 | 24,000 | 0.106 | Failure |
| | | | | | | 0218 | 30 | 0.04917 | 1,630 | 33,150 | 1,475 | 30,000 | 0.021 | Failure |

TABLE 24 – Continued

| Group Number | Material | Forging Thickness (in.) | Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor | Specimen Number | Hz | Cross-Sectional Area (sq in.) | Steady | | Alternating | | Number of Cycles to Failure, X $10^6$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Load (lb) | Stress (psi) | Load (lb) | Stress (psi) | | |
| 4 | 7075-T73 | 2 | Longitudinal | 0.05 | 3.0 | 0204 | 30 | 0.07111 | 786 | 11,050 | 711 | 10,000 | 0.048 | Failure |
| | | | | | | 0206 | 30 | 0.07111 | 707 | 9,945 | 640 | 9,000 | 0.043 | Failure |
| | | | | | | 0208 | 30 | 0.07078 | 626 | 8,840 | 566 | 8,000 | 0.179 | Failure |
| | | | | | | 0210 | 70 | 0.07083 | 548 | 7,740 | 496 | 7,000 | 51.901 | Runout |
| | | | | | | 0213 | 30 | 0.07078 | 861 | 12,160 | 779 | 11,000 | 0.037 | Failure |
| | | | | | | 0215 | 30 | 0.07106 | 589 | 8,290 | 533 | 7,500 | 0.333 | Failure |
| | | | | | | 0217 | 30 | 0.07102 | 942 | 13,260 | 852 | 12,000 | 0.023 | Failure |
| | | | | | | 0219 | 30 | 0.07083 | 548 | 7,740 | 496 | 7,000 | 0.375 | Failure |
| 5 | 7075-T73 | 6.7 | Longitudinal | 0.05 | 1.0 | 0602 | 30 | 0.04885 | 1,080 | 22,105 | 977 | 20,000 | 30.216 | Failure |
| | | | | | | 0603 | 30 | 0.04909 | 1,519 | 30,940 | 1,375 | 28,000 | – | Invalid |
| | | | | | | 0607 | 30 | 0.04924 | 1,361 | 27,632 | 1,231 | 25,000 | 0.106 | Failure |
| | | | | | | 0608 | 70 | 0.04924 | 1,252 | 25,415 | 1,133 | 23,000 | 0.664 | Failure |
| | | | | | | 0610 | 70 | 0.04936 | 1,200 | 24,310 | 1,086 | 22,000 | 0.196 | Failure |
| | | | | | | 0611 | 30 | 0.04905 | 1,518 | 30,940 | 1,373 | 28,000 | 0.029 | Failure |
| | | | | | | 0612 | 30 | 0.04940 | 1,583 | 32,045 | 1,433 | 29,000 | 0.013 | Failure |
| | | | | | | 0613 | 30 | 0.04901 | 1,140 | 23,210 | 1,031 | 21,000 | 0.096 | Failure |
| 6 | 7075-T73 | 6.7 | Short transverse | 0.05 | 1.0 | 0301 | 30 | 0.04905 | 1,247 | 25,415 | 1,128 | 23,000 | 0.024 | Failure |
| | | | | | | 0302 | 30 | 0.04917 | 1,141 | 23,205 | 1,032 | 21,000 | 0.030 | Failure |
| | | | | | | 0303 | 70 | 0.04897 | 812 | 16,575 | 735 | 15,000 | 0.075 | Failure |
| | | | | | | 0304 | 30 | 0.04921 | 1,033 | 20,995 | 935 | 19,000 | 0.042 | Failure |
| | | | | | | 0305 | 70 | 0.04909 | 542 | 11,050 | 491 | 10,000 | 1.645 | Failure |
| | | | | | | 0306 | 30 | 0.04980 | 715 | 14,365 | 647 | 13,000 | 0.179 | Failure |
| | | | | | | 0307 | 70 | 0.04940 | 437 | 8,840 | 395 | 8,000 | 63.639 | Runout |
| | | | | | | 0308 | 30 | 0.04936 | 491 | 9,945 | 444 | 9,000 | 51.282 | Runout |
| | | | | | | 0309 | 30 | 0.04913 | 1,357 | 27,630 | 1,228 | 25,000 | 0.013 | Failure |

TABLE 24 – Continued

| Group Number | Material | Forging Thickness (in.) | Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor | Specimen Number | Hz | Cross-Sectional Area (sq in.) | Steady | | Alternating | | Number of Cycles to Failure, X $10^6$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Load (lb) | Stress (psi) | Load (lb) | Stress (psi) | | |
| | | | | | | 0703 | 30 | 0.04928 | 1,525 | 30,940 | 1,380 | 28,000 | 0.058 | Failure |
| | | | | | | 0705 | 30 | 0.04925 | 1,469 | 29,840 | 1,330 | 27,000 | 0.124 | Failure |
| | | | | | | 0707 | 30 | 0.04917 | 1,275 | 25,970 | 1,154 | 23,500 | 0.106 | Failure |
| | | | | | | 0709 | 30 | 0.04917 | 1,413 | 28,730 | 1,278 | 26,000 | 0.123 | Failure |
| 7 | 7475-TMT1 | 1 | Longitudinal | 0.05 | 1.0 | | | | | | | | | |
| | | | | | | 0712 | 30 | 0.04917 | 1,304 | 26,520 | 1,180 | 24,000 | 0.612 | Failure |
| | | | | | | 0714 | 30 | 0.04925 | 1,224 | 24,860 | 1,108 | 22,500 | 0.069 | Failure |
| | | | | | | 0716 | 70 | 0.04909 | 1,085 | 22,100 | 982 | 20,000 | 0.246 | Failure |
| | | | | | | 0718 | 70 | 0.04928 | 980 | 19,890 | 887 | 18,000 | 0.532 | Failure |
| | | | | | | 0704 | 30 | 0.07069 | 937 | 13,260 | 848 | 12,000 | 0.015 | Failure |
| | | | | | | 0706 | 30 | 0.07054 | 858 | 12,160 | 776 | 11,000 | 0.022 | Failure |
| | | | | | | 0708 | 30 | 0.07059 | 780 | 11,050 | 706 | 10,000 | 0.046 | Failure |
| | | | | | | 0710 | 30 | 0.07078 | 704 | 9,950 | 637 | 9,000 | 0.066 | Failure |
| 8 | 7475-TMT1 | 1 | Longitudinal | 0.05 | 3.0 | | | | | | | | | |
| | | | | | | 0713 | 70 | 0.07069 | 625 | 8,840 | 565 | 8,000 | 0.179 | Failure |
| | | | | | | 0715 | 30 | 0.07054 | 545 | 7,730 | 494 | 7,000 | 14.651 | Failure |
| | | | | | | 0717 | 30 | 0.07059 | 468 | 6,630 | 424 | 6,000 | 51.577 | Runout |
| | | | | | | 0719 | 30 | 0.07045 | 584 | 8,290 | 528 | 7,500 | 0.120 | Failure |
| | | | | | | 0801 | 30 | 0.04909 | 0 | 0 | 2,455 | 50,000 | 0.015 | Failure |
| | | | | | | 0802 | 30 | 0.04913 | 0 | 0 | 1,965 | 40,000 | 0.072 | Failure |
| | | | | | | 0803 | 30 | 0.04909 | 0 | 0 | 1,718 | 35,000 | 0.184 | Failure |
| | | | | | | 0804 | 30 | 0.04917 | 0 | 0 | 1,475 | 30,000 | 1.117 | Failure |
| 9 | 7475-TMT1 | 2 | Longitudinal | –1 | 1.0 | | | | | | | | | |
| | | | | | | 0805 | 30 | 0.04901 | 0 | 0 | 2,695 | 55,000 | 0.003 | Failure |
| | | | | | | 0806 | 30 | 0.04909 | 0 | 0 | 2,602 | 53,000 | 0.009 | Failure |
| | | | | | | 0807 | 70 | 0.04909 | 0 | 0 | 1,227 | 25,000 | 12.343 | Failure |
| | | | | | | 0808 | 30 | 0.04909 | 0 | 0 | 1,129 | 23,000 | 51.617 | Runout |

TABLE 24 – Continued

| Group Number | Material | Forging Thickness (in.) | Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor | Specimen Number | Hz | Cross-Sectional Area (sq in.) | Steady | | Alternating | | Number of Cycles to Failure, X $10^6$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Load (lb) | Stress (psi) | Load (lb) | Stress (psi) | | |
| | | | | | | 0818 | 30 | 0.04870 | 1,614 | 33,150 | 1,461 | 30,000 | 0.022 | Failure |
| | | | | | | 0819 | 30 | 0.04917 | 1,521 | 30,940 | 1,377 | 28,000 | 0.039 | Failure |
| | | | | | | 0820 | 30 | 0.04909 | 1,410 | 28,730 | 1,276 | 26,000 | 0.172 | Failure |
| | | | | | | 0821 | 30 | 0.04909 | 1,356 | 27,630 | 1,227 | 25,000 | 0.231 | Failure |
| 10 | 7475-TMT1 | 2 | Longitudinal | 0.05 | 1.0 | | | | | | | | | |
| | | | | | | 0822 | 30 | 0.04909 | 1,329 | 27,070 | 1,203 | 24,500 | 0.242 | Failure |
| | | | | | | 0823 | 30 | 0.04909 | 1,302 | 26,520 | 1,178 | 24,000 | 3.117 | Failure |
| | | | | | | 0824 | 30 | 0.04909 | 1,464 | 29,840 | 1,325 | 27,000 | 0.173 | Failure |
| | | | | | | 0825 | 30 | 0.04909 | 1,275 | 25,970 | 1,154 | 23,500 | 1.656 | Failure |
| | | | | | | 0809 | 30 | 0.04909 | 2,945 | 60,000 | 982 | 20,000 | – | Yielded |
| | | | | | | 0810 | 30 | 0.04909 | 2,062 | 42,000 | 687 | 14,000 | 51.745 | Runout |
| | | | | | | 0811 | 30 | 0.04901 | 2,352 | 48,000 | 784 | 16,000 | – | Thread Failure |
| | | | | | | 0812 | 30 | 0.04901 | 2,352 | 48,000 | 784 | 16,000 | 0.151 | Failure |
| 11 | 7475-TMT1 | 2 | Longitudinal | 0.50 | 1.0 | 0813 | 30 | 0.04909 | 2,504 | 51,000 | 835 | 17,000 | – | Thread Failure |
| | | | | | | 0814 | 30 | 0.04909 | 2,504 | 51,000 | 835 | 17,000 | 0.115 | Failure |
| | | | | | | 0815 | 30 | 0.04913 | 2,653 | 54,000 | 884 | 18,000 | – | Yielded |
| | | | | | | 0816 | 70 | 0.04913 | 2,211 | 45,000 | 737 | 15,000 | 0.093 | Failure |
| | | | | | | 0817 | 30 | 0.04909 | 2,135 | 43,500 | 712 | 14,500 | 54.533 | Runout |
| | | | | | | 0845 | 30 | 0.07083 | 0 | 0 | 1,771 | 25,000 | 0.008 | Failure |
| | | | | | | 0846 | 30 | 0.07083 | 0 | 0 | 1,417 | 20,000 | 0.015 | Failure |
| | | | | | | 0847 | 30 | 0.07073 | 0 | 0 | 1,132 | 16,000 | 0.050 | Failure |
| | | | | | | 0848 | 30 | 0.07054 | 0 | 0 | 846 | 12,000 | 2.015 | Failure |
| 12 | 7475-TMT1 | 2 | Longitudinal | –1.0 | 3.0 | | | | | | | | | |
| | | | | | | 0849 | 30 | 0.07054 | 0 | 0 | 988 | 14,000 | 0.068 | Failure |
| | | | | | | 0850 | 30 | 0.07092 | 0 | 0 | 922 | 13,000 | 0.058 | Failure |
| | | | | | | 0851 | 70 | 0.07073 | 0 | 0 | 813 | 11,500 | 0.358 | Failure |
| | | | | | | 0852 | 30 | 0.07102 | 0 | 0 | 710 | 10,000 | 32.536 | Failure |

TABLE 24 – Continued

| Group Number | Material | Forging Thickness (in.) | Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor | Specimen Number | Hz | Cross-Sectional Area (sq in.) | Steady | | Alternating | | Number of Cycles to Failure, X $10^6$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Load (lb) | Stress (psi) | Load) (lb) | Stress (psi) | | |
| | | | | | | 0826 | 30 | 0.07078 | 939 | 13,260 | 849 | 12,000 | 0.025 | Failure |
| | | | | | | 0830 | 30 | 0.07069 | 781 | 11,050 | 707 | 10,000 | 0.059 | Failure |
| | | | | | | 0831 | 30 | 0.07078 | 626 | 8,840 | 566 | 8,000 | 0.910 | Failure |
| | | | | | | 0832 | 30 | 0.07087 | 862 | 12,160 | 780 | 11,000 | 0.063 | Failure |
| 13 | 7475-TMT1 | 2 | Longitudinal | 0.05 | 3.0 | | | | | | | | | |
| | | | | | | 0833 | 30 | 0.07069 | 703 | 9,950 | 636 | 9,000 | 0.192 | Failure |
| | | | | | | 0834 | 30 | 0.07092 | 548 | 7,730 | 496 | 7,000 | 54.099 | Runout |
| | | | | | | 0835 | 30 | 0.07063 | 664 | 9,390 | 601 | 8,500 | 0.111 | Failure |
| | | | | | | 0836 | 30 | 0.07083 | 587 | 8,290 | 531 | 7,500 | 0.818 | Failure |
| | | | | | | 0837 | 30 | 0.07073 | 1,062 | 15,000 | 354 | 5,000 | 54.299 | Runout |
| | | | | | | 0838 | 30 | 0.07069 | 1,272 | 18,000 | 424 | 6,000 | 0.862 | Failure |
| | | | | | | 0839 | 30 | 0.07069 | 1,484 | 21,000 | 495 | 7,000 | 0.101 | Failure |
| | | | | | | 0840 | 30 | 0.07092 | 1,596 | 22,500 | 532 | 7,500 | 0.072 | Failure |
| 14 | 7475-TMT1 | 2 | Longitudinal | 0.50 | 3.0 | | | | | | | | | |
| | | | | | | 0841 | 30 | 0.07059 | 1,377 | 19,500 | 459 | 6,500 | 0.126 | Failure |
| | | | | | | 0842 | 30 | 0.07078 | 1,274 | 18,000 | 425 | 6,000 | 0.291 | Failure |
| | | | | | | 0843 | 30 | 0.07092 | 1,170 | 16,500 | 390 | 5,500 | 54.459 | Runout |
| | | | | | | 0844 | 70 | 0.07054 | 1,270 | 18,000 | 423 | 6,000 | 0.121 | Failure |
| | | | | | | 1202 | 30 | 0.04928 | 1,471 | 29,840 | 1,331 | 27,000 | 0.079 | Failure |
| | | | | | | 1203 | 30 | 0.04917 | 1,413 | 28,730 | 1,278 | 26,000 | 0.042 | Failure |
| | | | | | | 1207 | 30 | 0.04909 | 1,356 | 27,630 | 1,227 | 25,000 | 0.193 | Failure |
| | | | | | | 1208 | 30 | 0.04909 | 1,302 | 26,520 | 1,178 | 24,000 | 1.566 | Failure |
| 15 | 7475-TMT1 | 6.7 | Longitudinal | 0.05 | 1.0 | | | | | | | | | |
| | | | | | | 1210 | 30 | 0.04925 | 1,252 | 25,420 | 1,133 | 23,000 | 0.231 | Failure |
| | | | | | | 1211 | 30 | 0.04913 | 1,140 | 23,210 | 1,032 | 21,000 | 19.008 | Failure |
| | | | | | | 1212 | 70 | 0.04909 | 1,085 | 22,100 | 982 | 20,000 | 1.810 | Failure |
| | | | | | | 1213 | 30 | 0.04928 | 1,035 | 20,995 | 936 | 19,000 | 50.016 | Runout |

TABLE 24 – Continued

| Group Number | Material | Forging Thickness (in.) | Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor | Specimen Number | Hz | Cross-Sectional Area (sq in.) | Steady | | Alternating | | Number of Cycles to Failure, X $10^6$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Load (lb) | Stress (psi) | Load (lb) | Stress (psi) | | |
| | | | | | | 0901 | 30 | 0.04909 | 1,356 | 27,630 | 1,227 | 25,000 | 0.019 | Failure |
| | | | | | | 0902 | 30 | 0.04913 | 1,249 | 25,420 | 1,130 | 23,000 | 0.051 | Failure |
| | | | | | | 0903 | 30 | 0.04909 | 1,139 | 23,210 | 1,031 | 21,000 | 1.172 | Failure |
| | | | Short | | | 0904 | 30 | 0.04909 | 1,302 | 26,520 | 1,178 | 24,000 | 0.014 | Failure |
| 16 | 7475-TMT1 | 6.7 | transverse | 0.05 | 1.0 | 0905 | 30 | 0.04909 | 1,193 | 24,310 | 1,080 | 22,000 | 0.295 | Failure |
| | | | | | | 0906 | 30 | 0.04913 | 1,086 | 22,100 | 983 | 20,000 | 0.075 | Failure |
| | | | | | | 0907 | 30 | 0.04913 | 977 | 19,890 | 884 | 18,000 | 2.821 | Failure |
| | | | | | | 0908 | 30 | 0.04909 | 1,086 | 22,100 | 983 | 20,000 | 1.819 | Failure |
| | | | | | | 0909 | 30 | 0.04909 | 922 | 18,790 | 835 | 17,000 | 2.621 | Failure |
| | | | | | | 1303 | 30 | 0.04909 | 1,356 | 27,630 | 1,227 | 25,000 | 0.583 | Failure |
| | | | | | | 1305 | 30 | 0.04909 | 1,248 | 25,420 | 1,129 | 23,000 | 2.858 | Failure |
| | | | | | | 1307 | 30 | 0.04909 | 1,085 | 22,100 | 982 | 20,000 | 28.791 | Failure |
| | | | | | | 1309 | 70 | 0.04909 | 1,031 | 20,995 | 933 | 19,000 | 64.700 | Runout |
| 17 | 7475-TMT2 | 1 | Longitudinal | 0.05 | 1.0 | | | | | | | | | |
| | | | | | | 1312 | 30 | 0.04909 | 1,410 | 28,730 | 1,276 | 26,000 | 0.110 | Failure |
| | | | | | | 1314 | 30 | 0.04909 | 1,302 | 26,520 | 1,178 | 24,000 | 0.448 | Failure |
| | | | | | | 1316 | 30 | 0.04909 | 1,464 | 29,840 | 1,325 | 27,000 | 0.100 | Failure |
| | | | | | | 1318 | 30 | 0.04909 | 1,519 | 30,940 | 1,375 | 28,000 | 0.053 | Failure |
| | | | | | | 1304 | 30 | 0.07069 | 703 | 9,950 | 636 | 9,000 | 0.070 | Failure |
| | | | | | | 1306 | 30 | 0.07069 | 860 | 12,160 | 778 | 11,000 | 0.033 | Failure |
| | | | | | | 1308 | 30 | 0.07054 | 779 | 11,050 | 705 | 10,000 | 0.028 | Failure |
| | | | | | | 1310 | 30 | 0.07069 | 625 | 8,840 | 565 | 8,000 | 2.183 | Failure |
| 18 | 7475-TMT2 | 1 | Longitudinal | 0.05 | 3.0 | | | | | | | | | |
| | | | | | | 1313 | 30 | 0.07045 | 934 | 13,260 | 845 | 12,000 | 0.018 | Failure |
| | | | | | | 1315 | 70 | 0.07069 | 546 | 7,730 | 495 | 7,000 | 62.339 | Runout |
| | | | | | | 1317 | 30 | 0.07045 | 662 | 9,390 | 599 | 8,500 | 0.226 | Failure |
| | | | | | | 1319 | 30 | 0.07069 | 586 | 8,290 | 530 | 7,500 | 0.310 | Failure |

TABLE 24 – Continued

| Group Number | Material | Forging Thickness (in.) | Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor | Specimen Number | Hz | Cross-Sectional Area (sq in.) | Steady | | Alternating | | Number of Cycles to Failure, X $10^6$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Load (lb) | Stress (psi) | Load (lb) | Stress (psi) | | |
| | | | | | | 1401 | 30 | 0.04913 | 0 | 0 | 2,456 | 50,000 | 0.014 | Failure |
| | | | | | | 1402 | 30 | 0.04909 | 0 | 0 | 1,964 | 40,000 | 0.066 | Failure |
| | | | | | | 1403 | 30 | 0.04913 | 0 | 0 | 1,719 | 35,000 | 0.176 | Failure |
| | | | | | | 1404 | 30 | 0.04913 | 0 | 0 | 1,474 | 30,000 | 1.359 | Failure |
| 19 | 7475-TMT2 | 2 | Longitudinal | −1.0 | 1.0 | | | | | | | | | |
| | | | | | | 1405 | 30 | 0.04909 | 0 | 0 | 2,209 | 45,000 | 0.023 | Failure |
| | | | | | | 1406 | 30 | 0.04909 | 0 | 0 | 1,227 | 25,000 | 0.422 | Failure |
| | | | | | | 1407 | 70 | 0.04913 | 0 | 0 | 1,032 | 21,000 | 1.116 | Failure |
| | | | | | | 1408 | 30 | 0.04913 | 0 | 0 | 884 | 18,000 | 50.355 | Runout |
| | | | | | | 1417 | 30 | 0.04913 | 1,629 | 33,150 | 1,474 | 30,000 | 0.013 | Failure |
| | | | | | | 1418 | 30 | 0.04909 | 1,519 | 30,940 | 1,375 | 28,000 | 0.043 | Failure |
| | | | | | | 1419 | 30 | 0.04909 | 1,464 | 29,840 | 1,325 | 27,000 | 0.043 | Failure |
| | | | | | | 1420 | 30 | 0.04909 | 1,410 | 28,730 | 1,276 | 26,000 | 0.899 | Failure |
| 20 | 7475-TMT2 | 2 | Longitudinal | 0.05 | 1.0 | 1421 | 30 | 0.04909 | 1,356 | 27,630 | 1,227 | 25,000 | 0.063 | Failure |
| | | | | | | 1422 | 30 | 0.04909 | 1,437 | 29,280 | 1,301 | 26,500 | 0.128 | Failure |
| | | | | | | 1423 | 70 | 0.04909 | 1,275 | 25,970 | 1,154 | 23,500 | 0.052 | Failure |
| | | | | | | 1424 | 30 | 0.04909 | 1,302 | 26,520 | 1,178 | 24,000 | 1.560 | Failure |
| | | | | | | 1425 | 70 | 0.04909 | 1,224 | 24,860 | 1,108 | 22,500 | 0.265 | Failure |
| | | | | | | 1409 | 30 | 0.04913 | 2,542 | 51,750 | 847 | 17,250 | 0.075 | Failure |
| | | | | | | 1410 | 30 | 0.04909 | 2,284 | 46,500 | 761 | 15,500 | 27.257 | Failure |
| | | | | | | 1411 | 30 | 0.04897 | 2,350 | 48,000 | 784 | 16,000 | 0.111 | Failure |
| | | | | | | 1412 | 30 | 0.04909 | 2,430 | 49,500 | 810 | 16,500 | 0.058 | Failure |
| 21 | 7475-TMT2 | 2 | Longitudinal | 0.50 | 1.0 | | | | | | | | | |
| | | | | | | 1413 | 30 | 0.04909 | 2,209 | 45,000 | 736 | 15,000 | 31.422 | Failure |
| | | | | | | 1414 | 30 | 0.04913 | 2,137 | 43,500 | 712 | 14,500 | 54.697 | Runout |
| | | | | | | 1415 | 30 | 0.04913 | 2,469 | 50,250 | 823 | 16,750 | 0.124 | Failure |
| | | | | | | 1416 | 30 | 0.04917 | 2,507 | 51,000 | 836 | 17,000 | 0.080 | Failure |

TABLE 24 – Continued

| Group Number | Material | Forging Thickness (in.) | Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor | Specimen Number | Hz | Cross-Sectional Area (sq in.) | Steady | | Alternating | | Number of Cycles to Failure, X $10^6$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Load (lb) | Stress (psi) | Load (lb) | Stress (psi) | | |
| | | | | | | 1445 | 30 | 0.07073 | 0 | 0 | 1,415 | 20,000 | 0.012 | Failure |
| | | | | | | 1446 | 30 | 0.07073 | 0 | 0 | 1,132 | 16,000 | 0.034 | Failure |
| | | | | | | 1447 | 30 | 0.07078 | 0 | 0 | 991 | 14,000 | 0.033 | Failure |
| | | | | | | 1448 | 30 | 0.07087 | 0 | 0 | 850 | 12,000 | 0.052 | Failure |
| 22 | 7475-TMT2 | 2 | Longitudinal | −1.0 | 3.0 | | | | | | | | | |
| | | | | | | 1449 | 30 | 0.07083 | 0 | 0 | 708 | 10,000 | 0.083 | Failure |
| | | | | | | 1450 | 30 | 0.07069 | 0 | 0 | 565 | 8,000 | 51.235 | Runout |
| | | | | | | 1451 | 30 | 0.07087 | 0 | 0 | 634 | 9,000 | 0.083 | Failure |
| | | | | | | 1452 | 30 | 0.07069 | 0 | 0 | 601 | 8,500 | 0.617 | Failure |
| | | | | | | 1426 | 30 | 0.07069 | 937 | 13,260 | 848 | 12,000 | 0.015 | Failure |
| | | | | | | 1430 | 30 | 0.07078 | 861 | 12,160 | 779 | 11,000 | 0.018 | Failure |
| | | | | | | 1431 | 30 | 0.07078 | 782 | 11,050 | 708 | 10,000 | 0.066 | Failure |
| | | | | | | 1432 | 30 | 0.07078 | 704 | 9,950 | 637 | 9,000 | 0.040 | Failure |
| 23 | 7475-TMT2 | 2 | Longitudinal | 0.05 | 3.0 | | | | | | | | | |
| | | | | | | 1433 | 30 | 0.07069 | 625 | 8,840 | 565 | 8,000 | 0.068 | Failure |
| | | | | | | 1434 | 30 | 0.07087 | 548 | 7,730 | 496 | 7,000 | 0.096 | Failure |
| | | | | | | 1435 | 30 | 0.07069 | 469 | 6,630 | 424 | 6,000 | 0.235 | Failure |
| | | | | | | 1436 | 30 | 0.07069 | 391 | 5,530 | 353 | 5,000 | 50.528 | Runout |
| | | | | | | 1437 | 30 | 0.07069 | 1,272 | 18,000 | 424 | 6,000 | 0.111 | Failure |
| | | | | | | 1438 | 30 | 0.07069 | 1,378 | 19,500 | 459 | 6,500 | 0.071 | Failure |
| | | | | | | 1439 | 70 | 0.07069 | 1,166 | 16,500 | 389 | 5,500 | 0.288 | Failure |
| | | | | | | 1440 | 30 | 0.07069 | 1,062 | 15,000 | 354 | 5,000 | 0.283 | Failure |
| 24 | 7475-TMT2 | 2 | Longitudinal | 0.50 | 3.0 | | | | | | | | | |
| | | | | | | 1441 | 70 | 0.07083 | 956 | 13,500 | 319 | 4,500 | 0.263 | Failure |
| | | | | | | 1442 | 70 | 0.07050 | 846 | 12,000 | 282 | 4,000 | 50.000 | Runout |
| | | | | | | 1443 | 70 | 0.07083 | 956 | 13,500 | 319 | 4,500 | 2.934 | Failure |
| | | | | | | 1444 | 30 | 0.07073 | 1,485 | 21,000 | 495 | 7,000 | 0.058 | Failure |

TABLE 24 – Continued

| Group Number | Material | Forging Thickness (in.) | Specimen Grain Direction | Stress Ratio, R | Stress Concentration Factor | Specimen Number | Hz | Cross-Sectional Area (sq in.) | Steady Load (lb) | Steady Stress (psi) | Alternating Load (lb) | Alternating Stress (psi) | Number of Cycles to Failure, X $10^6$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1802 | 30 | 0.04925 | 1,469 | 29,840 | 1,330 | 27,000 | 0.108 | Failure |
| | | | | | | 1803 | 30 | 0.04917 | 1,413 | 28,730 | 1,278 | 26,000 | 0.174 | Failure |
| | | | | | | 1807 | 30 | 0.04913 | 1,357 | 27,630 | 1,228 | 25,000 | 0.157 | Failure |
| | | | | | | 1808 | 30 | 0.04928 | 1,307 | 26,520 | 1,183 | 24,000 | 4.648 | Failure |
| 25 | 7475-TMT2 | 6.7 | Longitudinal | 0.05 | 1.0 | | | | | | | | | |
| | | | | | | 1810 | 30 | 0.04913 | 1,249 | 25,420 | 1,130 | 23,000 | 6.434 | Failure |
| | | | | | | 1811 | 30 | 0.04917 | 1,195 | 24,310 | 1,082 | 22,000 | 1.215 | Failure |
| | | | | | | 1812 | 30 | 0.04924 | 1,088 | 22,100 | 985 | 20,000 | 2.083 | Failure |
| | | | | | | 1813 | 30 | 0.04925 | 979 | 19,890 | 886 | 18,000 | 50.327 | Runout |
| | | | | | | 1501 | 30 | 0.04909 | 1,464 | 29,840 | 1,325 | 27,000 | 0.008 | Failure |
| | | | | | | 1502 | 30 | 0.04913 | 1,357 | 27,630 | 1,228 | 25,000 | 0.010 | Failure |
| | | | | | | 1503 | 30 | 0.04909 | 1,410 | 28,730 | 1,276 | 26,000 | 0.007 | Failure |
| | | | Short | | | | | | | | | | | |
| | | | | | | 1504 | 30 | 0.04909 | 814 | 16,580 | 736 | 15,000 | 0.109 | Failure |
| 26 | 7475-TMT2 | 6.7 | transverse | 0.05 | 1.0 | 1505 | 30 | 0.04913 | 1,249 | 25,420 | 1,130 | 23,000 | 0.028 | Failure |
| | | | | | | 1506 | 30 | 0.04913 | 1,086 | 22,100 | 983 | 20,000 | 0.010 | Failure |
| | | | | | | 1507 | 30 | 0.04913 | 706 | 14,370 | 639 | 13,000 | 0.065 | Failure |
| | | | | | | 1508 | 30 | 0.04909 | 597 | 12,160 | 540 | 11,000 | 0.033 | Failure |
| | | | | | | 1509 | 30 | 0.04913 | 543 | 11,050 | 492 | 10,000 | 0.139 | Failure |

TABLE 25. FATIGUE PERFORMANCE OF TASK II FORGINGS COMPARED TO 7075-T73 AT 50 x $10^6$ CYCLES

| Stress Ratio, R | Stress Concentration Factor, $K_T$ | Material | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 7475-TMT1 Thickness (in.) | | | | 7475-TMT2 Thickness (in.) | | | |
| | | | | 6.7 | | | | 6.7 | |
| | | 1 | 2 | L | S-T | 1 | 2 | L | S-T |
| −1.0 | 1.0 | – | 1.03[1] | – | – | – | 1.00[1] | – | – |
| | 3.0 | – | 1.43[2] | – | – | – | 1.14[2] | – | – |
| +0.05 | 1.0 | 1.26 | 1.00 | 1.01 | 1.73 | 1.16 | 1.00 | 1.06 | 0.80 |
| | 3.0 | 1.15 | 0.93 | – | – | 1.23 | 0.67 | – | – |
| +0.50 | 1.0 | – | 1.17[3] | – | – | – | 1.20[3] | – | – |
| | 3.0 | – | 1.25[4] | – | – | – | 1.06[4] | – | – |

NOTES: 1. Estimated 7075-T73 mean endurance limit ±23,000 psi
2. Estimated 7075-T73 mean endurance limit ± 7,000 psi
3. Estimated 7075-T73 mean endurance limit ±12,500 psi
4. Estimated 7075-T73 mean endurance limit ±12,500/3 = ±4,170 psi

Source of data on 7075-T73: Mehr, P.L., Spuhler, E.H., and Mayer, L.W., ALCOA ALLOY 7075-T73, Alcoa Green Letter, Revised June 1969 by R. A. Schultz, Aluminum Company of America, Application Engineering Division, Alcoa Center, PA.

TABLE 26. TYPICAL ROCKWELL-HARDNESS VALUES FOR SELECTED FATIGUE SPECIMENS

| Specimen Number | TMT | Original Material Thickness (in.) | Grain Orientation | Rockwell Hardness, $R_B$ |
|---|---|---|---|---|
| 0716 | 1 | 1 | 30° from longitudinal | 85.5 |
| 0906 | 1 | 6.7 | Short transverse | 84.0 |
| 1212 | 1 | 6.7 | Longitudinal | 83.5 |
| 1303 | 2 | 1 | Longitudinal | 84.0 |
| 1437 | 2 | 2 | Longitudinal | 80.0 |
| 1447 | 2 | 2 | Longitudinal | 80.0 |
| 1508 | 2 | 6.7 | Short transverse | 86.0 |
| 1807 | 2 | 6.7 | Longitudinal | 84.5 |

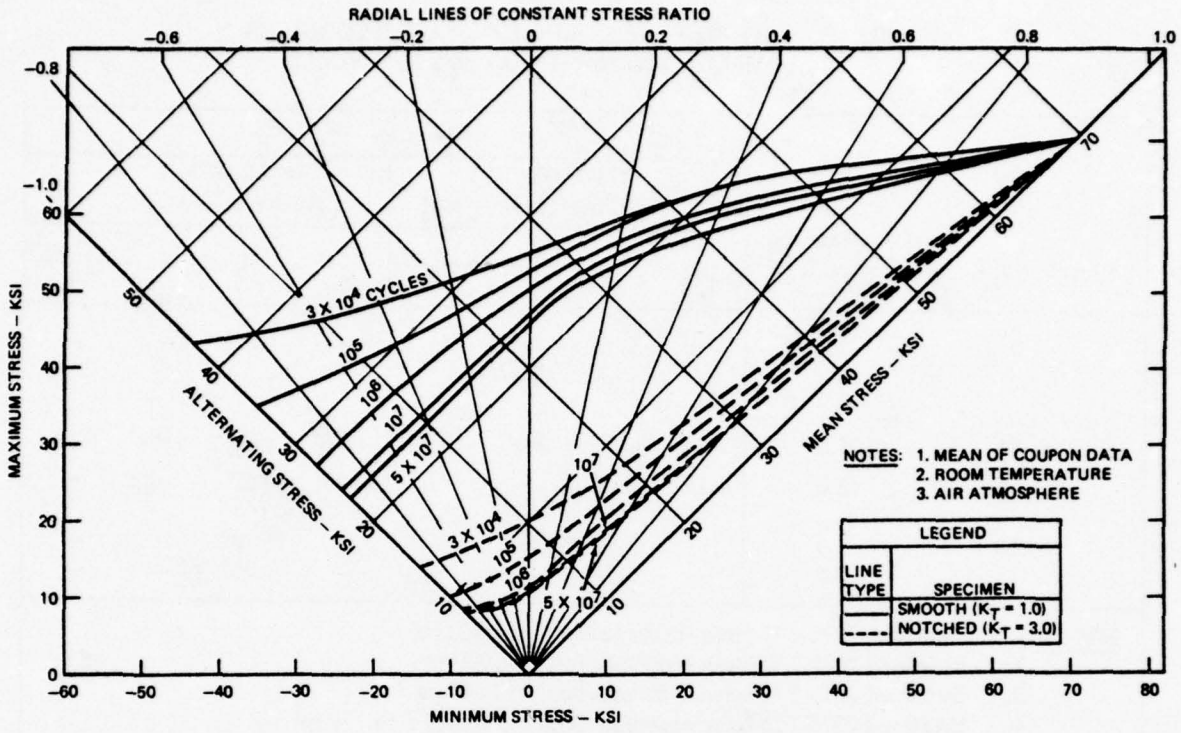



Figure 109. Goodman Diagram for 2-Inch-Thick Forging of 7475-TMT2 Aluminum Alloy.

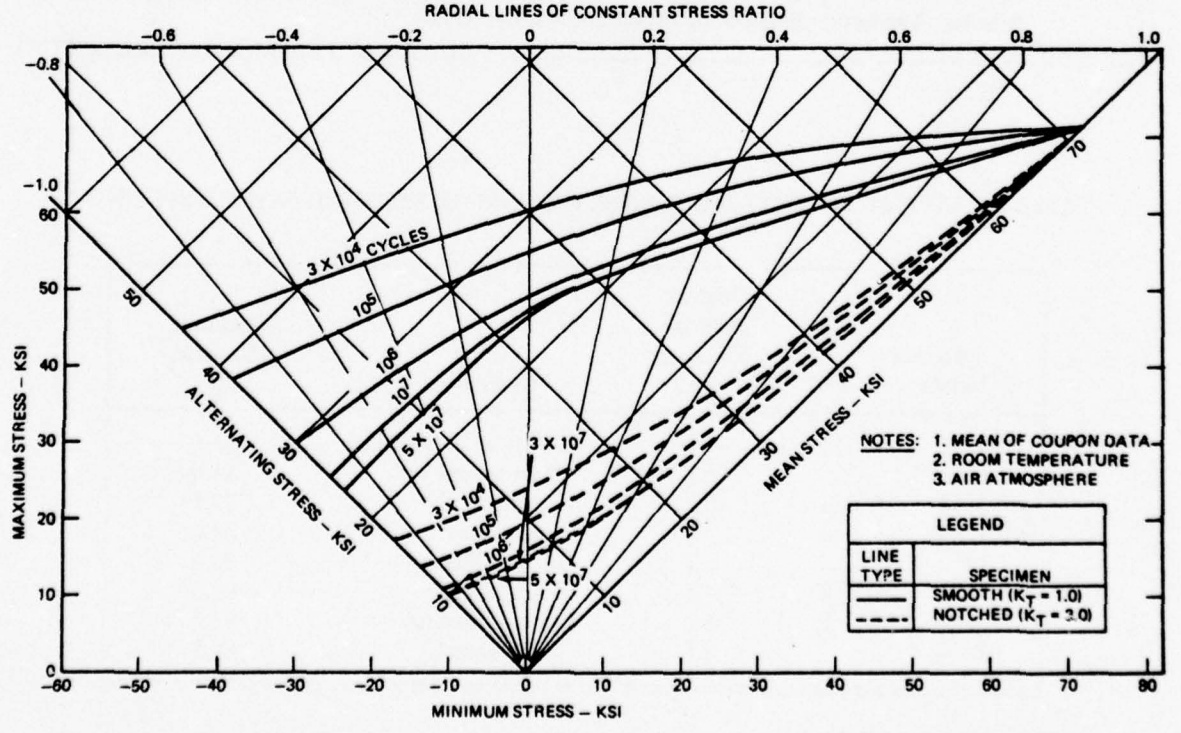



Figure 110. Goodman Diagram for 2-Inch-Thick Forging of 7475-TMT1 Aluminum Alloy.

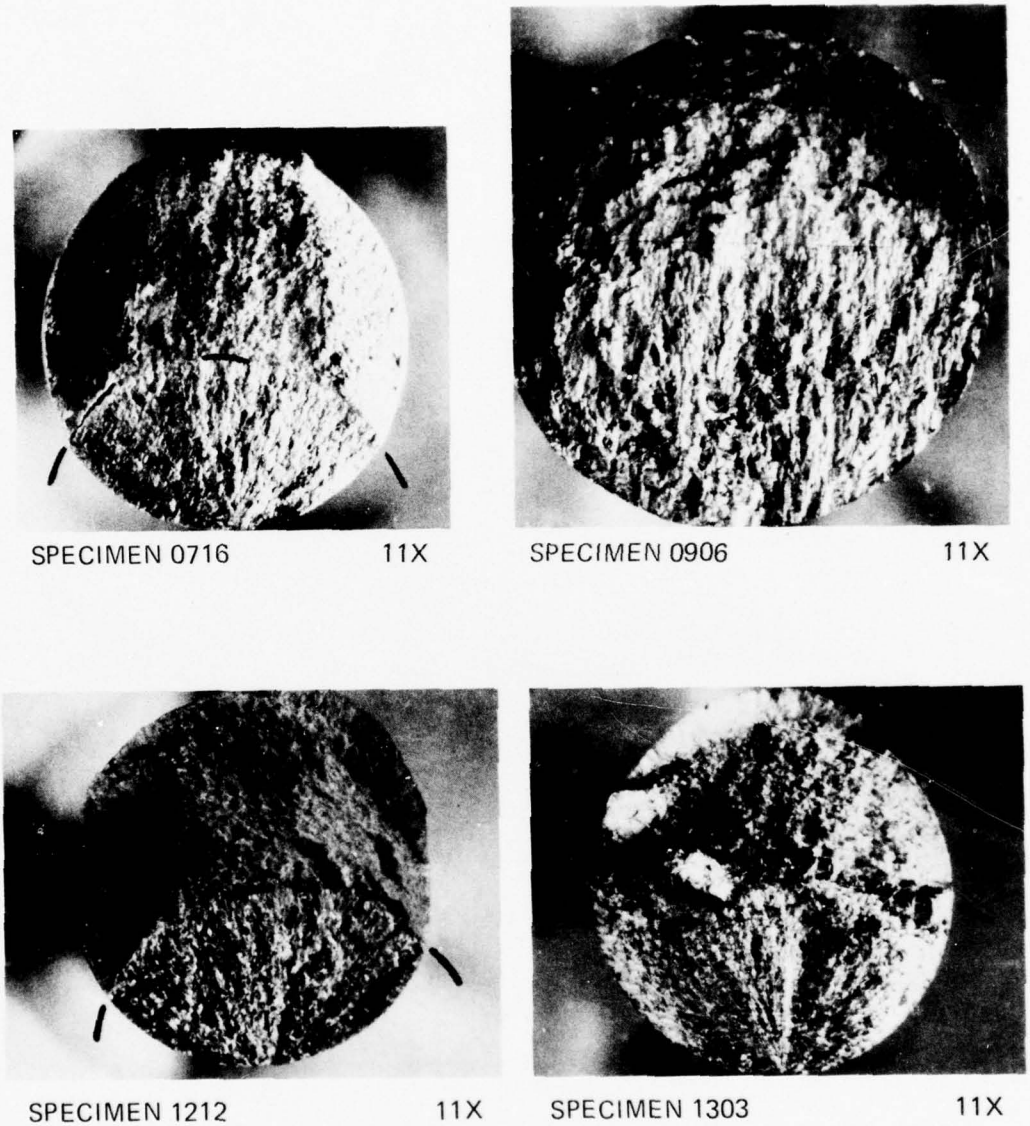
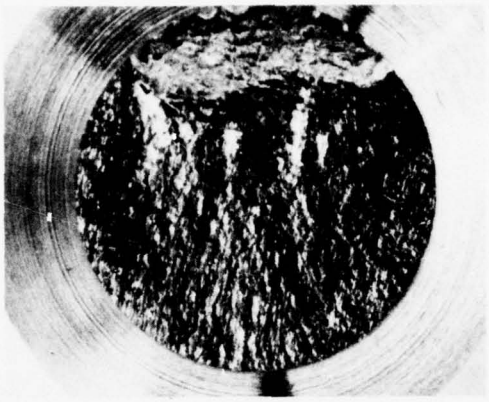


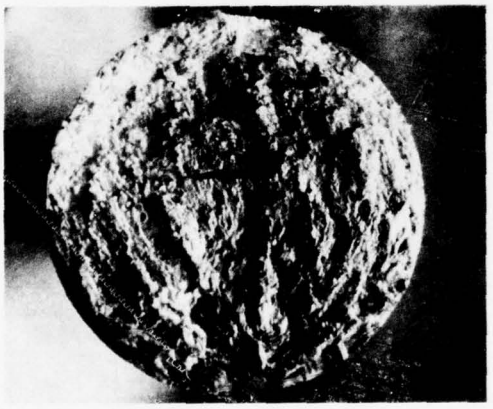

Figure 111. Fatigue-Fracture Surface and Origin of Failure for Specimens 0716, 0906, 1212, and 1303.



SPECIMEN 1437 8.5X



SPECIMEN 1447 8.5X



SPECIMEN 1508 11X



SPECIMEN 1807 11X

Figure 112. Fatigue-Fracture Surface and Origin of Failure for Specimens 1437, 1447, 1508, and 1807.

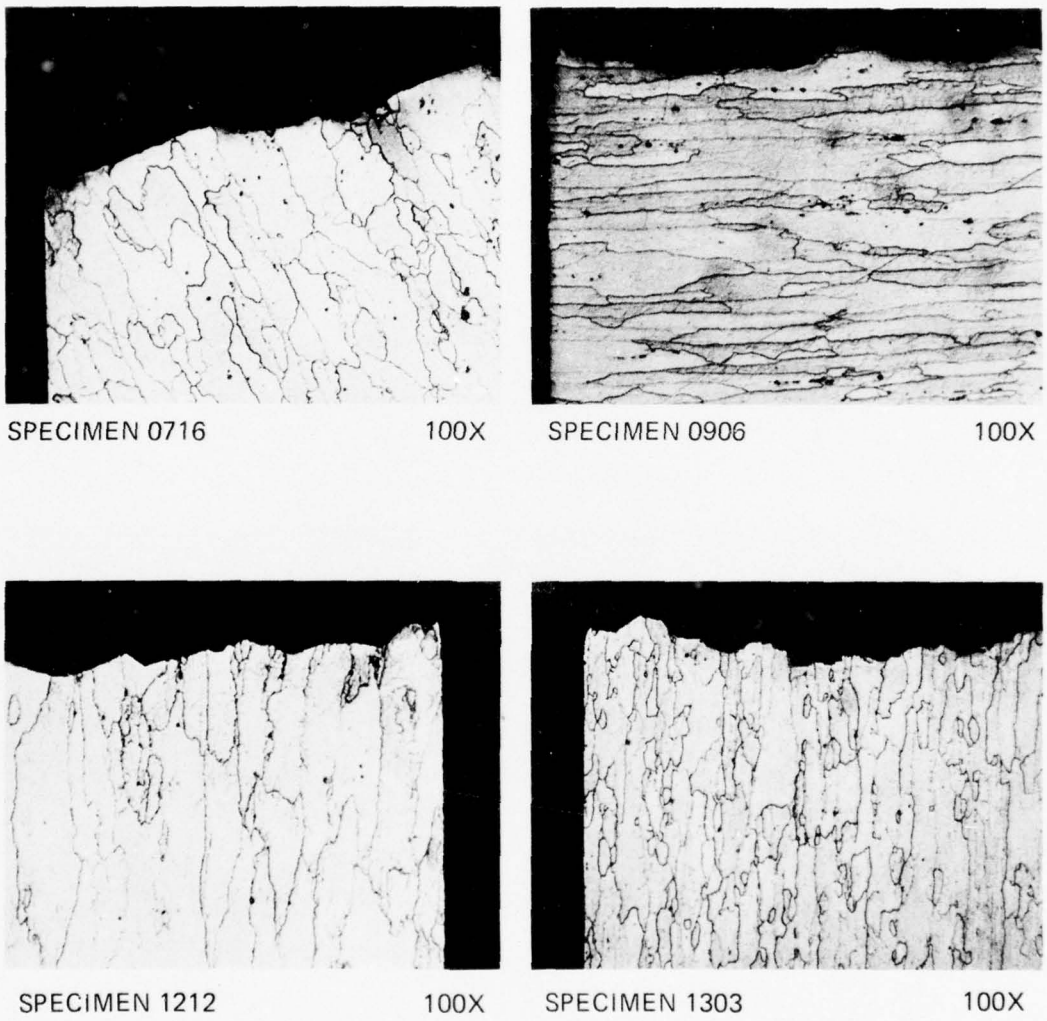
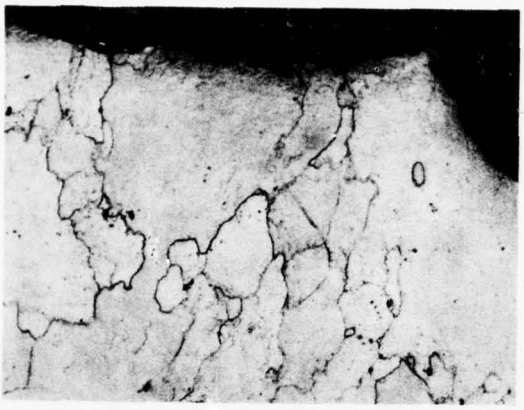
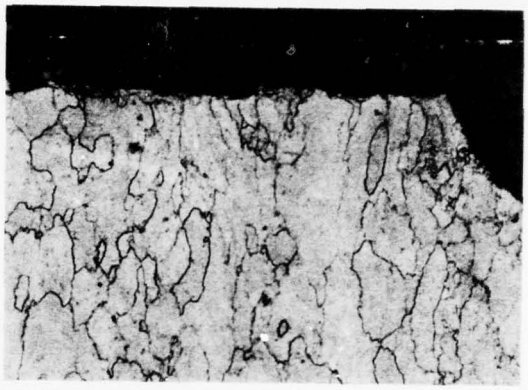


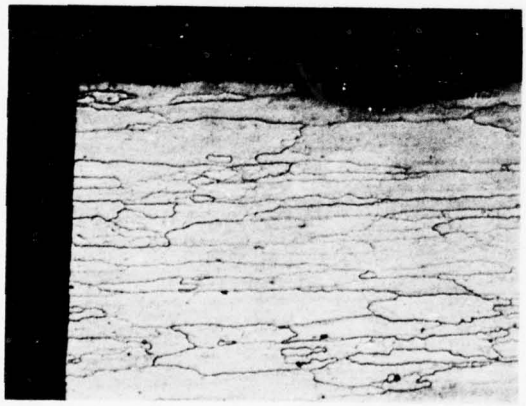

Figure 113. Grain Orientation and Grain Size for Specimens 0716, 0906, 1212, and 1303.



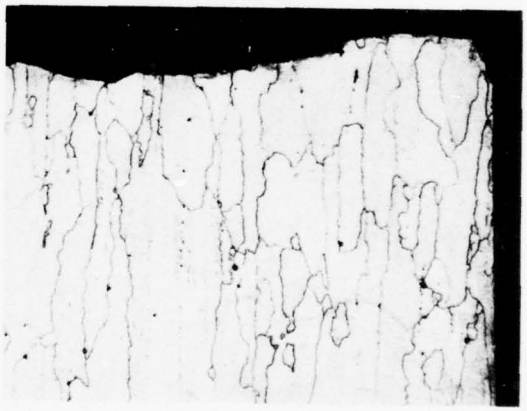
SPECIMEN 1437 100X



SPECIMEN 1447 100X



SPECIMEN 1508 100X



SPECIMEN 1807 100X

Figure 114. Grain Orientation and Grain Size for Specimens 1437, 1447, 1508, and 1807.

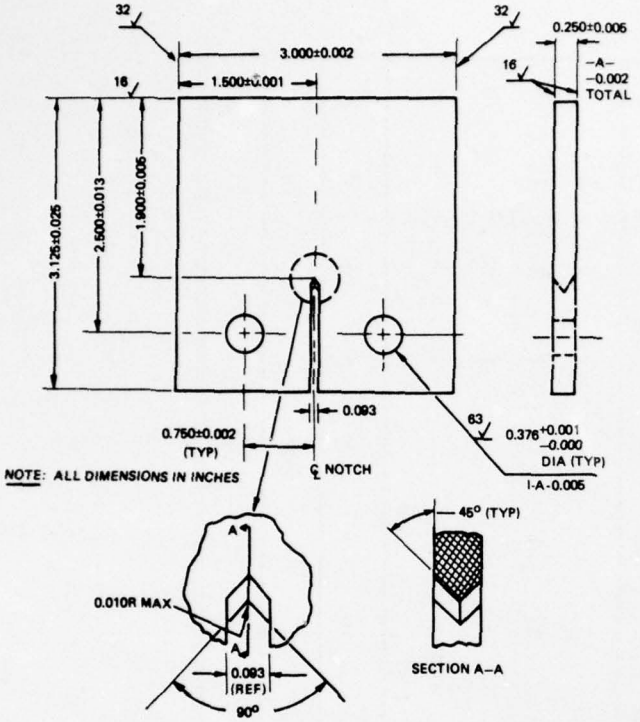



Figure 115. Configuration of Specimen for Fatigue-Crack-Rate Test.

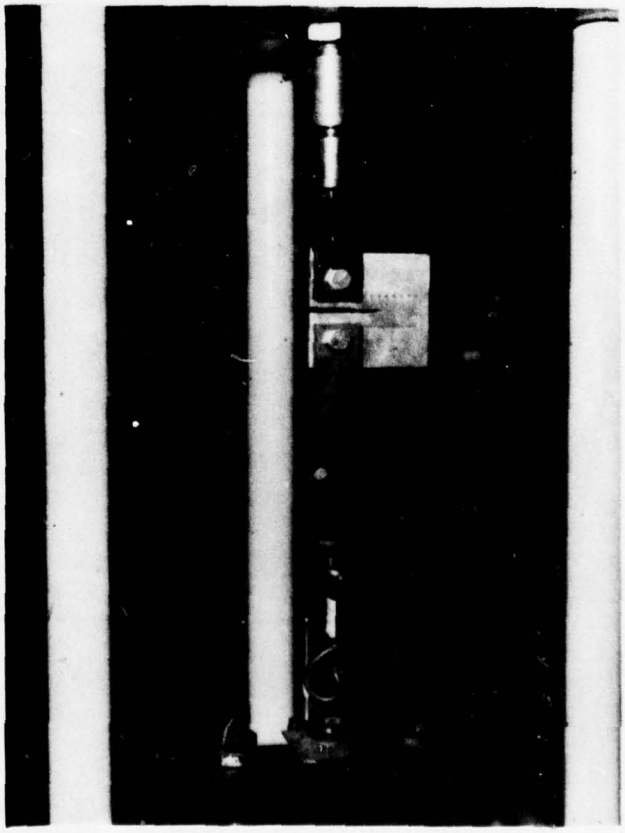


Figure 116. Typical Fatigue-Crack-Propagation Test Setup.

TABLE 27. FATIGUE-CRACK-PROPAGATION-RATE TEST MATRIX

| Test Parameters | | | Number of Specimens | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stress Ratio, R = +0.05 | | | Conventional Process 7075-T73 | | | Advanced Thermal/ Mechanical Treatment 7475-TMT1 | | | Advanced Thermal/ Mechanical Treatment 7475-TMT2 | | |
| Group Number | Specimen Grain Direction | Test Environment | Forging Thickness (in.) | | | Forging Thickness (in.) | | | Forging Thickness (in.) | | |
| | | | 1.0 | 2.0 | 6.7 | 1.0 | 2.0 | 6.7 | 1.0 | 2.0 | 6.7 |
| 1 | Longitudinal | Air, 70°F | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 1 |
| 2 | Longitudinal | 3.5% NaCl, 70°F | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | Short transverse | Air, 70°F | – | – | 1 | – | – | 1 | – | – | 1 |
| 4 | Short transverse | 3.5% NaCl, 70°F | – | – | 1 | – | – | 1 | – | – | 1 |
| | Subtotal | | 3 | 3 | 4 | 3 | 3 | 4 | 3 | 3 | 4 |
| | Subtotal | | 10 | | | 10 | | | 10 | | |
| | Total | | 30 | | | | | | | | |

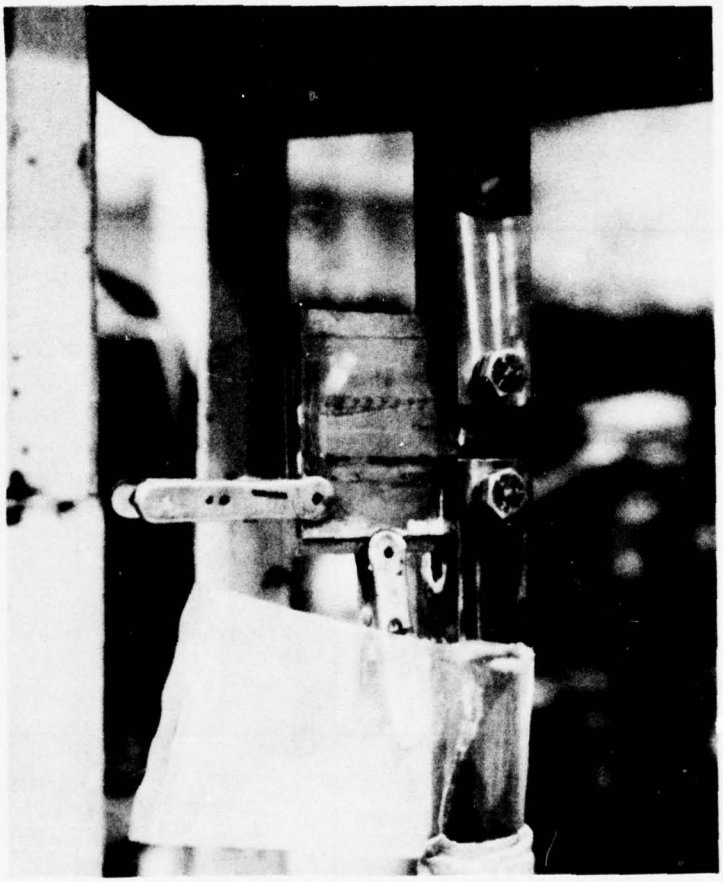


Figure 117. Fatigue-Crack-Propagation Test Setup With Specimen in 3.5-Percent Salt Solution.

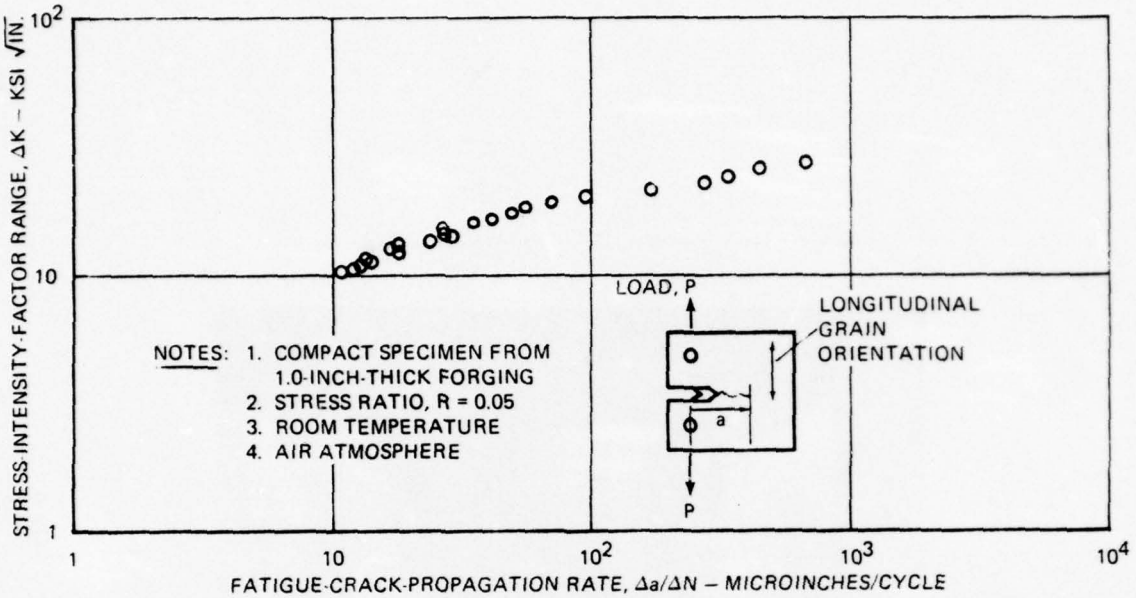



Figure 118. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0120.

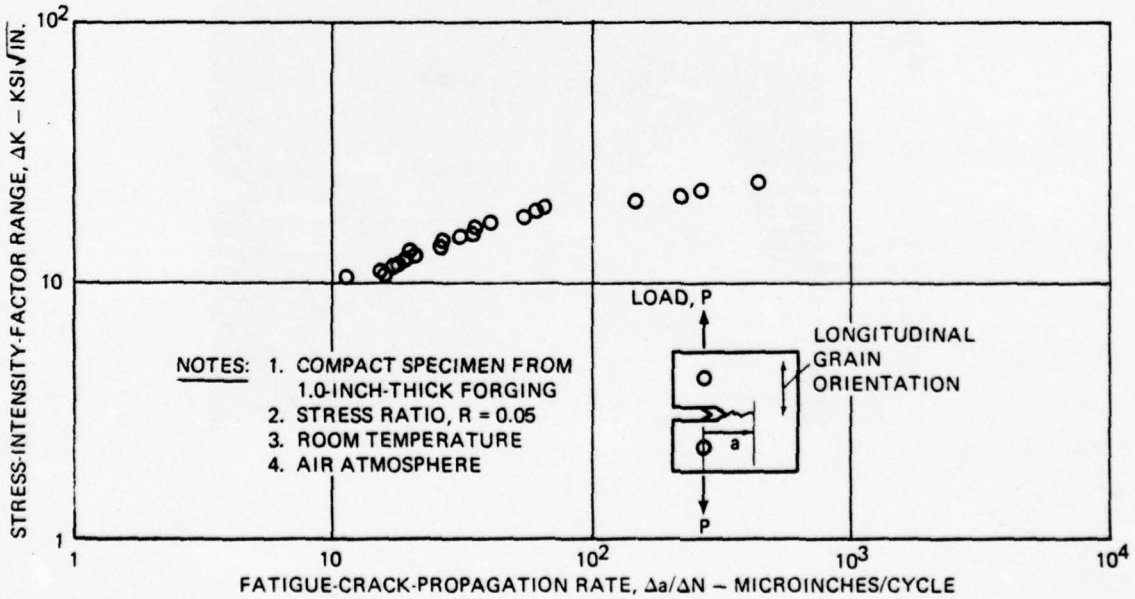



Figure 119. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0121.

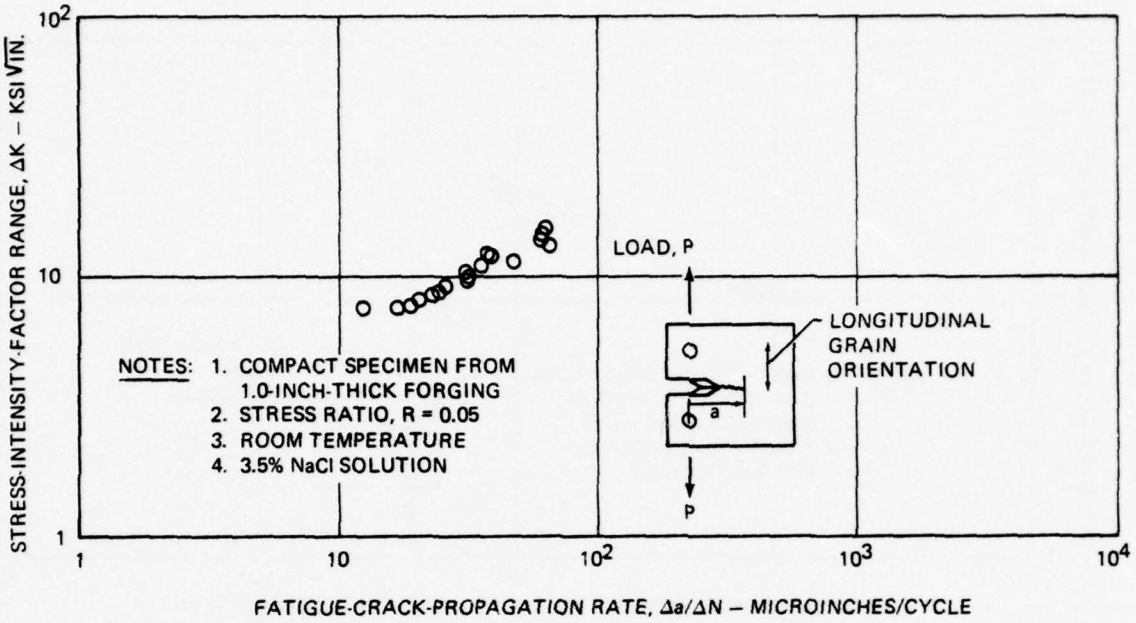



Figure 120. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0122.

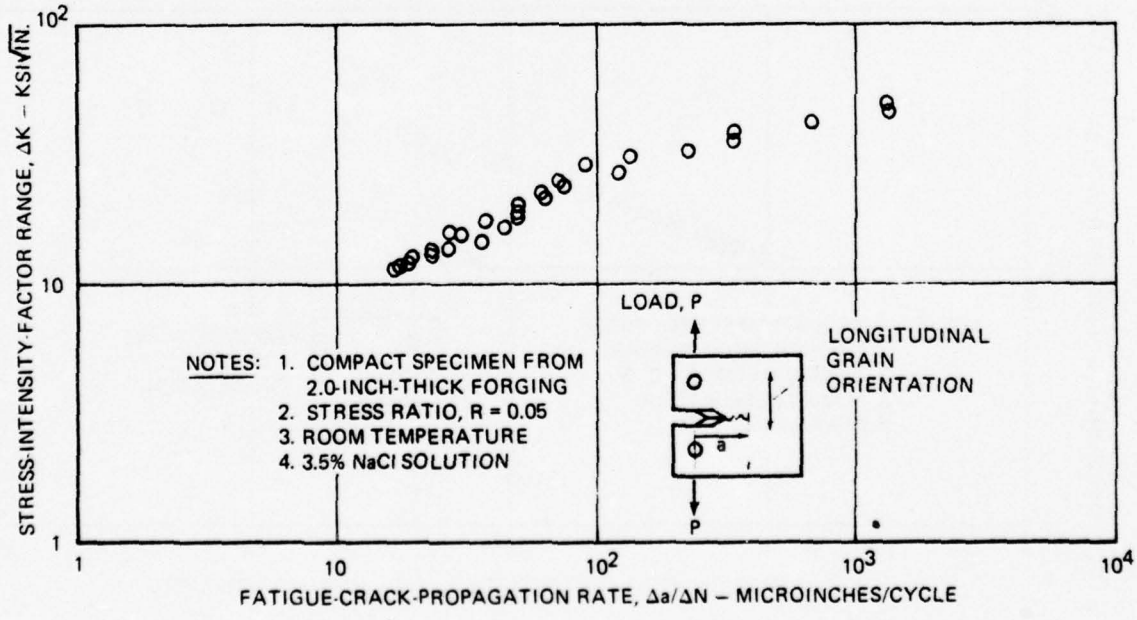



Figure 121. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0220.

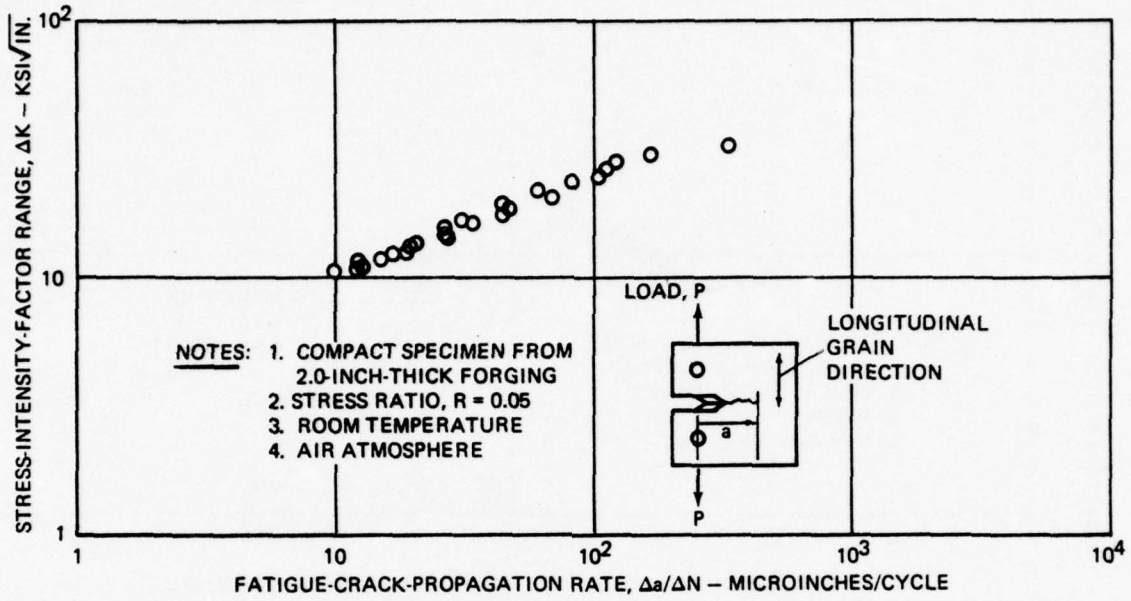



Figure 122. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0221.

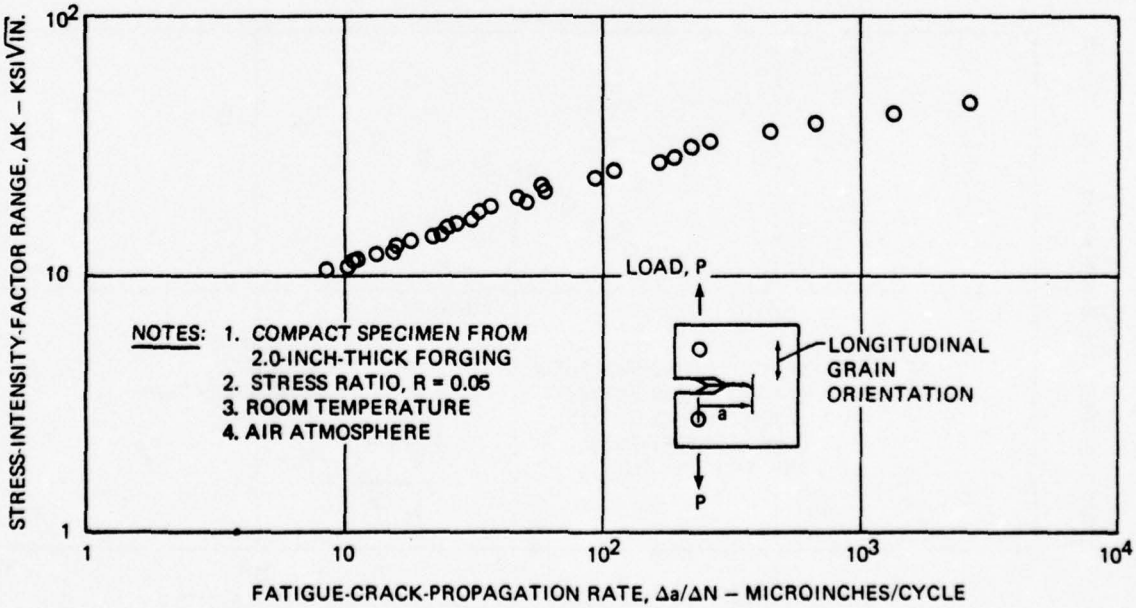



Figure 123. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0222.

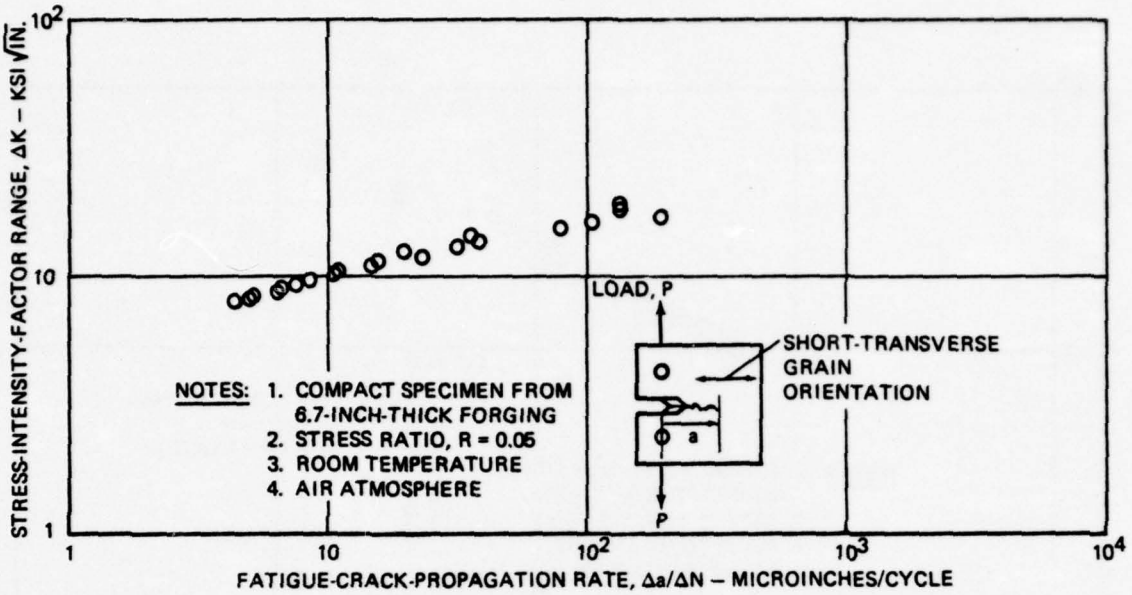



Figure 124. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0501.

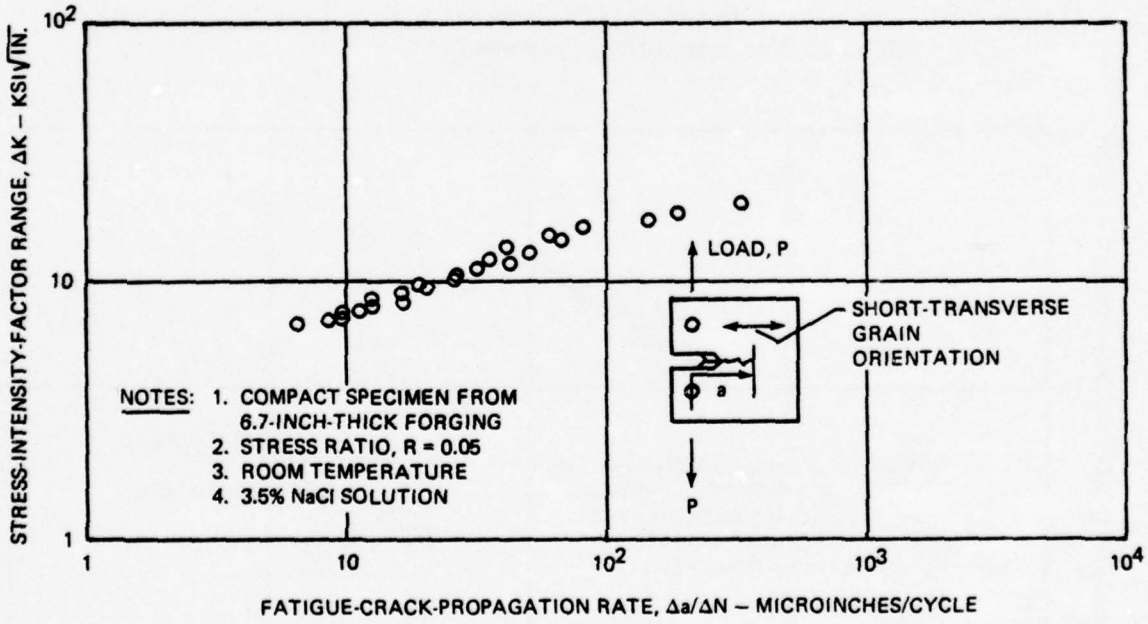



Figure 125. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0502.

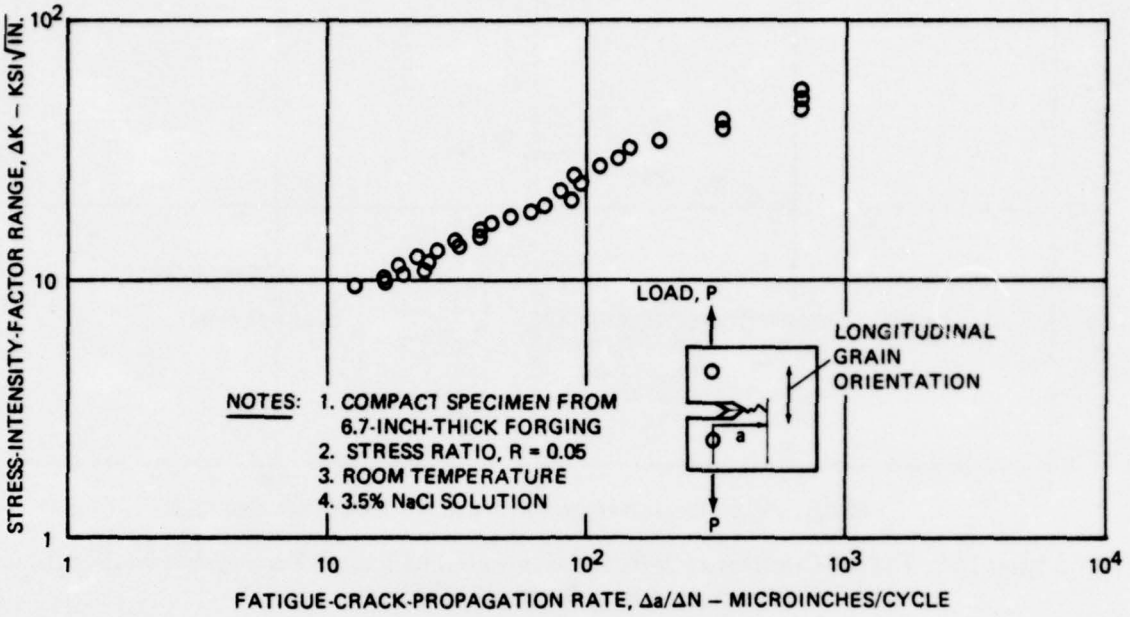



Figure 126. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0604.

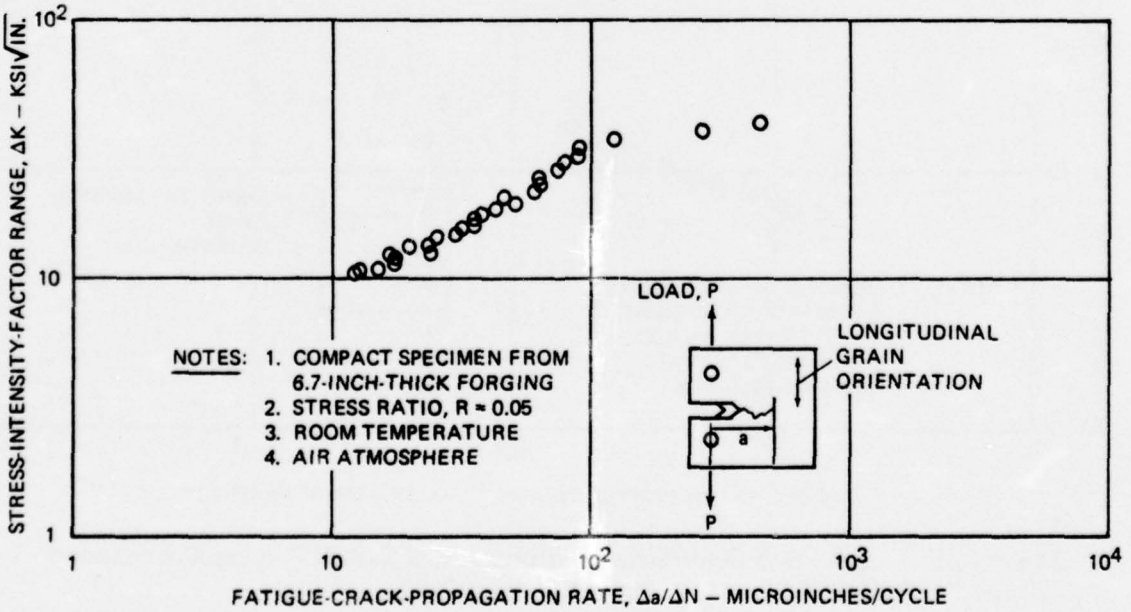



Figure 127. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0605.

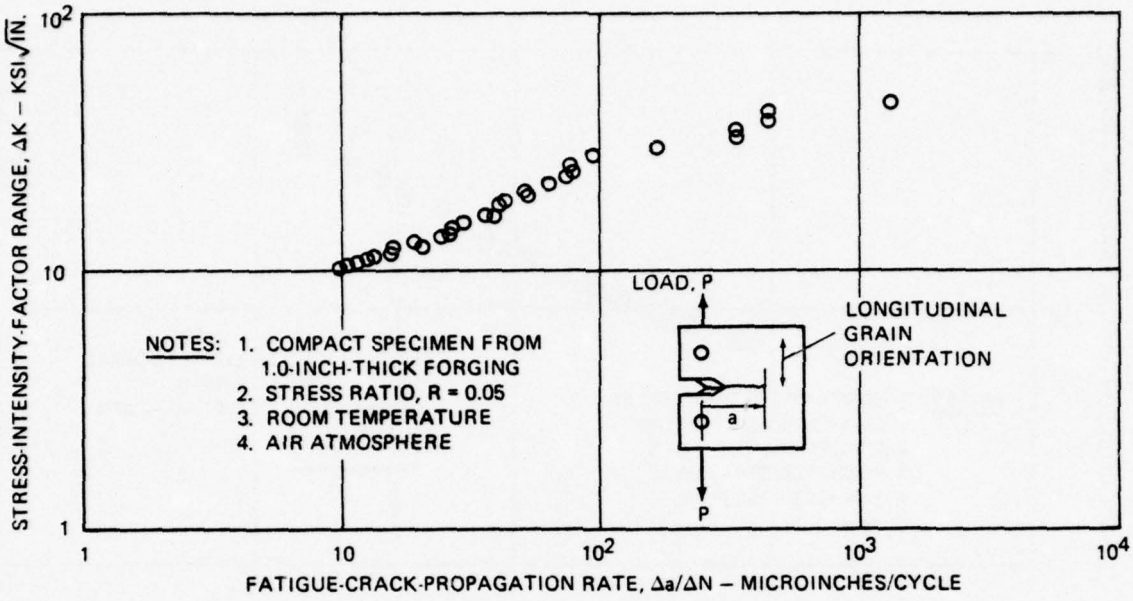



Figure 128. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0720.

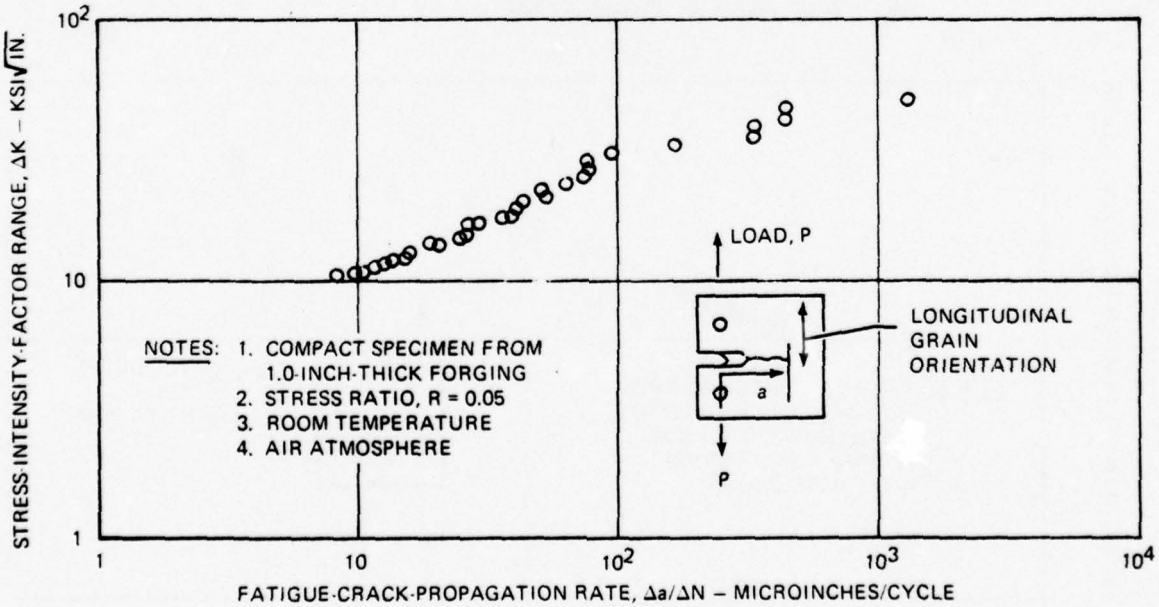



Figure 129. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0721.

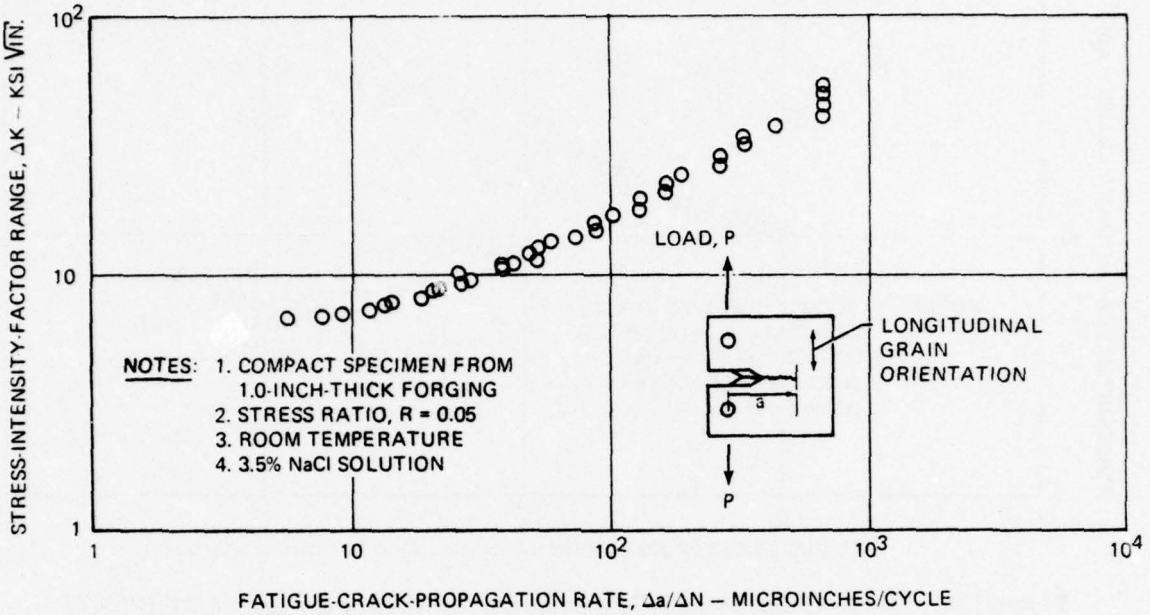



Figure 130. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0722.

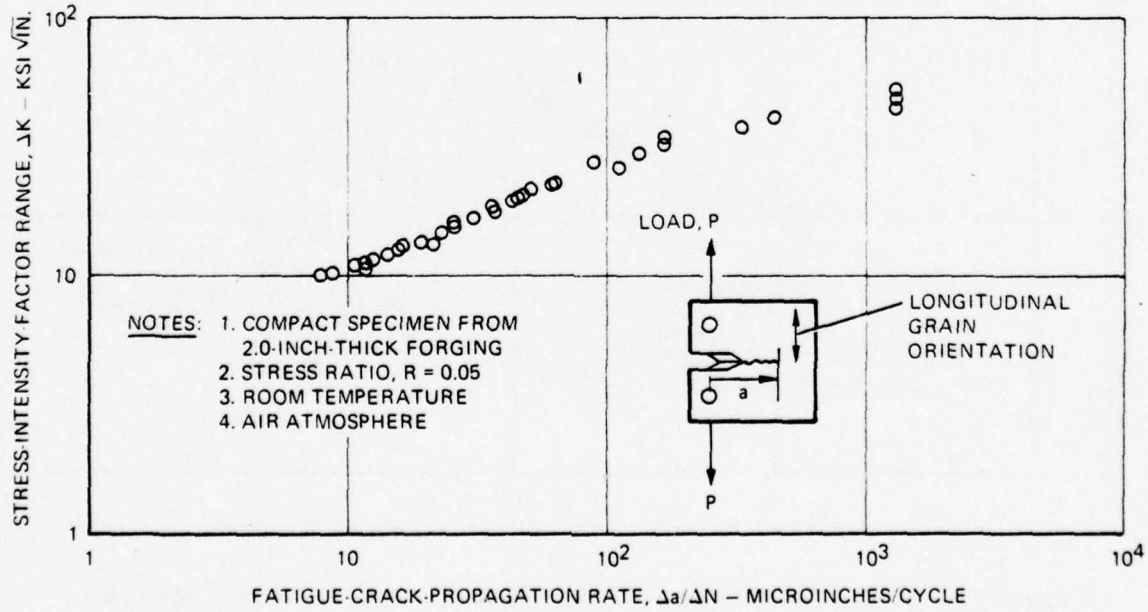



Figure 131. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0855.

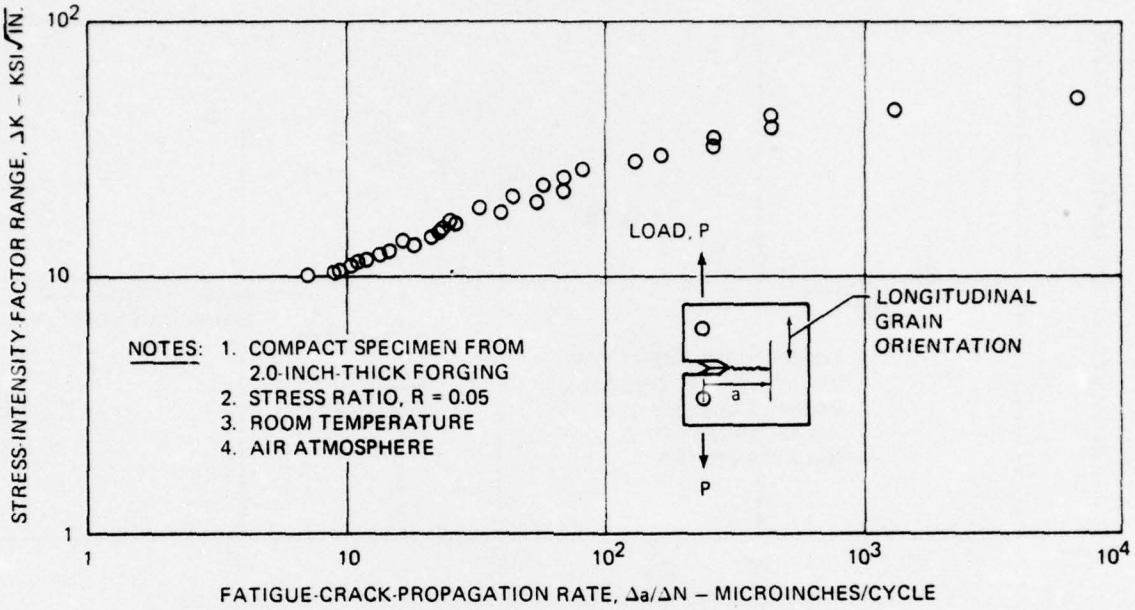



Figure 132. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0856.

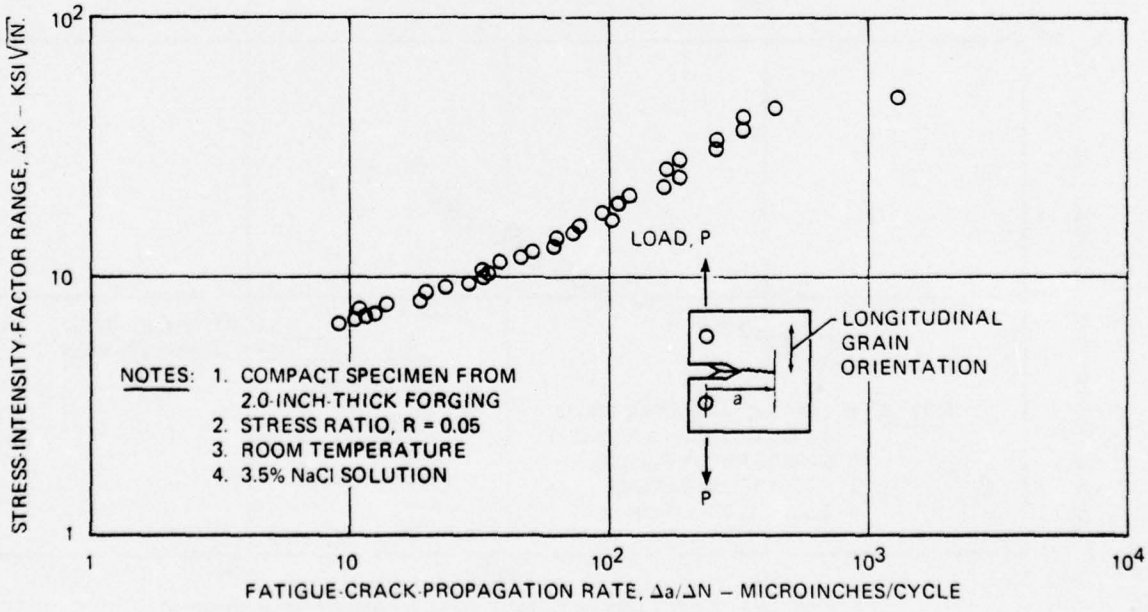



Figure 133. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0857.

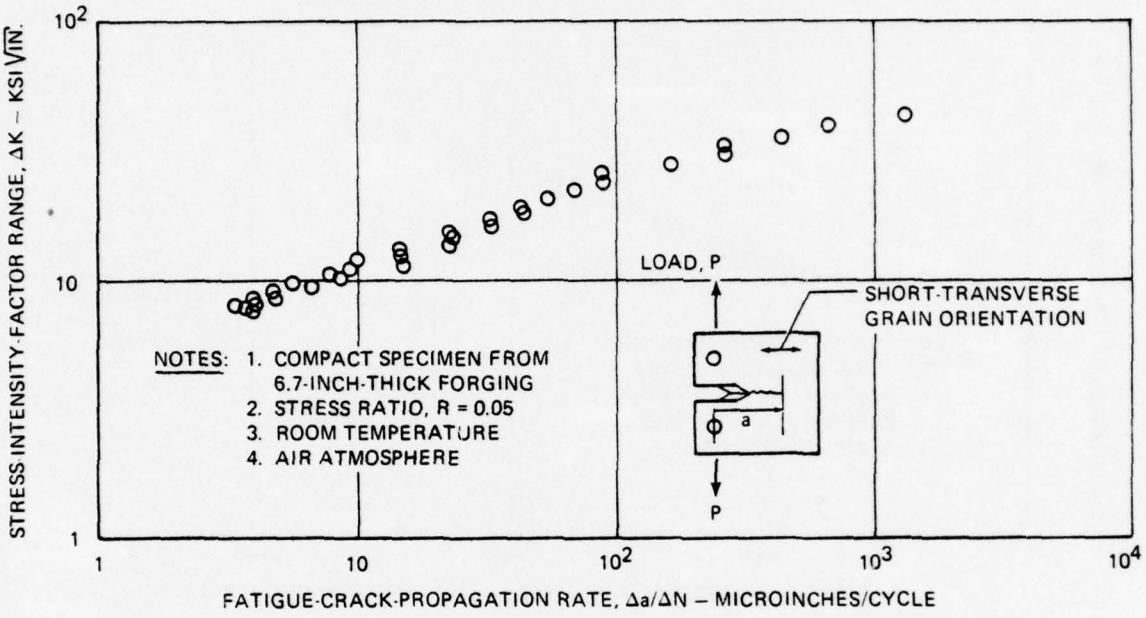



Figure 134. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 1101.

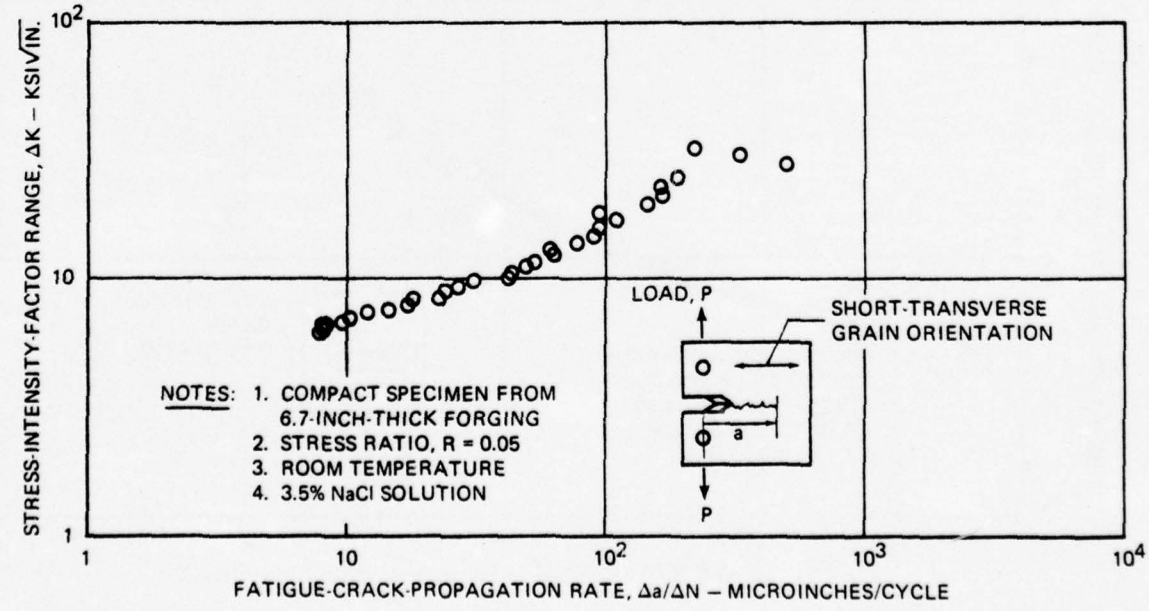



Figure 135. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 1102.

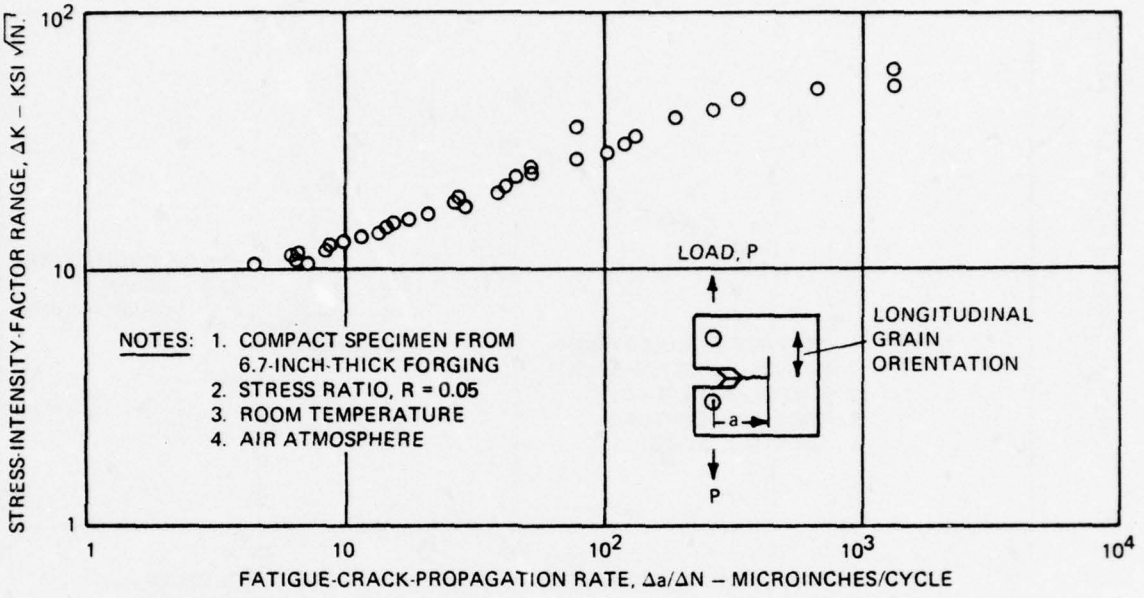



Figure 136. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 1204.

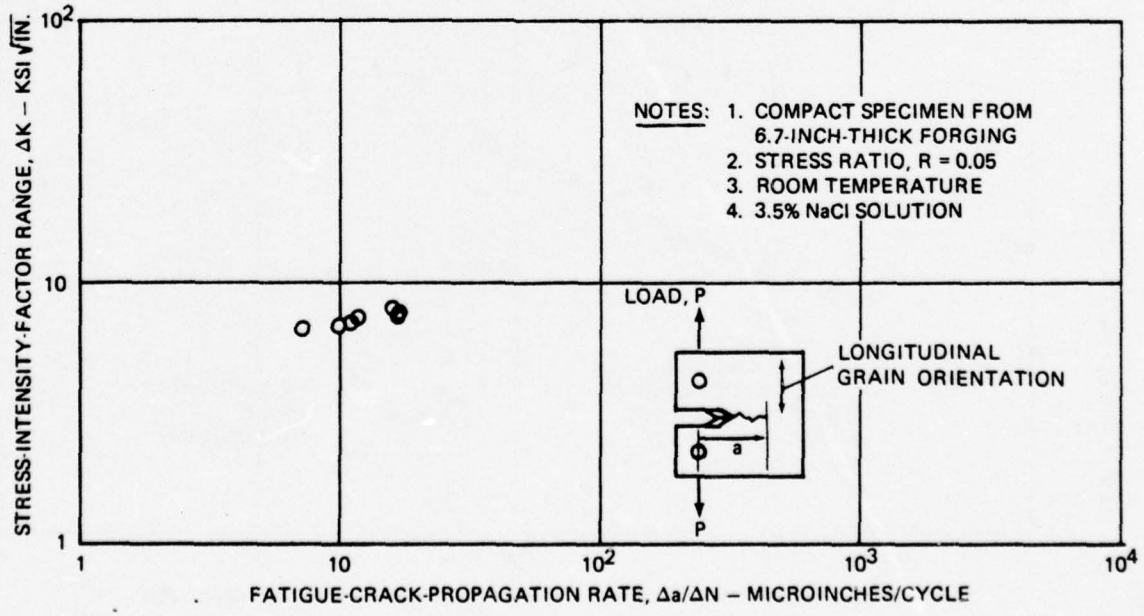



Figure 137. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 1205.

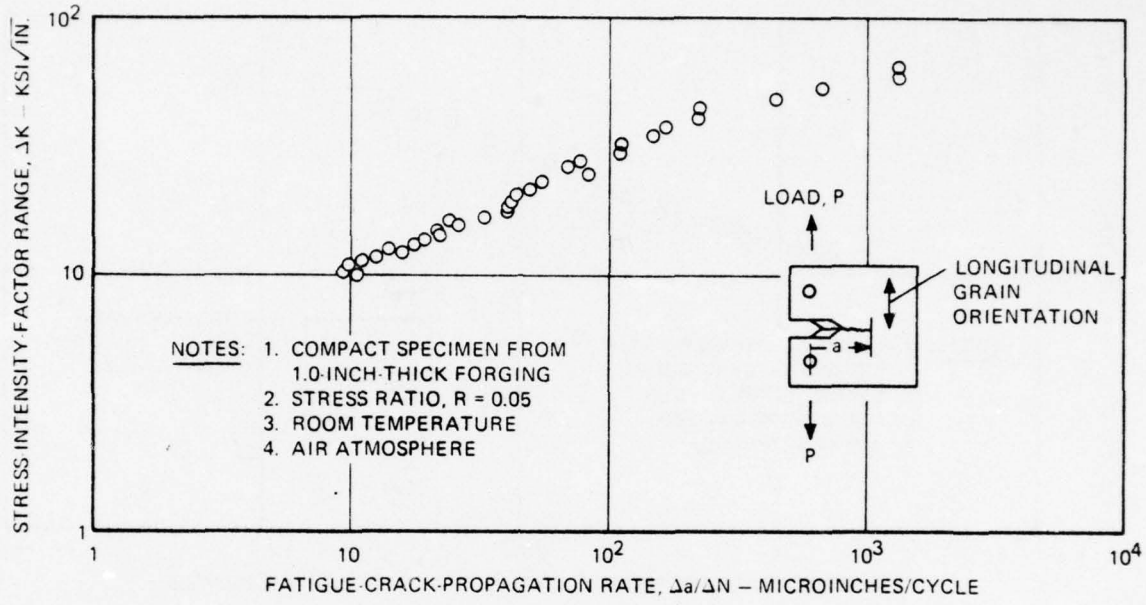



Figure 138. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1320.

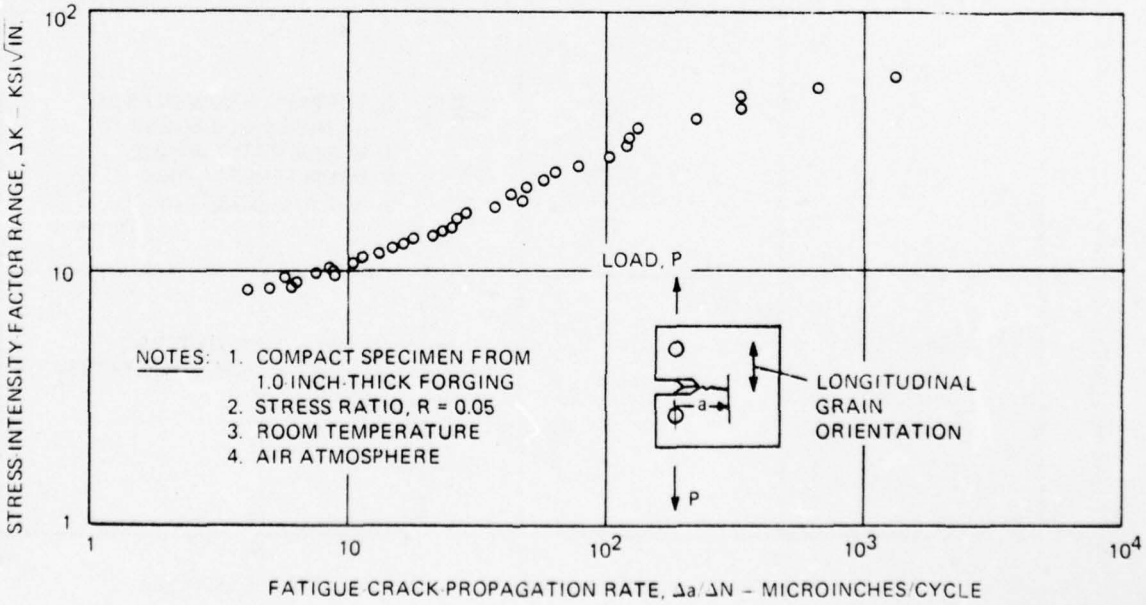



Figure 139. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1321.

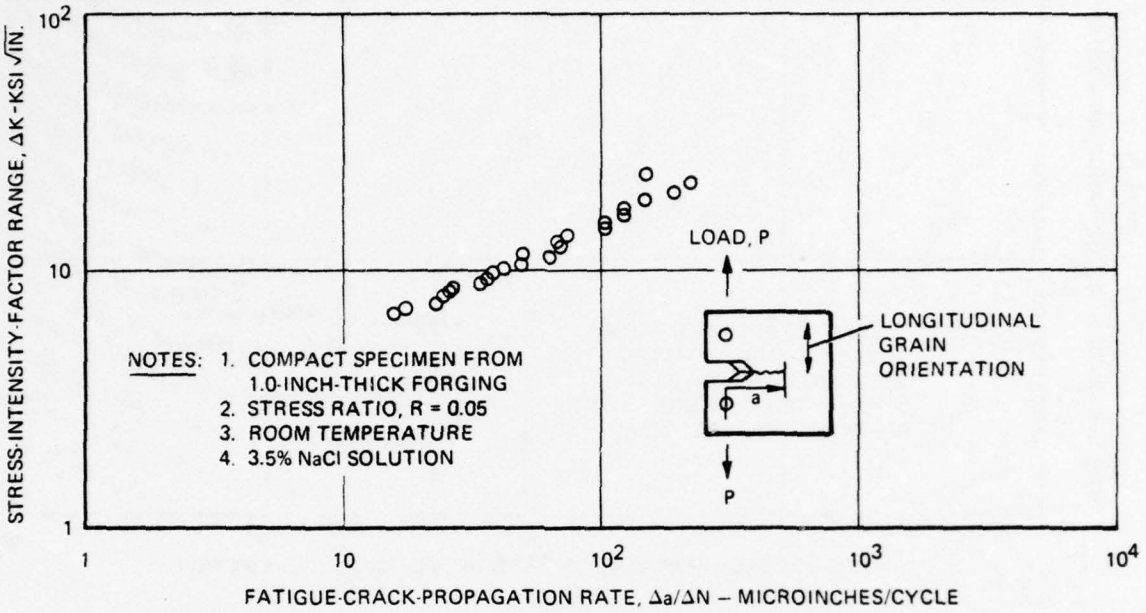



*Figure 140. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1322.*

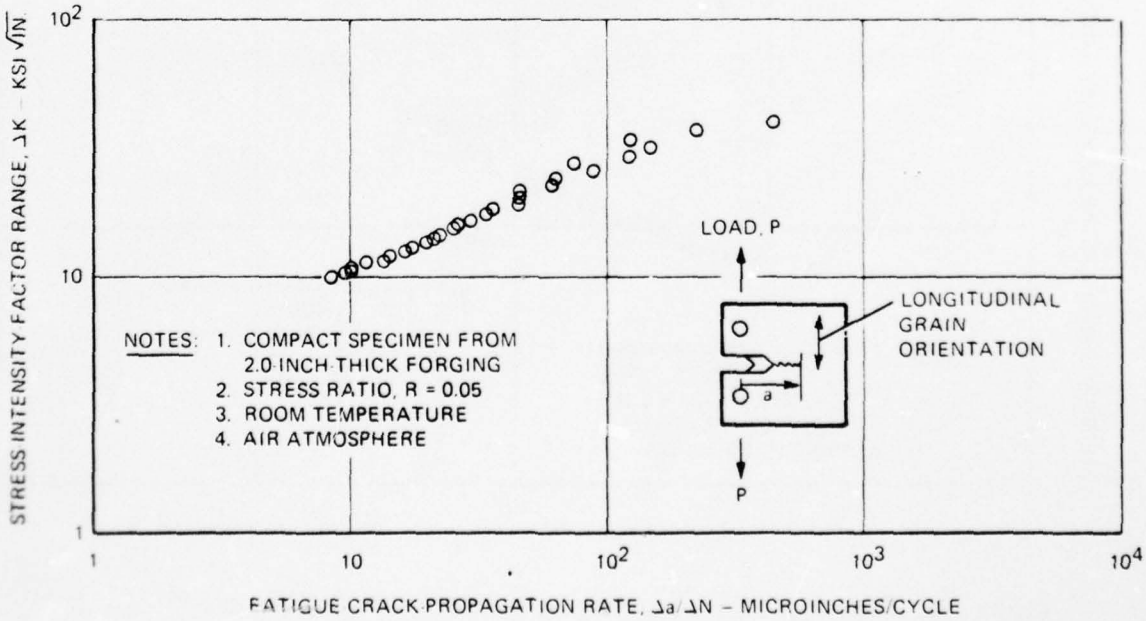



*Figure 141. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1455.*

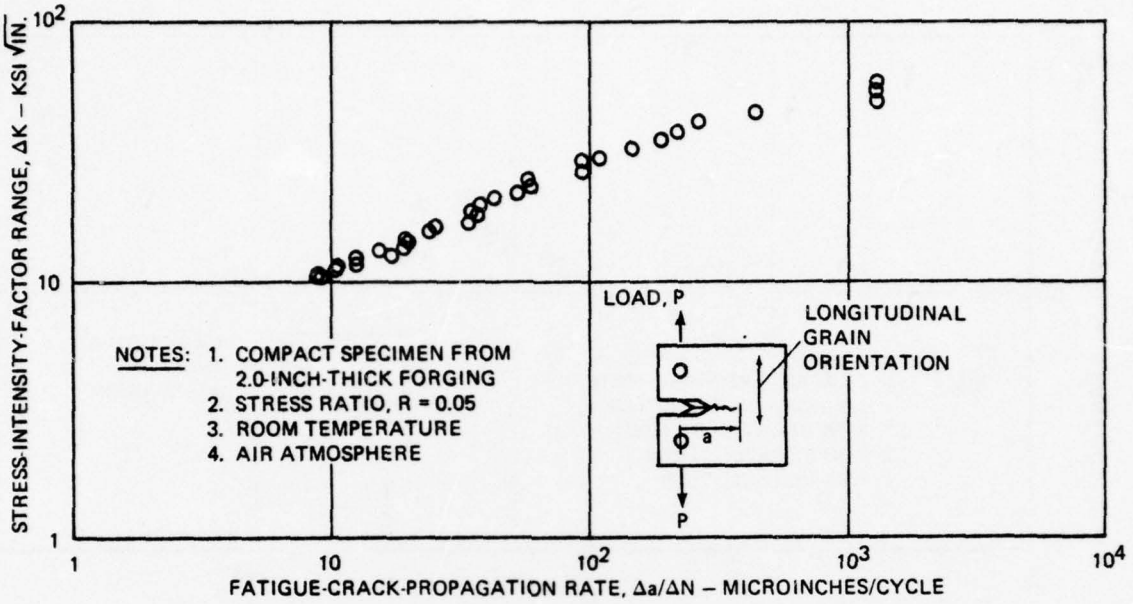



Figure 142. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1456.

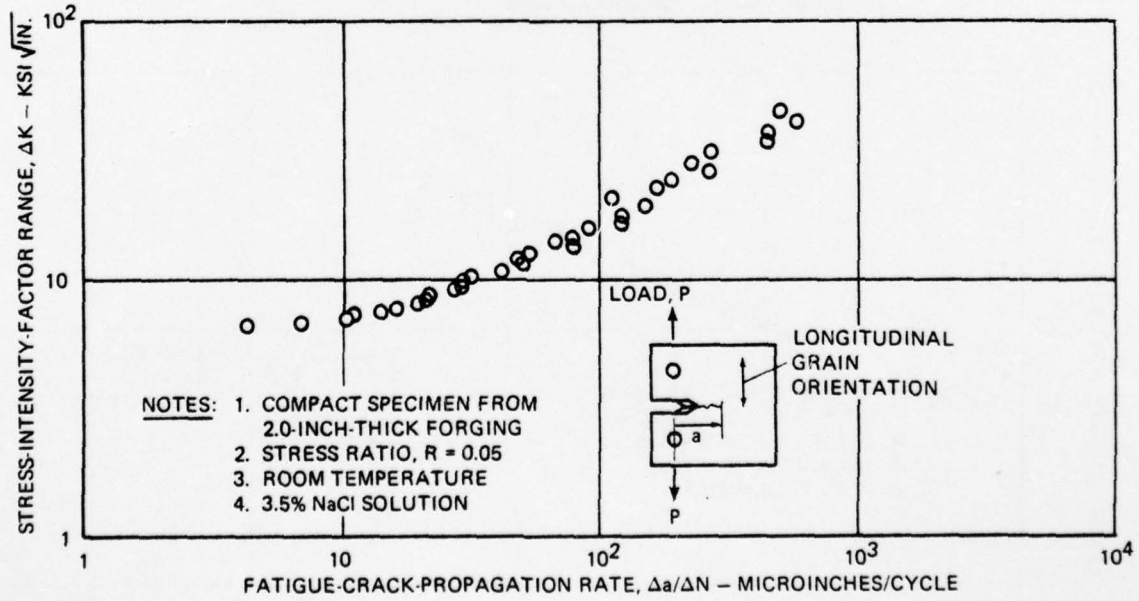



Figure 143. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1457.

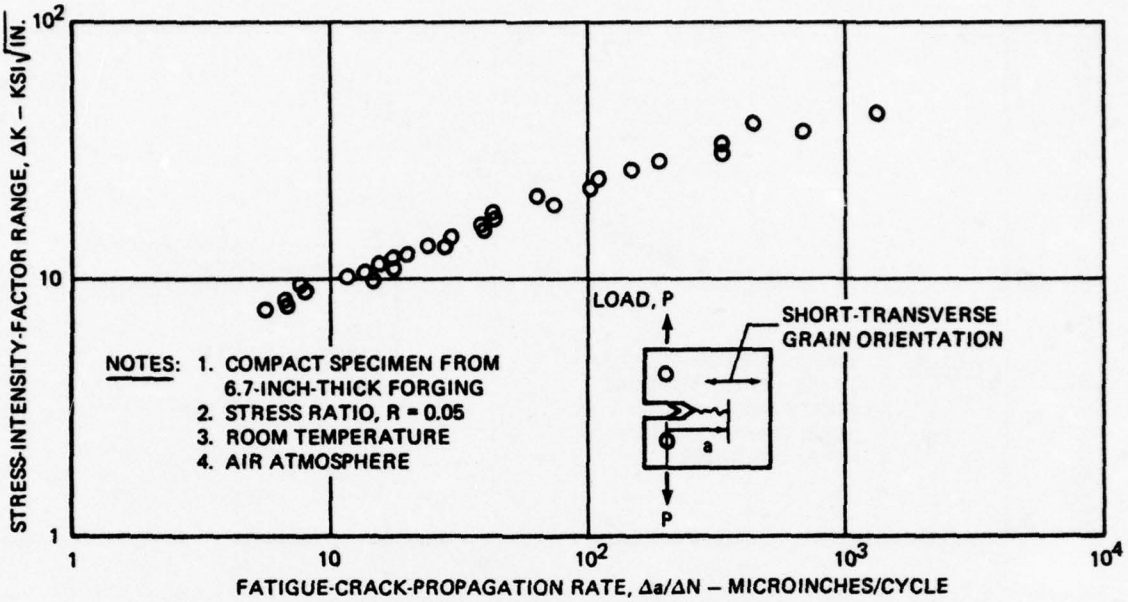



Figure 144. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1701.

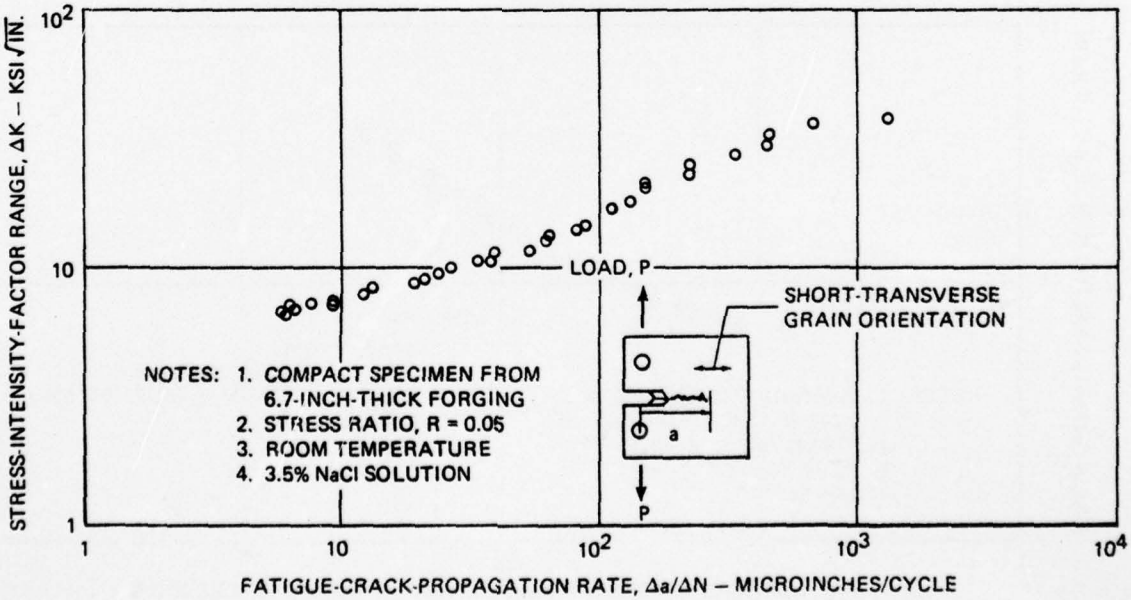



Figure 145. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1702.

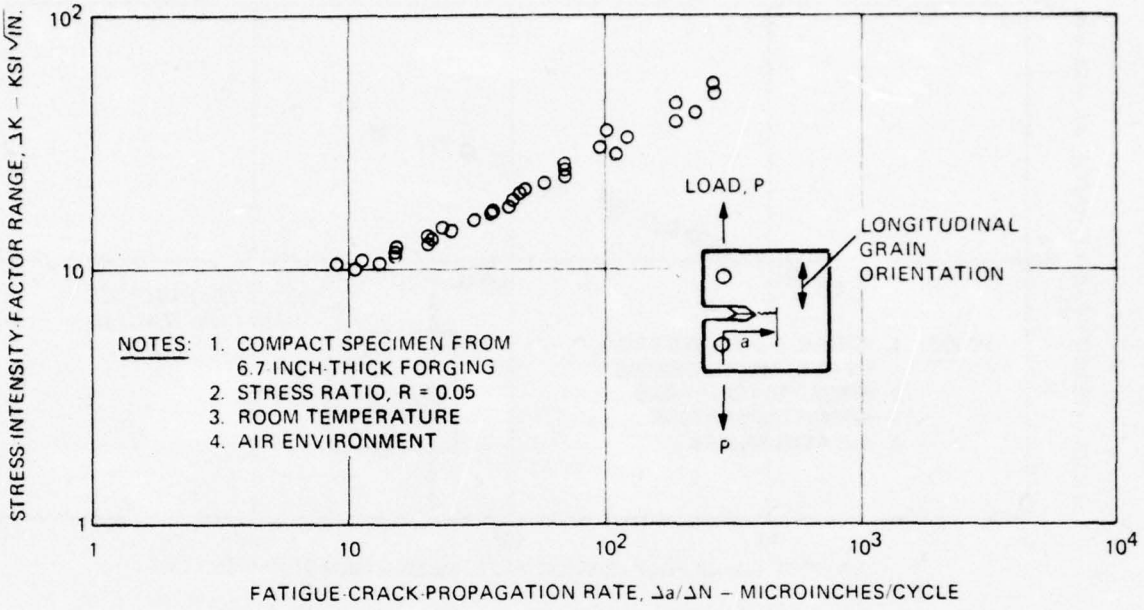



Figure 146. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1804.

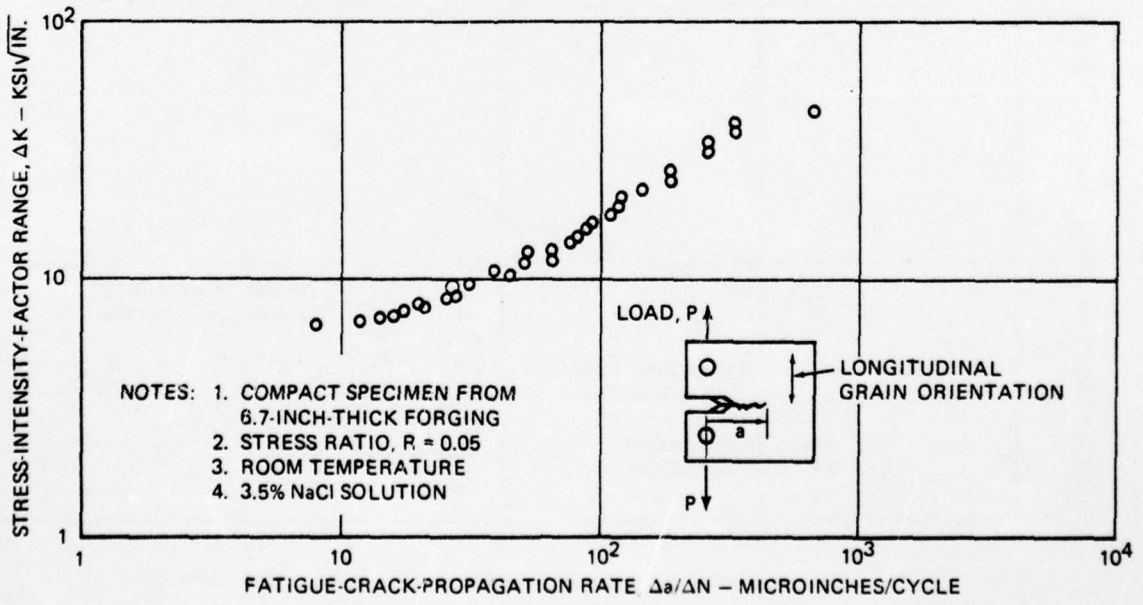



Figure 147. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1805.

TABLE 28. COMPARISON OF 7475-TMT CRACK-PROPAGATION RATES WITH 7075-T73 CRACK-PROPAGATION RATES

| Material | Environment | Original Forging Thickness (in.) | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 6.7 | |
| | | | | Longitudinal | Short transverse |
| 7475-TMT1 | Room Air | TMT1 rate is same as 7075-T73; maintains stable growth at higher ΔK's | TMT1 rate same as 7075-T73 | TMT1 slower than 7075-T73; maintains stable growth at higher ΔK's | TMT1 slower than 7075-T73; maintains stable growth at higher ΔK's |
| | 3.5% Salt Solution | TMT1 rate is 33% faster than 7075-T73 | TMT1 is 100% faster than 7075-T73 | – | Rates are the same; TMT1 maintains stable growth rate at higher ΔK's |
| 7475-TMT2 | Room Air | TMT2 is slower than 7075-T73; maintains stable growth rate at higher ΔK's | TMT2 is 100% slower than 7075-T73 | Rates are the same | TMT2 is slower than 7075-T73; maintains stable growth rate at higher ΔK's |
| | 3.5% Salt Solution | TMT2 is 33% faster than 7075-T73 | TMT2 is 100% faster than 7075-T73 | TMT2 is 100% faster than 7075-T73 | Rates are the same |

TABLE 29. COMPARISON OF LONGITUDINAL AND SHORT-TRANSVERSE CRACK-PROPAGATION RATES IN 6.7-INCH FORGING

| Material | Environment | |
|---|---|---|
| | Room Air | 3.5% Salt Solution |
| 7075-T73 | Influence of fracture toughness clearly indicated by instability of crack growth at high ΔK's | Short-transverse rate is 33% faster than longitudinal rate |
| 7475-TMT1 | Short-transverse rate is 14% faster than longitudinal | Short-transverse and longitudinal rates are the same |
| 7475-TMT2 | Short-transverse rate slightly faster than longitudinal rate | Short-transverse and longitudinal rates are the same |

## TABLE 30. RESISTANCE TO CORROSION OF 6.7-INCH-THICK 7075-T7X AND 7475-T7X HAND FORGINGS

| S-No. | 2nd-Step Aging at 350°F (hr) | Longitudinal Tensile Properties UTS (ksi) | YS (ksi) | El (%) | Elec Cond (% IACS) | Days to Failure of 1/8-In. ϕ Tensile Bars Exposed Stressed to Alternate Immersion (Method 823) for 84 Days: Longitudinal Stressed at 45 ksi Spec L2 | Spec L3 | Spec L4 | Short-Transverse Stressed at 45 ksi Spec N2 | Spec N4 | Spec N6 | Short-Transverse Stressed at 35 ksi Spec N5 | Spec N8 | Spec N11 | Short-Transverse Stressed at 25 ksi Spec N1 | Spec N7 | Spec N9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7075 Hand Forging – Unrecrystallized | | | | | | | | | | | | | | | | | |
| 437701-32 | 2 | 78.3 | 68.2 | 14.0 | 36.6 | OK 84 | OK 84 | OK 84 | F51 | F2 | F5 | F72 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 437701-33 | 4 | 77.2 | 67.1 | 14.0 | 38.7 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | F58 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 437701-34 | 6 | 72.8 | 61.0 | 14.0 | 40.7 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 437701-35 | 8 | 70.2 | 58.0 | 14.0 | 42.1 | OK 84 | Ok 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 7475 Hand Forging – Recrystallized Plus Hot-Worked (7475-TMT1) | | | | | | | | | | | | | | | | | |
| 438170-2 | 2 | 76.7 | 68.3 | 16.0 | 36.2 | OK 84 | OK 84 | OK 84 | F4 | F3 | F2 | F4 | F4 | F3 | F10 | OK 84 | F9 |
| 438170-3 | 4 | 75.6 | 67.0 | 14.0 | 38.6 | OK 84 | OK 84 | OK 84 | F81 | F80 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 438170-4 | 6 | 73.9 | 64.4 | 16.0 | 40.1 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 438170-6 | 9 | 73.7 | 63.2 | 14.0 | 40.3 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 7475 Hand Forging – Recrystallized Plus Hot-Worked (7475-TMT2) | | | | | | | | | | | | | | | | | |
| 438173-2 | 2 | 78.6 | 70.0 | 14.0 | 35.2 | OK 84 | OK 84 | OK 84 | F3 | F2 | F2 | OK 84 | F2 | F2 | F10 | F10 | F3 |
| 438173-3 | 4 | 74.2 | 65.6 | 18.0 | 39.0 | OK 84 | OK 84 | OK 84 | F16 | F30 | F9 | F62 | F78 | F5 | OK 84 | OK 84 | F78 |
| 438173-4 | 6 | 73.5 | 64.6 | 16.0 | 39.7 | OK 84 | OK 84 | OK 84 | F46 | OK 84 | F80 | OK 84 | OK 84 | OK84 | OK 84 | OK 84 | OK 84 |
| 438173-6 | 9 | 70.2 | 59.0 | 18.0 | 40.5 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 7475 Hand Forging – Unrecrystallized | | | | | | | | | | | | | | | | | |
| 438176-2 | 2 | 82.9 | 75.6 | 12.0 | 35.2 | OK 84 | OK 84 | OK 84 | F2 | F2 | F2 | F2 | F2 | F2 | F2 | F10 | OK 84 |
| 438176-3 | 4 | 77.0 | 70.7 | 6.0 | 37.7 | OK 84 | OK 84 | OK 84 | F10 | F3 | OK 84 | F24 | OK 84 | F84 | OK84 | F83 | OK 84 |
| 438176-4 | 6 | 75.9 | 67.6 | 10.0 | 38.9 | OK 84 | OK 84 | OK 84 | F30 | F10 | Not exposed | F25 | F37 | Not exposed | F83 | OK 84 | OK 84 |
| 438176-6 | 9 | 67.6 | 60.0 | 6.0 | 40.4 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | Not exposed | OK 84 | OK 84 | OK 84 | OK 84 |

NOTES:
1. Forgings heat-treated, quenched in cold water, aged 24 hours at 250°F plus indicated time at 350°F as 2-in.-thick sawed sections.
2. 7075 heat-treated at 880°F, 7475 heat-treated at 960°F.
3. Yield strength = 0.2% offset.

## TABLE 31. RESISTANCE TO CORROSION OF 2-INCH-THICK 7075-T7X AND 7475-T7X HAND FORGINGS

| S-No. | 2nd-Step Aging at 350°F (hr) | Longitudinal Tensile Properties UTS (ksi) | YS (ksi) | El (%) | Elec Cond (% IACS) | Days to Failure of 1/8-In. ϕ Tensile Bars Exposed Stressed to Alternate Immersion (Method 823) for 84 Days: Longitudinal Stressed at 45 ksi Spec L2 | Spec L3 | Spec L4 | Short-Transverse Stressed at 45 ksi Spec N2 | Spec N4 | Spec N6 | Short-Transverse Stressed at 35 ksi Spec N5 | Spec N8 | Spec N11 | Short-Transverse Stressed at 25 ksi Spec N1 | Spec N7 | Spec N9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7075 Hand Forging – Unrecrystallized | | | | | | | | | | | | | | | | | |
| 437701-22 | 2 | 83.7 | 73.4 | 12.0 | 36.0 | OK 84 | OK 84 | OK 84 | F3 | F34 | F43 | F72 | F10 | F72 | F10 | F3 | OK 84 |
| 437701-23 | 4 | 78.0 | 69.0 | 14.0 | 39.2 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 437701-24 | 6 | 76.3 | 65.4 | 14.0 | 39.6 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 437701-25 | 8 | 73.3 | 61.7 | 16.0 | 41.0 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 7475 Hand Forging – Recrystallized Plus Hot-Worked (7475-TMT1) | | | | | | | | | | | | | | | | | |
| 438169-2 | 2 | 82.0 | 74.9 | 14.0 | 37.2 | OK 84 | OK 84 | OK 84 | F2 | F2 | F2 | F2 | F2 | OK 84 | F3 | F3 | F3 |
| 438169-3 | 4 | 79.6 | 71.0 | 16.0 | 39.3 | OK 84 | OK 84 | OK 84 | F46 | F54 | F6 | F60 | OK 84 | F52 | OK 84 | OK 84 | OK 84 |
| 438169-4 | 6 | 79.4 | 70.2 | 16.0 | 40.7 | OK 84 | OK 84 | OK 84 | F66 | F60 | F58 | F71 | OK 84 | F80 | OK 84 | OK 84 | OK 84 |
| 438169-6 | 9 | 76.0 | 65.6 | 14.0 | 41.5 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 7475 Hand Forging – Recrystallized Plus Hot-Worked (7475-TMT2) | | | | | | | | | | | | | | | | | |
| 438172-2 | 2 | 80.3 | 72.0 | 14.0 | 38.0 | OK 84 | OK 84 | OK 84 | F2 | F2 | F2 | F3 | F2 | F3 | F2 | F3 | OK 84 |
| 438172-3 | 4 | 80.7 | 71.0 | 14.0 | 40.1 | OK 84 | OK 84 | OK 84 | F4 | F5 | F33 | F57 | F58 | F61 | OK 84 | OK 84 | OK 84 |
| 438172-4 | 6 | 76.4 | 67.3 | 16.0 | 40.5 | OK 84 | OK 84 | OK 84 | F54 | OK 84 | F27 | OK 84 | F64 | F58 | OK 84 | OK 84 | OK 84 |
| 438172-6 | 9 | 75.1 | 63.9 | 14.0 | 42.3 | OK 84 | OK 84 | OK 84 | F57 | Defect spec | F80 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 7475 Hand Forging – Unrecrystallized | | | | | | | | | | | | | | | | | |
| 438175-2 | 2 | 82.3 | 74.6 | 16.0 | 36.6 | OK 84 | OK 84 | OK 84 | F3 | F3 | F3 | F8 | F30 | F30 | OK 84 | OK 84 | OK 84 |
| 438175-3 | 4 | 79.6 | 71.7 | 16.0 | 39.7 | OK 84 | OK 84 | OK 84 | F19 | F24 | F5 | F26 | F30 | F30 | F57 | F58 | OK 84 |
| 438175-4 | 6 | 75.2 | 65.3 | 16.0 | 40.6 | OK 84 | OK 84 | OK 84 | Not exposed | Not exposed | OK 84 | OK 84 | OK 84 | F30 | OK 84 | OK 84 | OK 84 |
| 438175-6 | 9 | 73.4 | 63.9 | 16.0 | 42.2 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | F84 | OK 84 | OK 84 | OK 84 |

NOTES:
1. Forgings heat-treated, quenched in cold water, aged 24 hours at 250°F plus indicated time at 350°F.
2. 7075 forging heat-treated at 880°F, 7475 forgings heat-treated at 960°F.
3. Yield strength = 0.2% offset.

## TABLE 32. RESISTANCE TO CORROSION OF 1-INCH-THICK 7075-T7X AND 7475-T7X HAND FORGINGS

| S-No. | 2nd-Step Aging at 350°F (hr) | Longitudinal Tensile Properties UTS (ksi) | YS (ksi) | El (%) | Elec Cond (% IACS) | Days to Failure of Specimens Exposed Stressed to Alternate Immersion (Method 823) for 84 Days: Longitudinal 1/8-In. ϕ Tensile Bars Stressed at 45 ksi Spec L2 | Spec L3 | Spec L4 | Short-Transverse Stressed at 45 ksi Spec C1 | Spec C2 | 0.75-In. ϕ C-Rings Stressed at 35 ksi Spec C3 | Spec C4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7075 Hand Forging – Unrecrystallized | | | | | | | | | | | | |
| 437701-12 | 2 | 82.2 | 72.9 | 14.0 | 36.3 | OK 84 | OK 84 | OK 84 | OK 84[2] | OK 84[2] | Not exposed | Not exposed |
| 437701-13 | 4 | 79.9 | 69.5 | 16.0 | 37.4 | OK 84 | OK 84 | OK 84 | OK 84[1] | OK 84[1] | Not exposed | Not exposed |
| 437701-14 | 6 | 78.7 | 68.0 | 14.0 | 38.4 | OK 84 | OK 84 | OK 84 | OK 84[1] | OK 84[1] | Not exposed | Not exposed |
| 437701-15 | 8 | 74.5 | 62.7 | 16.0 | 40.6 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | Not exposed | Not exposed |
| 7475 Hand Forging – Recrystallized Plus Hot-Worked (7475-TMT1) | | | | | | | | | | | | |
| 438168-2 | 2 | 81.9 | 74.6 | 16.0 | 37.9 | OK 84 | OK 84 | OK 84 | OK 84[1] | OK 84[1] | OK 84[2] | OK 84[1] |
| 438168-3 | 4 | 81.0 | 72.7 | 16.0 | 40.0 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84[1] |
| 438168-4 | 6 | 78.5 | 69.3 | 16.0 | 41.0 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 438168-6 | 9 | 74.3 | 65.4 | 18.0 | 41.9 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 7475 Hand Forging-Recrystallized Plus Hot-Worked (7475-TMT2) | | | | | | | | | | | | |
| 438171-2 | 2 | 80.0 | 73.4 | 16.0 | 38.3 | OK 84 | OK 84 | OK 84 | F51DA | F51DA | OK 84[2] | OK 84[2] |
| 438171-3 | 4 | 79.0 | 71.6 | 16.0 | 40.2 | OK 84 | OK 84 | OK 84[2] | OK 84 | OK 84[1] | OK 84[1] | OK 84 |
| 438171-4 | 6 | 77.0 | 67.8 | 16.0 | 41.0 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 438171-6 | 9 | 74.6 | 64.4 | 16.0 | 42.1 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 7475 Hand Forging – Unrecrystallized | | | | | | | | | | | | |
| 438174-2 | 2 | 83.8 | 76.6 | 14.0 | 37.0 | OK 84 | OK 84 | OK 84 | OK 84[2] | OK 84[1] | Not exposed | Not exposed |
| 438174-3 | 4 | 80.2 | 72.4 | 14.0 | 39.1 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | Not exposed | Not exposed |
| 438174-4 | 6 | 77.4 | 69.0 | 18.0 | 40.1 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |
| 438174-6 | 9 | 74.8 | 64.9 | 18.0 | 41.3 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 | OK 84 |

NOTES:
1. Specimen did not fail but contained severe directional pitting.
2. Specimen did not fail but contained small directional cracks.
3. Forgings heat-treated, quenched in cold water, aged 24 hours at 250°F plus indicated time at 350°F.
4. 7075 forging heat-treated at 880°F, 7475 forgings heat-treated at 960°F.
5. Yield strength = 0.2% offset.

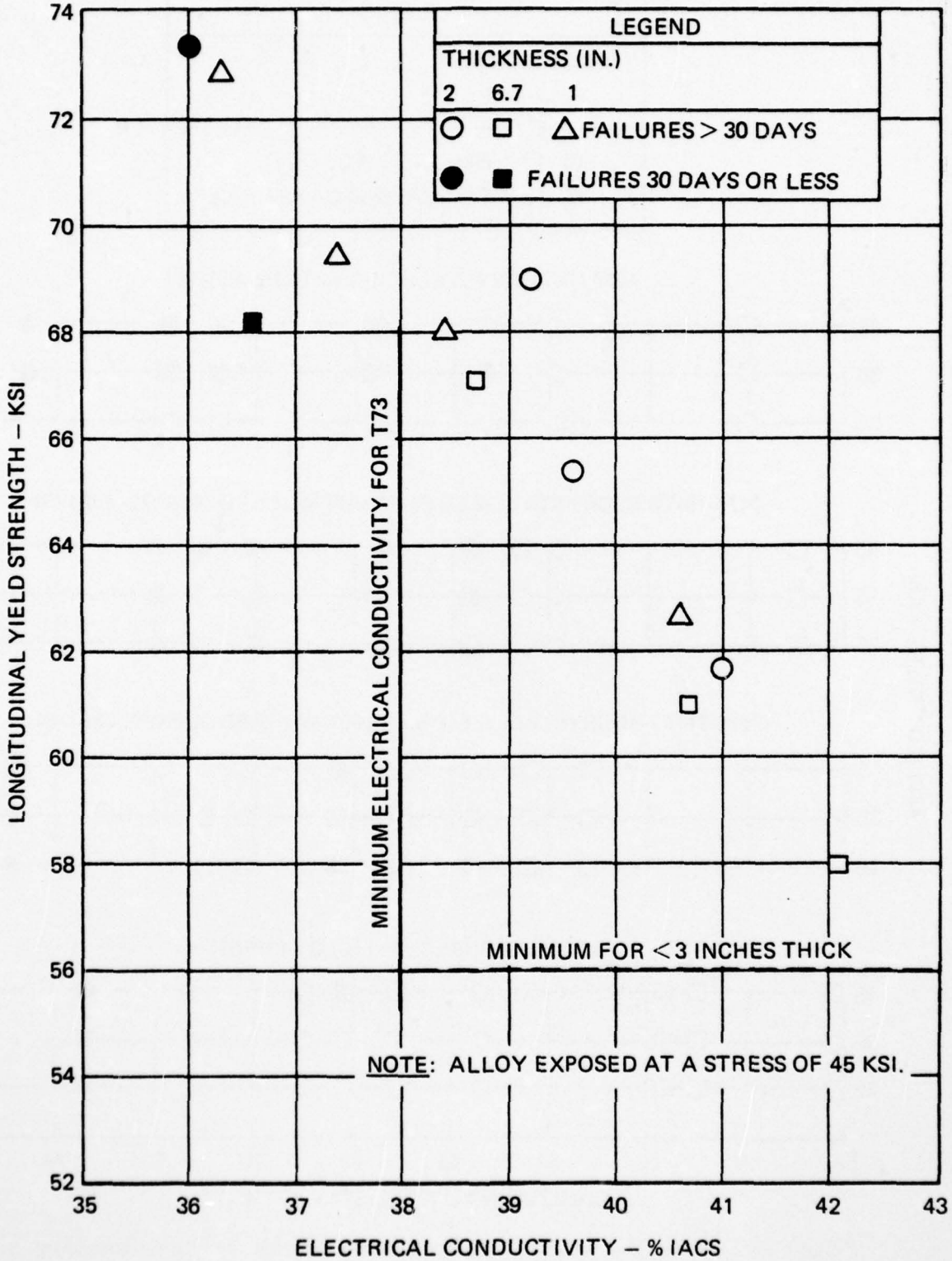



Figure 148. Longitudinal Yield Strength Versus Electrical Conductivity for Unrecrystallized 7075 Aluminum Alloy.

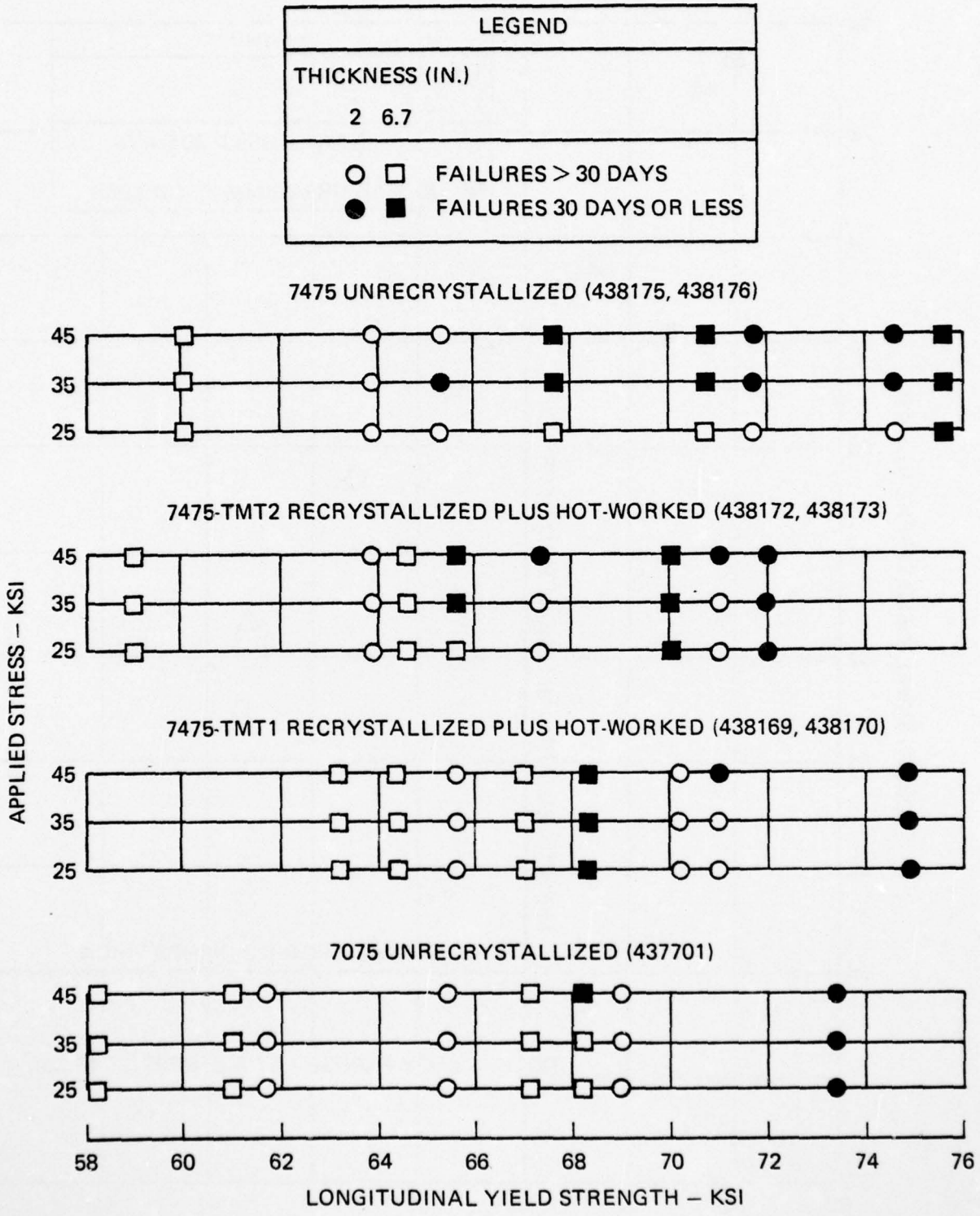



Figure 149. Applied Stress Versus Longitudinal Yield Strength for Aluminum Alloy.

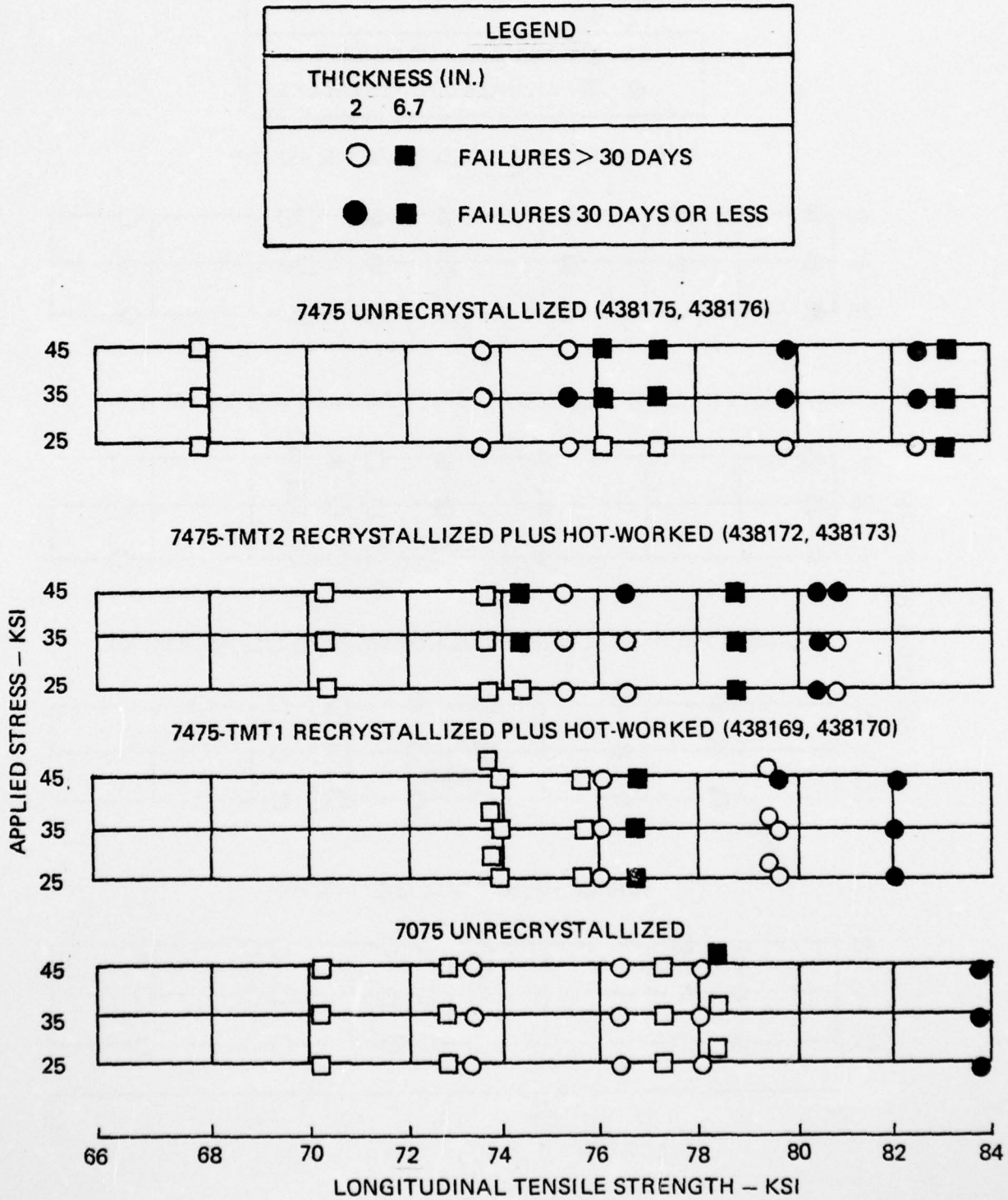



Figure 150. Applied Stress Versus Longitudinal Tensile Strength for Aluminum Alloy.

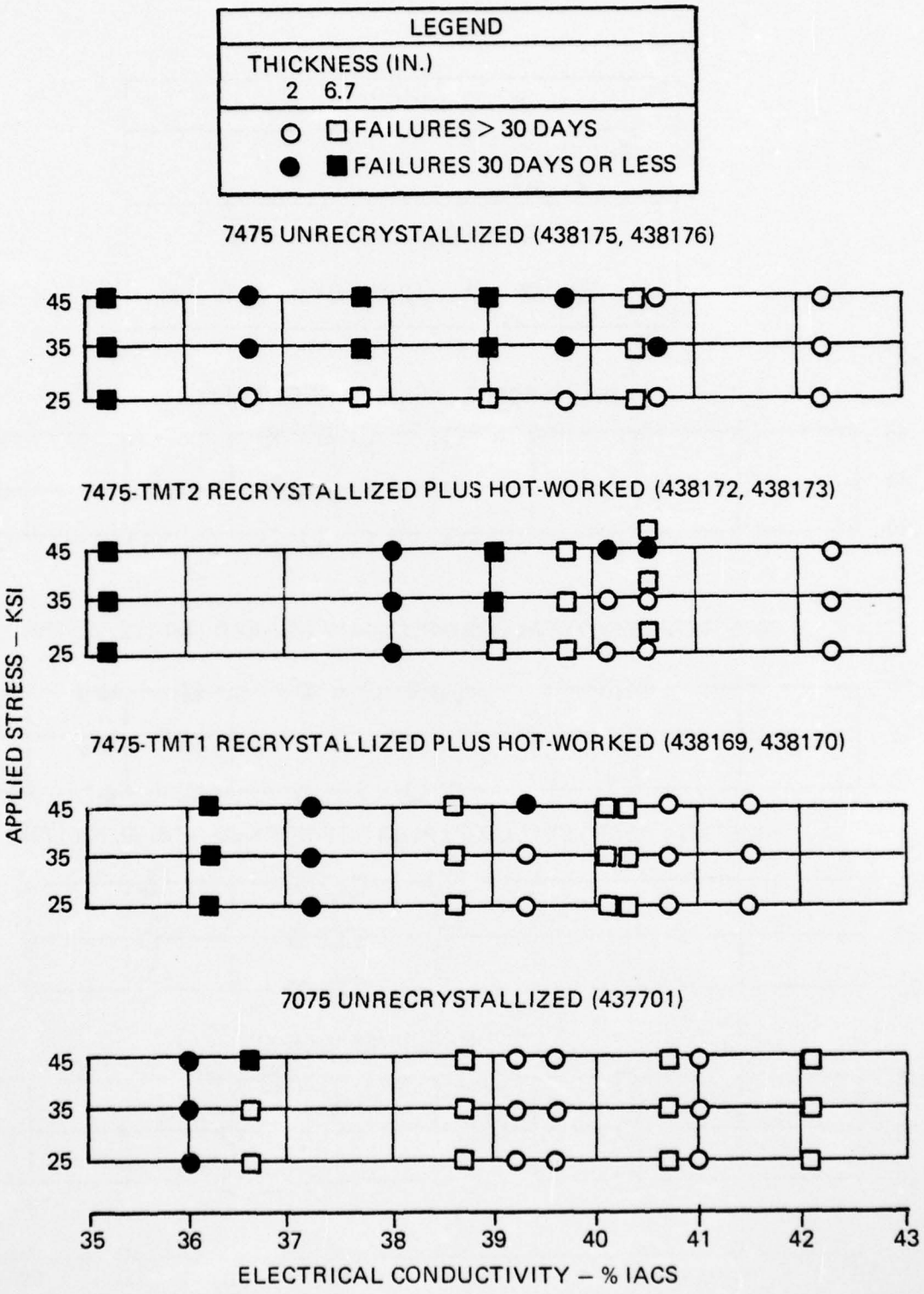



Figure 151. Applied Stress Versus Electrical Conductivity for Aluminum Alloy.

## TASK IV – DATA ANALYSIS AND EVALUATION

The objectives of this task are to analyze and evaluate the metallurgical and mechanical-properties data developed in the previous tasks and to assess the impact of improved mechanical properties on the weight and cost of helicopter components.

The properties obtained with the advanced-alloy/process combinations 7475-TMT1 and 7475-TMT2 were compared with the properties measured from the conventionally processed 7075-T73, and in some instances with 7075-T73 properties available in published literature. The advanced-alloy/process combinations are ranked in Table 33 with respect to their ability to improve tensile, fatigue, fracture, and stress-corrosion-resistance properties.

TABLE 33. RANKING OF 7475-TMT ALLOY FORGINGS

| Basis of Comparison | 7475-TMT1 | | 7475-TMT2 | |
|---|---|---|---|---|
| Tensile Properties | Longitudinal | A | Longitudinal | B |
| | Short-transverse | B | Short-transverse | A |
| Fatigue Properties | | A | | B |
| Fatigue-Crack-Propagation Properties | Low $\Delta K$ | A | Low $\Delta K$ | B |
| | High $\Delta K$ | B | High $\Delta K$ | A |
| Fracture Properties | | A | | B |
| Stress-Corrosion Resistance | | A | | B |

NOTE: A is superior to B.

The advantages of using advanced processes to produce forgings for helicopter components will be demonstrated by example.

In designing helicopter structural components, the selection of a material involves considerations of cost, weight, reliability, and maintainability as well as basic material properties. Weight is a primary concern and results directly from satisfying structural requirements for static strength, fatigue strength, and failsafe or damage-tolerance strength.

Many helicopter structural components are aluminum forgings which are generally sized first by fatigue-strength requirements. Advanced processes for aluminum forgings possessing increased fatigue strength have potential for weight savings in direct proportion to that increase in fatigue strength. This can be demonstrated for the YUH-61A horizontal-stabilizer spar fitting, part no. 179-25101, shown in Figure 152. This component is sized for fatigue strength and the critical areas are the lugs. The fitting lug is designed for 5,000 hours of fatigue life using 7075-T73 forging. Detailed calculations presented in Appendix E show that a 5-percent increase in the design-allowable fatigue strength results in a 5-percent reduction in component weight (see Figure 153).

Potential weight savings for helicopter components sized to damage-tolerance requirements are possible by using the 7475-TMT1 or 7475-TMT2 advanced-alloy/process combination. Consider the YUH-61A antitorque-rotor collective-pitch slider, part no. 179-57370, shown in Figure 154. The pitch slider can be designed to be failsafe if equipped with a fatigue-crack-detection device which provides a visible indication (failure warning) when a small crack exists. Assume the device is examined prior to each flight and that there is a criterion requiring the partially failed component to be capable of sustaining flight loads for 30 hours subsequent to the initial failure warning.

In designing the component for these requirements, two mechanical properties are of prime concern. First, the fatigue-crack propagation-rate properties determine how fast the fatigue crack grows. Second, the fracture-toughness property determines the critical crack length which the component can be expected to sustain under the maximum load anticipated in flight.

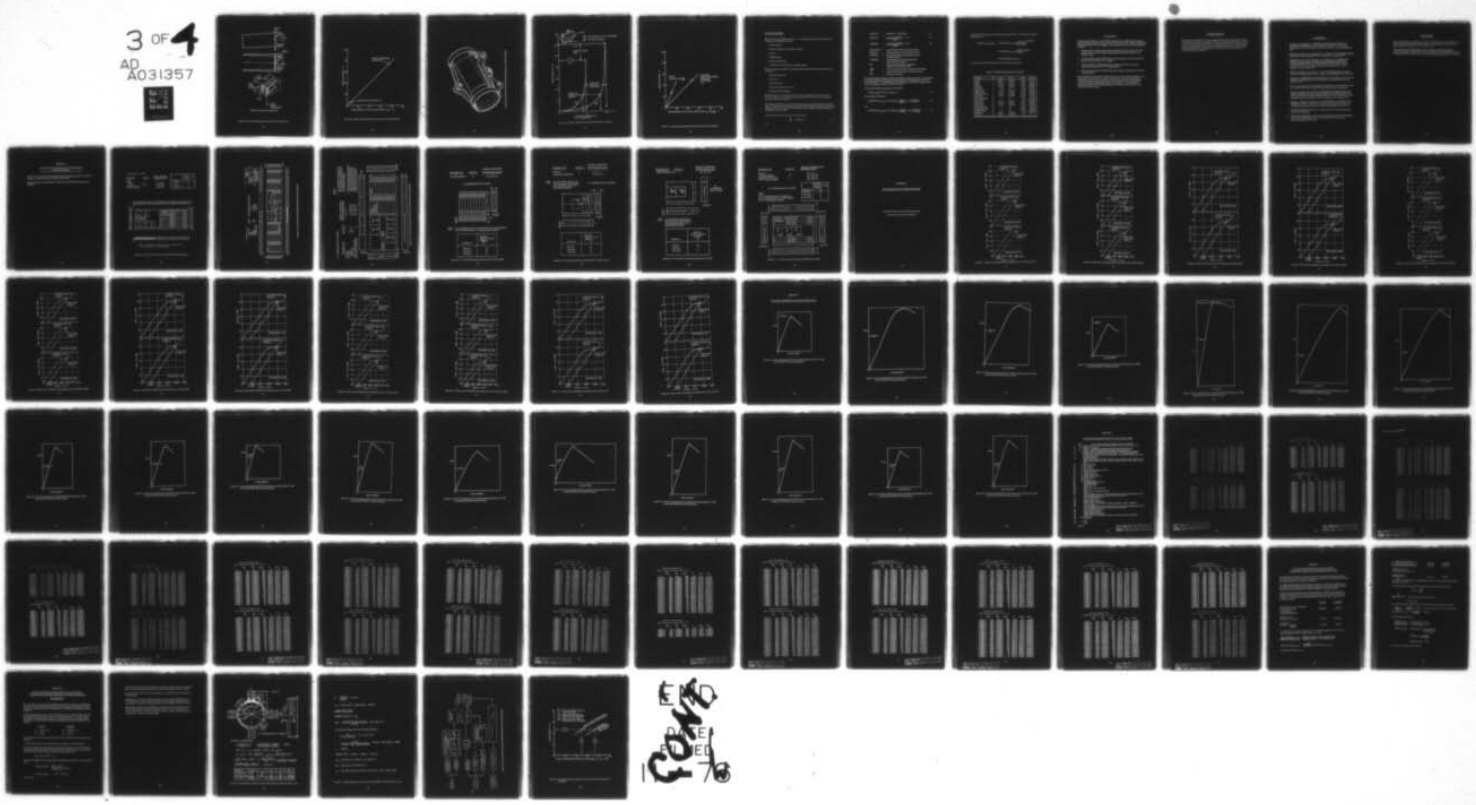
The predicted performance of the pitch slider is shown in Figure 155 and is based on the properties measured in Task III for conventional 7075-T73 and 7475-TMT2 alloy for fatigue-crack-propagation rate (Figures 127 and 146) and for fracture toughness (Table 21).

For this example, crack growth is predicted by using an RMS stress level of 865±1,605 psi with the crack model for a hollow cylinder and the Paris relationship for crack-growth rate. The computation procedure is detailed in Appendix F.

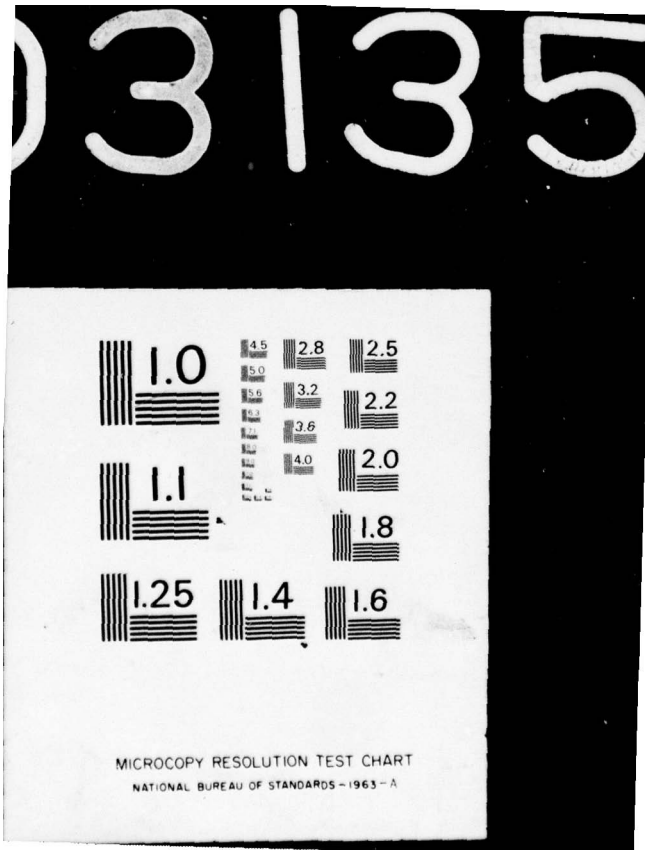
From the comparison shown in Figure 155, it can be seen that an improvement is possible with TMT forgings. This improvement can be used to provide additional reliability or to effect a weight saving and meet the original reliability. The weight saving as a function of improvement in fracture properties is shown in Figure 156. Computations are shown in Appendix F.

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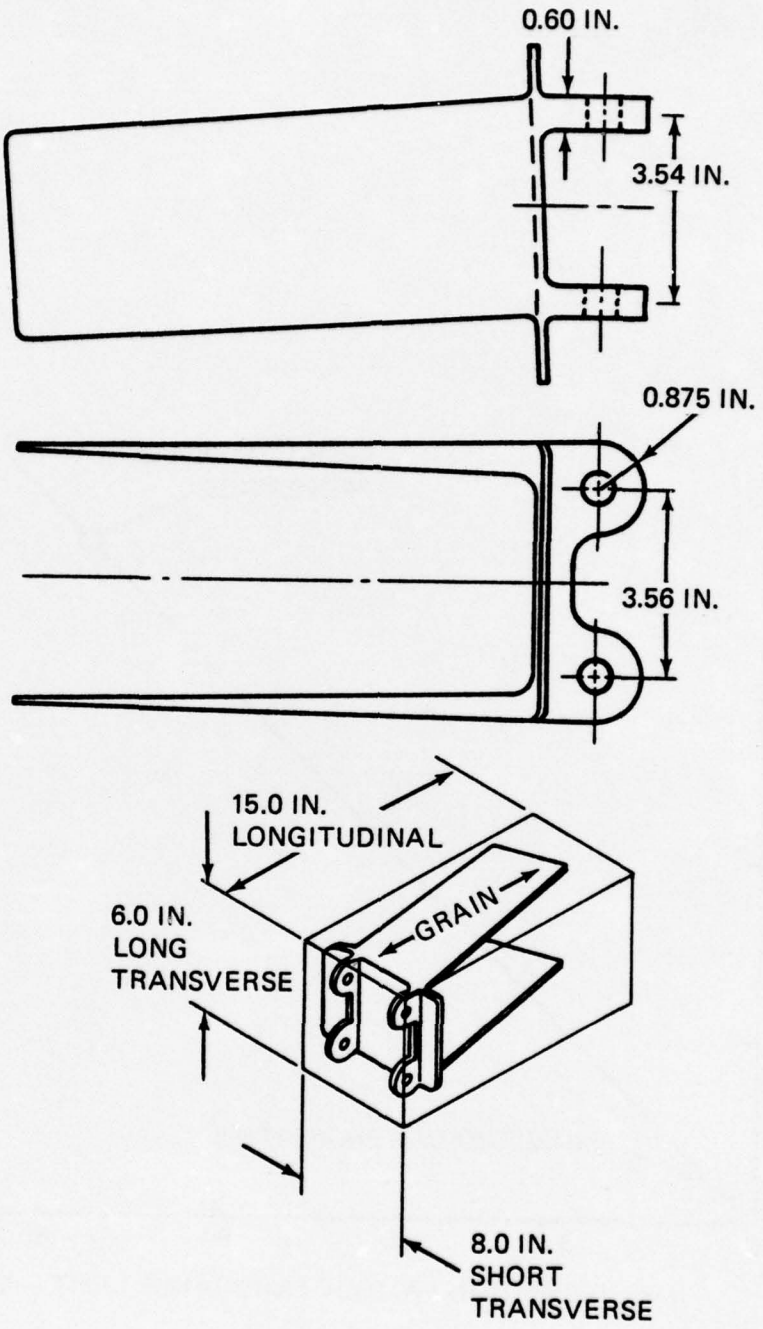



Figure 152. Horizontal Stabilizer Spar Fitting for YUH-61A UTTAS.

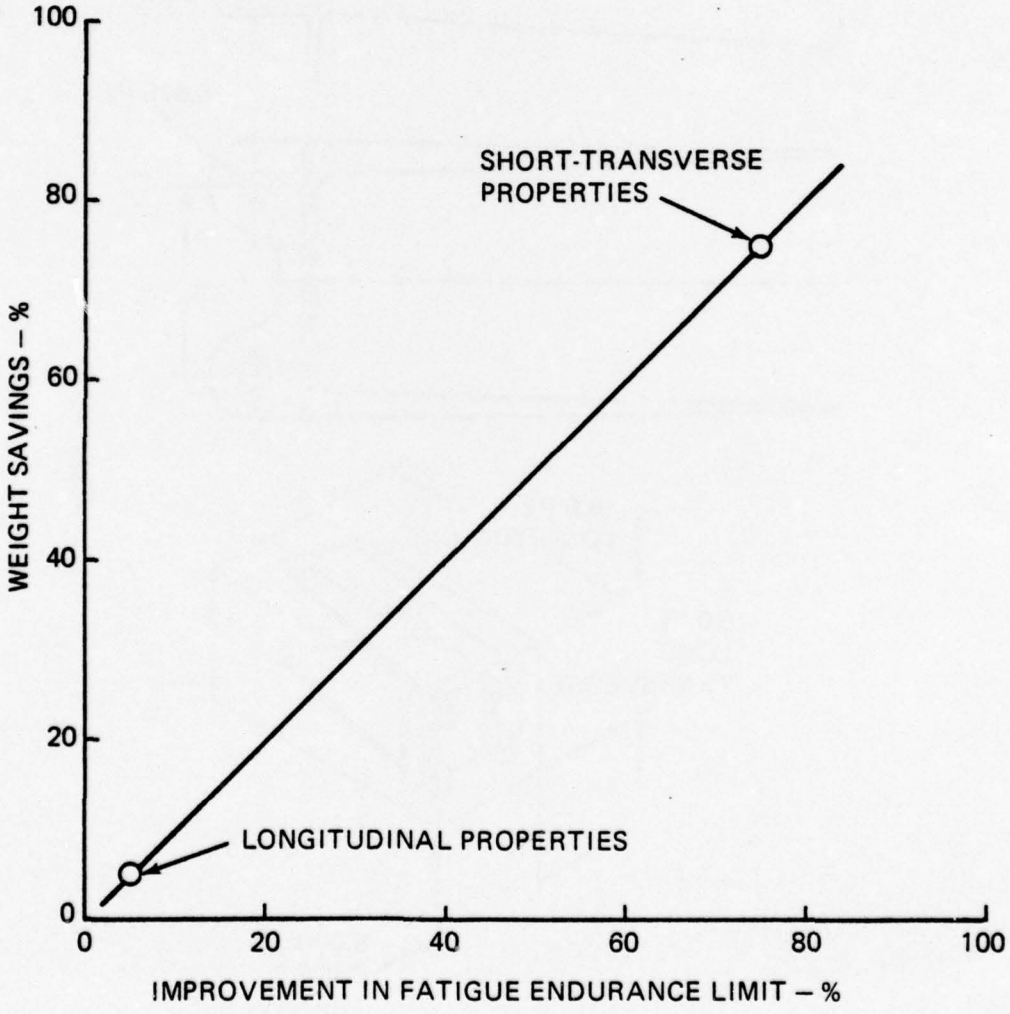



Figure 153. Weight Savings Available Through Improved Fatigue Properties.

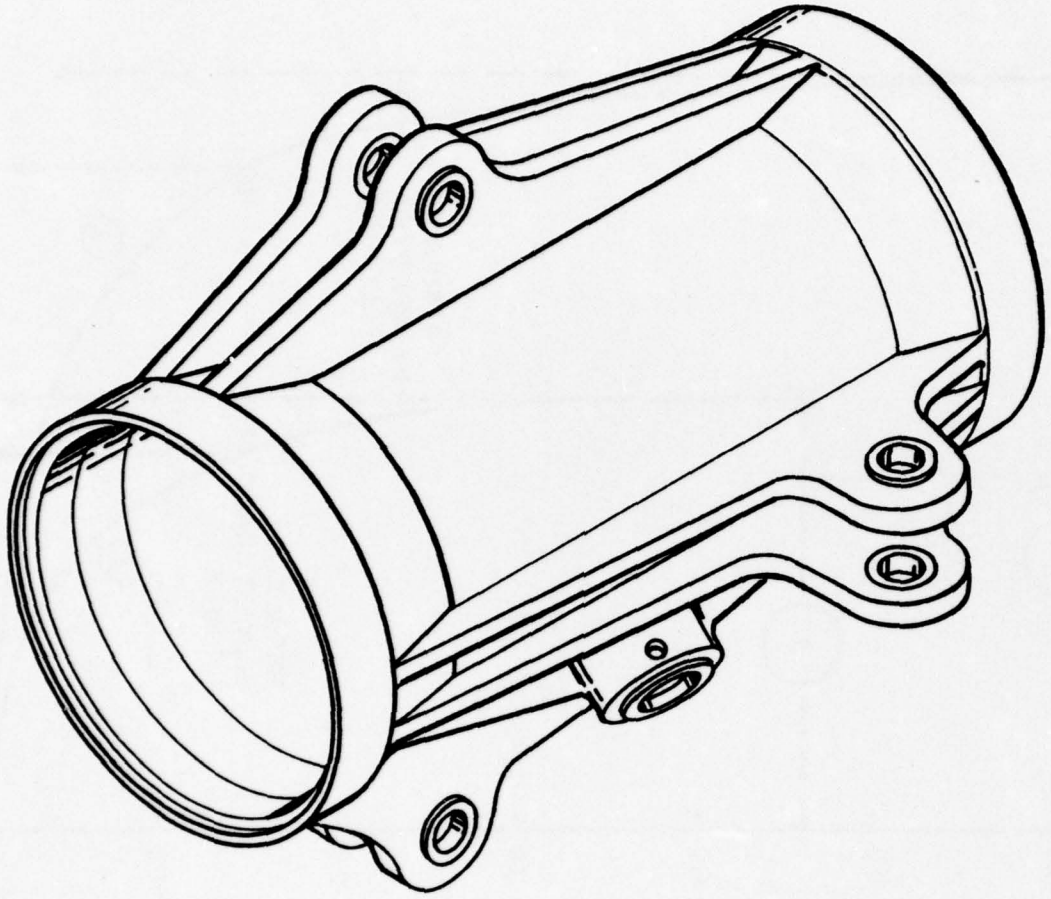


Figure 154. Collective Pitch Slider for Antitorque Rotor on YUH-61A UTTAS.

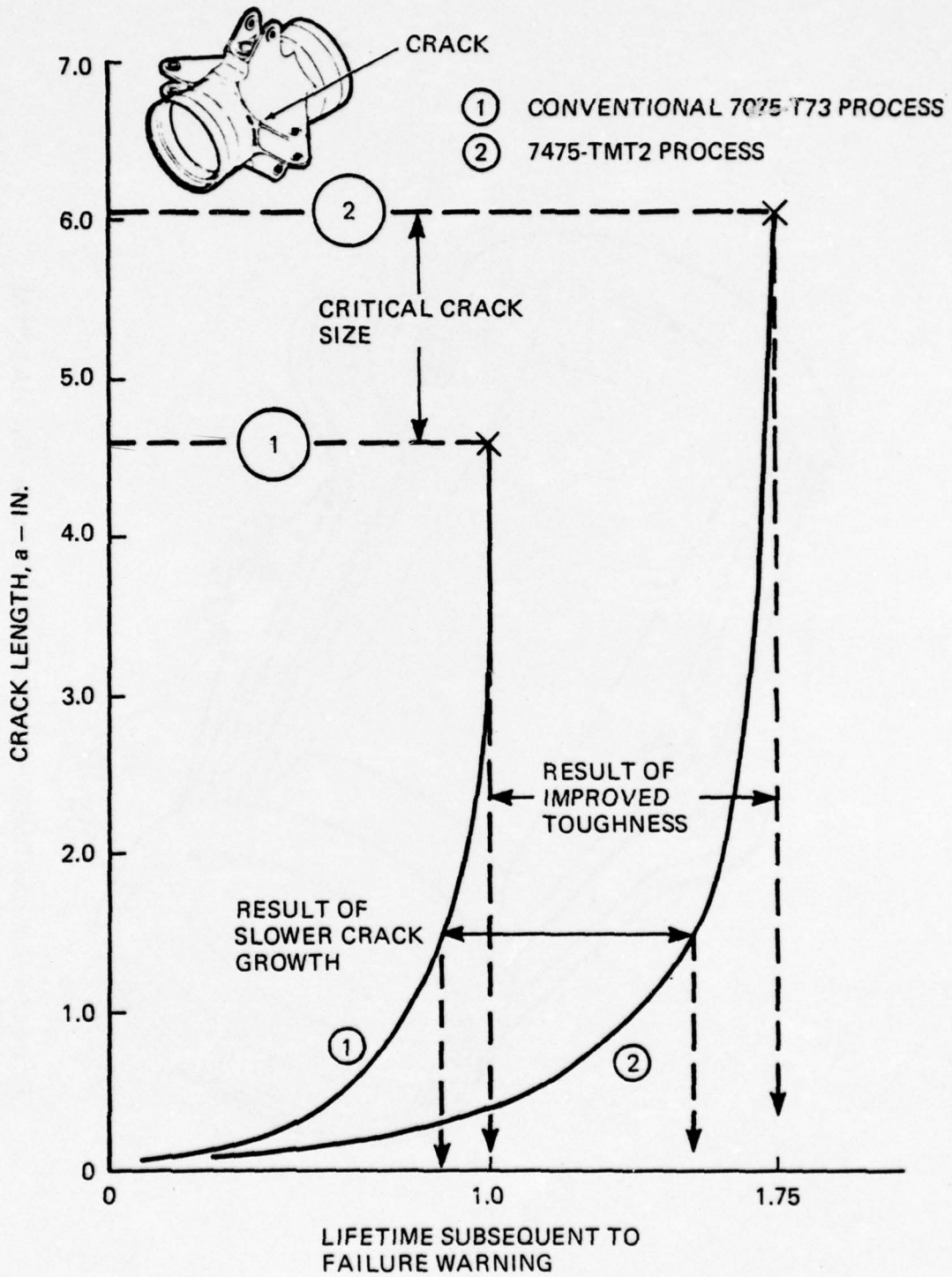



Figure 155. Improved Failsafety Through Enhanced Fracture Properties.

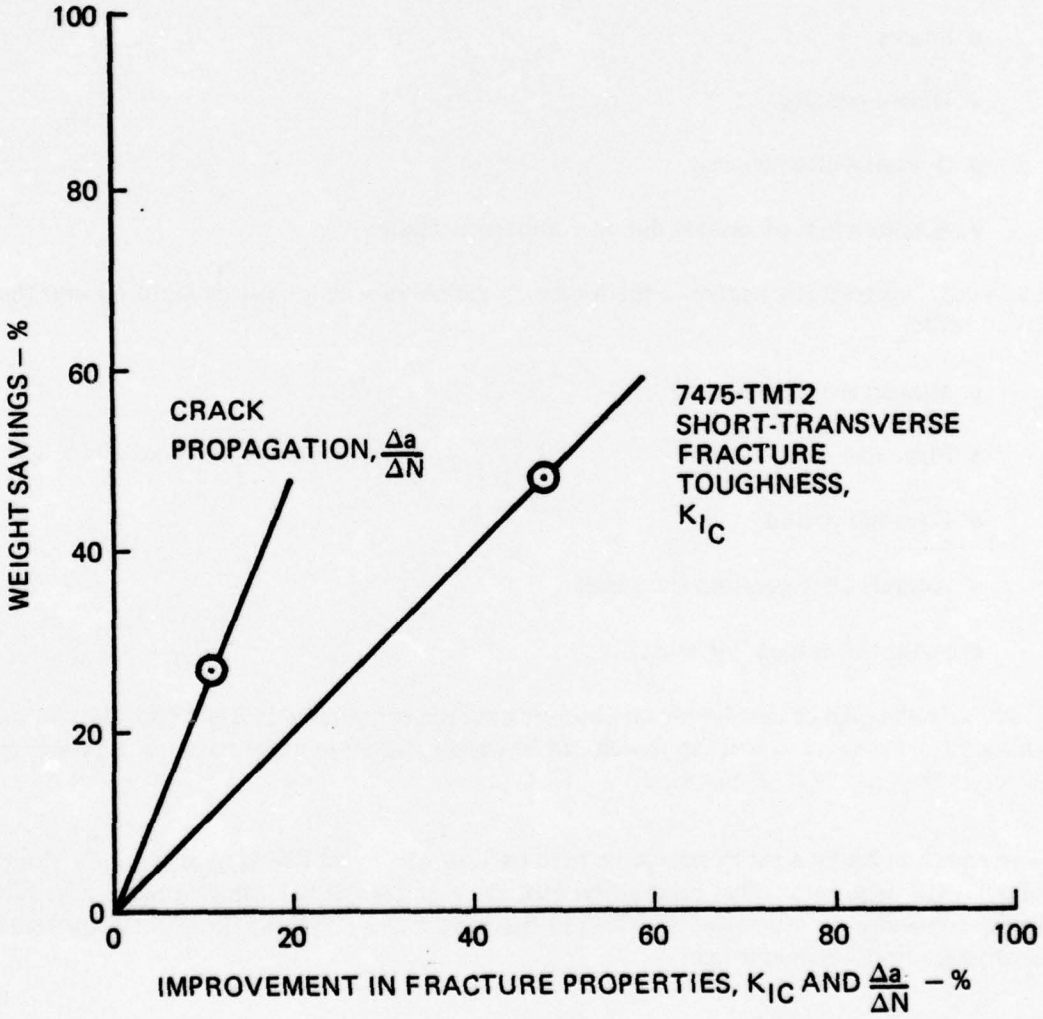



Figure 156. Weight Savings Available Through Improved Fracture Properties.

## COST EFFECTIVENESS

Weight savings are potentially cost-effective. A cost analysis involves many factors which can be grouped in the following categories:

- Unit investment
- Support (maintenance, equipment, training)
- Spares
- Weight penalty
- Operated effectiveness
- Attrition loss of aircraft due to component failure

Each cost category is sensitive to the following variables, which must be factored into the true cost profile:

- Mission requirements
- Fleet size
- Fleet life period
- Aircraft configuration (i.e., size)
- Projected dollars (inflation)

Obviously the goal of developing an absolute cost is a formidable task beyond the scope of this study. However, a basic approach can be demonstrated in order to place in proper perspective the relative costs involved.

The equation for flyaway costs can be used to illustrate a cost saving by using TMT aluminum alloys. The assumption that production quantities of TMT aluminum forgings can be fabricated as economically as conventional 7075-T73 has been made. Flyaway costs of the airframe are estimated by subsystem weight.

Average airframe per unit cost of one production aircraft

$$= \sum_{i=1}^{19} \text{CAFFCA (i)} \qquad \text{(I)}$$

and

$$CAFFCA(i) = CAFFCL(i) + CAFFCM(i) \quad (2)$$

$$CAFFCL(i) = \frac{A12L(i)\ S(i)^{B12L(i)}}{NPAC} \times G^{12} \quad (3)$$

$$CAFFCM(i) = \frac{A12M(I)\ S(i)^{B12M(i)}}{NPAC} \times G^{12} \quad (4)$$

where AVFCP = average flayaway cost of production aircraft

CAFFCA(i) = average subsystem cost of production aircraft

CAFFCL(i) = labor portion of the average subsystem cost of production aircraft

CAFFCM(i) = material portion of the average subsystem cost of production aircraft

S(i) = weight of subsystem times total aircraft produced = X(i) x (NPAC + NOP)

NPAC = number of production aircraft (excluding prototypes)

$G^{12}$ = gross modifier of the airframe portion of flyaway

NOP = number of prototypes.

The current baseline coefficients, B12L(i) and B12M(i), are given in Table 34. As an example, the production-aircraft cost savings will be demonstrated for a weight savings in the rotor system, subsystem 12. Since relative savings are of interest, it is possible to compare the flyaway cost equations for 7075-T73 and for 7475-TMT.

For a 5-percent weight saving in the rotor subsystem,

$$S(12)_{7475\text{-}TMT} = 0.95\ S(12)_{7075\text{-}T73}. \quad (5)$$

By substitution in equation 4,

$$CAFFCM(12)_{7075\text{-}T73} = \left\{A12M(12)\right\} \left(\frac{G12}{NPAC}\right) S(12)^{B12M(12)}_{7075\text{-}T73} \quad (6)$$

and

$$CAFFCM(12)_{7475\text{-}TMT} = \left\{A12M(12)\right\} \left(\frac{G12}{NPAC}\right) S(12)^{B12M(12)}_{7475\text{-}TMT} \quad (7)$$

The relative cost savings can be determined by dividing equation 7 by equation 6 and substituting equation 5:

$$CAFFCM(12)_{7475\text{-}TMT} = CAFFCM(12)_{7075\text{-}T73}\left(\frac{S(12)_{TMT}}{S(12)_{T73}}\right)^{B12M(12)}$$

$$= CAFFCM(12)_{7075\text{-}T\text{-}73}\left(\frac{0.95}{1.00}\right)^{0.84899}$$

$$= 0.96\ CAFFCM(12)_{7075\text{-}T73},$$

or a 4-percent savings in the flyaway cost of each production aircraft.

TABLE 34. SUBSYSTEM COST-WEIGHT COEFFICIENTS

| Subsystem | X(i) | A12L(i) | B12L(i) | A12M(i) | B12M(i) |
|---|---|---|---|---|---|
| Fuselage | 1 | 39,063.35 | 0.486394 | 126.88 | 0.812642 |
| Wings | 2 | 15,401.34 | 0.531771 | 98.45 | 0.809710 |
| Nacelles | 3 | 6,425.37 | 0.633160 | 484.84 | 0.846940 |
| Empennage | 4 | 24,383.69 | 0.468590 | 110.11 | 0.816530 |
| Armor Plate | 5 | 0.0 | 1.0 | 10.065 | 0.94226 |
| Alighting Gear | 6 | 1,953.87 | 0.623630 | 100.71 | 0.859430 |
| Flight Controls | 7 | 708.67 | 0.722290 | 255.48 | 0.854320 |
| Hydraulic/Electrical | 8 | 11,057.01 | 0.630270 | 613.32 | 0.865070 |
| Instruments | 9 | 1,914.29 | 0.697960 | 356.94 | 0.922710 |
| Air Cond & Deicing | 10 | 0 | 1.0 | 789.3 | 0.8635779 |
| Personal Accom | 11 | 0 | 1.0 | 35.935 | 0.8615416 |
| Rotor System | 12 | 2,889.21 | 0.646230 | 190.92 | 0.848990 |
| Drive System | 13 | 2,542.42 | 0.654770 | 267.82 | 0.847810 |
| Fuel System | 14 | 1,231.99 | 0.632870 | 312.42 | 0.857300 |
| Engine Accessories | 15 | 0 | 1.0 | 790.62 | 0.8550757 |
| Airframe Electronics | 16 | 0 | 1.0 | 1,391.2 | 0.8623805 |
| Passenger/Cargo | 17 | 0 | 1.0 | 69.647 | 0.8655591 |
| Propeller Inst | 18 | 2,889.21 | 0.646230 | 190.92 | 0.848990 |
| Integration | 19 | 54,852.0 | 0.4416448 | 0.0 | 1.0 |

## CONCLUSIONS

The goal of this program was to achieve ITMT aluminum-alloy forgings that have equivalent tensile properties and stress corrosion resistance, and 20 percent better toughness fatigue properties than conventional 7075-T73 forgings. This goal has been achieved and, in some instances, exceeded:

1. Tensile properties of ITMT aluminum-alloy forgings are better than those of 7075-T73 forgings in that the TMT materials have equivalent strength, higher elongation, and reduction in area.

2. Fracture-toughness values of ITMT aluminum-alloy forgings are as much as 62 percent higher than conventional 7075-T73 forgings.

3. Fatigue properties of ITMT aluminum-alloy forgings are as much as 62 percent higher than conventional 7075-T73 forging properties.

4. Stress-corrosion properties of TMT aluminum-alloy forgings are equivalent to 7075-T73 forging properties.

These advantages have been achieved within the limits of current industrial forging practices. Undoubtedly, the potential for still further improvements exists if present-day forging constraints imposed by machine capacity are expanded beyond today's industrial limits. It has been demonstrated that ITMT forgings are cost-effective. The development of further improvements in ITMT forging technology will, therefore, also improve the cost-effectiveness of these practices.

## RECOMMENDATIONS

The results of this program show that Intermediate Thermal-Mechanical Treatment (ITMT) is a technique for improving the properties of 7XXX-series aluminum-alloy forgings, and that it is a cost-effective means of saving weight in helicopter components. The next step recommended is a program for the fabrication of an actual helicopter component using an ITMT-processed aluminum alloy and for side-by-side test evaluation of this component with a conventional aluminum component.

## REFERENCES


1. Cebulak, W. S., and Truax, D. J., PROGRAM TO DEVELOP HIGH STRENGTH ALUMINUM POWDER METALLURGY PRODUCT, PHASE III – SCALE UP A, Final Report, U.S. Army Frankford Arsenal Contract DAAA25-70-C-0358, September 1972.

2. Sommer, A. W., Paton, N. E., and Folgner, D. G., EFFECTS OF THERMOMECHANICAL TREATMENTS ON ALUMINUM ALLOYS, AFML-TR-72-5, February 1972.

3. Thompson, D. S., Levy, S. A., Spangler, G. E., and Benson, D. K., PROGRAM TO IMPROVE THE FRACTURE TOUGHNESS AND FATIGUE RESISTANCE OF ALUMINUM SHEET AND PLATE FOR AIRCRAFT APPLICATIONS, WPAFB Contract F33615-72-C-1202, Semiannual report for the period June 1, 1972, to December 31, 1972, January 1973.

4. Conserva, M., DiRusso, E., and Gatto, F., A NEW THERMOMECHANICAL TREATMENT FOR Al-Zn-Mg TYPE ALLOYS, Alumino e Nuovo Metallurgia, 9, 441-445, 1968.

5. Ostermann, F., IMPROVED FATIGUE RESISTANCE OF Al-Zn-Mg-Cu (7075) ALLOYS THROUGH THERMOMECHANICAL PROCESSING, Metallurgical Transactions, 2, 2897-2902, 1971.

6. Ruch, L., and Sulinski, H., FINAL THERMAL MECHANICAL TREATMENT OF 7039, 7075, X7007, AND X7050 ALLOYS, Frankford Arsenal report (in preparation).

7. Hyatt, M. V., Early, D. O., and Pasley, D. H., PROGRAM TO IMPROVE THE FRACTURE TOUGHNESS AND FATIGUE RESISTANCE OF ALUMINUM SHEET AND PLATE FOR AIRFRAME APPLICATIONS, WPAFB Contract No. F33615-72-C-1649, Semiannual report for period July 1, 1972, to December 31, 1972, January 1973.

8. Waldman, J., Sulinski, H., and Markus, H., NEW PROCESSING TECHNIQUES FOR ALUMINUM ALLOYS, presented at the Army Materials Technology Conference on Solidification Technology, Wentworth by the Sea, New Hampshire, October 1972.

9. STANDARD TENSION TEST, E8-61T, American Society for Testing and Materials, Philadelphia, Pennsylvania.

10. TENTATIVE METHOD OF TEST FOR PLANE-STRAIN FRACTURE TOUGHNESS OF METALLIC MATERIALS, E399-72T, American Society for Testing and Materials, Philadelphia, Pennsylvania.

## BIBLIOGRAPHY

Boyd, J. D., Drennan, D. C., Martin, C. J., Price, C. W., Rosenfield, A. R., and Williams, D. N., RESEARCH ON SYNTHESIS OF HIGH STRENGTH ALUMINUM ALLOYS, Technical Report AFML-TR-72-199, July 1, 1971 to July 31, 1972.

1964 BOOK OF ASTM STANDARDS, PART 30, GENERAL TESTING METHODS; QUALITY CONTROL; APPEARANCE TESTS; TEMPERATURE MEASUREMENT; EFFECT OF TEMPERATURE, American Society for Testing and Materials, Philadelphia, Pennsylvania.

# APPENDIX A

## LOCATION AND ORIENTATION OF TEST SPECIMENS IN TASK II FORGINGS

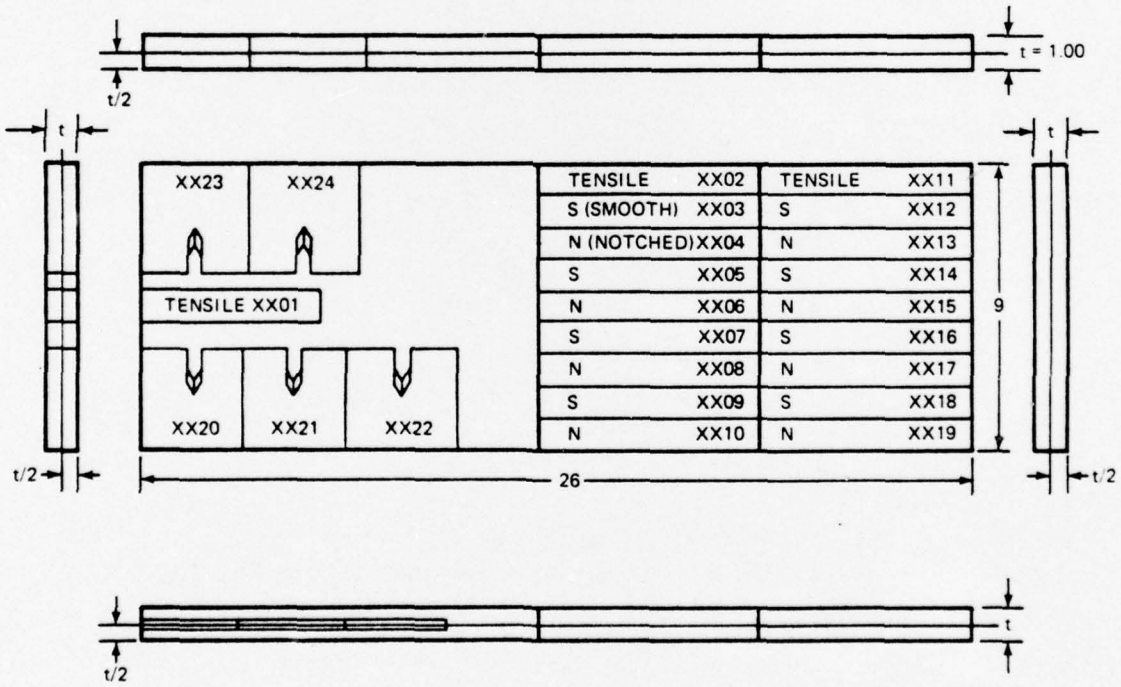
Figures A1, A2, and A3 indicate forging dimensions and define the sequence of events for producing the final sections used to fabricate test specimens.

The exact location of each individual test specimen can be identified from Figures A4 through A7.

ALL DIMENSIONS ARE IN INCHES.

| SPECIMEN TYPE | QUANTITY | NOMINAL DIMENSIONS FOR SPECIMEN BLANKS |
|---|---|---|
| TENSILE | 3 | 5.7 x 1 x 1 |
| FATIGUE | | |
| SMOOTH | 8 } 16 | 6.7 x 0.8 x 0.8 |
| NOTCHED | 8 } | 6.7 x 0.8 x 0.8 |
| CRACK-PROPAGATION | 3 | 3.2 x 3.2 x 0.6 |
| FRACTURE-TOUGHNESS | 2 | 3.5 x 3.4 x 1.0 |

| MATERIAL | SECTION IDENTIFICATION NUMBER, XX |
|---|---|
| 7075-T73 | 01 |
| 7475-TMT1 | 07 |
| 7475-TMT2 | 13 |




NOTE: t/2, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

Figure A1. One-Inch-Thick Forging for Specimens XX01 Through XX24.

ALL DIMENSIONS ARE IN INCHES.

| SPECIMEN TYPE | QUANTITY | | NOMINAL DIMENSIONS FOR SPECIMEN BLANKS |
|---|---|---|---|
| TENSILE | 3 | | 5.7 x 1 x 1 |
| FATIGUE | | | |
| SMOOTH | 25 | 49 | 6.7 x 0.8 x 0.8 |
| NOTCHED | 24 | | 6.7 x 0.8 x 0.8 |
| CRACK-PROPAGATION | 3 | | 3.2 x 3.2 x 0.6 |
| FRACTURE-TOUGHNESS | 2 | | 3.5 x 3.4 x 1.4 |

| MATERIAL | SECTION IDENTIFICATION NUMBER, XX |
|---|---|
| 7475-TMT1 | 08 |
| 7475-TMT2 | 14 |

NOTE: t/2, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

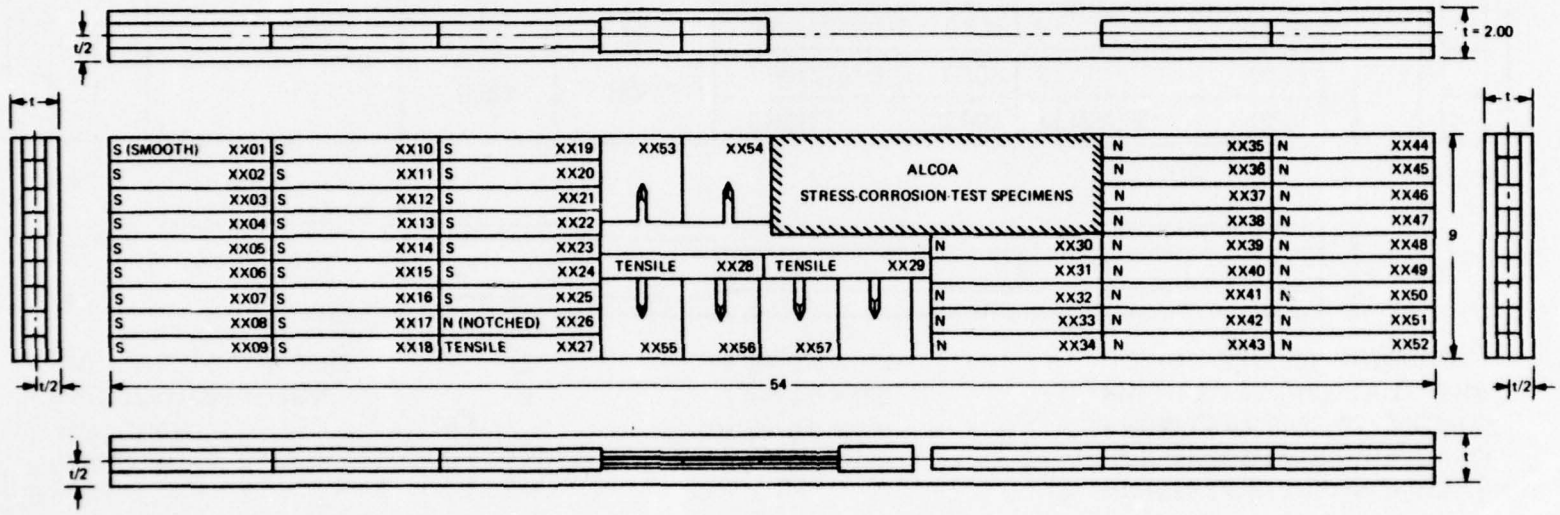



Figure A2. Two-Inch-Thick Forging for Specimens XX01 Through XX57.

ALL DIMENSIONS ARE IN INCHES.

| SPECIMEN TYPE | QUANTITY | NOMINAL DIMENSIONS FOR SPECIMEN BLANKS |
|---|---|---|
| TENSILE | 3 | 5.7 x 1 x 1 |
| FATIGUE | | |
| SMOOTH | 8 } 16 | 6.7 x 0.8 x 0.8 |
| NOTCHED | 8 } | 6.7 x 0.8 x 0.8 |
| CRACK-PROPAGATION | 3 | 3.2 x 3.2 x 0.6 |
| FRACTURE-TOUGHNESS | 2 | 3.5 x 3.4 x 1.4 |

NOTES:

1. t/2, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.
2. STRESS-CORROSION SPECIMENS FOR ALCOA WERE REMOVED FROM LEFT SIDE OF SECTION PRIOR TO DELIVERY TO THE BOEING VERTOL COMPANY.

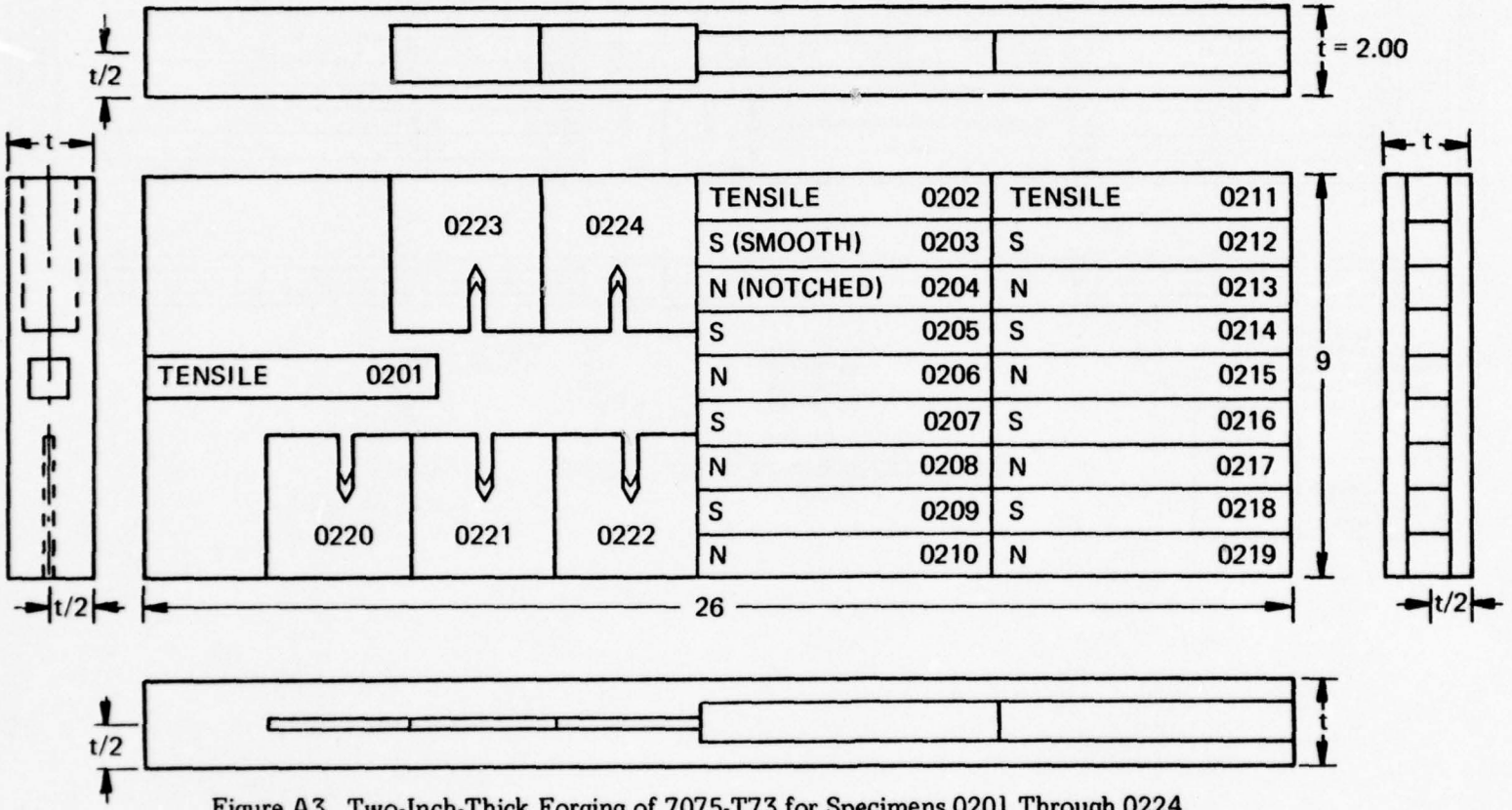
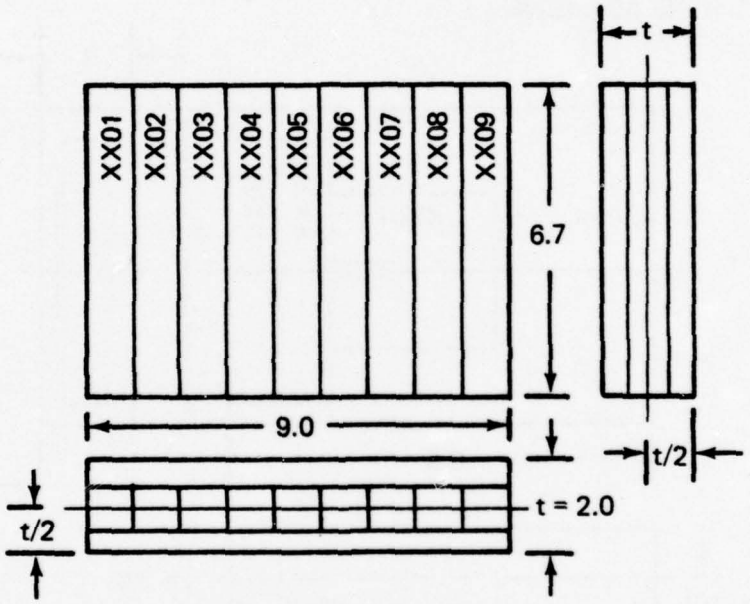



Figure A3. Two-Inch-Thick Forging of 7075-T73 for Specimens 0201 Through 0224.

| SPECIMEN TYPE | QUANTITY | NOMINAL DIMENSIONS FOR SPECIMEN BLANKS |
|---|---|---|
| FATIGUE, SMOOTH | 9 | 6.7 x 0.8 x 0.8 |

ALL DIMENSIONS ARE IN INCHES.




NOTE: t/2, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

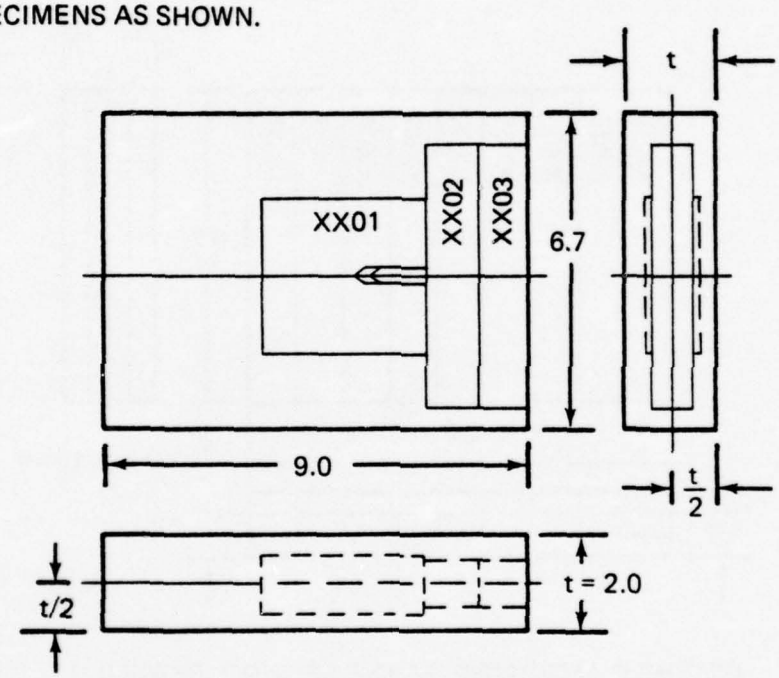
| MATERIAL | SECTION IDENTIFICATION NUMBER, XX |
|---|---|
| 7075-T73 | 03 |
| 7475-TMT1 | 09 |
| 7475-TMT2 | 15 |

Figure A4. 6.7-Inch-Thick Forging for Specimens XX01 Through XX08.

| SPECIMEN TYPE | QUANTITY | NOMINAL DIMENSIONS FOR SPECIMEN BLANKS |
|---|---|---|
| TENSILE | 2 | 5.7 x 1 x 1 |
| FRACTURE-TOUGHNESS | 1 | 3.5 x 3.4 x 1.4 |

NOTE: t/2, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

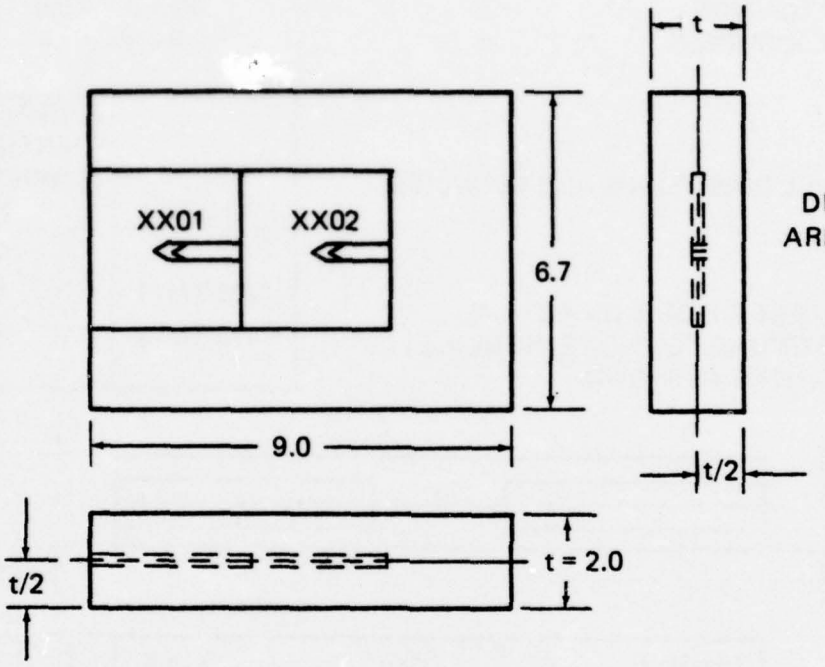
ALL DIMENSIONS ARE IN INCHES.




| MATERIAL | SECTION IDENTIFICATION NUMBER, XX |
|---|---|
| 7075-T73 | 04 |
| 7475-TMT1 | 10 |
| 7475-TMT2 | 16 |

Figure A5. 6.7-Inch-Thick Forging for Specimens XX01, XX02, and XX03.

| SPECIMEN TYPE | QUANTITY | NOMINAL DIMENSIONS FOR SPECIMEN BLANKS |
|---|---|---|
| CRACK-PROPAGATION | 2 | 3.2 x 3.2 x 0.6 |




ALL DIMENSIONS ARE IN INCHES.

NOTE: t/2, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

| MATERIAL | SECTION IDENTIFICATION NUMBER, XX |
|---|---|
| 7075-T73 | 05 |
| 7475-TMT1 | 11 |
| 7475-TMT2 | 17 |

Figure A6. 6.7-Inch-Thick Forging for Specimens XX01 and XX02.

| SPECIMEN TYPE | QUANTITY | NOMINAL DIMENSIONS FOR SPECIMEN BLANKS |
|---|---|---|
| TENSILE | 2 | 5.7 x 1 x 1 |
| FATIGUE, SMOOTH | 8 | 6.7 x 0.8 x 0.8 |
| CRACK-PROPAGATION | 2 | 3.2 x 3.2 x 0.6 |
| FRACTURE-TOUGHNESS | 1 | 3.5 x 3.4 x 1.4 |

ALL DIMENSIONS ARE IN INCHES.

| MATERIAL | SECTION IDENTIFICATION NUMBER, XX |
|---|---|
| 7075-T73 | 06 |
| 7475-TMT1 | 12 |
| 7475-TMT2 | 18 |

NOTE:

t/2, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

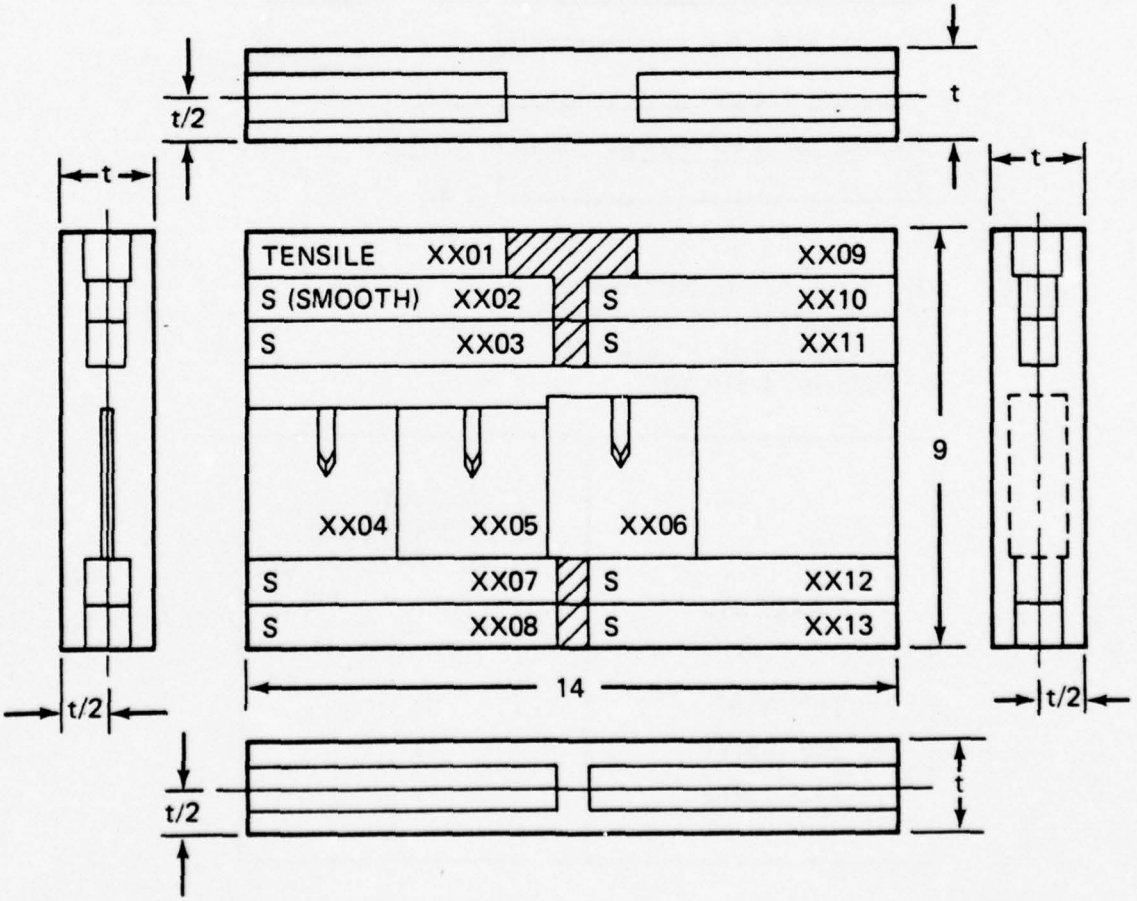



Figure A7. 6.7-Inch-Thick Forging for Specimens XX01 Through XX13.

# APPENDIX B

## LOAD-STRAIN PLOTS OF FORGING SPECIMENS

Load-strain traces for the 30 standard tension tests are presented in Figures B1 through B12.

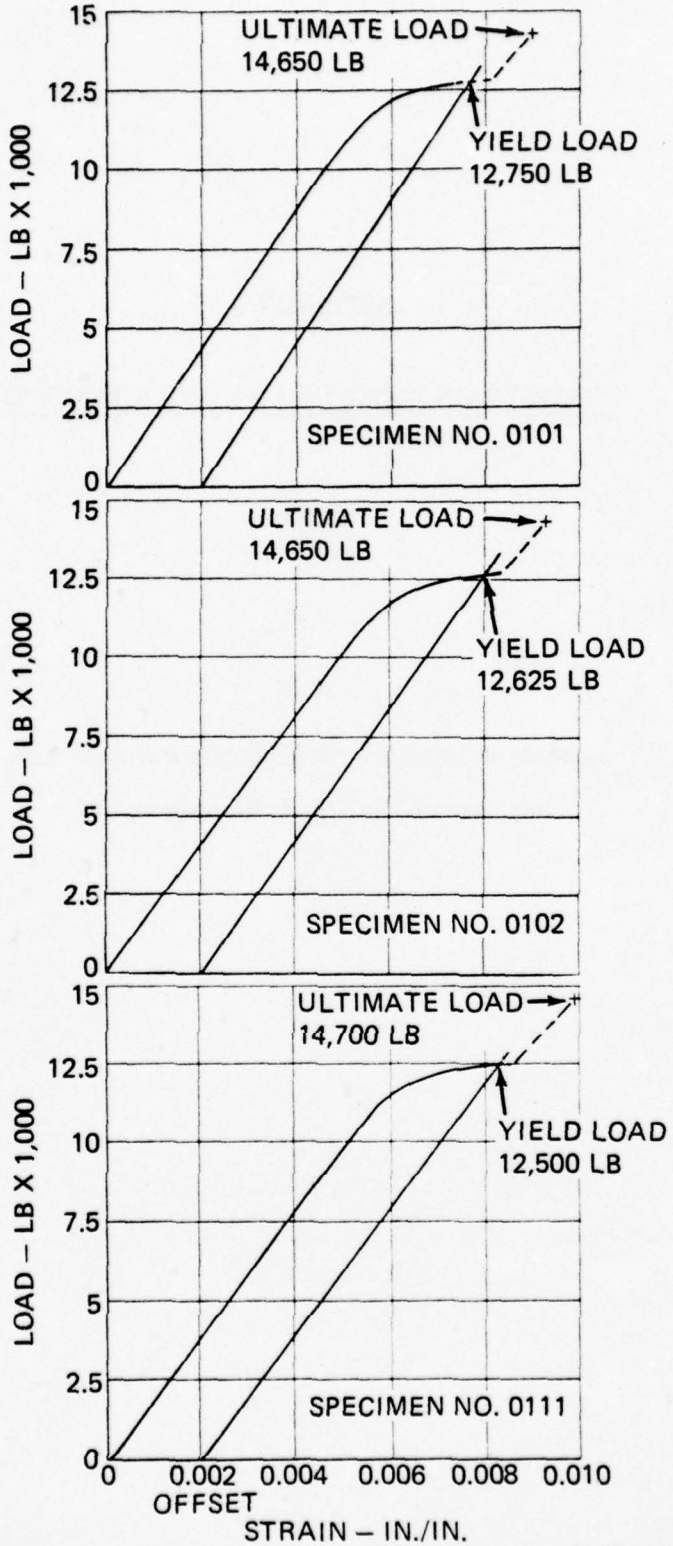



Figure B1. Tension Tests of Standard Round Specimens No. 0101, 0102, and 0111.

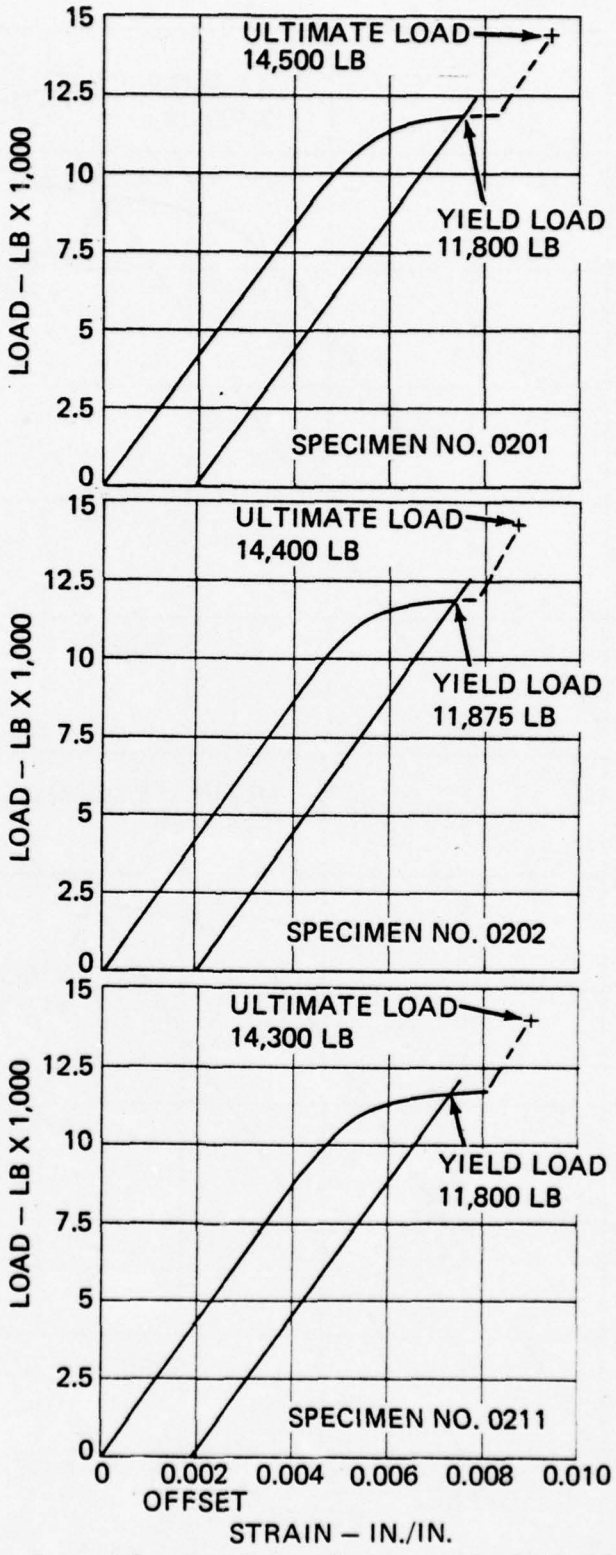



Figure B2. Tension Tests of Standard Round Specimens No. 0201, 0202, and 0211.

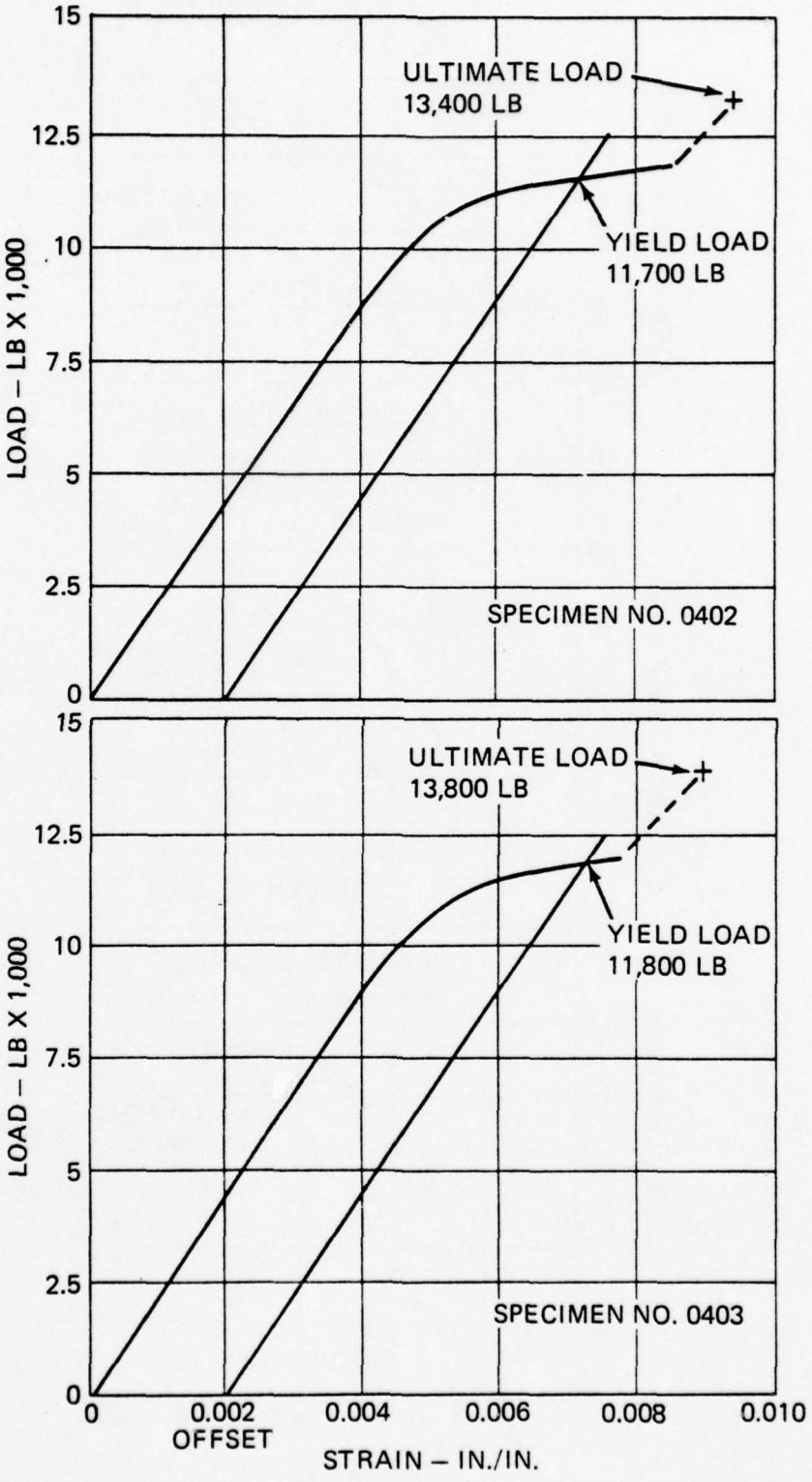



Figure B3. Tension Tests of Standard Round Specimens No. 0402 and 0403.

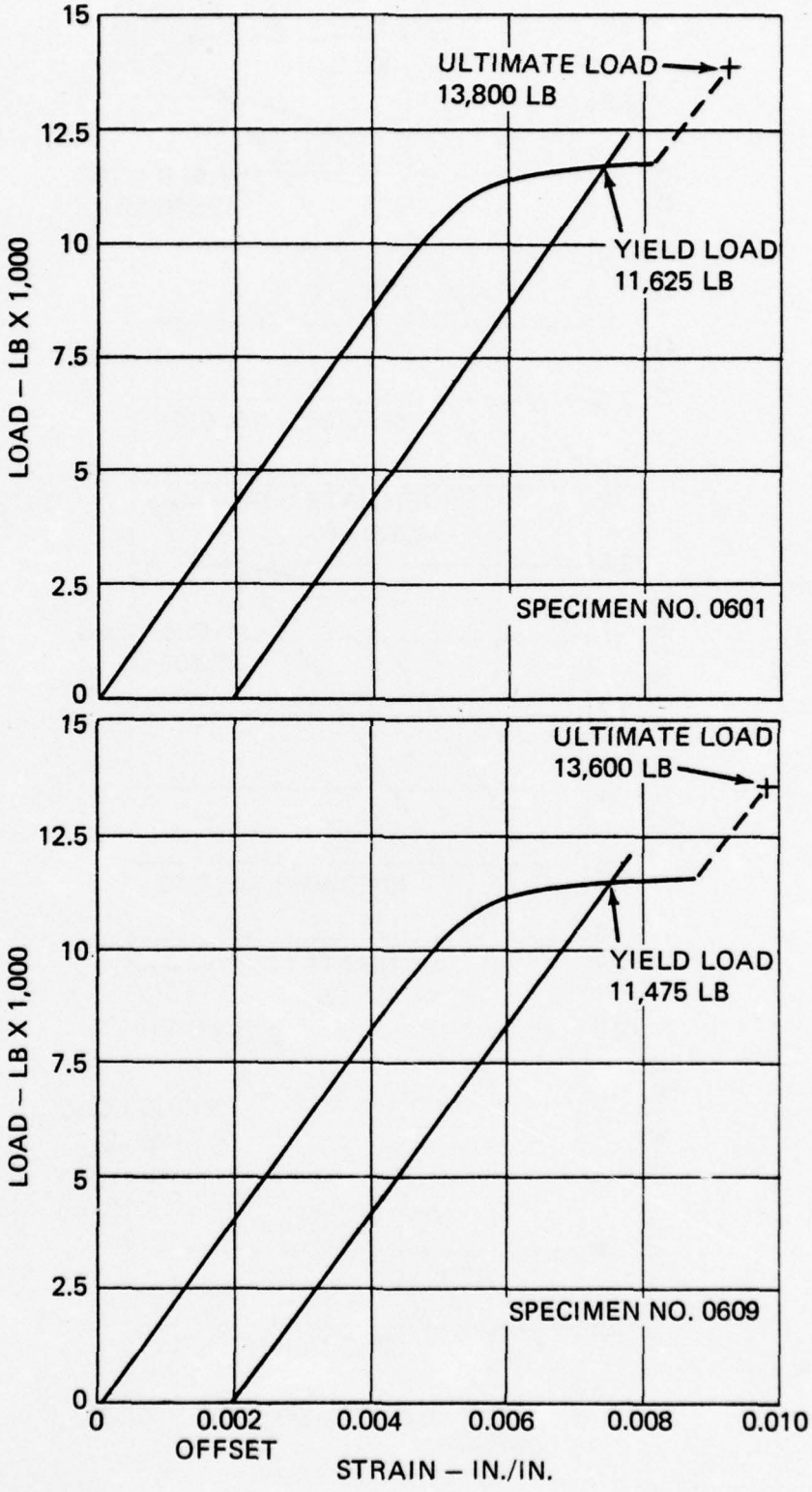



Figure B4. Tension Tests of Standard Round Specimens No. 0601 and 0609.

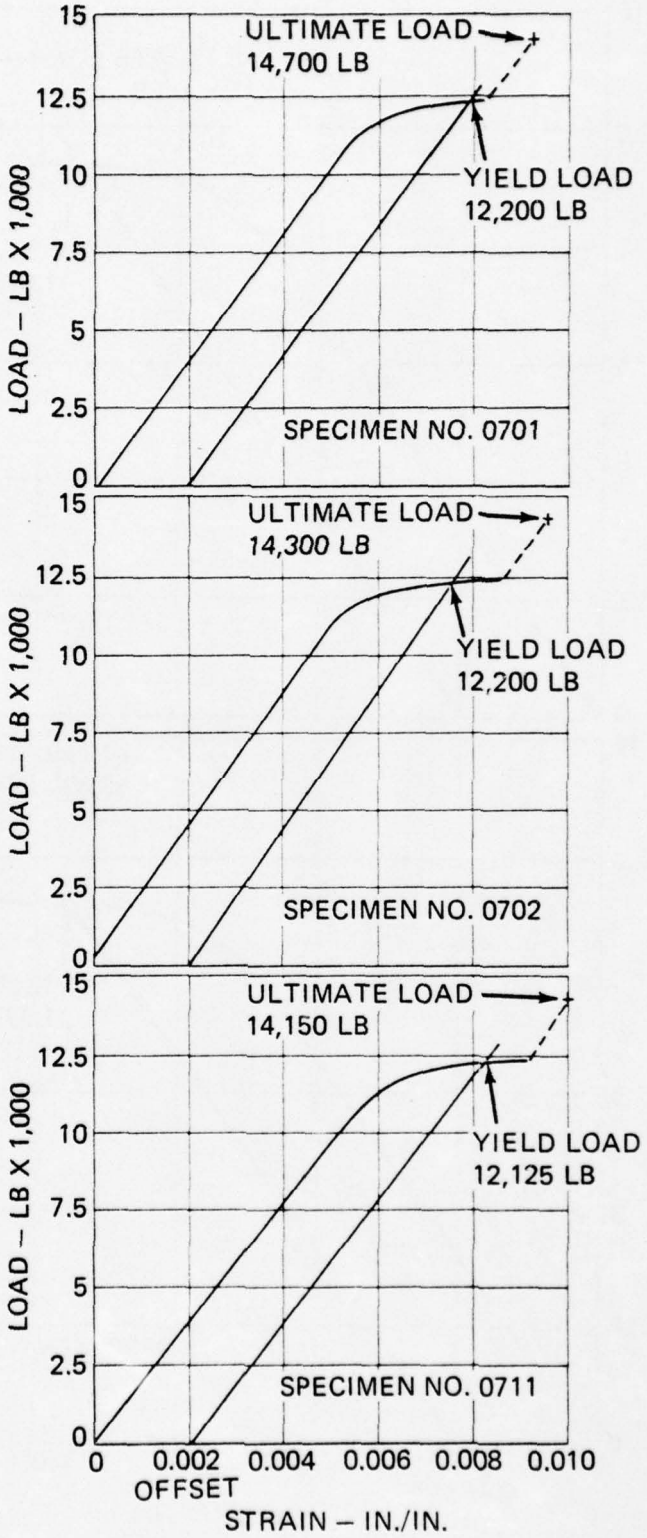



Figure B5. Tension Tests of Standard Round Specimens No. 0701, 0702, and 0711.

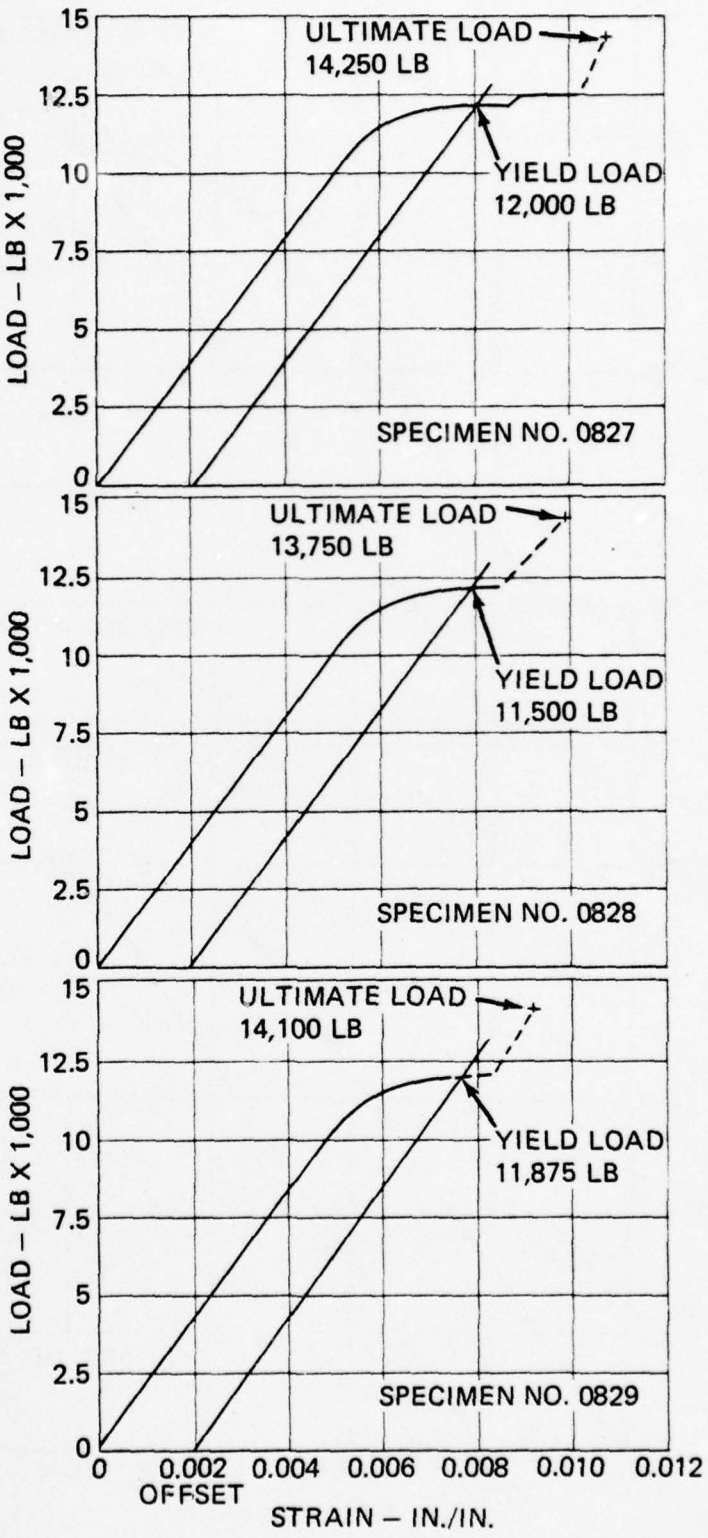



Figure B6. Tension Tests of Standard Round Specimens No. 0827, 0828, and 0829.

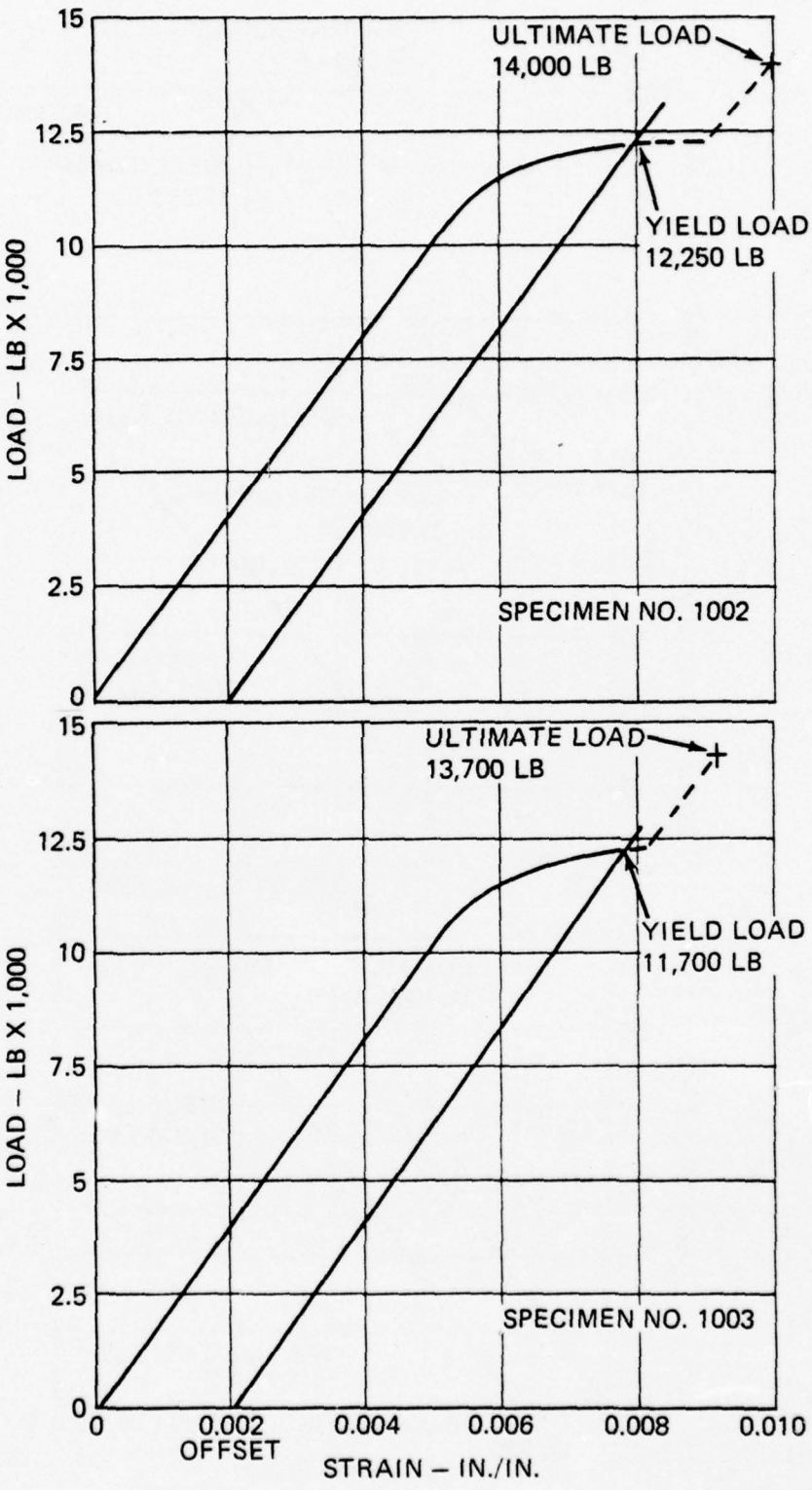



Figure B7. Tension Tests of Standard Round Specimens No. 1002 and 1003.

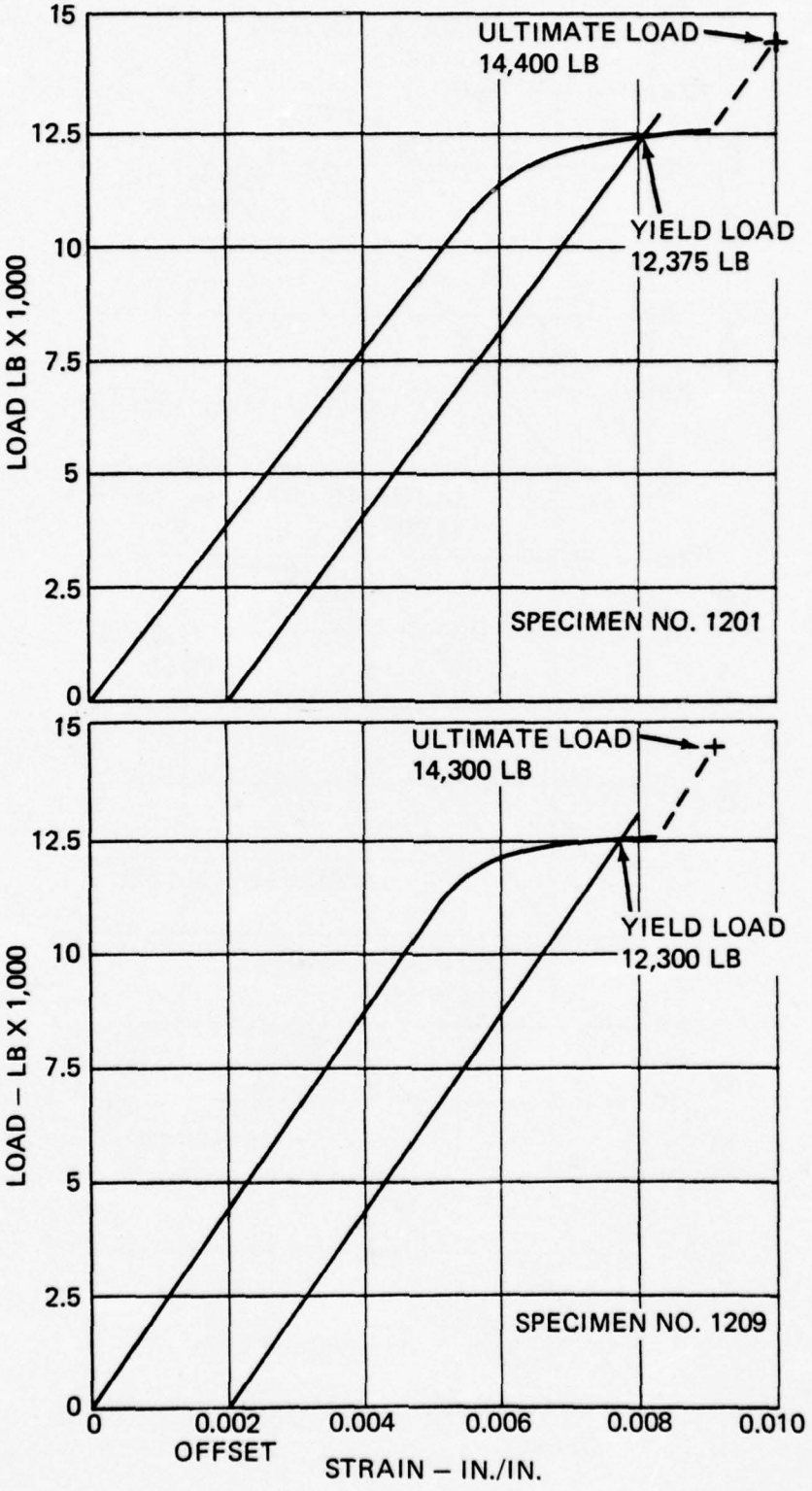



Figure B8. Tension Tests of Standard Round Specimens No. 1201 and 1209.

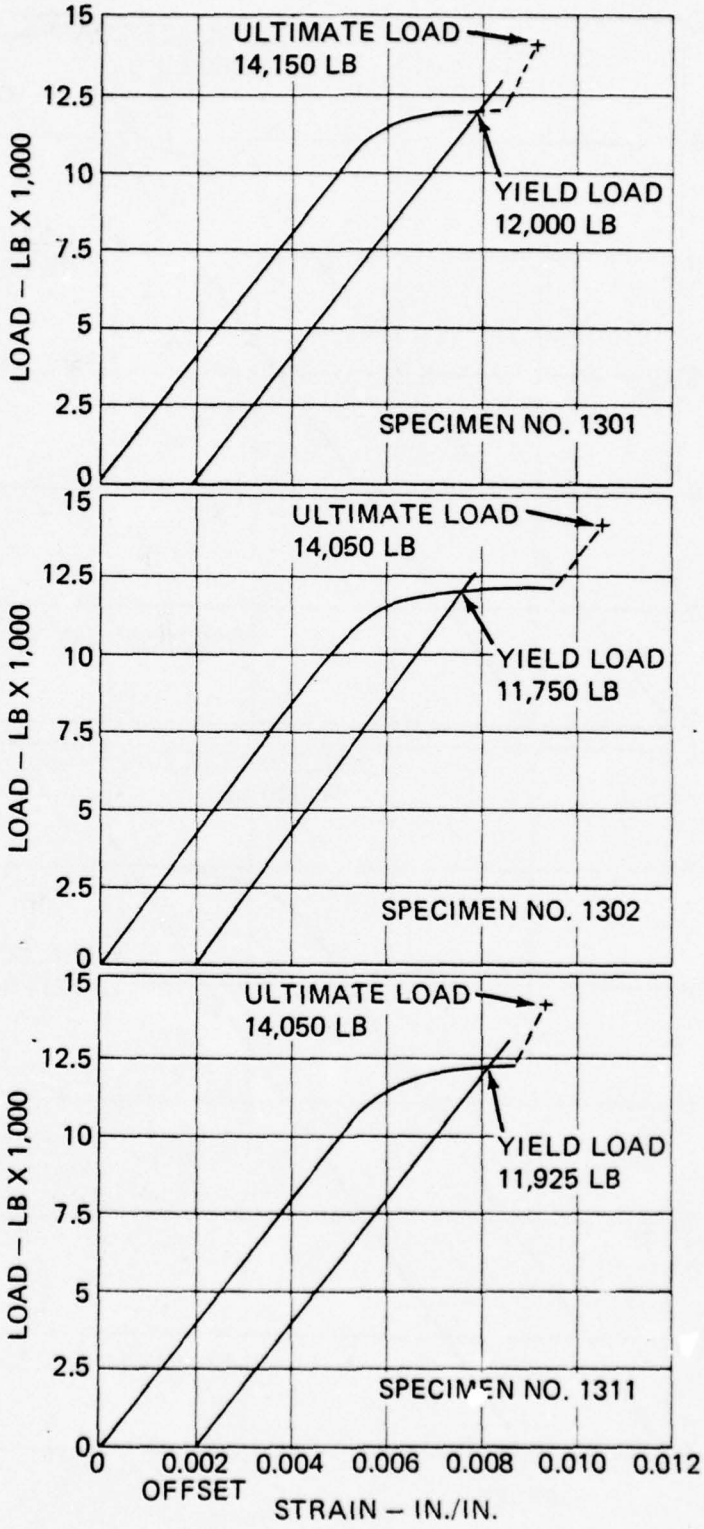



Figure B9. Tension Tests of Standard Round Specimens No. 1301, 1302, and 1311.

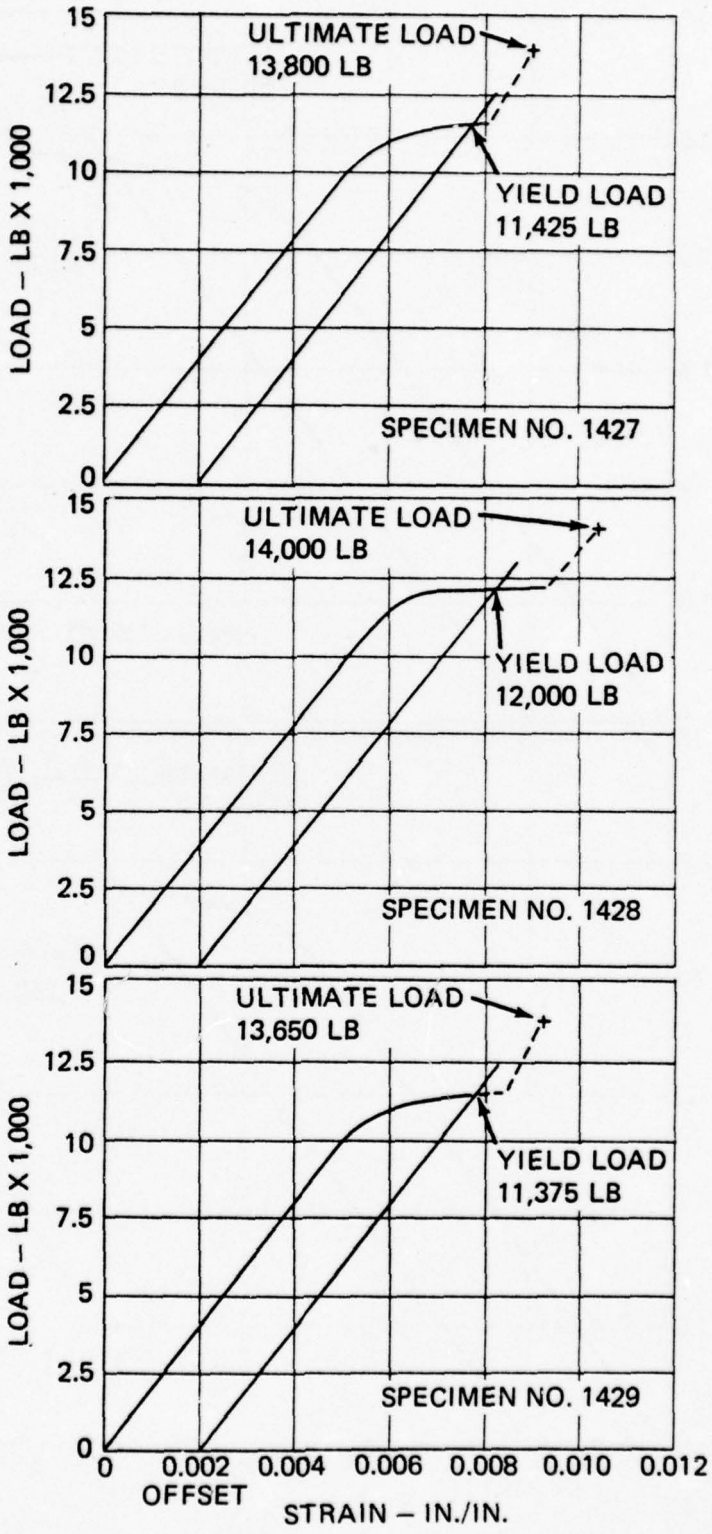



Figure B10. Tension Tests of Standard Round Specimens No. 1427, 1428, and 1429.

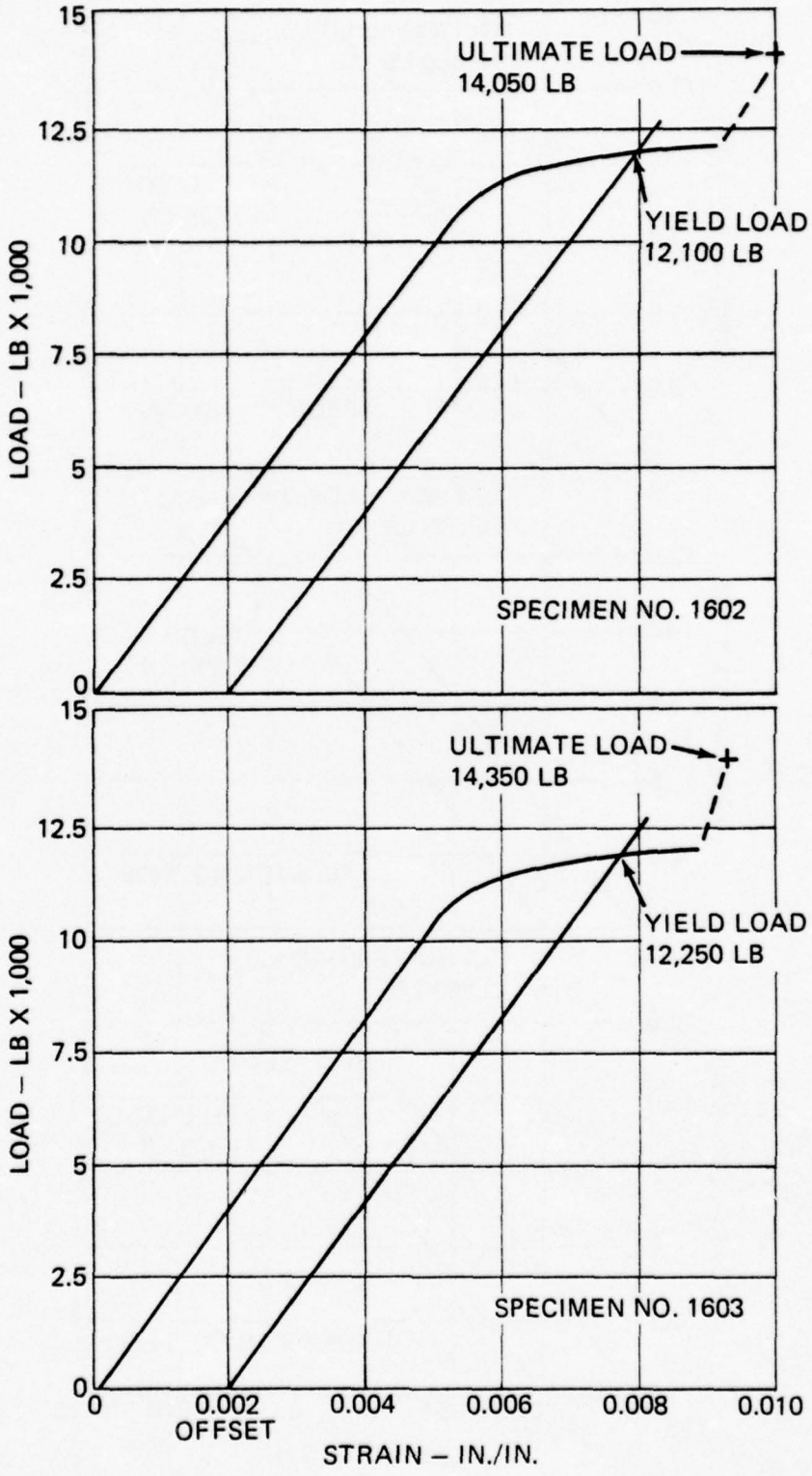



Figure B11. Tension Tests of Standard Round Specimens No. 1602 and 1603.

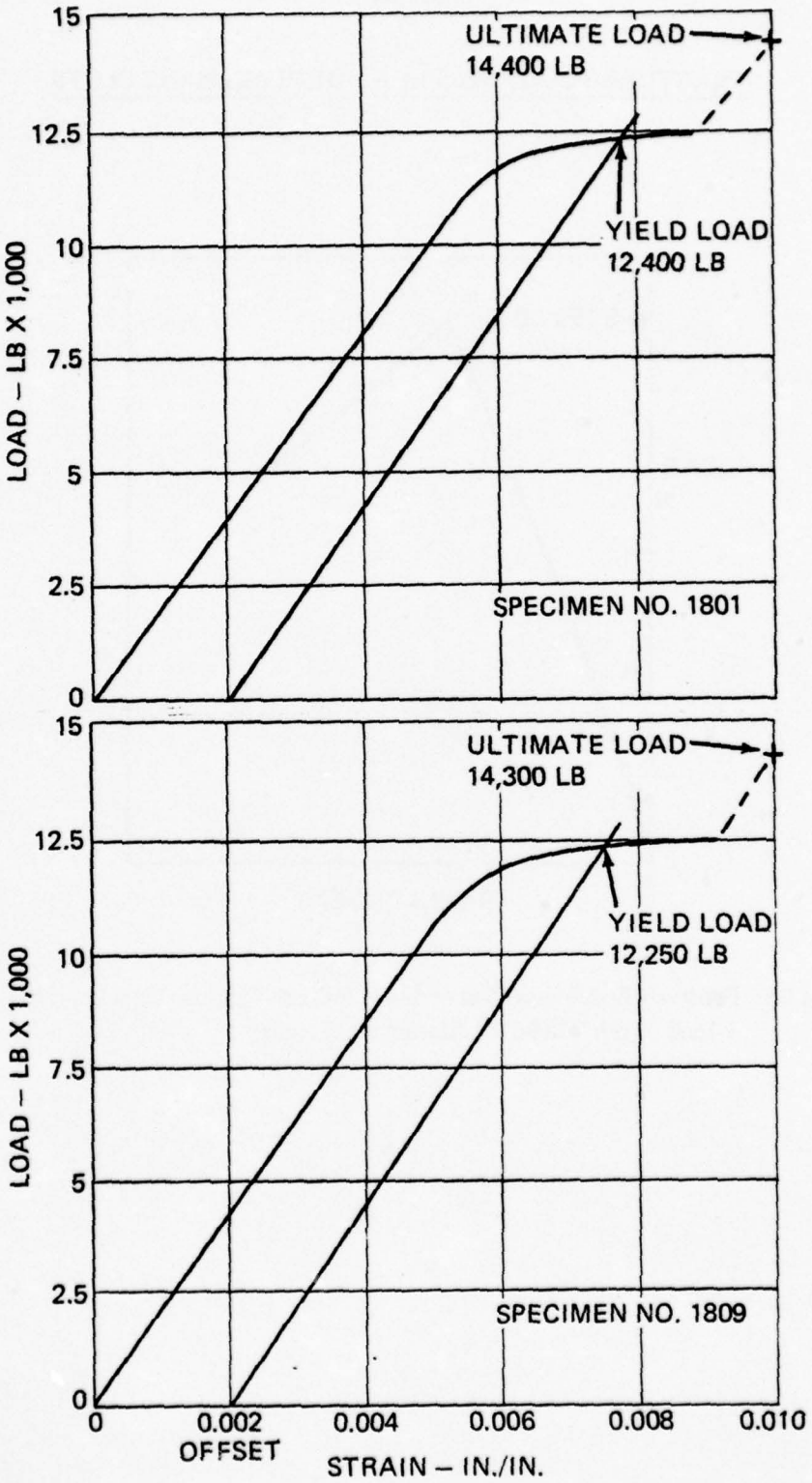



Figure B12. Tension Tests of Standard Round Specimens No. 1801 and 1809.

## APPENDIX C

## FRACTURE-TOUGHNESS LOAD-DISPLACEMENT PLOTS

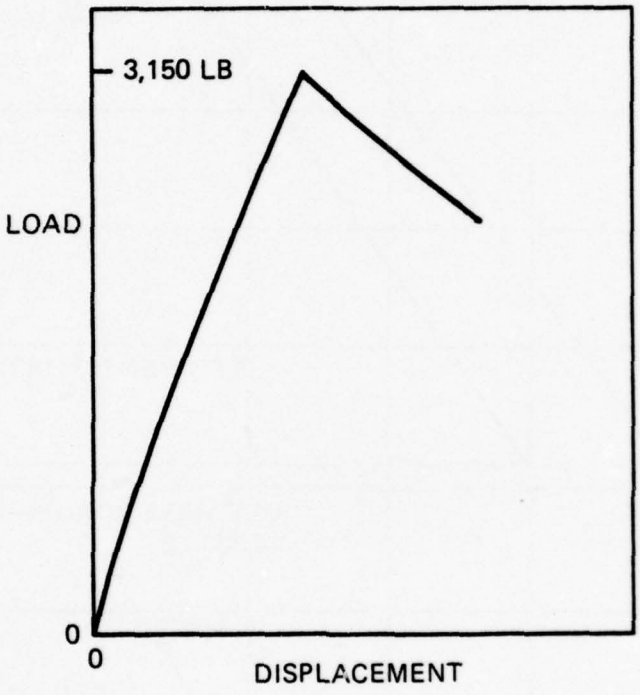



Figure C1. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0124, 1-Inch Thick 7075-T73 Aluminum Forging.

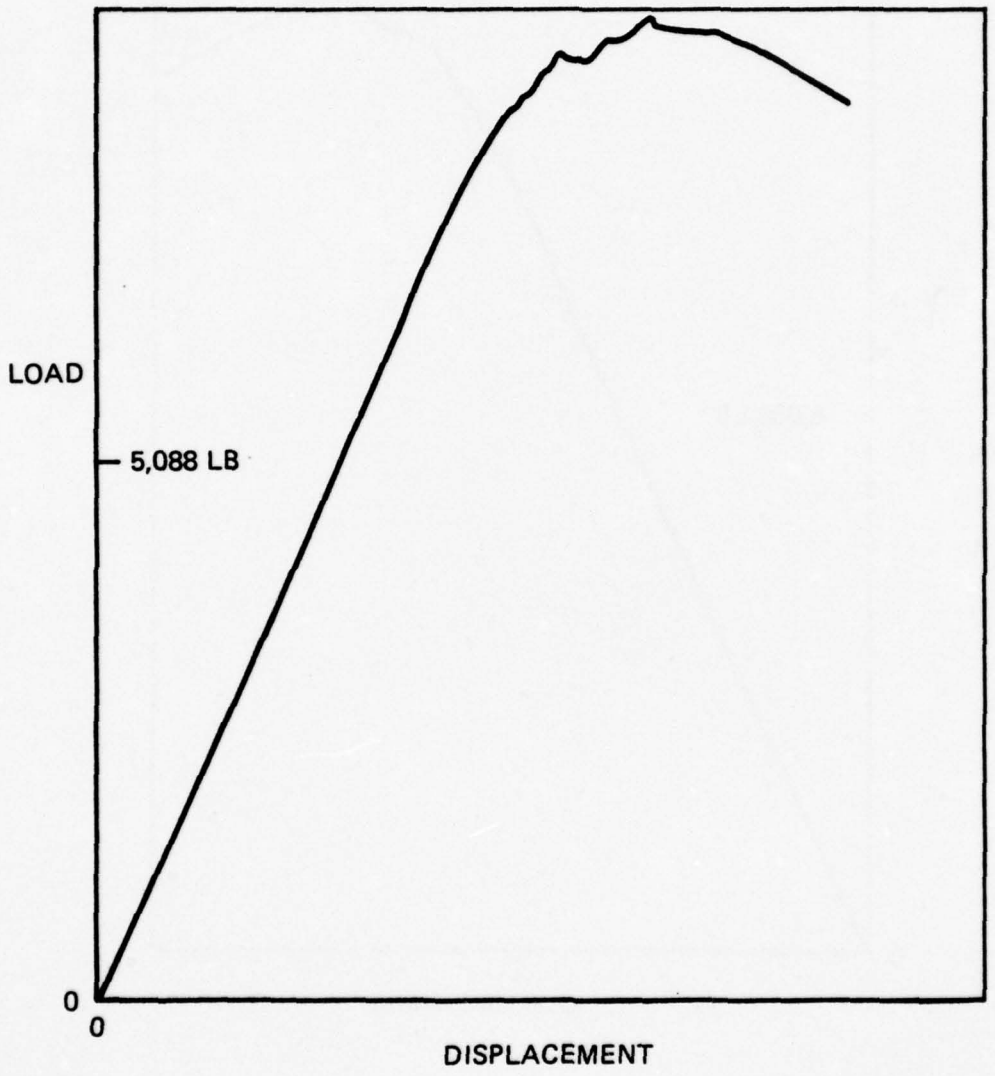



Figure C2. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0223, 2-Inch Thick 7075-T73 Aluminum Forging.

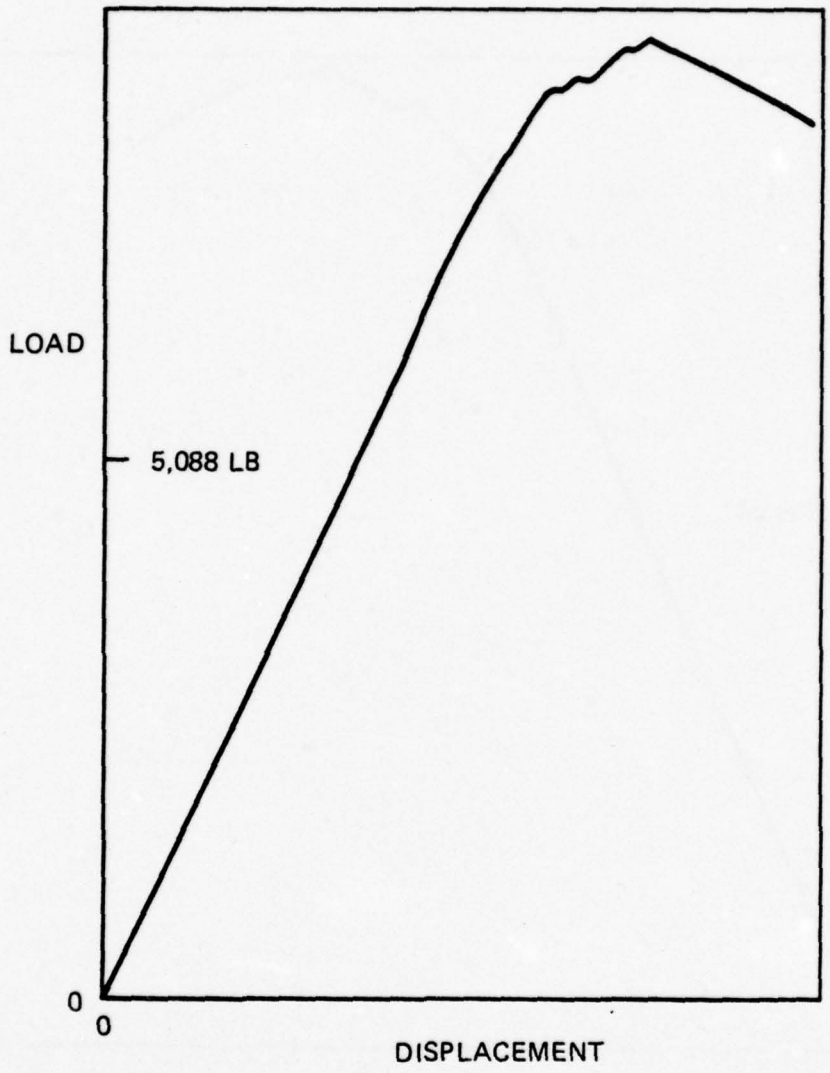



Figure C3. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0224, 2-Inch-Thick 7075-T73 Aluminum Forging.

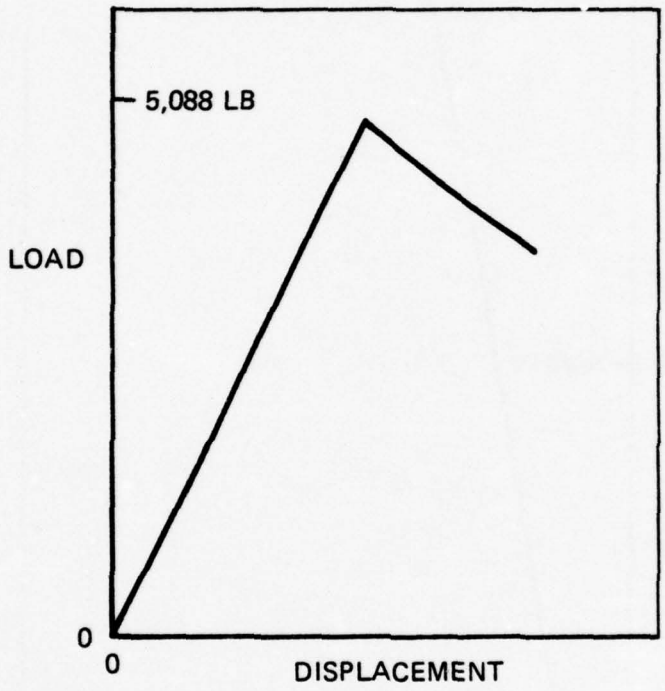



Figure C4. Fracture-Toughness Test of Short-Transverse-Compact Specimen No. 0401, 6.7-Inch-Thick 7075-T73 Aluminum Forging.

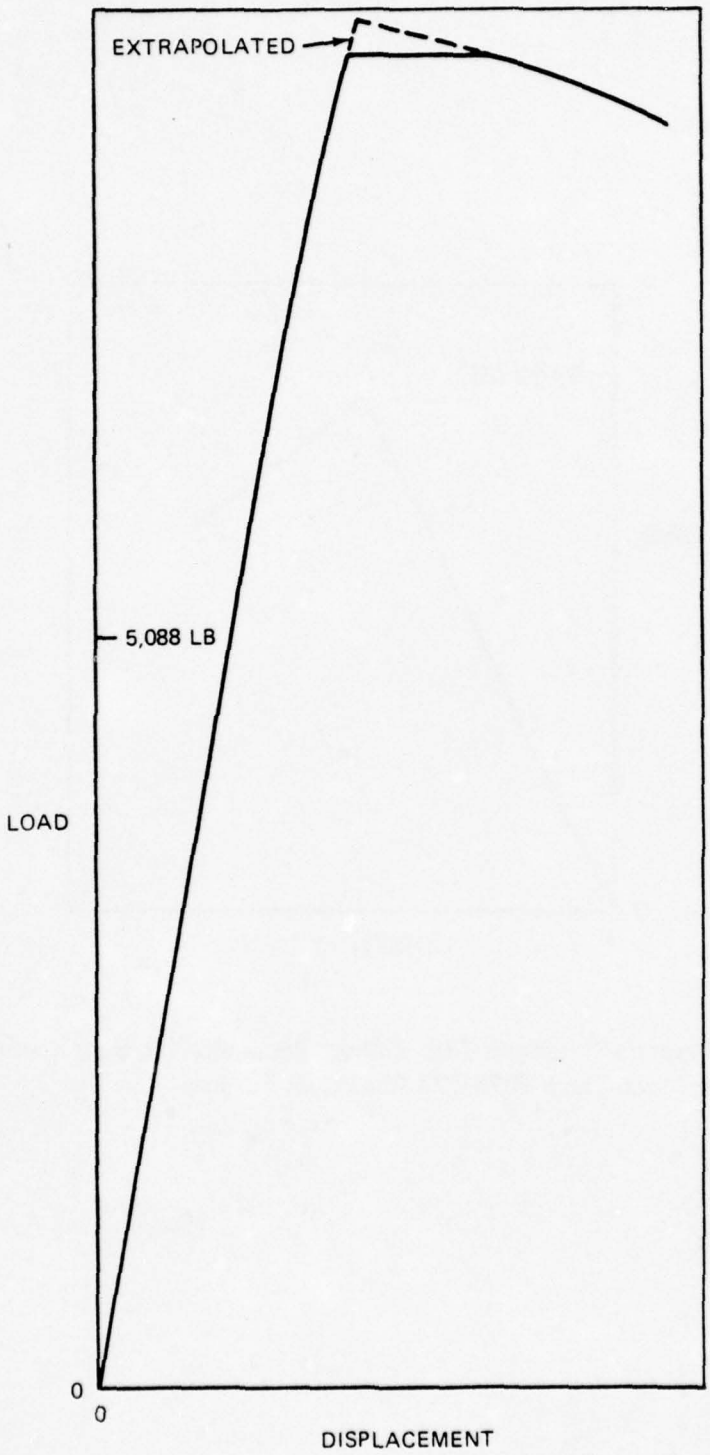



Figure C5. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0606, 6.7-Inch-Thick 7075-T73 Aluminum Forging.

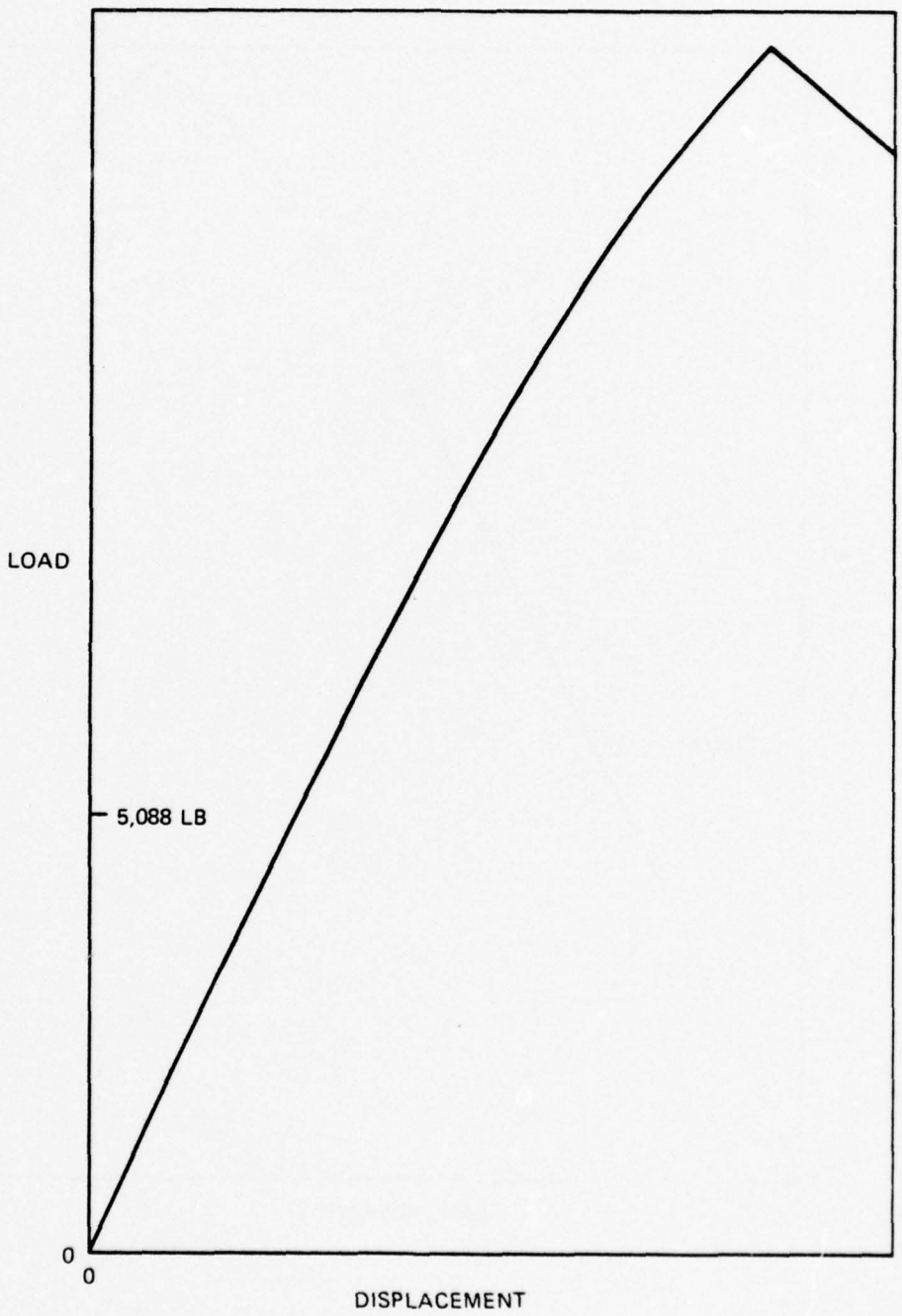



Figure C6. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0723, 1-Inch-Thick 7475-TMT1 Aluminum Forging.

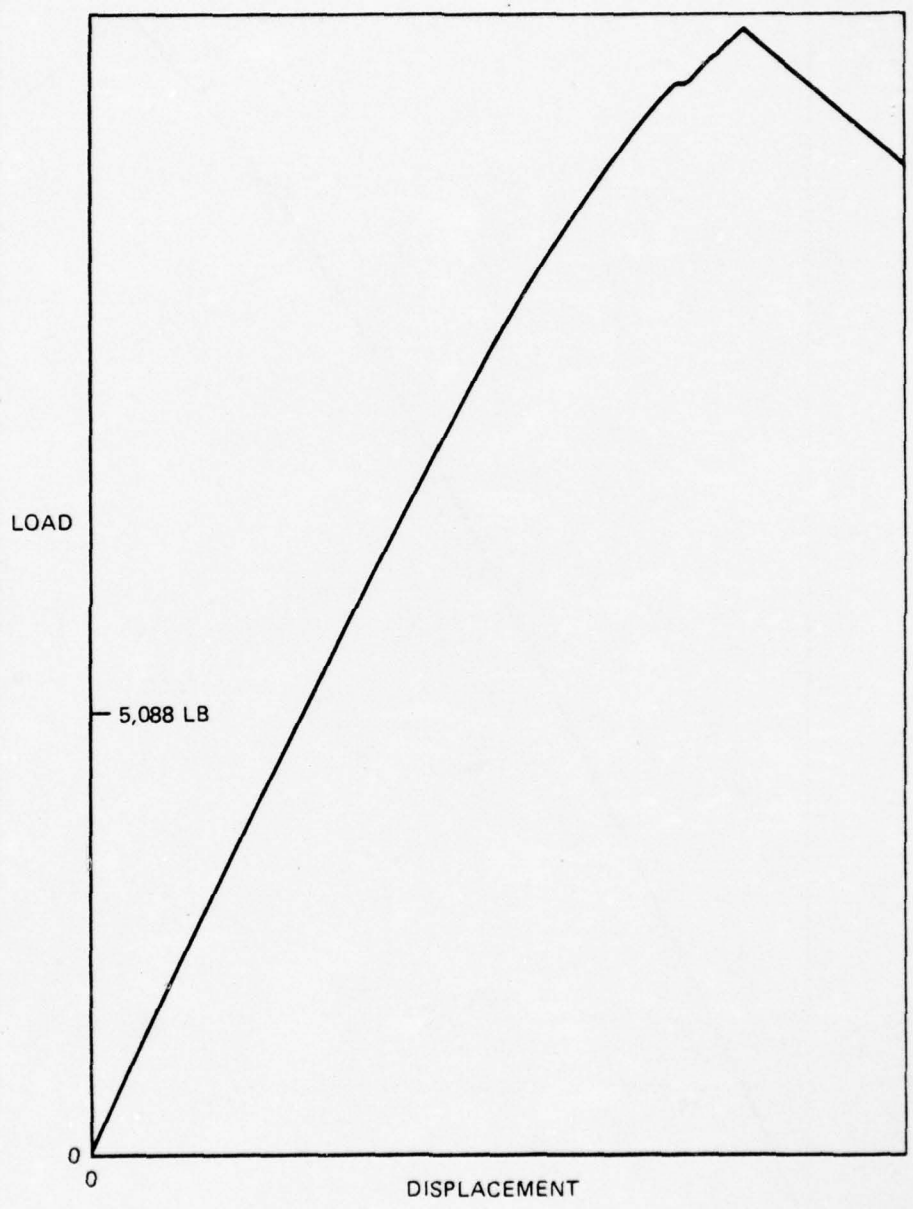



Figure C7. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0724, 1-Inch-Thick 7475-TMT1 Aluminum Forging.

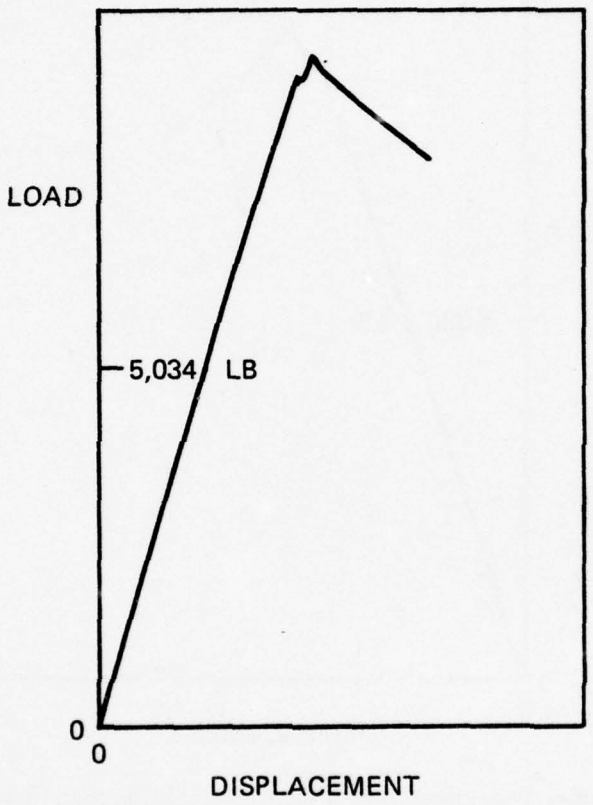



Figure C8. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0853, 2-Inch-Thick 7475-TMT1 Aluminum Forging.

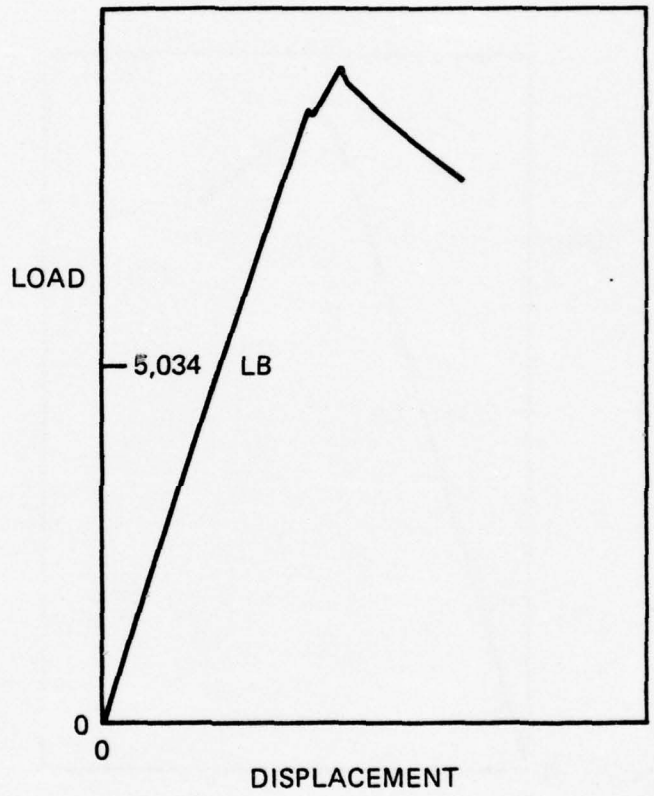



Figure C9. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0854, 2-Inch-Thick 7475-TMT1 Aluminum Forging.

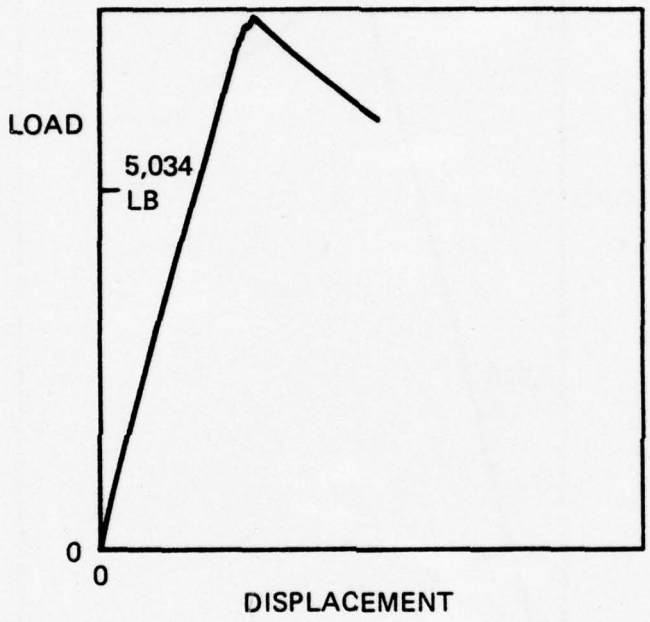



Figure C10. Fracture-Toughness Test of Short-Transverse-Compact Specimen No. 1001, 6.7-Inch-Thick 7475-TMT1 Aluminum Forging.

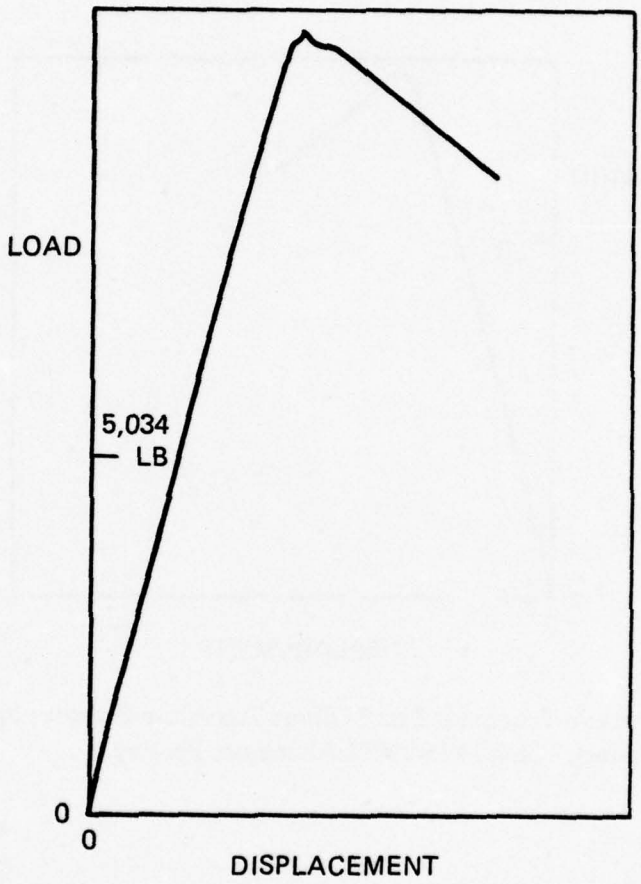



Figure C11. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1206, 6.7-Inch-Thick 7475-TMT1 Aluminum Forging.

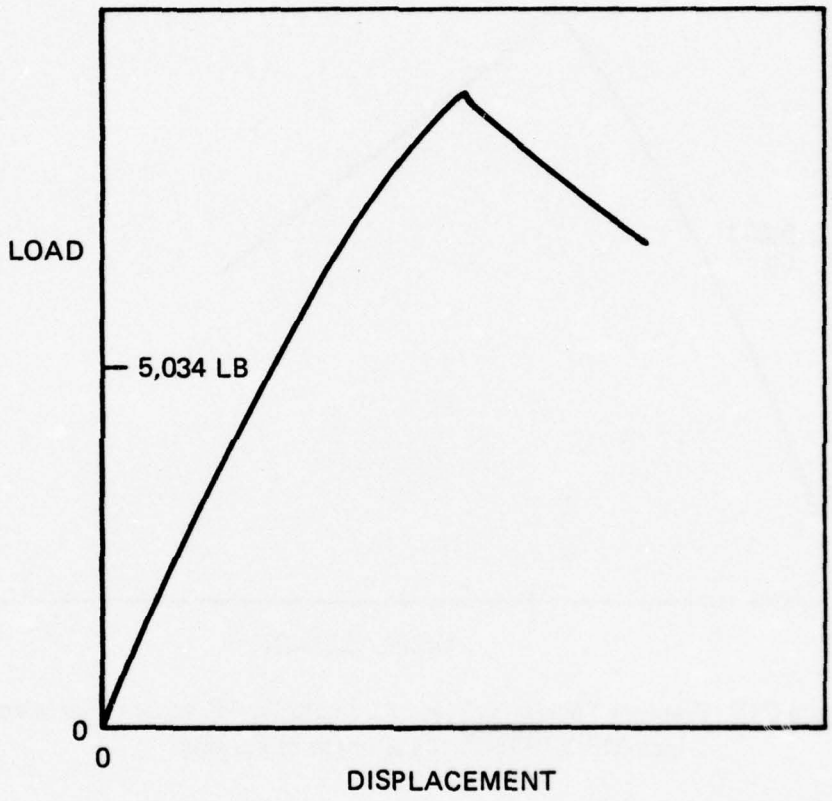



Figure C12. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1323, 1-Inch-Thick 7475-TMT2 Aluminum Forging.

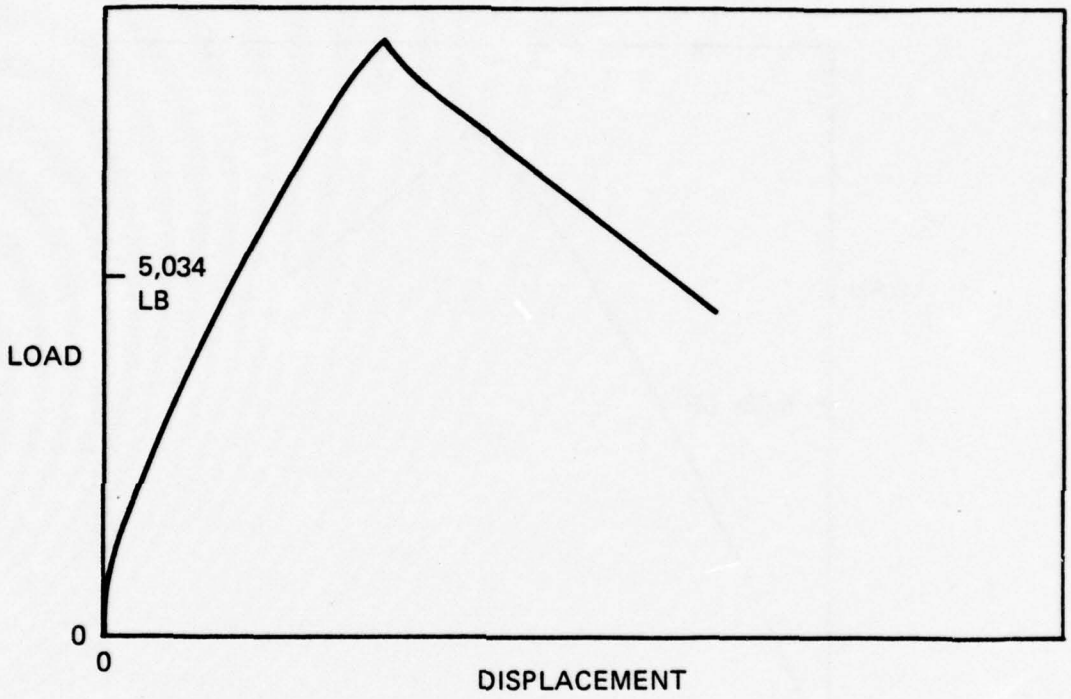



Figure C13. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1324, 1-Inch-Thick 7475-TMT2 Aluminum Forging.

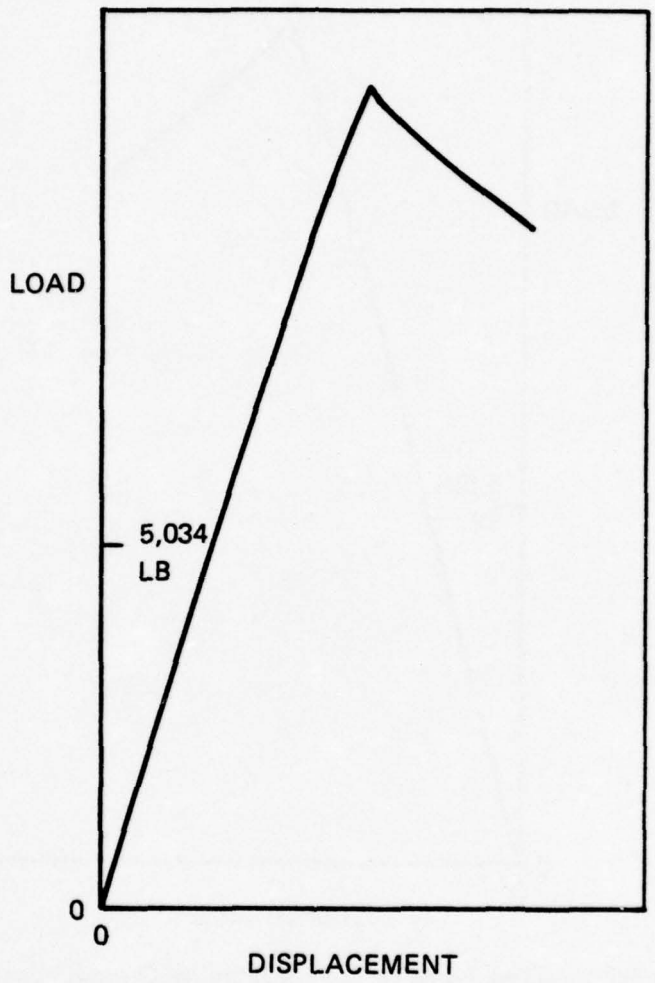



Figure C14. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1453, 2-Inch-Thick 7475-TMT2 Aluminum Forging.

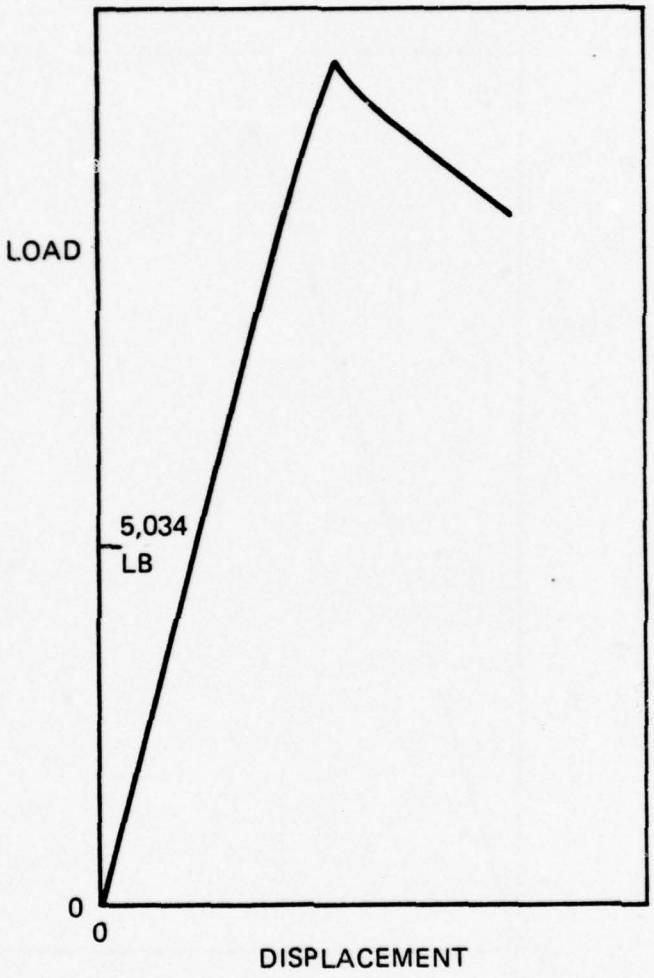



Figure C15. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1454, 2-Inch-Thick 7475-TMT2 Aluminum Forging.

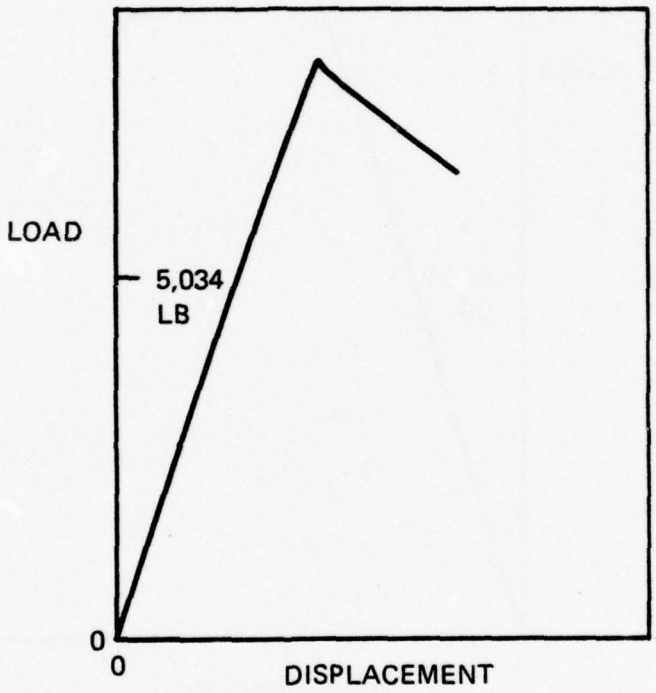



Figure C16. Fracture-Toughness Test of Short-Transverse-Compact Specimen No. 1601, 6.7-Inch-Thick 7475-TMT2 Aluminum Forging.

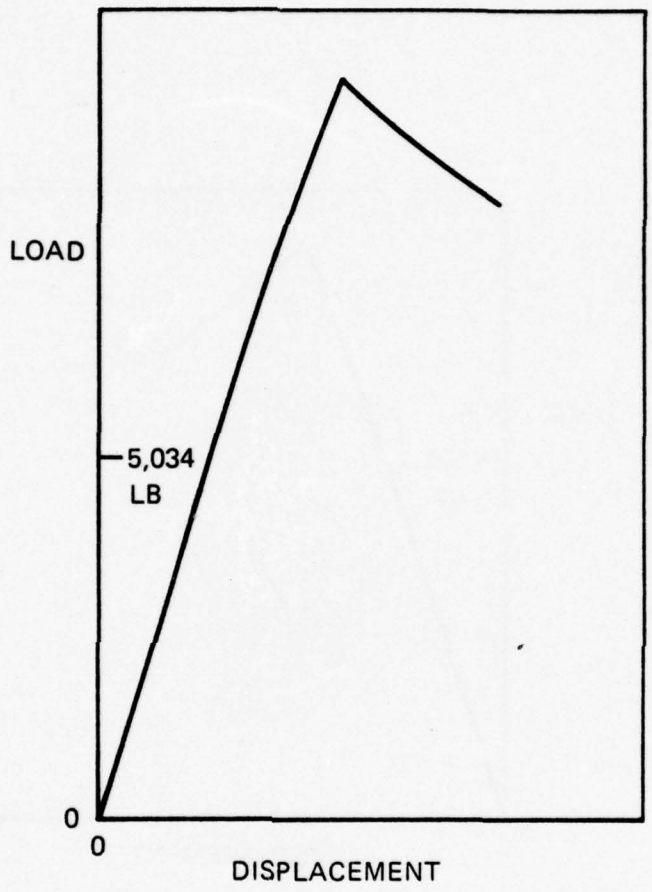



Figure C17. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1806, 6.7-Inch-Thick 7475-TMT2 Aluminum Forging.

# APPENDIX D

## FATIGUE-CRACK PROPAGATION-RATE DATA TABULATIONS

```
      $JOB            ZOLA,KP=29,LINES=50,PAGES=90,TIME=30,RUN=CHECK
 1      20  FORMAT(1H1,T10,'FATIGUE CRACK PROPAGATION DATA FOR 7475 TMT')
 2      30 FORMAT(1H0,17A4)
 3     2     FORMAT (/14X4HPMAX10X4HPMIN10X2HAO10X2HNO10X1HB10X1HW)
 4     3     FORMAT (12XF7.0,6XF7.0,6XF7.5,4XF7.0,7XF7.5,5XF7.5)
 5       7 FORMAT(/6X1HA13X1HN9X4HDELA10X4HDELN8X4HKMAX7X4HDELK8X4HDADN)
 6       8 FORMAT(2XE11.5,3XF9.0,3XE11.5,1XF9.0,3XF8.2,3XF8.2,3XE11.5)
 7         DIMENSION ALP(17),A(100),XN(100),DELK(100),DADN(100),DELA(100),DEL
          1N(100),XKMAX(100)
 8         COMMON RDT(226)
 9         EQUIVALENCE (RDT(10),PMAX),(RDT(11),PMIN),(RDT(12),B),(RDT(13),W),
          1(RDT(14),AO),(RDT(15),XNO),(RDT(16),XA),(RDT(17),A(1)),(RDT(116),X
          2N(1))
10         DO 69 I=1,226
11       69 RDT(I)=0.0
12         DO 15 I=1,17
13       15 ALP(I)=0.0
14       10 READ,N,M,(RDT(N+K-1),K=1,M)
15         IF(N-1)25,25,10
16       25 NN=RDT(1)+.01
17         IF(NN-1)60,70,55
18       55 READ9,(ALP(N),N=1,17)
19        9 FORMAT(17A4)
20       45 GO TO 10
21       70 DELP=PMAX-PMIN
22         COEF=DELP/(B*(W**0.5))
23         RATIO=PMAX/DELP
24         N=RDT(16)+.001
25         PRINT 20
26         PRINT 30,(ALP(K),K=1,17)
27         PRINT 2
28         PRINT 3,PMAX,PMIN,AO,XNO,B,W
29         PRINT 7
30         DELK(1)=COEF*(29.6*(A(1)/W)**0.5+655.7*(A(1)/W)**2.5+638.9*(A(1)/W
          1)**4.5-185.5*(A(1)/W)**1.5-1017.*(A(1)/W)**3.5)
31         XKMAX(1)=RATIO*DELK(1)
32         DELA(1)=A(1)-AO
33         DELN(1)=XN(1)-XNO
34         DADN(1)=DELA(1)/DELN(1)
35         PRINT 8,A(1),XN(1),DELA(1),DELN(1),XKMAX(1),DELK(1),DADN(1)
36         DO 100 J=2,N
37         DELK(J)=COEF*(29.6*(A(J)/W)**0.5+655.7*(A(J)/W)**2.5+638.9*(A(J)/W
          1)**4.5-185.5*(A(J)/W)**1.5-1017.*(A(J)/W)**3.5)
38         XKMAX(J)=RATIO*DELK(J)
39         DELA(J)=A(J)-A(J-1)
40         DELN(J)=XN(J)-XN(J-1)
41         DADN(J)=DELA(J)/DELN(J)
42         PRINT 8,A(J),XN(J),DELA(J),DELN(J),XKMAX(J),DELK(J),DADN(J)
43      100 CONTINUE
44         GO TO 10

45       60 STOP
46         END

      $ENTRY
```

COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0122 LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | ΔD | RD | R | K |
|---|---|---|---|---|---|
| 540. | 20. | 0.63940 | 0. | 0.25000 | 2.50000 |

| A | N | DELA | DELN | SMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.67940E 00 | 3270. | 0.40000E-01 | 3270. | 7892.97 | 7498.33 | 0.12232E-04 |
| 0.71940E 00 | 5610. | 0.40000E-01 | 2340. | 8104.13 | 7698.92 | 0.17094E-04 |
| 0.75940E 00 | 7710. | 0.40000E-01 | 2100. | 8340.05 | 7923.75 | 0.19044E-04 |
| 0.79940E 00 | 9660. | 0.40000E-01 | 1950. | 8617.21 | 8186.36 | 0.20513E-04 |
| 0.83940E 00 | 11400. | 0.40000E-01 | 1740. | 8910.02 | 8470.23 | 0.22988E-04 |
| 0.87940E 00 | 13050. | 0.40000E-01 | 1650. | 9241.21 | 8779.15 | 0.24242E-04 |
| 0.91940E 00 | 14610. | 0.40000E-01 | 1560. | 9591.99 | 9112.39 | 0.25641E-04 |
| 0.95940E 00 | 16110. | 0.40000E-01 | 1500. | 9967.94 | 9469.54 | 0.26667E-04 |
| 0.99940E 00 | 17370. | 0.40000E-01 | 1260. | 10369.28 | 9850.80 | 0.31746E-04 |
| 0.10394E 01 | 18660. | 0.40000E-01 | 1236. | 10797.19 | 10257.34 | 0.32520E-04 |
| 0.10794E 01 | 19860. | 0.40000E-01 | 1260. | 11253.59 | 10690.73 | 0.31746E-04 |
| 0.11194E 01 | 20970. | 0.40000E-01 | 1110. | 11740.95 | 11153.91 | 0.36036E-04 |
| 0.11594E 01 | 21810. | 0.40000E-01 | 840. | 12265.61 | 11650.43 | 0.47619E-04 |
| 0.11994E 01 | 22650. | 0.40000E-01 | 1020. | 12828.28 | 12184.97 | 0.39216E-04 |
| 0.12394E 01 | 23580. | 0.40000E-01 | 1050. | 13435.15 | 12765.40 | 0.38095E-04 |
| 0.12794E 01 | 24480. | 0.40000E-01 | 600. | 14097.65 | 13392.75 | 0.66667E-04 |
| 0.13194E 01 | 25140. | 0.40000E-01 | 660. | 14822.65 | 14081.52 | 0.60606E-04 |
| 0.13594E 01 | 25800. | 0.40000E-01 | 660. | 15620.10 | 14839.10 | 0.60606E-04 |
| 0.13994E 01 | 26430. | 0.40000E-01 | 630. | 16501.87 | 15676.78 | 0.63492E-04 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0F LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | ΔD | RD | R | K |
|---|---|---|---|---|---|
| 779. | 39. | 0.72570 | 0. | 0.24970 | 2.50000 |

| A | N | DELA | DELN | SMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.76570E 00 | 2430. | 0.40000E-01 | 2430. | 11640.76 | 11095.98 | 0.16461E-04 |
| 0.80570E 00 | 4740. | 0.40000E-01 | 2310. | 12044.63 | 11480.63 | 0.17316E-04 |
| 0.84570E 00 | 6870. | 0.40000E-01 | 2130. | 12488.70 | 11861.57 | 0.18779E-04 |
| 0.88570E 00 | 8910. | 0.40000E-01 | 2040. | 12945.28 | 12297.18 | 0.19608E-04 |
| 0.92570E 00 | 10650. | 0.40000E-01 | 1740. | 13439.29 | 12788.47 | 0.22989E-04 |
| 0.96570E 00 | 12390. | 0.40000E-01 | 1740. | 13948.42 | 13269.11 | 0.22989E-04 |
| 0.10057E 01 | 13890. | 0.40000E-01 | 1500. | 14533.07 | 13805.50 | 0.26667E-04 |
| 0.10457E 01 | 15000. | 0.40000E-01 | 1110. | 15135.01 | 14377.30 | 0.36036E-04 |
| 0.10857E 01 | 16320. | 0.40000E-01 | 1320. | 15777.10 | 14987.25 | 0.30303E-04 |
| 0.11257E 01 | 17790. | 0.40000E-01 | 1470. | 16483.59 | 15639.15 | 0.27211E-04 |
| 0.11657E 01 | 18690. | 0.40000E-01 | 900. | 17199.57 | 16358.50 | 0.44444E-04 |
| 0.12057E 01 | 19770. | 0.40000E-01 | 1080. | 17992.88 | 17091.01 | 0.37037E-04 |
| 0.12457E 01 | 20580. | 0.40000E-01 | 810. | 18851.88 | 17967.89 | 0.49383E-04 |
| 0.12857E 01 | 21390. | 0.40000E-01 | 810. | 19747.38 | 18798.74 | 0.49383E-04 |
| 0.13257E 01 | 22200. | 0.40000E-01 | 810. | 20811.94 | 19770.02 | 0.49383E-04 |
| 0.13657E 01 | 22830. | 0.40000E-01 | 630. | 21940.05 | 20841.88 | 0.63492E-04 |
| 0.14057E 01 | 23490. | 0.40000E-01 | 660. | 23188.17 | 22027.29 | 0.60606E-04 |
| 0.14457E 01 | 24030. | 0.40000E-01 | 540. | 24574.17 | 23340.88 | 0.74074E-04 |
| 0.14857E 01 | 24600. | 0.40000E-01 | 570. | 26121.85 | 24813.91 | 0.70175E-04 |
| 0.15257E 01 | 24930. | 0.40000E-01 | 330. | 27851.28 | 26458.85 | 0.12121E-03 |
| 0.15657E 01 | 25380. | 0.40000E-01 | 450. | 29749.51 | 28298.19 | 0.88889E-04 |
| 0.16057E 01 | 25680. | 0.40000E-01 | 300. | 31944.29 | 30384.05 | 0.13333E-03 |
| 0.16457E 01 | 25860. | 0.40000E-01 | 180. | 34404.25 | 32664.75 | 0.22222E-03 |
| 0.16857E 01 | 25980. | 0.40000E-01 | 120. | 37148.77 | 35244.97 | 0.33333E-03 |
| 0.17257E 01 | 26100. | 0.40000E-01 | 120. | 40228.44 | 38210.83 | 0.33333E-03 |
| 0.17657E 01 | 26160. | 0.40000E-01 | 60. | 43683.21 | 41598.27 | 0.66667E-03 |
| 0.18057E 01 | 26190. | 0.40000E-01 | 30. | 47555.21 | 45174.45 | 0.13333E-02 |
| 0.18457E 01 | 26220. | 0.40000E-01 | 30. | 51887.75 | 49290.07 | 0.13333E-02 |

COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0221 CARD 3 (1X,4HMAX STRESS = F10.0,5X,TEST FREQ = F6.2,3HHZ

| | | | | | | |
|---|---|---|---|---|---|---|
| PMAX 1140. | PMIN 570. | DP 0.853470 | NO 0. | A 0.253029 | M 2.50000 | |
| N | DELN | DELN | AMAX | DELK | DADN | |
| 0.071420E 00 | 4020. | 0.402000E-01 | 4020. | 10930.06 | 10930.37 | 0.449503E-03 |
| 0.214260E 00 | 4020. | 0.402000E-01 | 3870. | 11663.74 | 10001.84 | 0.412236E-04 |
| 0.357100E 00 | 4020. | 0.402000E-01 | 3870. | 11334.01 | 10470.14 | 0.416495E-04 |
| 0.499940E 00 | 4020. | 0.402000E-01 | 3870. | 11470.34 | 11367.21 | 0.420595E-04 |
| 0.642780E 00 | 4020. | 0.402000E-01 | 3840. | 12338.34 | 11717.22 | 0.431536E-04 |
| 0.785620E 00 | 4020. | 0.402000E-01 | 3900. | 12178.13 | 12144.13 | 0.416667E-04 |
| 0.928460E 00 | 4020. | 0.402000E-01 | 3900. | 13267.01 | 12092.87 | 0.419080E-04 |
| 0.107130E 01 | 4020. | 0.402000E-01 | 3810. | 13185.06 | 13094.45 | 0.419401E-04 |
| 0.121414E 01 | 4020. | 0.402000E-01 | 3720. | 14334.33 | 13860.30 | 0.420433E-04 |
| 0.135698E 01 | 4020. | 0.402000E-01 | 3720. | 14760.06 | 14180.71 | 0.427211E-04 |
| 0.149982E 01 | 4020. | 0.402000E-01 | 3600. | 15556.47 | 14774.14 | 0.426667E-04 |
| 0.164266E 01 | 4020. | 0.402000E-01 | 3600. | 16223.76 | 15410.27 | 0.426667E-04 |
| 0.178550E 01 | 3930. | 0.392000E-01 | 3570. | 16948.46 | 16039.48 | 0.341886E-04 |
| 0.192834E 01 | 3930. | 0.392000E-01 | 3600. | 17722.44 | 16835.38 | 0.351740E-04 |
| 0.207118E 01 | 3930. | 0.392000E-01 | 3480. | 18560.16 | 17630.48 | 0.444444E-04 |
| 0.221402E 01 | 3930. | 0.392000E-01 | 3480. | 19470.71 | 18479.44 | 0.447620E-04 |
| 0.235686E 01 | 3930. | 0.392000E-01 | 3480. | 20466.46 | 19441.74 | 0.444444E-04 |
| 0.249970E 01 | 3930. | 0.392000E-01 | 3420. | 21561.04 | 20481.82 | 0.451735E-04 |
| 0.264254E 01 | 3930. | 0.392000E-01 | 3360. | 22770.31 | 21630.41 | 0.460806E-04 |
| 0.278538E 01 | 3930. | 0.392000E-01 | 3360. | 24171.38 | 23240.60 | 0.483336E-04 |
| 0.292822E 01 | 3930. | 0.392000E-01 | 3420. | 25808.38 | 24706.30 | 0.410230E-03 |
| 0.307106E 01 | 3910. | 0.392000E-01 | 3300. | 27720.88 | 26535.78 | 0.411111E-03 |
| 0.321390E 01 | 3910. | 0.392000E-01 | 3300. | 29853.22 | 28506.88 | 0.412121E-03 |
| 0.335674E 01 | 3910. | 0.392000E-01 | 3240. | 32418.22 | 30221.47 | 0.410667E-03 |
| 0.349958E 01 | 3910. | 0.392000E-01 | 3120. | 34240.41 | 32320.80 | 0.433333E-03 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0222 CARD 3 (1X,4HMAX STRESS = F10.0,5X,TEST FREQ = F6.2,3HHZ

| | | | | | | |
|---|---|---|---|---|---|---|
| PMAX 770. | PMIN 385. | DP 0.856170 | NO 0. | A 0.253040 | M 2.50000 | |
| N | DELN | DELN | AMAX | DELK | DADN | |
| 0.701200E 00 | 2700. | 0.270000E-01 | 2700. | 11094.37 | 10534.95 | 0.833333E-03 |
| 0.741200E 00 | 2700. | 0.270000E-01 | 2700. | 11410.55 | 10834.30 | 0.102504E-04 |
| 0.781200E 00 | 1740. | 0.174000E-01 | 2700. | 11788.27 | 11174.11 | 0.106424E-04 |
| 0.821200E 00 | 1740. | 0.174000E-01 | 2700. | 12165.23 | 11530.22 | 0.111204E-04 |
| 0.861200E 00 | 1740. | 0.174000E-01 | 2700. | 12594.83 | 11936.85 | 0.113333E-04 |
| 0.901200E 00 | 2610. | 0.261000E-01 | 2580. | 13084.71 | 12413.40 | 0.119504E-04 |
| 0.941200E 00 | 2610. | 0.261000E-01 | 2520. | 13574.99 | 12893.29 | 0.119873E-04 |
| 0.981200E 00 | 2520. | 0.252000E-01 | 2430. | 14115.10 | 13404.43 | 0.117857E-04 |
| 0.102120E 01 | 2520. | 0.252000E-01 | 2400. | 14691.23 | 13953.74 | 0.122222E-04 |
| 0.106120E 01 | 2520. | 0.252000E-01 | 2370. | 15305.27 | 14533.03 | 0.124242E-04 |
| 0.110120E 01 | 2430. | 0.243000E-01 | 2370. | 15960.73 | 15161.84 | 0.123457E-04 |
| 0.114120E 01 | 2430. | 0.243000E-01 | 2340. | 16662.20 | 15826.04 | 0.127778E-04 |
| 0.118120E 01 | 2340. | 0.234000E-01 | 2250. | 17415.45 | 16544.05 | 0.131496E-04 |
| 0.122120E 01 | 2340. | 0.234000E-01 | 2220. | 18224.50 | 17311.96 | 0.133333E-04 |
| 0.126120E 01 | 2340. | 0.234000E-01 | 2190. | 19112.52 | 18133.77 | 0.137037E-04 |
| 0.130120E 01 | 2250. | 0.225000E-01 | 2130. | 20075.92 | 19071.43 | 0.140845E-04 |
| 0.134120E 01 | 2250. | 0.225000E-01 | 2100. | 21139.41 | 20076.69 | 0.147619E-04 |
| 0.138120E 01 | 2250. | 0.225000E-01 | 2070. | 22301.14 | 21174.45 | 0.150406E-04 |
| 0.142120E 01 | 2160. | 0.216000E-01 | 2010. | 23544.81 | 22341.34 | 0.154717E-04 |
| 0.146120E 01 | 2160. | 0.216000E-01 | 1980. | 25033.49 | 23761.91 | 0.159259E-04 |
| 0.150120E 01 | 2160. | 0.216000E-01 | 1950. | 26646.75 | 25307.02 | 0.111111E-03 |
| 0.154120E 01 | 4020. | 0.402000E-01 | 2040. | 28434.16 | 27015.40 | 0.166667E-03 |
| 0.158120E 01 | 4020. | 0.402000E-01 | 2010. | 30455.63 | 28930.41 | 0.190485E-03 |
| 0.162120E 01 | 4020. | 0.402000E-01 | 1980. | 32714.48 | 31081.80 | 0.225225E-03 |
| 0.166120E 01 | 4020. | 0.402000E-01 | 1950. | 35251.49 | 33495.14 | 0.256667E-03 |
| 0.170120E 01 | 4020. | 0.402000E-01 | 1920. | 38117.36 | 36204.84 | 0.294444E-03 |
| 0.174120E 01 | 4020. | 0.402000E-01 | 1890. | 41361.74 | 39254.03 | 0.333333E-03 |
| 0.178120E 01 | 4020. | 0.402000E-01 | 1860. | 44915.47 | 42587.23 | 0.133333E-02 |
| 0.182120E 01 | 4020. | 0.402000E-01 | 1830. | 48941.24 | 46341.24 | 0.266667E-02 |

COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0501 [illegible] SW STRESS RATIO 0.05 TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | 0. | 0.25100 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.71210E 00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.75210E 00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.79210E 00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.83210E 00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.87210E 00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.91210E 00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.95210E 00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.99210E 00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.10321E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.10721E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.11121E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.11521E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.11921E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.12321E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.12721E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.13121E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.13521E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.13921E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.14321E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.14721E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.15121E 01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0005 LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 497. | 25. | 0.04250 | 0. | 0.24960 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.68250E 00 | 6120. | 0.40000E-01 | 6120. | 7029.80 | 6676.19 | 0.65360E-05 |
| 0.72250E 00 | 10740. | 0.40000E-01 | 4620. | 7219.64 | 6856.49 | 0.86580E-05 |
| 0.76250E 00 | 14880. | 0.40000E-01 | 4140. | 7430.75 | 7062.68 | 0.96618E-05 |
| 0.80250E 00 | 18990. | 0.40000E-01 | 4110. | 7679.76 | 7293.46 | 0.97324E-05 |
| 0.84250E 00 | 26500. | 0.40000E-01 | 3510. | 7947.23 | 7547.48 | 0.11396E-04 |
| 0.88250E 00 | 25620. | 0.40000E-01 | 3120. | 8238.12 | 7823.73 | 0.12821E-04 |
| 0.92250E 00 | 28020. | 0.40000E-01 | 2400. | 8551.63 | 8121.47 | 0.16667E-04 |
| 0.96250E 00 | 31140. | 0.40000E-01 | 3120. | 8887.52 | 8440.47 | 0.12821E-04 |
| 0.10025E 01 | 33540. | 0.40000E-01 | 2400. | 9246.07 | 8780.99 | 0.16666E-04 |
| 0.10425E 01 | 35490. | 0.40000E-01 | 1950. | 9628.34 | 9144.02 | 0.20513E-04 |
| 0.10825E 01 | 37530. | 0.40001E-01 | 2040. | 10036.00 | 9531.18 | 0.19608E-04 |
| 0.11225E 01 | 39060. | 0.40000E-01 | 1530. | 10471.65 | 9944.89 | 0.26144E-04 |
| 0.11625E 01 | 40560. | 0.40000E-01 | 1500. | 10938.80 | 10388.57 | 0.26667E-04 |
| 0.12025E 01 | 41820. | 0.40000E-01 | 1260. | 11441.92 | 10866.38 | 0.31746E-04 |
| 0.12425E 01 | 42750. | 0.40000E-01 | 930. | 11986.59 | 11383.66 | 0.43011E-04 |
| 0.12825E 01 | 43860. | 0.40000E-01 | 1110. | 12579.60 | 11946.83 | 0.36036E-04 |
| 0.13225E 01 | 44640. | 0.40000E-01 | 780. | 13228.63 | 12563.22 | 0.51282E-04 |
| 0.13625E 01 | 45600. | 0.40000E-01 | 960. | 13943.05 | 13241.68 | 0.41667E-04 |
| 0.14025E 01 | 46290. | 0.40000E-01 | 690. | 14733.09 | 13992.00 | 0.57971E-04 |
| 0.14425E 01 | 46950. | 0.40000E-01 | 660. | 15610.77 | 14825.54 | 0.60606E-04 |
| 0.14825E 01 | 47430. | 0.40000E-01 | 480. | 16588.98 | 15754.54 | 0.83333E-04 |
| 0.15225E 01 | 47700. | 0.40000E-01 | 270. | 17685.18 | 16793.70 | 0.14815E-03 |
| 0.15625E 01 | 47910. | 0.40000E-01 | 210. | 18908.62 | 17957.50 | 0.19048E-03 |
| 0.16025E 01 | 48030. | 0.40000E-01 | 120. | 20284.17 | 19263.86 | 0.33333E-03 |

COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0404 LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | R | K |
|---|---|---|---|---|---|
| 831. | 31. | 0.79290 | 0. | 0.25000 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.8329DE 00 | 5180. | 0.40000E-01 | 5180. | 9851.38 | 9340.81 | 0.12579E-04 |
| 0.8729DE 00 | 5540. | 0.40000E-01 | 2400. | 10147.36 | 9678.82 | 0.16667E-04 |
| 0.9129DE 00 | 6010. | 0.40000E-01 | 2430. | 10571.67 | 10045.95 | 0.16461E-04 |
| 0.9529DE 00 | 13020. | 0.40000E-01 | 2010. | 10984.07 | 10435.75 | 0.19901E-04 |
| 0.9929DE 00 | 11760. | 0.40000E-01 | 1680. | 11424.52 | 10854.22 | 0.23810E-04 |
| 0.10329E 01 | 13800. | 0.40000E-01 | 2100. | 11894.03 | 11300.30 | 0.19048E-04 |
| 0.10729E 01 | 15420. | 0.40000E-01 | 1620. | 12394.76 | 11776.03 | 0.24691E-04 |
| 0.11129E 01 | 17220. | 0.40000E-01 | 1800. | 12929.50 | 12284.07 | 0.22222E-04 |
| 0.11529E 01 | 18720. | 0.40000E-01 | 1500. | 13502.55 | 12828.35 | 0.26667E-04 |
| 0.11929E 01 | 19950. | 0.40000E-01 | 1230. | 14118.70 | 13413.91 | 0.32520E-04 |
| 0.12329E 01 | 21240. | 0.40000E-01 | 1290. | 14785.06 | 14047.01 | 0.31008E-04 |
| 0.12729E 01 | 22680. | 0.40000E-01 | 1020. | 15509.49 | 14735.28 | 0.39216E-04 |
| 0.13129E 01 | 23280. | 0.40000E-01 | 1020. | 16301.65 | 15487.61 | 0.39216E-04 |
| 0.13529E 01 | 24210. | 0.40000E-01 | 930. | 17171.92 | 16314.71 | 0.43011E-04 |
| 0.13929E 01 | 25980. | 0.40001E-01 | 780. | 18135.80 | 17228.45 | 0.51285E-04 |
| 0.14329E 01 | 25950. | 0.40000E-01 | 870. | 19200.80 | 18242.32 | 0.46006E-04 |
| 0.14729E 01 | 28220. | 0.40000E-01 | 570. | 20379.34 | 19371.71 | 0.70175E-04 |
| 0.15129E 01 | 28470. | 0.40000E-01 | 450. | 21717.98 | 20633.85 | 0.88889E-04 |
| 0.15529E 01 | 27140. | 0.40000E-01 | 510. | 23205.58 | 22046.98 | 0.78431E-04 |
| 0.15929E 01 | 27030. | 0.40000E-01 | 420. | 24874.43 | 23632.73 | 0.95238E-04 |
| 0.16329E 01 | 28050. | 0.40000E-01 | 450. | 26747.95 | 25412.72 | 0.88889E-04 |
| 0.16729E 01 | 28410. | 0.40000E-01 | 390. | 28851.80 | 27411.59 | 0.11111E-03 |
| 0.17129E 01 | 28710. | 0.40000E-01 | 300. | 31219.79 | 29658.58 | 0.13333E-03 |
| 0.17529E 01 | 29040. | 0.40000E-01 | 270. | 33888.85 | 32178.07 | 0.14815E-03 |
| 0.17929E 01 | 29190. | 0.40000E-01 | 210. | 36839.18 | 35000.19 | 0.19048E-03 |
| 0.18329E 01 | 29310. | 0.40000E-01 | 120. | 40167.98 | 38142.84 | 0.33333E-03 |
| 0.18729E 01 | 29460. | 0.40000E-01 | 120. | 43869.57 | 41698.65 | 0.33333E-03 |
| 0.19129E 01 | 29490. | 0.40000E-01 | 60. | 48063.02 | 45648.77 | 0.66667E-03 |
| 0.19529E 01 | 29550. | 0.40000E-01 | 60. | 52771.55 | 50041.29 | 0.66667E-03 |
| 0.19929E 01 | 29610. | 0.40000E-01 | 60. | 57819.83 | 54930.49 | 0.66667E-03 |

FATIGUE CRACK PROPAGATION DATA

SPECIMEN NO. 0405 [illegible] 4000 LB STRESS RATIO 0.05 TRS

| PMAX | PMIN | AO | NO | R | K |
|---|---|---|---|---|---|
| 774. | 39. | 0.79100 | 0. | 0.25060 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.6M100E 00 | 3270. | 0.40000E-01 | 3270. | 10484.30 | 10415.34 | 0.12232E-04 |
| 0.72100E 00 | 5820. | 0.40000E-01 | 2550. | 11654.07 | 10845.40 | 0.12694E-04 |
| 0.76100E 00 | 4060. | 0.40000E-01 | 2040. | 11594.43 | 11015.88 | 0.15152E-04 |
| 0.80100E 00 | 11340. | 0.40000E-01 | 2280. | 11974.32 | 11374.45 | 0.17544E-04 |
| 0.84100E 00 | 13590. | 0.40000E-01 | 2250. | 12340.47 | 11720.16 | 0.17778E-04 |
| 0.88100E 00 | 13440. | 0.40000E-01 | 2400. | 12883.24 | 12200.27 | 0.16667E-04 |
| 0.92100E 00 | 17640. | 0.40000E-01 | 1050. | 13331.41 | 12664.00 | 0.24242E-04 |
| 0.96100E 00 | 19950. | 0.40000E-01 | 2010. | 13954.39 | 13160.79 | 0.19901E-04 |
| 0.10010E 01 | 21140. | 0.40000E-01 | 1680. | 14612.44 | 13741.38 | 0.23810E-04 |
| 0.10410E 01 | 22470. | 0.40000E-01 | 1590. | 15305.21 | 14356.45 | 0.25157E-04 |
| 0.10810E 01 | 24270. | 0.40000E-01 | 1350. | 15963.05 | 14954.90 | 0.29630E-04 |
| 0.11210E 01 | 25530. | 0.40000E-01 | 1260. | 16521.41 | 15504.31 | 0.31746E-04 |
| 0.11610E 01 | 26970. | 0.40000E-01 | 1140. | 17048.77 | 16145.25 | 0.35088E-04 |
| 0.12010E 01 | 27810. | 0.40000E-01 | 1140. | 17632.01 | 16439.28 | 0.35088E-04 |
| 0.12410E 01 | 28980. | 0.40000E-01 | 1050. | 18274.72 | 17144.55 | 0.38095E-04 |
| 0.12810E 01 | 29760. | 0.40000E-01 | 930. | 19002.37 | 17821.01 | 0.43011E-04 |
| 0.13210E 01 | 30570. | 0.40000E-01 | 750. | 20012.20 | 18780.28 | 0.53262E-04 |
| 0.13610E 01 | 31440. | 0.40000E-01 | 870. | 21723.27 | 20035.73 | 0.45977E-04 |
| 0.14010E 01 | 32100. | 0.40000E-01 | 660. | 22452.02 | 21402.96 | 0.60606E-04 |
| 0.14410E 01 | 32760. | 0.40000E-01 | 630. | 24318.88 | 23044.30 | 0.63492E-04 |
| 0.14810E 01 | 33480. | 0.40000E-01 | 630. | 25837.75 | 24344.22 | 0.63492E-04 |
| 0.15210E 01 | 34200. | 0.40000E-01 | 540. | 27538.18 | 26134.52 | 0.74074E-04 |
| 0.15610E 01 | 34410. | 0.40000E-01 | 510. | 29443.50 | 27989.46 | 0.78431E-04 |
| 0.16010E 01 | 34680. | 0.40000E-01 | 450. | 31581.62 | 30000.53 | 0.88889E-04 |
| 0.16410E 01 | 35310. | 0.40000E-01 | 450. | 33971.77 | 32210.53 | 0.88889E-04 |
| 0.16810E 01 | 35580. | 0.40000E-01 | 330. | 36677.12 | 34640.94 | 0.12121E-03 |
| 0.17210E 01 | 35760. | 0.40000E-01 | 150. | 39704.23 | 37716.50 | 0.26667E-03 |
| 0.17610E 01 | 35940. | 0.40000E-01 | 90. | 43101.07 | 40993.28 | 0.44444E-03 |



COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0720 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 779. | 39. | 0.60540 | 0. | 0.25040 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.60540E 00 | 4800. | 0.00000E 00 | 4800. | 10539.83 | 10012.17 | 0.00000E 00 |
| 0.64540E 00 | 8910. | 0.40000E-01 | 4110. | 10748.29 | 10210.20 | 0.97324E-05 |
| 0.68540E 00 | 12750. | 0.40000E-01 | 3840. | 11003.32 | 10452.46 | 0.10417E-04 |
| 0.72540E 00 | 16200. | 0.40000E-01 | 3450. | 11303.14 | 10737.27 | 0.11594E-04 |
| 0.76540E 00 | 19380. | 0.40000E-01 | 3180. | 11645.41 | 11062.40 | 0.12579E-04 |
| 0.80540E 00 | 22320. | 0.40000E-01 | 2940. | 12027.87 | 11425.71 | 0.13605E-04 |
| 0.84540E 00 | 24930. | 0.40000E-01 | 2610. | 12448.49 | 11825.27 | 0.15326E-04 |
| 0.88540E 00 | 27450. | 0.40000E-01 | 2520. | 12905.55 | 12259.46 | 0.15873E-04 |
| 0.92540E 00 | 29400. | 0.40000E-01 | 1950. | 13397.96 | 12727.21 | 0.20513E-04 |
| 0.96540E 00 | 31500. | 0.40000E-01 | 2100. | 13925.25 | 13228.11 | 0.19048E-04 |
| 0.10054E 01 | 33150. | 0.40000E-01 | 1650. | 14488.06 | 13762.74 | 0.24242E-04 |
| 0.10454E 01 | 34680. | 0.40000E-01 | 1530. | 15088.04 | 14332.68 | 0.26144E-04 |
| 0.10854E 01 | 36180. | 0.40000E-01 | 1500. | 15728.07 | 14940.67 | 0.26667E-04 |
| 0.11254E 01 | 37530. | 0.40000E-01 | 1350. | 16412.00 | 15590.36 | 0.29630E-04 |
| 0.11654E 01 | 38640. | 0.40000E-01 | 1110. | 17145.66 | 16287.29 | 0.36036E-04 |
| 0.12054E 01 | 39660. | 0.40001E-01 | 1020. | 17936.20 | 17038.25 | 0.39217E-04 |
| 0.12454E 01 | 40650. | 0.40000E-01 | 990. | 18792.36 | 17851.55 | 0.40404E-04 |
| 0.12854E 01 | 41580. | 0.40000E-01 | 930. | 19724.72 | 18737.23 | 0.43011E-04 |
| 0.13254E 01 | 42330. | 0.40000E-01 | 750. | 20745.78 | 19707.14 | 0.53333E-04 |
| 0.13654E 01 | 43110. | 0.40000E-01 | 780. | 21869.80 | 20774.92 | 0.51282E-04 |
| 0.14054E 01 | 43740. | 0.40000E-01 | 630. | 23113.50 | 21956.36 | 0.63492E-04 |
| 0.14454E 01 | 44280. | 0.40000E-01 | 540. | 24495.48 | 23269.16 | 0.74074E-04 |
| 0.14854E 01 | 44790. | 0.40000E-01 | 510. | 26036.32 | 24732.85 | 0.78431E-04 |
| 0.15254E 01 | 45300. | 0.40000E-01 | 510. | 27759.67 | 26369.92 | 0.78431E-04 |
| 0.15654E 01 | 45720. | 0.40000E-01 | 420. | 29690.69 | 28204.46 | 0.95238E-04 |
| 0.16054E 01 | 45960. | 0.40000E-01 | 240. | 31857.49 | 30262.60 | 0.16667E-03 |
| 0.16454E 01 | 46080. | 0.40000E-01 | 120. | 34290.79 | 32574.07 | 0.33333E-03 |
| 0.16854E 01 | 46200. | 0.40000E-01 | 120. | 37022.98 | 35169.44 | 0.33333E-03 |
| 0.17254E 01 | 46290. | 0.40000E-01 | 90. | 40091.40 | 38084.29 | 0.44444E-03 |
| 0.17654E 01 | 46380. | 0.40000E-01 | 90. | 43533.71 | 41354.26 | 0.44444E-03 |
| 0.18054E 01 | 46410. | 0.40000E-01 | 30. | 47391.54 | 45018.95 | 0.13333E-02 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 07210 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 779. | 39. | 0.60540 | 0. | 0.24970 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.60540E 00 | 4800. | 0.00000E-01 | 4800. | 10778.43 | 10238.82 | 0.83333E-05 |
| 0.64540E 00 | 8910. | 0.40000E-01 | 4110. | 11034.17 | 10481.76 | 0.97324E-05 |
| 0.72540E 00 | 12750. | 0.40000E-01 | 3840. | 11334.83 | 10767.37 | 0.10417E-04 |
| 0.76540E 00 | 16200. | 0.40000E-01 | 3450. | 11678.05 | 11093.41 | 0.11594E-04 |
| 0.80540E 00 | 19380. | 0.40000E-01 | 3180. | 12061.59 | 11457.74 | 0.12579E-04 |
| 0.84540E 00 | 22320. | 0.40000E-01 | 2940. | 12483.39 | 11858.43 | 0.13605E-04 |
| 0.88540E 00 | 24930. | 0.40000E-01 | 2610. | 12941.73 | 12293.83 | 0.15326E-04 |
| 0.92540E 00 | 27450. | 0.40000E-01 | 2520. | 13435.52 | 12762.89 | 0.15873E-04 |
| 0.96540E 00 | 29400. | 0.40000E-01 | 1950. | 13964.30 | 13265.20 | 0.20513E-04 |
| 0.10054E 01 | 31500. | 0.40000E-01 | 2100. | 14528.68 | 13801.32 | 0.19047E-04 |
| 0.10454E 01 | 33150. | 0.40000E-01 | 1650. | 15130.34 | 14372.84 | 0.24242E-04 |
| 0.10854E 01 | 34680. | 0.40000E-01 | 1530. | 15772.16 | 14982.55 | 0.26144E-04 |
| 0.11254E 01 | 36180. | 0.40000E-01 | 1500. | 16458.00 | 15634.06 | 0.26667E-04 |
| 0.11654E 01 | 37530. | 0.40000E-01 | 1350. | 17193.73 | 16332.95 | 0.29630E-04 |
| 0.12054E 01 | 38640. | 0.40001E-01 | 1110. | 17986.48 | 17086.02 | 0.36037E-04 |
| 0.12454E 01 | 39660. | 0.40000E-01 | 1020. | 18845.08 | 17901.40 | 0.39216E-04 |
| 0.12854E 01 | 40650. | 0.40000E-01 | 990. | 19780.02 | 18789.76 | 0.40404E-04 |
| 0.13254E 01 | 41580. | 0.40000E-01 | 930. | 20803.90 | 19762.39 | 0.43011E-04 |
| 0.13654E 01 | 42330. | 0.40000E-01 | 750. | 21931.11 | 20833.16 | 0.53333E-04 |
| 0.14054E 01 | 43110. | 0.40000E-01 | 780. | 23178.30 | 22017.91 | 0.51282E-04 |
| 0.14454E 01 | 43740. | 0.40000E-01 | 630. | 24564.16 | 23334.39 | 0.63492E-04 |
| 0.14854E 01 | 44280. | 0.40000E-01 | 540. | 26109.31 | 24802.19 | 0.74074E-04 |
| 0.15254E 01 | 44790. | 0.40000E-01 | 510. | 27837.49 | 26443.85 | 0.78431E-04 |
| 0.15654E 01 | 45300. | 0.40000E-01 | 510. | 29774.13 | 28283.53 | 0.78431E-04 |
| 0.16054E 01 | 45720. | 0.40000E-01 | 420. | 31946.80 | 30347.44 | 0.95238E-04 |
| 0.16454E 01 | 45960. | 0.40000E-01 | 240. | 34386.92 | 32665.39 | 0.16667E-03 |
| 0.16854E 01 | 46080. | 0.40000E-01 | 120. | 37126.73 | 35268.04 | 0.33333E-03 |
| 0.17254E 01 | 46200. | 0.40000E-01 | 120. | 40203.79 | 38191.05 | 0.33333E-03 |
| 0.17654E 01 | 46290. | 0.40000E-01 | 90. | 43655.75 | 41470.19 | 0.44444E-03 |
| 0.18054E 01 | 46380. | 0.40000E-01 | 90. | 47524.39 | 45148.15 | 0.44444E-03 |
| 0.18454E 01 | 46410. | 0.40000E-01 | 30. | 51853.55 | 49257.58 | 0.13333E-02 |



COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0722 LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 497. | 25. | 0,64790 | 0. | 0,25330 | 2,50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0,68790E 00 | 6990. | 0,40000E-01 | 6990. | 6950,75 | 6601,12 | 0,57225E-05 |
| 0,72790E 00 | 12120. | 0,40000E-01 | 5130. | 7141,49 | 6782,27 | 0,77973E-05 |
| 0,76790E 00 | 16440. | 0,40000E-01 | 4320. | 7359,03 | 6988,86 | 0,92592E-05 |
| 0,80790E 00 | 19800. | 0,40000E-01 | 3360. | 7601,80 | 7219,42 | 0,11905E-04 |
| 0,84790E 00 | 22800. | 0,40000E-01 | 3000. | 7868,52 | 7472,73 | 0,13333E-04 |
| 0,88790E 00 | 25560. | 0,40000E-01 | 2760. | 8158,17 | 7747,81 | 0,14493E-04 |
| 0,92790E 00 | 27660. | 0,40000E-01 | 2100. | 8470,13 | 8044,07 | 0,19048E-04 |
| 0,96790E 00 | 29610. | 0,40000E-01 | 1950. | 8804,07 | 8361,22 | 0,20513E-04 |
| 0,10079E 01 | 31410. | 0,40000E-01 | 1800. | 9160,51 | 8699,73 | 0,22222E-04 |
| 0,10479E 01 | 32910. | 0,40000E-01 | 1500. | 9540,43 | 9060,54 | 0,26667E-04 |
| 0,10879E 01 | 34290. | 0,40000E-01 | 1380. | 9945,68 | 9445,40 | 0,28985E-04 |
| 0,11279E 01 | 35850. | 0,40000E-01 | 1560. | 10378,86 | 9856,79 | 0,25641E-04 |
| 0,11679E 01 | 36870. | 0,40000E-01 | 1020. | 10843,77 | 10298,32 | 0,39216E-04 |
| 0,12079E 01 | 37890. | 0,40000E-01 | 1020. | 11344,69 | 10774,04 | 0,39216E-04 |
| 0,12479E 01 | 38640. | 0,40000E-01 | 750. | 11887,43 | 11289,48 | 0,53333E-04 |
| 0,12879E 01 | 39450. | 0,40000E-01 | 810. | 12478,72 | 11851,03 | 0,49383E-04 |
| 0,13279E 01 | 40200. | 0,40000E-01 | 750. | 13124,46 | 12466,19 | 0,53333E-04 |
| 0,13679E 01 | 40860. | 0,40000E-01 | 660. | 13839,84 | 13143,69 | 0,60606E-04 |
| 0,14079E 01 | 41400. | 0,40000E-01 | 540. | 14629,33 | 13893,46 | 0,74074E-04 |
| 0,14479E 01 | 41850. | 0,40000E-01 | 450. | 15506,79 | 14726,79 | 0,88889E-04 |
| 0,14879E 01 | 42300. | 0,40000E-01 | 450. | 16485,21 | 15655,99 | 0,88889E-04 |
| 0,15279E 01 | 42690. | 0,40000E-01 | 390. | 17579,86 | 16695,57 | 0,10256E-03 |
| 0,15679E 01 | 42990. | 0,40000E-01 | 300. | 18804,55 | 17860,57 | 0,13333E-03 |
| 0,16079E 01 | 43290. | 0,40000E-01 | 300. | 20183,17 | 19167,94 | 0,13333E-03 |
| 0,16479E 01 | 43530. | 0,40000E-01 | 240. | 21728,91 | 20635,93 | 0,16667E-03 |
| 0,16879E 01 | 43770. | 0,40000E-01 | 240. | 23464,86 | 22284,55 | 0,16667E-03 |
| 0,17279E 01 | 43980. | 0,40000E-01 | 210. | 25413,82 | 24135,48 | 0,19048E-03 |
| 0,17679E 01 | 44130. | 0,40001E-01 | 150. | 27600,31 | 26211,99 | 0,26667E-03 |
| 0,18079E 01 | 44280. | 0,40000E-01 | 150. | 30050,99 | 28539,40 | 0,26667E-03 |
| 0,18479E 01 | 44400. | 0,40000E-01 | 120. | 32792,81 | 31143,30 | 0,33333E-03 |
| 0,18879E 01 | 44520. | 0,40000E-01 | 120. | 35856,38 | 34052,77 | 0,33333E-03 |
| 0,19279E 01 | 44610. | 0,40000E-01 | 90. | 39274,42 | 37298,88 | 0,44444E-03 |
| 0,19679E 01 | 44670. | 0,40000E-01 | 60. | 43078,74 | 40911,84 | 0,66667E-03 |
| 0,20079E 01 | 44730. | 0,40000E-01 | 60. | 47306,60 | 44927,04 | 0,66667E-03 |
| 0,20479E 01 | 44790. | 0,40000E-01 | 60. | 51994,97 | 49379,57 | 0,66667E-03 |
| 0,20879E 01 | 44850. | 0,40000E-01 | 60. | 57184,74 | 54308,30 | 0,66667E-03 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0855 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 779. | 39. | 0,60760 | 0. | 0,25510 | 2,50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0,64760E 00 | 5070. | 0,40000E-01 | 5070. | 10562,88 | 10034,06 | 0,78894E-05 |
| 0,68760E 00 | 9630. | 0,40000E-01 | 4560. | 10815,70 | 10274,23 | 0,87719E-05 |
| 0,72760E 00 | 13980. | 0,40000E-01 | 4350. | 11112,27 | 10555,95 | 0,91954E-05 |
| 0,76760E 00 | 16800. | 0,40000E-01 | 3720. | 11450,45 | 10877,20 | 0,10753E-04 |
| 0,80760E 00 | 20220. | 0,40000E-01 | 3420. | 11827,98 | 11235,84 | 0,11696E-04 |
| 0,84760E 00 | 23430. | 0,40000E-01 | 3210. | 12242,83 | 11629,91 | 0,12461E-04 |
| 0,88760E 00 | 26220. | 0,40000E-01 | 2790. | 12693,48 | 12058,00 | 0,14337E-04 |
| 0,92760E 00 | 28800. | 0,40000E-01 | 2580. | 13178,44 | 12518,88 | 0,15504E-04 |
| 0,96760E 00 | 31260. | 0,40000E-01 | 2460. | 13698,17 | 13012,59 | 0,16260E-04 |
| 0,10076E 01 | 33330. | 0,40000E-01 | 2070. | 14252,61 | 13539,07 | 0,19324E-04 |
| 0,10476E 01 | 35190. | 0,40000E-01 | 1860. | 14843,60 | 14100,68 | 0,21505E-04 |
| 0,10876E 01 | 36930. | 0,40000E-01 | 1740. | 15471,98 | 14699,30 | 0,22988E-04 |
| 0,11276E 01 | 38500. | 0,40000E-01 | 1570. | 16147,90 | 15339,48 | 0,25478E-04 |
| 0,11676E 01 | 40080. | 0,40000E-01 | 1580. | 16871,00 | 16024,38 | 0,25316E-04 |
| 0,12076E 01 | 41400. | 0,40000E-01 | 1320. | 17650,27 | 16766,64 | 0,30303E-04 |
| 0,12476E 01 | 42480. | 0,40000E-01 | 1080. | 18490,34 | 17568,45 | 0,37037E-04 |
| 0,12876E 01 | 43590. | 0,40000E-01 | 1110. | 19414,06 | 18442,13 | 0,36036E-04 |
| 0,13276E 01 | 44520. | 0,40000E-01 | 930. | 20421,40 | 19399,04 | 0,43011E-04 |
| 0,13676E 01 | 45360. | 0,40001E-01 | 840. | 21530,82 | 20452,91 | 0,47620E-04 |
| 0,14076E 01 | 46140. | 0,40000E-01 | 780. | 22758,68 | 21619,27 | 0,51282E-04 |
| 0,14476E 01 | 46770. | 0,40000E-01 | 630. | 24123,13 | 22915,44 | 0,63492E-04 |
| 0,14876E 01 | 47430. | 0,40000E-01 | 660. | 25644,68 | 24360,82 | 0,60606E-04 |
| 0,15276E 01 | 47790. | 0,40000E-01 | 360. | 27348,73 | 25977,66 | 0,11111E-03 |
| 0,15676E 01 | 48240. | 0,40000E-01 | 450. | 29254,31 | 27789,74 | 0,88889E-04 |
| 0,16076E 01 | 48540. | 0,40000E-01 | 300. | 31394,88 | 29823,14 | 0,13333E-03 |
| 0,16476E 01 | 48780. | 0,40000E-01 | 240. | 33798,73 | 32106,65 | 0,16667E-03 |
| 0,16876E 01 | 49020. | 0,40000E-01 | 240. | 36497,72 | 34670,52 | 0,16667E-03 |
| 0,17276E 01 | 49140. | 0,40000E-01 | 120. | 39528,63 | 37549,69 | 0,33333E-03 |
| 0,17676E 01 | 49230. | 0,40000E-01 | 90. | 42928,26 | 40779,13 | 0,44444E-03 |
| 0,18076E 01 | 49260. | 0,40000E-01 | 30. | 46738,58 | 44398,69 | 0,13333E-02 |
| 0,18476E 01 | 49290. | 0,40000E-01 | 30. | 51003,45 | 48450,04 | 0,13333E-02 |
| 0,18876E 01 | 49320. | 0,40000E-01 | 30. | 55767,45 | 52975,73 | 0,13333E-02 |



COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0856 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | N |
|---|---|---|---|---|---|
| 779. | 39. | 0.60930 | 0. | 0.25560 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.64930E 00 | 5550. | 0.40000E-01 | 5550. | 10551.98 | 10023.71 | 0.72072E-05 |
| 0.68930E 00 | 9900. | 0.40000E-01 | 4350. | 10806.25 | 10265.26 | 0.91954E-05 |
| 0.72930E 00 | 14160. | 0.40000E-01 | 4260. | 11104.05 | 10548.15 | 0.93897E-05 |
| 0.76930E 00 | 18000. | 0.40000E-01 | 3840. | 11443.29 | 10870.39 | 0.10417E-04 |
| 0.80930E 00 | 21630. | 0.40000E-01 | 3630. | 11821.73 | 11229.89 | 0.11019E-04 |
| 0.84930E 00 | 25050. | 0.40000E-01 | 3420. | 12237.23 | 11624.60 | 0.11696E-04 |
| 0.88930E 00 | 28020. | 0.40000E-01 | 2970. | 12688.42 | 12053.19 | 0.13468E-04 |
| 0.92930E 00 | 30750. | 0.40000E-01 | 2730. | 13174.22 | 12514.67 | 0.14652E-04 |
| 0.96930E 00 | 32910. | 0.40000E-01 | 2160. | 13694.16 | 13008.59 | 0.18518E-04 |
| 0.10093E 01 | 35310. | 0.40000E-01 | 2400. | 14249.00 | 13535.64 | 0.16667E-04 |
| 0.10493E 01 | 37140. | 0.40000E-01 | 1830. | 14840.47 | 14097.51 | 0.21858E-04 |
| 0.10893E 01 | 38910. | 0.40000E-01 | 1770. | 15471.39 | 14696.84 | 0.22599E-04 |
| 0.11293E 01 | 40590. | 0.40000E-01 | 1680. | 16145.96 | 15337.64 | 0.23809E-04 |
| 0.11693E 01 | 42090. | 0.40000E-01 | 1500. | 16869.85 | 16025.29 | 0.26667E-04 |
| 0.12093E 01 | 43650. | 0.40000E-01 | 1560. | 17650.13 | 16766.50 | 0.25641E-04 |
| 0.12493E 01 | 44640. | 0.40000E-01 | 990. | 18495.67 | 17569.71 | 0.40404E-04 |
| 0.12893E 01 | 45870. | 0.40000E-01 | 1230. | 19416.91 | 18444.84 | 0.32520E-04 |
| 0.13293E 01 | 46590. | 0.40000E-01 | 720. | 20426.37 | 19403.75 | 0.55556E-04 |
| 0.13693E 01 | 47490. | 0.40000E-01 | 900. | 21538.26 | 20459.98 | 0.44444E-04 |
| 0.14093E 01 | 48150. | 0.40000E-01 | 660. | 22769.04 | 21629.15 | 0.60606E-04 |
| 0.14493E 01 | 48840. | 0.40000E-01 | 690. | 24137.12 | 22928.73 | 0.57971E-04 |
| 0.14893E 01 | 49410. | 0.40000E-01 | 570. | 25662.90 | 24378.13 | 0.70175E-04 |
| 0.15293E 01 | 49890. | 0.40000E-01 | 480. | 27369.93 | 25999.69 | 0.83333E-04 |
| 0.15693E 01 | 50190. | 0.40000E-01 | 300. | 29282.89 | 27816.89 | 0.13333E-03 |
| 0.16093E 01 | 50430. | 0.40000E-01 | 240. | 31429.80 | 29856.31 | 0.16667E-03 |
| 0.16493E 01 | 50580. | 0.40000E-01 | 150. | 33840.74 | 32146.55 | 0.26667E-03 |
| 0.16893E 01 | 50730. | 0.40000E-01 | 150. | 36548.21 | 34718.48 | 0.26667E-03 |
| 0.17293E 01 | 50820. | 0.40000E-01 | 90. | 39587.78 | 37605.88 | 0.44444E-03 |
| 0.17693E 01 | 50910. | 0.40001E-01 | 90. | 42997.70 | 40845.09 | 0.44445E-03 |
| 0.18093E 01 | 50940. | 0.40000E-01 | 30. | 46819.40 | 44475.46 | 0.13333E-02 |
| 0.18493E 01 | 51000. | 0.40000E-01 | 60. | 51094.75 | 48536.77 | 0.66667E-03 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0857 LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | N |
|---|---|---|---|---|---|
| 497. | 25. | 0.64830 | 0. | 0.25400 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.68830E 00 | 4380. | 0.40000E-01 | 4380. | 6933.35 | 6584.59 | 0.91324E-05 |
| 0.72830E 00 | 8100. | 0.40000E-01 | 3720. | 7123.88 | 6765.54 | 0.10753E-04 |
| 0.76830E 00 | 11520. | 0.40000E-01 | 3420. | 7341.03 | 6971.77 | 0.11696E-04 |
| 0.80830E 00 | 14640. | 0.40000E-01 | 3120. | 7583.38 | 7201.93 | 0.12821E-04 |
| 0.84830E 00 | 18240. | 0.40000E-01 | 3600. | 7849.61 | 7454.77 | 0.11111E-04 |
| 0.88830E 00 | 21090. | 0.40000E-01 | 2850. | 8138.73 | 7729.54 | 0.14035E-04 |
| 0.92830E 00 | 23190. | 0.40000E-01 | 2100. | 8449.99 | 8024.95 | 0.19048E-04 |
| 0.96830E 00 | 25230. | 0.40000E-01 | 2040. | 8783.26 | 8341.46 | 0.19608E-04 |
| 0.10083E 01 | 27240. | 0.40000E-01 | 2010. | 9138.91 | 8679.21 | 0.19900E-04 |
| 0.10483E 01 | 28920. | 0.40000E-01 | 1680. | 9518.00 | 9039.24 | 0.23809E-04 |
| 0.10883E 01 | 30300. | 0.40000E-01 | 1380. | 9922.44 | 9423.33 | 0.28986E-04 |
| 0.11283E 01 | 31500. | 0.40000E-01 | 1200. | 10354.79 | 9833.95 | 0.33333E-04 |
| 0.11683E 01 | 32670. | 0.40000E-01 | 1170. | 10818.63 | 10274.05 | 0.34188E-04 |
| 0.12083E 01 | 33870. | 0.40000E-01 | 1200. | 11318.60 | 10749.24 | 0.33333E-04 |
| 0.12483E 01 | 34890. | 0.40000E-01 | 1020. | 11860.35 | 11263.77 | 0.39216E-04 |
| 0.12883E 01 | 35760. | 0.40000E-01 | 870. | 12450.48 | 11826.21 | 0.45977E-04 |
| 0.13283E 01 | 36540. | 0.40001E-01 | 780. | 13097.06 | 12439.27 | 0.51285E-04 |
| 0.13683E 01 | 37170. | 0.40000E-01 | 630. | 13809.14 | 13114.53 | 0.63492E-04 |
| 0.14083E 01 | 37800. | 0.40000E-01 | 630. | 14597.34 | 13864.08 | 0.63492E-04 |
| 0.14483E 01 | 38340. | 0.40000E-01 | 540. | 15473.30 | 14694.98 | 0.74074E-04 |
| 0.14883E 01 | 38850. | 0.40000E-01 | 510. | 16450.30 | 15622.83 | 0.78431E-04 |
| 0.15283E 01 | 39240. | 0.40000E-01 | 390. | 17542.87 | 16660.45 | 0.10256E-03 |
| 0.15683E 01 | 39660. | 0.40000E-01 | 420. | 18767.81 | 17823.77 | 0.95238E-04 |
| 0.16083E 01 | 40020. | 0.40000E-01 | 360. | 20142.18 | 19128.97 | 0.11111E-03 |
| 0.16483E 01 | 40350. | 0.40000E-01 | 330. | 21685.45 | 20594.68 | 0.12121E-03 |
| 0.16883E 01 | 40590. | 0.40000E-01 | 240. | 23418.61 | 22240.68 | 0.16667E-03 |
| 0.17283E 01 | 40800. | 0.40000E-01 | 210. | 25364.32 | 24088.08 | 0.19048E-03 |
| 0.17683E 01 | 41040. | 0.40000E-01 | 240. | 27547.51 | 26161.84 | 0.16667E-03 |
| 0.18083E 01 | 41250. | 0.40000E-01 | 210. | 29993.86 | 28485.13 | 0.19048E-03 |
| 0.18483E 01 | 41400. | 0.40000E-01 | 150. | 32731.78 | 31085.30 | 0.26667E-03 |
| 0.18883E 01 | 41550. | 0.40000E-01 | 150. | 35790.49 | 33990.20 | 0.26667E-03 |
| 0.19283E 01 | 41670. | 0.40000E-01 | 120. | 39201.83 | 37229.95 | 0.33333E-03 |
| 0.19683E 01 | 41790. | 0.40000E-01 | 120. | 42999.89 | 40838.96 | 0.33333E-03 |
| 0.20083E 01 | 41880. | 0.40000E-01 | 90. | 47220.34 | 44845.11 | 0.44444E-03 |
| 0.20483E 01 | 41910. | 0.40000E-01 | 30. | 51900.61 | 49269.98 | 0.13333E-02 |



COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1101 TRANS GRAIN ROOM AIR TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 5AS. | 29. | 0.04340 | 0. | 0.25340 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.68390E 00 | 9990. | 0.40000E-01 | 9990. | 8157.57 | 7753.19 | 0.40040E-05 |
| 0.72390E 00 | 21840. | 0.40000E-01 | 11850. | 8378.81 | 7965.46 | 0.33755E-05 |
| 0.76390E 00 | 31620. | 0.40000E-01 | 9780. | 8631.63 | 8203.75 | 0.40900E-05 |
| 0.80390E 00 | 41760. | 0.40000E-01 | 10140. | 8914.38 | 8472.48 | 0.39448E-05 |
| 0.84390E 00 | 50010. | 0.40000E-01 | 8250. | 9225.46 | 8768.14 | 0.48485E-05 |
| 0.88390E 00 | 58350. | 0.40000E-01 | 8340. | 9563.62 | 9089.54 | 0.47962E-05 |
| 0.92390E 00 | 64320. | 0.40000E-01 | 5970. | 9928.00 | 9435.85 | 0.67002E-05 |
| 0.96390E 00 | 71340. | 0.40000E-01 | 7020. | 10318.41 | 9806.91 | 0.56980E-05 |
| 0.10039E 01 | 75990. | 0.40000E-01 | 4650. | 10735.06 | 10202.90 | 0.86021E-05 |
| 0.10439E 01 | 81090. | 0.40000E-01 | 5100. | 11179.23 | 10625.06 | 0.78431E-05 |
| 0.10839E 01 | 85410. | 0.40001E-01 | 4320. | 11652.94 | 11075.28 | 0.92595E-05 |
| 0.11239E 01 | 88050. | 0.40000E-01 | 2640. | 12159.23 | 11556.48 | 0.15152E-04 |
| 0.11639E 01 | 92070. | 0.40000E-01 | 4020. | 12702.24 | 12072.57 | 0.99502E-05 |
| 0.12039E 01 | 94800. | 0.40000E-01 | 2730. | 13287.14 | 12628.47 | 0.14652E-04 |
| 0.12439E 01 | 97500. | 0.40000E-01 | 2700. | 13920.46 | 13230.40 | 0.14815E-04 |
| 0.12839E 01 | 99240. | 0.40000E-01 | 1740. | 14610.05 | 13885.80 | 0.22988E-04 |
| 0.13239E 01 | 100950. | 0.40000E-01 | 1710. | 15365.09 | 14603.42 | 0.23392E-04 |
| 0.13639E 01 | 102720. | 0.40000E-01 | 1770. | 16196.17 | 15393.30 | 0.22599E-04 |
| 0.14039E 01 | 103920. | 0.40000E-01 | 1200. | 17115.50 | 16267.05 | 0.33333E-04 |
| 0.14439E 01 | 105150. | 0.40000E-01 | 1230. | 18136.93 | 17237.85 | 0.32520E-04 |
| 0.14839E 01 | 106050. | 0.40000E-01 | 900. | 19275.55 | 18320.03 | 0.44444E-04 |
| 0.15239E 01 | 106980. | 0.40000E-01 | 930. | 20549.07 | 19530.42 | 0.43011E-04 |
| 0.15639E 01 | 107700. | 0.40000E-01 | 720. | 21975.70 | 20886.52 | 0.55556E-04 |
| 0.16039E 01 | 108270. | 0.40000E-01 | 570. | 23576.93 | 22408.18 | 0.70175E-04 |
| 0.16439E 01 | 108720. | 0.40000E-01 | 450. | 25374.79 | 24116.91 | 0.88889E-04 |
| 0.16839E 01 | 109170. | 0.40000E-01 | 450. | 27393.24 | 26035.30 | 0.88889E-04 |
| 0.17239E 01 | 109410. | 0.40000E-01 | 240. | 29660.16 | 28189.86 | 0.16667E-03 |
| 0.17639E 01 | 109560. | 0.40000E-01 | 150. | 32203.91 | 30607.50 | 0.26667E-03 |
| 0.18039E 01 | 109710. | 0.40000E-01 | 150. | 35054.57 | 33316.86 | 0.26667E-03 |
| 0.18439E 01 | 109800. | 0.40000E-01 | 90. | 38244.23 | 36348.40 | 0.44444E-03 |
| 0.18839E 01 | 109860. | 0.40000E-01 | 60. | 41810.33 | 39737.71 | 0.66667E-03 |
| 0.19239E 01 | 109890. | 0.40000E-01 | 30. | 45787.79 | 43518.00 | 0.13333E-02 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1102 TRANS GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 4A7. | 23. | 0.68800 | 0. | 0.25340 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.72800E 00 | 4890. | 0.40000E-01 | 4890. | 6708.27 | 6377.88 | 0.81800E-05 |
| 0.76800E 00 | 9720. | 0.40000E-01 | 4830. | 6912.59 | 6572.15 | 0.82814E-05 |
| 0.80800E 00 | 13920. | 0.40000E-01 | 4200. | 7140.69 | 6789.01 | 0.95238E-05 |
| 0.84800E 00 | 17820. | 0.40000E-01 | 3900. | 7391.27 | 7027.25 | 0.10256E-04 |
| 0.88800E 00 | 21150. | 0.40000E-01 | 3330. | 7663.42 | 7285.99 | 0.12012E-04 |
| 0.92800E 00 | 23880. | 0.40000E-01 | 2730. | 7956.43 | 7564.57 | 0.14652E-04 |
| 0.96800E 00 | 26190. | 0.40000E-01 | 2310. | 8270.20 | 7862.89 | 0.17316E-04 |
| 0.10080E 01 | 28380. | 0.40000E-01 | 2190. | 8605.04 | 8181.24 | 0.18265E-04 |
| 0.10480E 01 | 30150. | 0.40000E-01 | 1770. | 8961.97 | 8520.59 | 0.22599E-04 |
| 0.10880E 01 | 31800. | 0.40000E-01 | 1650. | 9342.41 | 8882.49 | 0.24242E-04 |
| 0.11280E 01 | 33270. | 0.40000E-01 | 1470. | 9749.59 | 9269.42 | 0.27211E-04 |
| 0.11680E 01 | 34560. | 0.40000E-01 | 1290. | 10184.33 | 9680.65 | 0.31008E-04 |
| 0.12080E 01 | 35520. | 0.40000E-01 | 960. | 10656.96 | 10132.10 | 0.41667E-04 |
| 0.12480E 01 | 36450. | 0.40000E-01 | 930. | 11166.81 | 10616.88 | 0.43011E-04 |
| 0.12880E 01 | 37260. | 0.40000E-01 | 810. | 11722.32 | 11144.99 | 0.49383E-04 |
| 0.13280E 01 | 38010. | 0.40000E-01 | 750. | 12330.91 | 11723.61 | 0.53333E-04 |
| 0.13680E 01 | 38640. | 0.40000E-01 | 630. | 13001.04 | 12360.73 | 0.63492E-04 |
| 0.14080E 01 | 39300. | 0.40000E-01 | 660. | 13742.78 | 13065.94 | 0.60606E-04 |
| 0.14480E 01 | 39810. | 0.40000E-01 | 510. | 14567.21 | 13849.77 | 0.78431E-04 |
| 0.14880E 01 | 40260. | 0.40000E-01 | 450. | 15486.35 | 14723.64 | 0.88889E-04 |
| 0.15280E 01 | 40680. | 0.40000E-01 | 420. | 16514.95 | 15701.58 | 0.95238E-04 |
| 0.15680E 01 | 41040. | 0.40000E-01 | 360. | 17667.47 | 16797.34 | 0.11111E-03 |
| 0.16080E 01 | 41460. | 0.40000E-01 | 420. | 18960.65 | 18026.83 | 0.95238E-04 |
| 0.16480E 01 | 41730. | 0.40000E-01 | 270. | 20413.19 | 19407.80 | 0.14815E-03 |
| 0.16880E 01 | 41970. | 0.40000E-01 | 240. | 22043.76 | 20958.10 | 0.16667E-03 |
| 0.17280E 01 | 42210. | 0.40000E-01 | 240. | 23875.22 | 22699.36 | 0.16667E-03 |
| 0.17680E 01 | 42420. | 0.40000E-01 | 210. | 25929.48 | 24652.45 | 0.19048E-03 |
| 0.18080E 01 | 42540. | 0.40000E-01 | 120. | 28283.69 | 28031.61 | 0.50000E-03 |
| 0.18480E 01 | 42660. | 0.40000E-01 | 120. | 32207.58 | 30621.31 | 0.33333E-03 |
| 0.18880E 01 | 42790. | 0.20000E-01 | 90. | 33686.42 | 32027.35 | 0.22222E-03 |

COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1204 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 779. | 39. | 0.60730 | 0. | 0.24930 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.64730E 00 | 8880. | 0.40000E-01 | 8880. | 10806.84 | 10265.82 | 0.45045E-05 |
| 0.68730E 00 | 14370. | 0.40000E-01 | 5490. | 11065.21 | 10511.25 | 0.72860E-05 |
| 0.72730E 00 | 20550. | 0.40000E-01 | 6180. | 11368.36 | 10799.25 | 0.64725E-05 |
| 0.76730E 00 | 26940. | 0.40000E-01 | 6390. | 11714.13 | 11127.68 | 0.62598E-05 |
| 0.80730E 00 | 32940. | 0.40000E-01 | 6000. | 12100.15 | 11494.38 | 0.66667E-05 |
| 0.84730E 00 | 37650. | 0.40000E-01 | 4710. | 12524.41 | 11897.39 | 0.84926E-05 |
| 0.88730E 00 | 42180. | 0.40000E-01 | 4530. | 12985.12 | 12335.04 | 0.88300E-05 |
| 0.92730E 00 | 46230. | 0.40000E-01 | 4050. | 13481.36 | 12806.43 | 0.98765E-05 |
| 0.96730E 00 | 49650. | 0.40000E-01 | 3420. | 14012.75 | 13311.23 | 0.11696E-04 |
| 0.10073E 01 | 52590. | 0.40000E-01 | 2940. | 14579.80 | 13849.88 | 0.13606E-04 |
| 0.10473E 01 | 55320. | 0.40000E-01 | 2730. | 15184.20 | 14424.03 | 0.14652E-04 |
| 0.10873E 01 | 57930. | 0.40000E-01 | 2610. | 15829.01 | 15036.56 | 0.15326E-04 |
| 0.11273E 01 | 60180. | 0.40000E-01 | 2250. | 16518.27 | 15691.31 | 0.17778E-04 |
| 0.11673E 01 | 62070. | 0.40000E-01 | 1890. | 17257.78 | 16393.79 | 0.21164E-04 |
| 0.12073E 01 | 63420. | 0.40000E-01 | 1350. | 18054.69 | 17150.81 | 0.29630E-04 |
| 0.12473E 01 | 64950. | 0.40000E-01 | 1530. | 18917.86 | 17970.77 | 0.26144E-04 |
| 0.12873E 01 | 66390. | 0.40000E-01 | 1440. | 19858.41 | 18864.23 | 0.27778E-04 |
| 0.13273E 01 | 67410. | 0.40000E-01 | 1020. | 20888.39 | 19842.65 | 0.39216E-04 |
| 0.13673E 01 | 68370. | 0.40000E-01 | 960. | 22022.87 | 20920.33 | 0.41667E-04 |
| 0.14073E 01 | 69240. | 0.40000E-01 | 870. | 23278.15 | 22112.77 | 0.45977E-04 |
| 0.14473E 01 | 69990. | 0.40000E-01 | 750. | 24673.34 | 23438.11 | 0.53333E-04 |
| 0.14873E 01 | 70740. | 0.40000E-01 | 750. | 26229.30 | 24916.18 | 0.53333E-04 |
| 0.15273E 01 | 71250. | 0.40000E-01 | 510. | 27969.12 | 26568.89 | 0.78431E-04 |
| 0.15673E 01 | 71640. | 0.40000E-01 | 390. | 29919.30 | 28421.44 | 0.10256E-03 |
| 0.16073E 01 | 71970. | 0.40000E-01 | 330. | 32107.71 | 30500.29 | 0.12121E-03 |
| 0.16473E 01 | 72000. | 0.40000E-01 | 30. | 34565.13 | 32836.68 | 0.13333E-02 |
| 0.16873E 01 | 72510. | 0.40000E-01 | 510. | 37325.61 | 35456.96 | 0.78431E-04 |
| 0.17273E 01 | 72720. | 0.40000E-01 | 210. | 40423.66 | 38399.91 | 0.19048E-03 |
| 0.17673E 01 | 72870. | 0.40000E-01 | 150. | 43899.97 | 41702.19 | 0.26667E-03 |
| 0.18073E 01 | 72990. | 0.40000E-01 | 120. | 47796.05 | 45403.21 | 0.33333E-03 |
| 0.18473E 01 | 73050. | 0.40000E-01 | 60. | 52154.83 | 49543.78 | 0.66667E-03 |
| 0.18873E 01 | 73080. | 0.40000E-01 | 30. | 57026.49 | 54171.55 | 0.13333E-02 |
| 0.19273E 01 | 73110. | 0.40001E-01 | 30. | 62459.77 | 59352.82 | 0.13334E-02 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1205 LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 497. | 25. | 0.64810 | 0. | 0.25220 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.68810E 00 | 5610. | 0.40000E-01 | 5610. | 6981.93 | 6630.73 | 0.71301E-05 |
| 0.72810E 00 | 9660. | 0.40000E-01 | 4050. | 7173.68 | 6812.84 | 0.98765E-05 |
| 0.76810E 00 | 13290. | 0.40000E-01 | 3630. | 7392.25 | 7020.41 | 0.11019E-04 |
| 0.80810E 00 | 16680. | 0.40000E-01 | 3390. | 7636.23 | 7252.12 | 0.11799E-04 |
| 0.84810E 00 | 19080. | 0.40000E-01 | 2400. | 7904.23 | 7506.64 | 0.16667E-04 |
| 0.88810E 00 | 21420. | 0.40000E-01 | 2340. | 8195.29 | 7783.06 | 0.17094E-04 |
| 0.92810E 00 | 23940. | 0.40000E-01 | 2520. | 8508.63 | 8080.64 | 0.15873E-04 |



COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1320 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 779. | 39. | 0.60860 | 0. | 0.25420 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.64860E 00 | 3810. | 0.40000E-01 | 3810. | 10606.07 | 10075.09 | 0.10499E-04 |
| 0.68860E 00 | 8070. | 0.40000E-01 | 4260. | 10860.86 | 10317.13 | 0.93897E-05 |
| 0.72860E 00 | 12240. | 0.40000E-01 | 4170. | 11159.63 | 10600.94 | 0.95923E-05 |
| 0.76860E 00 | 16320. | 0.40000E-01 | 4080. | 11499.98 | 10924.25 | 0.98039E-05 |
| 0.80860E 00 | 19950. | 0.40000E-01 | 3630. | 11879.86 | 11285.11 | 0.11019E-04 |
| 0.84860E 00 | 23160. | 0.40000E-01 | 3210. | 12297.06 | 11681.43 | 0.12461E-04 |
| 0.88860E 00 | 25710. | 0.40000E-01 | 2550. | 12750.17 | 12111.85 | 0.15686E-04 |
| 0.92860E 00 | 28560. | 0.40000E-01 | 2850. | 13237.93 | 12575.20 | 0.14035E-04 |
| 0.96860E 00 | 30840. | 0.40000E-01 | 2280. | 13760.12 | 13071.24 | 0.17544E-04 |
| 0.10086E 01 | 32910. | 0.40000E-01 | 2070. | 14317.45 | 13600.67 | 0.19324E-04 |
| 0.10486E 01 | 34710. | 0.40000E-01 | 1800. | 14911.47 | 14164.95 | 0.22222E-04 |
| 0.10886E 01 | 36540. | 0.40000E-01 | 1830. | 15545.13 | 14766.89 | 0.21858E-04 |
| 0.11286E 01 | 38070. | 0.40000E-01 | 1530. | 16222.58 | 15410.43 | 0.26144E-04 |
| 0.11686E 01 | 39720. | 0.40000E-01 | 1650. | 16949.45 | 16100.91 | 0.24242E-04 |
| 0.12086E 01 | 40920. | 0.40000E-01 | 1200. | 17733.05 | 16845.27 | 0.33333E-04 |
| 0.12486E 01 | 41910. | 0.40000E-01 | 990. | 18581.86 | 17651.59 | 0.40404E-04 |
| 0.12886E 01 | 42900. | 0.40000E-01 | 990. | 19506.88 | 18530.29 | 0.40404E-04 |
| 0.13286E 01 | 43830. | 0.40000E-01 | 930. | 20520.20 | 19492.89 | 0.43011E-04 |
| 0.13686E 01 | 44730. | 0.40000E-01 | 900. | 21636.36 | 20553.17 | 0.44444E-04 |
| 0.14086E 01 | 45540. | 0.40000E-01 | 810. | 22871.64 | 21726.61 | 0.49383E-04 |
| 0.14486E 01 | 46260. | 0.40000E-01 | 720. | 24244.71 | 23030.93 | 0.55556E-04 |
| 0.14886E 01 | 46740. | 0.40000E-01 | 480. | 25776.12 | 24485.68 | 0.83333E-04 |
| 0.15286E 01 | 47310. | 0.40000E-01 | 570. | 27488.78 | 26112.60 | 0.70175E-04 |
| 0.15686E 01 | 47820. | 0.40000E-01 | 510. | 29408.47 | 27936.18 | 0.78431E-04 |
| 0.16086E 01 | 48180. | 0.40000E-01 | 360. | 31563.00 | 29982.85 | 0.11111E-03 |
| 0.16486E 01 | 48540. | 0.40000E-01 | 360. | 33982.04 | 32280.79 | 0.11111E-03 |
| 0.16886E 01 | 48810. | 0.40000E-01 | 270. | 36698.87 | 34861.60 | 0.14815E-03 |
| 0.17286E 01 | 49050. | 0.40000E-01 | 240. | 39748.55 | 37758.61 | 0.16667E-03 |
| 0.17686E 01 | 49230. | 0.40001E-01 | 180. | 43171.11 | 41009.81 | 0.22223E-03 |
| 0.18086E 01 | 49410. | 0.40000E-01 | 180. | 47005.80 | 44652.53 | 0.22222E-03 |
| 0.18486E 01 | 49500. | 0.40000E-01 | 90. | 51297.13 | 48729.02 | 0.44444E-03 |
| 0.18886E 01 | 49560. | 0.40000E-01 | 60. | 56091.45 | 53283.31 | 0.66667E-03 |
| 0.19286E 01 | 49590. | 0.40000E-01 | 30. | 61439.39 | 58363.42 | 0.13333E-02 |
| 0.19686E 01 | 49620. | 0.40000E-01 | 30. | 67392.06 | 64018.19 | 0.13333E-02 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1321 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 621. | 31. | 0.60100 | 0. | 0.24930 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.64100E 00 | 9840. | 0.40000E-01 | 9840. | 8585.89 | 8157.30 | 0.40650E-05 |
| 0.68100E 00 | 17850. | 0.40000E-01 | 8010. | 8786.05 | 8347.46 | 0.49938E-05 |
| 0.72100E 00 | 24480. | 0.40000E-01 | 6630. | 9022.25 | 8571.88 | 0.60332E-05 |
| 0.76100E 00 | 30840. | 0.40000E-01 | 6360. | 9292.60 | 8828.73 | 0.62893E-05 |
| 0.80100E 00 | 37890. | 0.40000E-01 | 7050. | 9595.42 | 9116.43 | 0.56738E-05 |
| 0.84100E 00 | 42390. | 0.40000E-01 | 4500. | 9928.89 | 9433.25 | 0.88889E-05 |
| 0.88100E 00 | 46890. | 0.40000E-01 | 4500. | 10291.71 | 9777.96 | 0.88889E-05 |
| 0.92100E 00 | 51600. | 0.40000E-01 | 4710. | 10682.90 | 10149.62 | 0.84926E-05 |
| 0.96100E 00 | 55470. | 0.40000E-01 | 3870. | 11101.97 | 10547.78 | 0.10336E-04 |
| 0.10010E 01 | 59010. | 0.40000E-01 | 3540. | 11549.56 | 10973.02 | 0.11300E-04 |
| 0.10410E 01 | 62040. | 0.40000E-01 | 3030. | 12026.57 | 11426.21 | 0.13201E-04 |
| 0.10810E 01 | 64740. | 0.40000E-01 | 2700. | 12535.29 | 11909.54 | 0.14815E-04 |
| 0.11210E 01 | 67140. | 0.40000E-01 | 2400. | 13078.88 | 12426.00 | 0.16667E-04 |
| 0.11610E 01 | 69360. | 0.40000E-01 | 2220. | 13661.73 | 12979.76 | 0.18018E-04 |
| 0.12010E 01 | 71250. | 0.40000E-01 | 1890. | 14289.38 | 13576.07 | 0.21164E-04 |
| 0.12410E 01 | 72960. | 0.40000E-01 | 1710. | 14968.67 | 14221.45 | 0.23392E-04 |
| 0.12810E 01 | 74520. | 0.40000E-01 | 1560. | 15708.02 | 14923.89 | 0.25641E-04 |
| 0.13210E 01 | 76020. | 0.40000E-01 | 1500. | 16517.23 | 15692.71 | 0.26667E-04 |
| 0.13610E 01 | 77400. | 0.40000E-01 | 1380. | 17407.56 | 16538.60 | 0.28985E-04 |
| 0.14010E 01 | 78480. | 0.40000E-01 | 1080. | 18392.21 | 17474.09 | 0.37037E-04 |
| 0.14410E 01 | 79320. | 0.40000E-01 | 840. | 19485.75 | 18513.04 | 0.47619E-04 |
| 0.14810E 01 | 80250. | 0.40000E-01 | 930. | 20704.63 | 19671.08 | 0.43011E-04 |
| 0.15210E 01 | 81060. | 0.40000E-01 | 810. | 22067.24 | 20965.67 | 0.49383E-04 |
| 0.15610E 01 | 81750. | 0.40000E-01 | 690. | 23594.04 | 22416.25 | 0.57971E-04 |
| 0.16010E 01 | 82380. | 0.40000E-01 | 630. | 25307.38 | 24044.07 | 0.63492E-04 |
| 0.16410E 01 | 82890. | 0.40000E-01 | 510. | 27230.70 | 25871.38 | 0.78431E-04 |
| 0.16810E 01 | 83280. | 0.40000E-01 | 390. | 29390.58 | 27923.43 | 0.10256E-03 |
| 0.17210E 01 | 83610. | 0.40000E-01 | 330. | 31816.30 | 30228.06 | 0.12121E-03 |
| 0.17610E 01 | 83940. | 0.40000E-01 | 330. | 34538.30 | 32814.18 | 0.12121E-03 |
| 0.18010E 01 | 84240. | 0.40000E-01 | 300. | 37589.15 | 35712.75 | 0.13333E-03 |
| 0.18410E 01 | 84420. | 0.40000E-01 | 180. | 41003.10 | 38956.27 | 0.22222E-03 |
| 0.18810E 01 | 84540. | 0.40000E-01 | 120. | 44819.75 | 42582.39 | 0.33333E-03 |
| 0.19210E 01 | 84660. | 0.40000E-01 | 120. | 49077.94 | 46628.03 | 0.33333E-03 |
| 0.19610E 01 | 84720. | 0.40001E-01 | 60. | 53820.00 | 51133.37 | 0.66668E-03 |
| 0.20010E 01 | 84750. | 0.40000E-01 | 30. | 59090.93 | 56141.17 | 0.13333E-02 |



COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1322 LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 497. | 25. | 0.72820 | 0. | 0.25390 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.76820E 00 | 2610. | 0.40000E-01 | 2610. | 7343.34 | 6973.96 | 0.15324E-04 |
| 0.80820E 00 | 4890. | 0.40000E-01 | 2280. | 7585.74 | 7204.17 | 0.17544E-04 |
| 0.84820E 00 | 6660. | 0.40000E-01 | 1770. | 7852.00 | 7457.04 | 0.22599E-04 |
| 0.88820E 00 | 8250. | 0.40000E-01 | 1590. | 8141.14 | 7731.64 | 0.25157E-04 |
| 0.92820E 00 | 9900. | 0.40000E-01 | 1650. | 8452.51 | 8027.34 | 0.24242E-04 |
| 0.96820E 00 | 11460. | 0.40000E-01 | 1560. | 8785.82 | 8343.88 | 0.25641E-04 |
| 0.10082E 01 | 12960. | 0.40000E-01 | 1500. | 9141.64 | 8681.81 | 0.26666E-04 |
| 0.10482E 01 | 14130. | 0.40000E-01 | 1170. | 9520.79 | 9041.89 | 0.34188E-04 |
| 0.10882E 01 | 15240. | 0.40000E-01 | 1110. | 9925.26 | 9426.01 | 0.36036E-04 |
| 0.11282E 01 | 16290. | 0.40000E-01 | 1050. | 10357.70 | 9836.70 | 0.38095E-04 |
| 0.11682E 01 | 17250. | 0.40000E-01 | 960. | 10821.68 | 10277.34 | 0.41667E-04 |
| 0.12082E 01 | 18060. | 0.40001E-01 | 810. | 11321.79 | 10752.30 | 0.49384E-04 |
| 0.12482E 01 | 18690. | 0.40000E-01 | 630. | 11863.61 | 11266.86 | 0.63492E-04 |
| 0.12882E 01 | 19500. | 0.40000E-01 | 810. | 12453.90 | 11827.46 | 0.49383E-04 |
| 0.13282E 01 | 20070. | 0.40000E-01 | 570. | 13100.56 | 12441.59 | 0.70175E-04 |
| 0.13682E 01 | 20670. | 0.40000E-01 | 600. | 13812.77 | 13117.97 | 0.66667E-04 |
| 0.14082E 01 | 21210. | 0.40000E-01 | 540. | 14600.97 | 13866.53 | 0.74074E-04 |
| 0.14482E 01 | 21600. | 0.40000E-01 | 390. | 15477.04 | 14698.53 | 0.10256E-03 |
| 0.14882E 01 | 21990. | 0.40000E-01 | 390. | 16454.02 | 15626.37 | 0.10256E-03 |
| 0.15282E 01 | 22320. | 0.40000E-01 | 330. | 17546.84 | 16664.21 | 0.12121E-03 |
| 0.15682E 01 | 22650. | 0.40000E-01 | 330. | 18771.94 | 17827.70 | 0.12121E-03 |
| 0.16082E 01 | 22920. | 0.40000E-01 | 270. | 20146.26 | 19132.89 | 0.14815E-03 |
| 0.16482E 01 | 23130. | 0.40000E-01 | 210. | 21689.80 | 20598.79 | 0.19048E-03 |
| 0.16882E 01 | 23310. | 0.40000E-01 | 180. | 23423.01 | 22244.81 | 0.22222E-03 |
| 0.17282E 01 | 23580. | 0.40000E-01 | 270. | 25369.18 | 24093.09 | 0.14815E-03 |
| 0.17682E 01 | 24060. | 0.40000E-01 | 480. | 27552.62 | 26166.70 | 0.83333E-04 |
| 0.18082E 01 | 24450. | 0.40000E-01 | 390. | 29999.02 | 28490.04 | 0.10256E-03 |
| 0.18482E 01 | 24870. | 0.40000E-01 | 420. | 32737.08 | 31090.38 | 0.95238E-04 |
| 0.18882E 01 | 25200. | 0.40000E-01 | 330. | 35796.13 | 33995.55 | 0.12121E-03 |
| 0.19282E 01 | 25470. | 0.40000E-01 | 270. | 39208.21 | 37236.00 | 0.14815E-03 |
| 0.19682E 01 | 25650. | 0.40000E-01 | 180. | 43006.87 | 40843.58 | 0.22222E-03 |
| 0.20082E 01 | 25830. | 0.40000E-01 | 180. | 47227.76 | 44852.16 | 0.22222E-03 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1455 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 779. | 39. | 0.60720 | 0. | 0.25460 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.64720E 00 | 4740. | 0.40000E-01 | 4740. | 10581.29 | 10051.55 | 0.84388E-05 |
| 0.68720E 00 | 8940. | 0.40000E-01 | 4200. | 10834.18 | 10291.78 | 0.95238E-05 |
| 0.72720E 00 | 12900. | 0.40000E-01 | 3960. | 11130.91 | 10573.66 | 0.10101E-04 |
| 0.76720E 00 | 16890. | 0.40000E-01 | 3990. | 11469.36 | 10895.17 | 0.10025E-04 |
| 0.80720E 00 | 20370. | 0.40000E-01 | 3480. | 11847.29 | 11254.17 | 0.11494E-04 |
| 0.84720E 00 | 23310. | 0.40000E-01 | 2940. | 12262.62 | 11648.71 | 0.13605E-04 |
| 0.88720E 00 | 26100. | 0.40000E-01 | 2790. | 12713.68 | 12077.20 | 0.14337E-04 |
| 0.92720E 00 | 28500. | 0.40000E-01 | 2400. | 13199.47 | 12538.66 | 0.16667E-04 |
| 0.96720E 00 | 30750. | 0.40000E-01 | 2250. | 13719.72 | 13032.87 | 0.17778E-04 |
| 0.10072E 01 | 32760. | 0.40000E-01 | 2010. | 14274.87 | 13560.22 | 0.19901E-04 |
| 0.10472E 01 | 34680. | 0.40000E-01 | 1920. | 14866.67 | 14122.39 | 0.20833E-04 |
| 0.10872E 01 | 36480. | 0.40000E-01 | 1800. | 15497.88 | 14722.00 | 0.22222E-04 |
| 0.11272E 01 | 38070. | 0.40000E-01 | 1590. | 16172.59 | 15362.93 | 0.25157E-04 |
| 0.11672E 01 | 39570. | 0.40000E-01 | 1500. | 16896.60 | 16050.70 | 0.26667E-04 |
| 0.12072E 01 | 40920. | 0.40000E-01 | 1350. | 17676.81 | 16791.85 | 0.29630E-04 |
| 0.12472E 01 | 42090. | 0.40000E-01 | 1170. | 18521.92 | 17594.65 | 0.34188E-04 |
| 0.12872E 01 | 43200. | 0.40000E-01 | 1110. | 19442.51 | 18469.15 | 0.36036E-04 |
| 0.13272E 01 | 44070. | 0.40000E-01 | 870. | 20450.88 | 19427.04 | 0.45977E-04 |
| 0.13672E 01 | 44940. | 0.40000E-01 | 870. | 21561.47 | 20482.03 | 0.45977E-04 |
| 0.14072E 01 | 45810. | 0.40000E-01 | 870. | 22790.29 | 21649.33 | 0.45977E-04 |
| 0.14472E 01 | 46470. | 0.40000E-01 | 660. | 24156.06 | 22948.73 | 0.60606E-04 |
| 0.14872E 01 | 47100. | 0.40000E-01 | 630. | 25678.83 | 24393.26 | 0.63492E-04 |
| 0.15272E 01 | 47550. | 0.40000E-01 | 450. | 27382.68 | 26011.77 | 0.88889E-04 |
| 0.15672E 01 | 48090. | 0.40000E-01 | 540. | 29291.72 | 27825.27 | 0.74074E-04 |
| 0.16072E 01 | 48420. | 0.40000E-01 | 330. | 31433.77 | 29860.09 | 0.12121E-03 |
| 0.16472E 01 | 48690. | 0.40000E-01 | 270. | 33839.39 | 32145.27 | 0.14815E-03 |
| 0.16872E 01 | 49020. | 0.40000E-01 | 330. | 36541.05 | 34711.68 | 0.12121E-03 |
| 0.17272E 01 | 49200. | 0.40000E-01 | 180. | 39573.66 | 37592.46 | 0.22222E-03 |
| 0.17672E 01 | 49290. | 0.40001E-01 | 90. | 42976.66 | 40825.10 | 0.44445E-03 |
| 0.18072E 01 | 49530. | 0.40000E-01 | 240. | 46790.69 | 44448.18 | 0.16667E-03 |
| 0.18472E 01 | 49560. | 0.40000E-01 | 30. | 51058.73 | 48502.55 | 0.13333E-02 |
| 0.18872E 01 | 49590. | 0.40000E-01 | 30. | 55826.62 | 53031.75 | 0.13333E-02 |



COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1456 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | W |
|---|---|---|---|---|---|
| 779. | 39. | 0.60910 | 0. | 0.25520 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.64910E 00 | 4380. | 0.40000E-01 | 4380. | 10567.41 | 10038.37 | 0.91324E-05 |
| 0.68910E 00 | 8820. | 0.40000E-01 | 4440. | 10821.79 | 10280.02 | 0.90090E-05 |
| 0.72910E 00 | 13230. | 0.40000E-01 | 4410. | 11119.88 | 10563.18 | 0.90703E-05 |
| 0.76910E 00 | 17010. | 0.40000E-01 | 3780. | 11459.42 | 10885.73 | 0.10582E-04 |
| 0.80910E 00 | 20730. | 0.40000E-01 | 3720. | 11838.26 | 11245.59 | 0.10753E-04 |
| 0.84910E 00 | 23940. | 0.40000E-01 | 3210. | 12254.38 | 11640.89 | 0.12461E-04 |
| 0.88910E 00 | 27120. | 0.40000E-01 | 3180. | 12706.07 | 12069.96 | 0.12579E-04 |
| 0.92910E 00 | 29460. | 0.40000E-01 | 2340. | 13192.30 | 12531.85 | 0.17094E-04 |
| 0.96910E 00 | 32010. | 0.40000E-01 | 2550. | 13712.92 | 13026.40 | 0.15686E-04 |
| 0.10091E 01 | 34080. | 0.40000E-01 | 2070. | 14268.50 | 13554.17 | 0.19324E-04 |
| 0.10491E 01 | 36060. | 0.40000E-01 | 1980. | 14860.64 | 14116.66 | 0.20202E-04 |
| 0.10891E 01 | 38100. | 0.40000E-01 | 2040. | 15492.37 | 14716.77 | 0.19608E-04 |
| 0.11291E 01 | 39750. | 0.40000E-01 | 1650. | 16167.73 | 15358.32 | 0.24242E-04 |
| 0.11691E 01 | 41310. | 0.40000E-01 | 1560. | 16892.55 | 16046.85 | 0.25641E-04 |
| 0.12091E 01 | 42480. | 0.40000E-01 | 1170. | 17673.69 | 16788.89 | 0.34188E-04 |
| 0.12491E 01 | 43560. | 0.40000E-01 | 1080. | 18520.18 | 17592.99 | 0.37037E-04 |
| 0.12891E 01 | 44700. | 0.40000E-01 | 1140. | 19442.43 | 18469.07 | 0.35088E-04 |
| 0.13291E 01 | 45750. | 0.40000E-01 | 1050. | 20453.05 | 19429.10 | 0.38095E-04 |
| 0.13691E 01 | 46680. | 0.40000E-01 | 930. | 21566.18 | 20486.51 | 0.43011E-04 |
| 0.14091E 01 | 47430. | 0.40000E-01 | 750. | 22798.16 | 21656.80 | 0.53333E-04 |
| 0.14491E 01 | 48090. | 0.40000E-01 | 660. | 24167.64 | 22957.73 | 0.60606E-04 |
| 0.14891E 01 | 48780. | 0.40001E-01 | 690. | 25695.31 | 24408.92 | 0.57972E-04 |
| 0.15291E 01 | 49200. | 0.40000E-01 | 420. | 27403.83 | 26031.90 | 0.95238E-04 |
| 0.15691E 01 | 49620. | 0.40000E-01 | 420. | 29318.76 | 27850.96 | 0.95238E-04 |
| 0.16091E 01 | 49980. | 0.40000E-01 | 360. | 31467.50 | 29892.13 | 0.11111E-03 |
| 0.16491E 01 | 50250. | 0.40000E-01 | 270. | 33880.93 | 32186.73 | 0.14815E-03 |
| 0.16891E 01 | 50460. | 0.40000E-01 | 210. | 36591.35 | 34759.46 | 0.19048E-03 |
| 0.17291E 01 | 50640. | 0.40000E-01 | 180. | 39633.80 | 37649.59 | 0.22222E-03 |
| 0.17691E 01 | 50790. | 0.40000E-01 | 150. | 43047.65 | 40892.54 | 0.26667E-03 |
| 0.18091E 01 | 50880. | 0.40000E-01 | 90. | 46872.04 | 44525.46 | 0.44444E-03 |
| 0.18491E 01 | 50910. | 0.40000E-01 | 30. | 51152.20 | 48591.34 | 0.13333E-02 |
| 0.18891E 01 | 50940. | 0.40000E-01 | 30. | 55934.80 | 53134.51 | 0.13333E-02 |
| 0.19291E 01 | 50970. | 0.40000E-01 | 30. | 61268.39 | 58201.08 | 0.13333E-02 |
| 0.19691E 01 | 51000. | 0.40000E-01 | 30. | 67206.19 | 63841.64 | 0.13333E-02 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1457 LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | W |
|---|---|---|---|---|---|
| 497. | 25. | 0.64880 | 0. | 0.25300 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.68880E 00 | 9450. | 0.40000E-01 | 9450. | 6962.95 | 6612.71 | 0.42328E-05 |
| 0.72880E 00 | 15300. | 0.40000E-01 | 5850. | 7154.59 | 6794.71 | 0.68376E-05 |
| 0.76880E 00 | 19170. | 0.40000E-01 | 3870. | 7372.95 | 7002.08 | 0.10336E-04 |
| 0.80880E 00 | 22800. | 0.40000E-01 | 3630. | 7616.52 | 7233.40 | 0.11019E-04 |
| 0.84880E 00 | 25620. | 0.40000E-01 | 2820. | 7884.13 | 7487.55 | 0.14184E-04 |
| 0.88880E 00 | 28080. | 0.40000E-01 | 2460. | 8174.61 | 7763.42 | 0.16260E-04 |
| 0.92880E 00 | 30120. | 0.40000E-01 | 2040. | 8487.39 | 8060.47 | 0.19608E-04 |
| 0.96880E 00 | 32100. | 0.40000E-01 | 1980. | 8822.26 | 8378.50 | 0.20202E-04 |
| 0.10088E 01 | 33930. | 0.40000E-01 | 1830. | 9179.64 | 8717.89 | 0.21858E-04 |
| 0.10488E 01 | 35400. | 0.40001E-01 | 1470. | 9560.57 | 9079.67 | 0.27211E-04 |
| 0.10888E 01 | 36750. | 0.40000E-01 | 1350. | 9966.87 | 9465.53 | 0.29630E-04 |
| 0.11288E 01 | 38070. | 0.40000E-01 | 1320. | 10401.31 | 9876.11 | 0.30303E-04 |
| 0.11688E 01 | 39330. | 0.40000E-01 | 1260. | 10867.48 | 10320.84 | 0.31746E-04 |
| 0.12088E 01 | 40290. | 0.40000E-01 | 960. | 11369.89 | 10797.98 | 0.41667E-04 |
| 0.12488E 01 | 41100. | 0.40000E-01 | 810. | 11914.30 | 11315.00 | 0.49383E-04 |
| 0.12888E 01 | 41940. | 0.40000E-01 | 840. | 12507.45 | 11878.32 | 0.47619E-04 |
| 0.13288E 01 | 42690. | 0.40000E-01 | 750. | 13157.30 | 12495.48 | 0.53333E-04 |
| 0.13688E 01 | 43200. | 0.40000E-01 | 510. | 13873.16 | 13175.33 | 0.78431E-04 |
| 0.14088E 01 | 43800. | 0.40000E-01 | 600. | 14665.48 | 13927.80 | 0.66667E-04 |
| 0.14488E 01 | 44310. | 0.40000E-01 | 510. | 15546.09 | 14764.11 | 0.78431E-04 |
| 0.14888E 01 | 44760. | 0.40000E-01 | 450. | 16520.25 | 15690.86 | 0.88889E-04 |
| 0.15288E 01 | 45090. | 0.40000E-01 | 330. | 17626.69 | 16740.05 | 0.12121E-03 |
| 0.15688E 01 | 45420. | 0.40000E-01 | 330. | 18858.32 | 17909.73 | 0.12121E-03 |
| 0.16088E 01 | 45690. | 0.40000E-01 | 270. | 20239.86 | 19221.78 | 0.14815E-03 |
| 0.16488E 01 | 46050. | 0.40000E-01 | 360. | 21791.53 | 20695.39 | 0.11111E-03 |
| 0.16888E 01 | 46290. | 0.40000E-01 | 240. | 23534.23 | 22350.44 | 0.16667E-03 |
| 0.17288E 01 | 46500. | 0.40000E-01 | 210. | 25490.67 | 24208.46 | 0.19048E-03 |
| 0.17688E 01 | 46650. | 0.40000E-01 | 150. | 27685.52 | 26292.91 | 0.26667E-03 |
| 0.18088E 01 | 46830. | 0.40000E-01 | 180. | 30144.55 | 28628.26 | 0.22222E-03 |
| 0.18488E 01 | 46980. | 0.40000E-01 | 150. | 32897.21 | 31242.45 | 0.26667E-03 |
| 0.18888E 01 | 47070. | 0.40000E-01 | 90. | 35972.00 | 34162.58 | 0.44444E-03 |
| 0.19288E 01 | 47160. | 0.40000E-01 | 90. | 39401.98 | 37420.02 | 0.44444E-03 |
| 0.19688E 01 | 47229. | 0.40000E-01 | 69. | 43219.91 | 41045.91 | 0.57971E-03 |
| 0.20088E 01 | 47310. | 0.40000E-01 | 81. | 47462.79 | 45075.37 | 0.49383E-03 |



COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1701 TRANS GRAIN ROOM AIR TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | W |
|---|---|---|---|---|---|
| 585. | 29. | 0,64830 | 0. | 0,25370 | 2,50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0,68830E 00 | 7140. | 0,40000E-01 | 7140. | 8170,63 | 7765,60 | 0,56022E-05 |
| 0,72830E 00 | 12990. | 0,40000E-01 | 5850. | 8395,16 | 7979,00 | 0,68376E-05 |
| 0,76830E 00 | 18990. | 0,40000E-01 | 6000. | 8651,07 | 8222,22 | 0,66667E-05 |
| 0,80830E 00 | 24690. | 0,40000E-01 | 5700. | 8936,66 | 8493,66 | 0,70175E-05 |
| 0,84830E 00 | 29640. | 0,40000E-01 | 4950. | 9250,41 | 8791,85 | 0,80808E-05 |
| 0,88830E 00 | 35220. | 0,40000E-01 | 5580. | 9591,12 | 9115,67 | 0,71685E-05 |
| 0,92830E 00 | 40470. | 0,40000E-01 | 5250. | 9957,94 | 9464,30 | 0,76191E-05 |
| 0,96830E 00 | 43200. | 0,40000E-01 | 2730. | 10350,68 | 9837,57 | 0,14652E-04 |
| 0,10083E 01 | 46620. | 0,40000E-01 | 3420. | 10769,78 | 10235,91 | 0,11696E-04 |
| 0,10483E 01 | 49530. | 0,40000E-01 | 2910. | 11216,53 | 10660,51 | 0,13746E-04 |
| 0,10883E 01 | 51780. | 0,40000E-01 | 2250. | 11693,14 | 11113,49 | 0,17778E-04 |
| 0,11283E 01 | 54330. | 0,40000E-01 | 2550. | 12202,64 | 11597,74 | 0,15686E-04 |
| 0,11683E 01 | 56640. | 0,40000E-01 | 2310. | 12749,26 | 12117,26 | 0,17316E-04 |
| 0,12083E 01 | 58650. | 0,40000E-01 | 2010. | 13338,45 | 12677,24 | 0,19900E-04 |
| 0,12483E 01 | 60060. | 0,40000E-01 | 1410. | 13976,88 | 13284,02 | 0,28369E-04 |
| 0,12883E 01 | 61650. | 0,40000E-01 | 1620. | 14672,33 | 13945,00 | 0,24691E-04 |
| 0,13283E 01 | 63030. | 0,40001E-01 | 1350. | 15434,29 | 14669,18 | 0,29630E-04 |
| 0,13683E 01 | 64050. | 0,40000E-01 | 1020. | 16273,44 | 15466,74 | 0,39216E-04 |
| 0,14083E 01 | 65070. | 0,40000E-01 | 1020. | 17202,29 | 16349,55 | 0,39216E-04 |
| 0,14483E 01 | 65970. | 0,40000E-01 | 900. | 18234,59 | 17330,66 | 0,44444E-04 |
| 0,14883E 01 | 66900. | 0,40000E-01 | 930. | 19385,92 | 18424,93 | 0,43011E-04 |
| 0,15283E 01 | 67440. | 0,40000E-01 | 540. | 20673,47 | 19648,65 | 0,74074E-04 |
| 0,15683E 01 | 68070. | 0,40000E-01 | 630. | 22117,01 | 21020,63 | 0,63492E-04 |
| 0,16083E 01 | 68460. | 0,40000E-01 | 390. | 23736,59 | 22559,93 | 0,10256E-03 |
| 0,16483E 01 | 68820. | 0,40000E-01 | 360. | 25555,32 | 24288,49 | 0,11111E-03 |
| 0,16883E 01 | 69090. | 0,40000E-01 | 270. | 27597,77 | 26229,70 | 0,14815E-03 |
| 0,17283E 01 | 69300. | 0,40000E-01 | 210. | 29890,70 | 28408,94 | 0,19048E-03 |
| 0,17683E 01 | 69420. | 0,40000E-01 | 120. | 32463,48 | 30854,21 | 0,33333E-03 |
| 0,18083E 01 | 69540. | 0,40000E-01 | 120. | 35346,38 | 33594,20 | 0,33333E-03 |
| 0,18483E 01 | 69600. | 0,40000E-01 | 60. | 38572,86 | 36660,73 | 0,66667E-03 |
| 0,18883E 01 | 69690. | 0,40000E-01 | 90. | 42177,46 | 40086,65 | 0,44444E-03 |
| 0,19283E 01 | 69720. | 0,40000E-01 | 30. | 46197,57 | 43907,47 | 0,13333E-02 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1702 TRANS GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | W |
|---|---|---|---|---|---|
| 467. | 23. | 0,64640 | 0. | 0,25050 | 2,50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0,68640E 00 | 6780. | 0,40000E-01 | 6780. | 6597,90 | 6272,95 | 0,58997E-05 |
| 0,72640E 00 | 13630. | 0,40000E-01 | 7050. | 6778,16 | 6444,34 | 0,56738E-05 |
| 0,76640E 00 | 19950. | 0,40000E-01 | 6120. | 6983,89 | 6639,94 | 0,65359E-05 |
| 0,80640E 00 | 26490. | 0,40000E-01 | 6540. | 7213,71 | 6858,44 | 0,61162E-05 |
| 0,84640E 00 | 31740. | 0,40000E-01 | 5250. | 7466,27 | 7098,56 | 0,76191E-05 |
| 0,88640E 00 | 35970. | 0,40000E-01 | 4230. | 7740,73 | 7359,50 | 0,94563E-05 |
| 0,92640E 00 | 40170. | 0,40000E-01 | 4200. | 8036,29 | 7640,50 | 0,95238E-05 |
| 0,96640E 00 | 43410. | 0,40000E-01 | 3240. | 8352,86 | 7941,48 | 0,12346E-04 |
| 0,10064E 01 | 46410. | 0,40000E-01 | 3000. | 8690,68 | 8262,66 | 0,13333E-04 |
| 0,10464E 01 | 48510. | 0,40000E-01 | 2100. | 9050,77 | 8605,02 | 0,19048E-04 |
| 0,10864E 01 | 50400. | 0,40000E-01 | 1890. | 9434,90 | 8970,23 | 0,21164E-04 |
| 0,11264E 01 | 52050. | 0,40000E-01 | 1650. | 9845,44 | 9360,55 | 0,24242E-04 |
| 0,11664E 01 | 53550. | 0,40000E-01 | 1500. | 10285,90 | 9779,32 | 0,26667E-04 |
| 0,12064E 01 | 54750. | 0,40000E-01 | 1200. | 10760,60 | 10230,64 | 0,33333E-04 |
| 0,12464E 01 | 55800. | 0,40000E-01 | 1050. | 11274,68 | 10719,40 | 0,38095E-04 |
| 0,12864E 01 | 56820. | 0,40000E-01 | 1020. | 11834,58 | 11251,73 | 0,39216E-04 |
| 0,13264E 01 | 57570. | 0,40000E-01 | 750. | 12447,87 | 11834,80 | 0,53333E-04 |
| 0,13664E 01 | 58230. | 0,40000E-01 | 660. | 13123,16 | 12476,84 | 0,60606E-04 |
| 0,14064E 01 | 58860. | 0,40000E-01 | 630. | 13870,37 | 13187,25 | 0,63492E-04 |
| 0,14464E 01 | 59340. | 0,40000E-01 | 480. | 14700,73 | 13976,72 | 0,83333E-04 |
| 0,14864E 01 | 59790. | 0,40000E-01 | 450. | 15626,43 | 14856,83 | 0,88889E-04 |
| 0,15264E 01 | 60270. | 0,40000E-01 | 480. | 16662,18 | 15841,57 | 0,83333E-04 |
| 0,15664E 01 | 60630. | 0,40000E-01 | 360. | 17822,58 | 16944,81 | 0,11111E-03 |
| 0,16064E 01 | 60930. | 0,40000E-01 | 300. | 19124,87 | 18182,96 | 0,13333E-03 |
| 0,16464E 01 | 61200. | 0,40001E-01 | 270. | 20587,25 | 19573,32 | 0,14815E-03 |
| 0,16864E 01 | 61470. | 0,40000E-01 | 270. | 22229,59 | 21134,77 | 0,14815E-03 |
| 0,17264E 01 | 61650. | 0,40000E-01 | 180. | 24073,32 | 22887,70 | 0,22222E-03 |
| 0,17664E 01 | 61830. | 0,40000E-01 | 180. | 26142,16 | 24854,65 | 0,22222E-03 |
| 0,18064E 01 | 61950. | 0,40000E-01 | 120. | 28460,57 | 27058,88 | 0,33333E-03 |
| 0,18464E 01 | 62040. | 0,40000E-01 | 90. | 31054,75 | 29525,30 | 0,44444E-03 |
| 0,18864E 01 | 62130. | 0,40000E-01 | 90. | 33953,77 | 32281,54 | 0,44444E-03 |
| 0,19264E 01 | 62190. | 0,40000E-01 | 60. | 37187,58 | 35356,08 | 0,66667E-03 |
| 0,19664E 01 | 62220. | 0,40000E-01 | 30. | 40788,40 | 38779,56 | 0,13333E-02 |



COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1804 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 779. | 39. | 0.60440 | 0. | 0.25190 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.64440E 00 | 3780. | 0.40000E-01 | 3780. | 10678.53 | 10143.93 | 0.10582E-04 |
| 0.68440E 00 | 8220. | 0.40000E-01 | 4440. | 10930.93 | 10383.69 | 0.90090E-05 |
| 0.72440E 00 | 11250. | 0.40000E-01 | 3030. | 11227.83 | 10665.73 | 0.13201E-04 |
| 0.76440E 00 | 14820. | 0.40000E-01 | 3570. | 11567.02 | 10987.93 | 0.11204E-04 |
| 0.80440E 00 | 17460. | 0.40000E-01 | 2640. | 11946.25 | 11348.18 | 0.15152E-04 |
| 0.84440E 00 | 20100. | 0.40000E-01 | 2640. | 12363.47 | 11744.51 | 0.15152E-04 |
| 0.88440E 00 | 22680. | 0.40000E-01 | 2580. | 12816.89 | 12175.23 | 0.15504E-04 |
| 0.92440E 00 | 24630. | 0.40000E-01 | 1950. | 13305.47 | 12639.35 | 0.20513E-04 |
| 0.96440E 00 | 26520. | 0.40000E-01 | 1890. | 13828.79 | 13136.47 | 0.21164E-04 |
| 0.10044E 01 | 28440. | 0.40000E-01 | 1920. | 14387.38 | 13667.10 | 0.20833E-04 |
| 0.10444E 01 | 30030. | 0.40000E-01 | 1590. | 14982.83 | 14232.74 | 0.25157E-04 |
| 0.10844E 01 | 31740. | 0.40000E-01 | 1710. | 15617.94 | 14836.05 | 0.23392E-04 |
| 0.11244E 01 | 33030. | 0.40000E-01 | 1290. | 16296.69 | 15480.82 | 0.31008E-04 |
| 0.11644E 01 | 34140. | 0.40000E-01 | 1110. | 17024.77 | 16172.45 | 0.36036E-04 |
| 0.12044E 01 | 35220. | 0.40000E-01 | 1080. | 17809.04 | 16917.46 | 0.37037E-04 |
| 0.12444E 01 | 36180. | 0.40000E-01 | 960. | 18658.29 | 17724.19 | 0.41667E-04 |
| 0.12844E 01 | 37110. | 0.40000E-01 | 930. | 19583.00 | 18602.61 | 0.43011E-04 |
| 0.13244E 01 | 37980. | 0.40000E-01 | 870. | 20595.55 | 19564.47 | 0.45977E-04 |
| 0.13644E 01 | 38790. | 0.40000E-01 | 810. | 21710.30 | 20623.41 | 0.49383E-04 |
| 0.14044E 01 | 39480. | 0.40000E-01 | 690. | 22943.43 | 21794.80 | 0.57971E-04 |
| 0.14444E 01 | 40050. | 0.40000E-01 | 570. | 24313.42 | 23096.21 | 0.70175E-04 |
| 0.14844E 01 | 40620. | 0.40000E-01 | 570. | 25840.66 | 24546.99 | 0.70175E-04 |
| 0.15244E 01 | 41190. | 0.40000E-01 | 570. | 27549.25 | 26170.04 | 0.70175E-04 |
| 0.15644E 01 | 41550. | 0.40000E-01 | 360. | 29463.18 | 27988.15 | 0.11111E-03 |
| 0.16044E 01 | 41970. | 0.40000E-01 | 420. | 31610.79 | 30028.25 | 0.95238E-04 |
| 0.16444E 01 | 42300. | 0.40000E-01 | 330. | 34022.86 | 32319.55 | 0.12121E-03 |
| 0.16844E 01 | 42690. | 0.40000E-01 | 390. | 36730.62 | 34891.75 | 0.10256E-03 |
| 0.17244E 01 | 42900. | 0.40000E-01 | 210. | 39771.97 | 37780.85 | 0.19048E-03 |
| 0.17644E 01 | 43080. | 0.40000E-01 | 180. | 43184.23 | 41022.28 | 0.22222E-03 |
| 0.18044E 01 | 43290. | 0.40001E-01 | 210. | 47007.63 | 44654.26 | 0.19048E-03 |
| 0.18444E 01 | 43440. | 0.40000E-01 | 150. | 51287.52 | 48719.88 | 0.26667E-03 |
| 0.18844E 01 | 43590. | 0.40000E-01 | 150. | 56070.22 | 53263.15 | 0.26667E-03 |

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1805 LONG GRAIN ROOM SALT TEST F 5 HZ

| PMAX | PMIN | AO | NO | B | M |
|---|---|---|---|---|---|
| 497. | 25. | 0.64580 | 0. | 0.25260 | 2.50000 |

| A | N | DELA | DELN | KMAX | DELK | DADN |
|---|---|---|---|---|---|---|
| 0.68580E 00 | 4980. | 0.40000E-01 | 4980. | 6980.71 | 6610.58 | 0.80321E-05 |
| 0.72580E 00 | 8340. | 0.40000E-01 | 3360. | 7150.57 | 6790.89 | 0.11905E-04 |
| 0.76580E 00 | 11160. | 0.40000E-01 | 2820. | 7367.51 | 6998.73 | 0.14184E-04 |
| 0.80580E 00 | 13650. | 0.40000E-01 | 2490. | 7609.48 | 7226.70 | 0.16064E-04 |
| 0.84580E 00 | 15930. | 0.40000E-01 | 2280. | 7875.68 | 7479.53 | 0.17544E-04 |
| 0.88580E 00 | 17820. | 0.40000E-01 | 1890. | 8164.98 | 7754.28 | 0.21164E-04 |
| 0.92580E 00 | 19800. | 0.40000E-01 | 1980. | 8478.61 | 8050.23 | 0.20202E-04 |
| 0.96580E 00 | 21360. | 0.40000E-01 | 1560. | 8810.34 | 8367.17 | 0.25641E-04 |
| 0.10058E 01 | 22800. | 0.40000E-01 | 1440. | 9166.55 | 8705.46 | 0.27778E-04 |
| 0.10458E 01 | 24240. | 0.40000E-01 | 1440. | 9546.24 | 9066.06 | 0.27778E-04 |
| 0.10858E 01 | 25500. | 0.40000E-01 | 1260. | 9951.17 | 9450.62 | 0.31746E-04 |
| 0.11258E 01 | 26670. | 0.40000E-01 | 1170. | 10384.09 | 9861.77 | 0.34188E-04 |
| 0.11658E 01 | 27540. | 0.40000E-01 | 870. | 10848.51 | 10302.82 | 0.45977E-04 |
| 0.12058E 01 | 28560. | 0.40000E-01 | 1020. | 11348.80 | 10777.95 | 0.39216E-04 |
| 0.12458E 01 | 29340. | 0.40000E-01 | 780. | 11890.67 | 11292.56 | 0.51282E-04 |
| 0.12858E 01 | 29940. | 0.40000E-01 | 600. | 12480.47 | 11853.07 | 0.66667E-04 |
| 0.13258E 01 | 30690. | 0.40000E-01 | 750. | 13127.19 | 12466.88 | 0.53333E-04 |
| 0.13658E 01 | 31290. | 0.40000E-01 | 600. | 13838.78 | 13142.68 | 0.66667E-04 |
| 0.14058E 01 | 31800. | 0.40000E-01 | 510. | 14628.26 | 13890.54 | 0.78431E-04 |
| 0.14458E 01 | 32280. | 0.40000E-01 | 480. | 15501.15 | 14721.43 | 0.83333E-04 |
| 0.14858E 01 | 32730. | 0.40000E-01 | 450. | 16476.54 | 15647.75 | 0.88889E-04 |
| 0.15258E 01 | 33150. | 0.40000E-01 | 420. | 17567.85 | 16684.17 | 0.95238E-04 |
| 0.15658E 01 | 33510. | 0.40000E-01 | 360. | 18790.26 | 17845.09 | 0.11111E-03 |
| 0.16058E 01 | 33720. | 0.40000E-01 | 210. | 20162.41 | 19148.22 | 0.19048E-03 |
| 0.16458E 01 | 34050. | 0.40000E-01 | 330. | 21703.24 | 20611.55 | 0.12121E-03 |
| 0.16858E 01 | 34320. | 0.40000E-01 | 270. | 23433.27 | 22254.56 | 0.14815E-03 |
| 0.17258E 01 | 34530. | 0.40000E-01 | 210. | 25375.79 | 24049.37 | 0.19048E-03 |
| 0.17658E 01 | 34740. | 0.40001E-01 | 210. | 27555.28 | 26169.22 | 0.19048E-03 |
| 0.18058E 01 | 34860. | 0.40000E-01 | 120. | 29998.10 | 28489.23 | 0.33333E-03 |
| 0.18458E 01 | 35010. | 0.40000E-01 | 150. | 32731.48 | 31085.06 | 0.26667E-03 |
| 0.18858E 01 | 35160. | 0.40000E-01 | 150. | 35786.53 | 33988.43 | 0.26667E-03 |
| 0.19258E 01 | 35280. | 0.40000E-01 | 120. | 39193.66 | 37222.21 | 0.33333E-03 |
| 0.19658E 01 | 35430. | 0.40000E-01 | 120. | 42987.59 | 40825.27 | 0.33333E-03 |
| 0.20058E 01 | 35460. | 0.40000E-01 | 60. | 47203.77 | 44829.38 | 0.66667E-03 |



COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

## APPENDIX E

## CALCULATION OF POTENTIAL WEIGHT SAVINGS IN THE YUH-61A HORIZONTAL-STABILIZER SPAR FITTING

The fatigue life of a helicopter component is based on a design-allowable fatigue-endurance limit which must be used to account for variables other than basic material properties affecting the fatigue performance of helicopter components.

The design-allowable fatigue-endurance limit for helicopter components is established by reducing the mean-endurance limit of material-coupon data to account for component-coupon size effects and to accommodate the statistical probabilities of component failure.

Results of the Task III material-coupon tests indicate that 7475-TMT1 has a higher mean-endurance limit than 7075-T73 has for the design conditions which apply to the horizontal stabilizer. The corresponding design-allowable fatigue-endurance limit for each material is determined as follows:

| | 7075-T73 | 7475-TMT1 |
|---|---|---|
| Mean-Endurance-Limit Coupon Data<br>Stress Ratio, R = 0.05<br>6.7-Inch Forging<br>Longitudinal Properties | 20,000 psi | 21,000 psi |
| (Mean-3$\sigma$), 13%<br>Coefficient of Variation | 13,169 psi | 13,829 psi |
| Reduction for<br>Size Effect, $\left\{\frac{\text{M-3}\sigma}{1.95}\right\}$ | 6,753 psi | 7,092 psi |

An adjustment is necessary for stress ratio, R. To estimate the allowable at R = 0.52, the Goodman diagram for 2-inch forgings, Figure 110, is used.

$$\frac{\text{Design Allowable}_{R = 0.52}}{\text{Design Allowable}_{R = 0.05}} = \frac{\text{Endurance Limit @ } 5 \times 10^7 \text{ cycles } (R = 0.52)}{\text{Endurance Limit @ } 5 \times 10^7 \text{ cycles } (R = 0.05)}$$

$$\text{Design Allowable}_{R = 0.52} = \left\{\frac{14{,}700}{23{,}000}\right\} \text{Design Allowable}_{R = 0.05} =$$

$$0.64 \text{ Design Allowable}_{R = 0.05}$$

| DESIGN-ALLOWABLE FATIGUE-ENDURANCE LIMIT | 7075-T73 | 7475-TMT1 |
|---|---|---|
| | 4,322 psi | 4,533 psi |

Adjustment for Stress Concentration Factor, $K_t = 3.5$

| $\frac{\text{Design Allowable}}{K_t}$ = | 1,235 psi | 1,295 psi |
|---|---|---|

7475-TMT1 alloy demonstrates a design allowable which is 5 percent higher than the design allowable for 7075-T73.

A 5-percent increase in allowable stress translates into a 5-percent weight reduction:

$$\text{Stress} = \frac{\text{Load}}{\text{Area}}$$

and

$$\text{Weight/unit length} = (\text{volume/unit length}) \times \text{material density}$$

$$= (\text{area} \times 1) \times \rho.$$

Given the same load, an allowable stress of 1,235 psi generates a requirement for an area,

$A = \frac{\text{Load}}{\text{Allowable}} = \frac{1{,}560 \text{ lb}}{1{,}235 \text{ psi}} = 1.263 \text{ in.}^2$ and an allowable stress of 1,295 psi generates a requirement for an area, $A = \frac{1{,}560 \text{ lb}}{1{,}295 \text{ psi}} = 1.205 \text{ in.}^2$

The weight relationship is then

$$\frac{\text{Weight}_{7075\text{-T73}}}{\text{Weight}_{7475\text{-TMT1}}} = \frac{(\text{Area}_{7075\text{-T73}} \times 1) \times \rho}{(\text{Area}_{7475\text{-TMT1}} \times 1) \times \rho}$$

$$\text{Weight}_{7475\text{-TMT1}} = \text{Weight}_{7075\text{-T73}} \frac{\text{Area}_{7475\text{-TMT1}}}{\text{Area}_{7075\text{-T73}}}$$

$$= \text{Weight}_{7075\text{-T73}} \left\{\frac{1.205}{1.263}\right\}$$

$$= \text{Weight}_{7075\text{-T73}} = (0.95)$$

or, conversely, a 5-percent weight reduction.

## APPENDIX F

## PREDICTED WEIGHT SAVINGS IN THE YUH-61A ANTITORQUE-ROTOR COLLECTIVE-PITCH SLIDER SIZED TO DAMAGE TOLERANCE

### REQUIREMENTS

The predicted crack growth in the pitch slider shown in Figure 155 is based on an RMS stress in the slider, the material properties measured in Task III, the crack-stress model for a hollow cylinder, and the Paris equation for crack-growth rate. The RMS stress is determined as shown in Figure F1.

Fatigue-crack-propagation rates for 7075-T73 (Figure 127) and 7475-TMT2 (Figure 146) and short-transverse fracture-toughness values for 6.7-inch forging (Table 21) have been used in this example. The Paris equation was selected for illustration purposes to present a simpler computation. The coefficients for fatigue-crack propagation-rate data from Figures 127 and 146 are:

| 7075-T73 | 7475-TMT2 |
|---|---|
| $C_P = 6.0493 \times 10^{-7}$ | $C_P = 8.0902 \times 10^{-8}$ |
| $n_P = 1.8329$ | $n_P = 2.03514$ |

The crack-stress model for stress-intensity factor and the computation procedure are shown in Figure F2.

A weight savings due to the improvement in fracture properties can be demonstrated.

Based on the measured short-transverse fracture-toughness value for 6.7-inch 7075-T73 forging, the pitch slider can sustain a 4.60-inch crack prior to catastrophic failure. This is based on the geometry of the slider and the relationship for stress-intensity factor:

$$K_{IC} = \sigma_{limit} \sqrt{\pi a_c} \quad f_{(a_c)} .$$

Using this relationship and the increased fracture toughness of 7475-TMT2, one can determine that:

$$\sigma_{limit_{7475\text{-}TMT2}} = \left( \frac{K_{IC\ TMT}}{K_{IC\ T73}} \right) \sigma_{limit\ T73}$$

$$\sigma_{limit_{7475\text{-}TMT2}} = (1.48) \quad \sigma_{limit\ T73} .$$

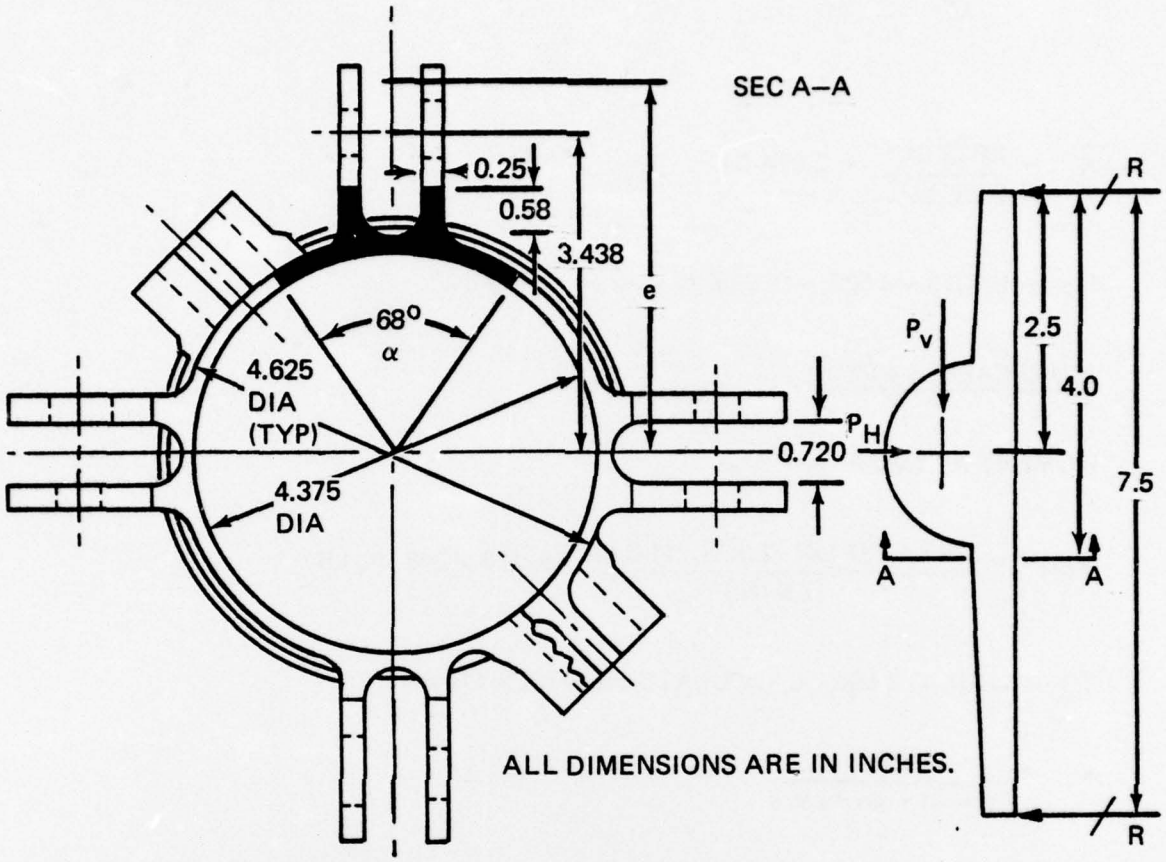
See Figure F3.

An increase in the allowable stress translates into a decrease in weight as shown in Appendix E. Hence, a 48-percent increase in allowable stress results in a 48-percent decrease in weight.

As shown in Figure 153, the slower crack-growth rate in 7475-TMT2 can be advantageous in reducing weight.

Crack-growth rate is directly affected by stress level. By increasing the RMS stress in the 7475-TMT2 slider, a tradeoff in weight is possible, with the maximum weight reduction occurring when the crack-growth rates are identical for the 7475-TMT2 and 7075-T73 sliders.

By an iterative solution, the 7475-TMT2 slider can demonstrate the same failsafe life as the 7075-T73 slider while functioning at a stress level of 890 ± 1,650 psi. Compared to the 7075-T73 slider at 700 ± 1,296 psi, this shows a 27-percent increase in allowable stress and, consequently, a 27-percent reduction in weight.




SECTION A–A PROPERTIES

$$\bar{X} = \frac{2 \sin \alpha (R^3 - r^3)}{3 \alpha (R^2 - r^2)} = \frac{2 (.93) (2.3125^3 - 2.1875^3)}{3 (1.19) (2.3125^2 - 2.1875^2)} = 1.759 \text{ IN.}$$

$$\text{AREA} = (R^2 - r^2) \alpha = (2.3125^2 - 2.1875^2) (1.19) = 0.67 \text{ IN.}^2$$

$$I_{yy} = \frac{\alpha}{4} (R^4 - r^4) \left(1 + \frac{\sin \alpha \cos \alpha}{\alpha}\right) - \frac{1}{\alpha (R^2 - r^2)} \left(\frac{2 \sin \alpha (R^3 - r^3)}{3}\right)^2$$

$$= \frac{1.19}{4} (2.3125^4 - 2.1875^4) \left(1 + \frac{(0.93) (0.376)}{1.19}\right) - \left(\frac{1}{(1.19) (2.3125^2 - 2.1875^2)}\right)$$

$$\left(\frac{2 (0.93) (2.3125^3 - 2.1875^3}{3}\right)^2 = 0.12317 \text{ IN.}^4$$

| SECTION | AREA | X | Ax | $Ax^2$ | Ioyy |
|---|---|---|---|---|---|
| CIR SECTION | 0.67 | 1.759 | 1.178 | 2.073 | 0.12317 |
| RECTANGULAR | 0.29 | 2.603 | 0.755 | 1.964 | 0.00813 |
| Σ | 0.96 | | 1.933 | 4.037 | 0.13130 |

Figure F1. Stress Analysis of Tail-Rotor Collective-Pitch Slider for YUH-61A (Sheet 1 of 2).

$$\bar{X}' = \frac{1.933 \text{ IN.}^3}{0.96 \text{ IN.}^2} = 2.014 \text{ IN.}$$

$$I_{yy} = 0.1313 + 4.037 - (1.933)(2.014) = 0.276 \text{ IN.}^4$$

LOAD CALCULATION:

MOMENT AT SEC A–A = $M_A$

$$M_{PH} = \frac{(141 \pm 261 \text{ LB})(2.5 \text{ IN.})(4.0 \text{ IN.})}{(7.5 \text{ IN.})} = 188 \pm 348 \text{ IN.-LB}$$

TO CALCULATE $M_{PV}$, CALCULATE SHEAR CENTER e:

$$e = \frac{2R}{(\pi - \theta) + \sin\theta \cos\theta} \quad [(\pi - \theta)\cos\theta + \sin\theta]$$

$$e = \frac{2(2.25)}{(3.14159 - 1.96) + (0.9205)(0.39073)} \quad [(3.14159 - 1.96)(0.39073) + 0.9205]$$

$$e = 4.035 \text{ IN.}$$

MOMENT ARM = (4.035 IN. – 3.438 IN.) = 0.597 IN.

$M_{PV}$ = (0.597 IN.) (141 ± 261 LB) = 84 ± 156 IN.-LB

$M_A = M_{PH} + M_{PV} = 272 \pm 504$ IN.-LB

$f_b = 0.81 (272 \pm 504 \text{ IN.-LB})(0.875 \text{ IN.})/(0.276 \text{ IN.}^4) = 700 \pm 1{,}296$ psi (RMS)

Figure F1. Stress Analysis of Tail-Rotor Collective-Pitch Slider for YUH-61A (Sheet 2 of 2).

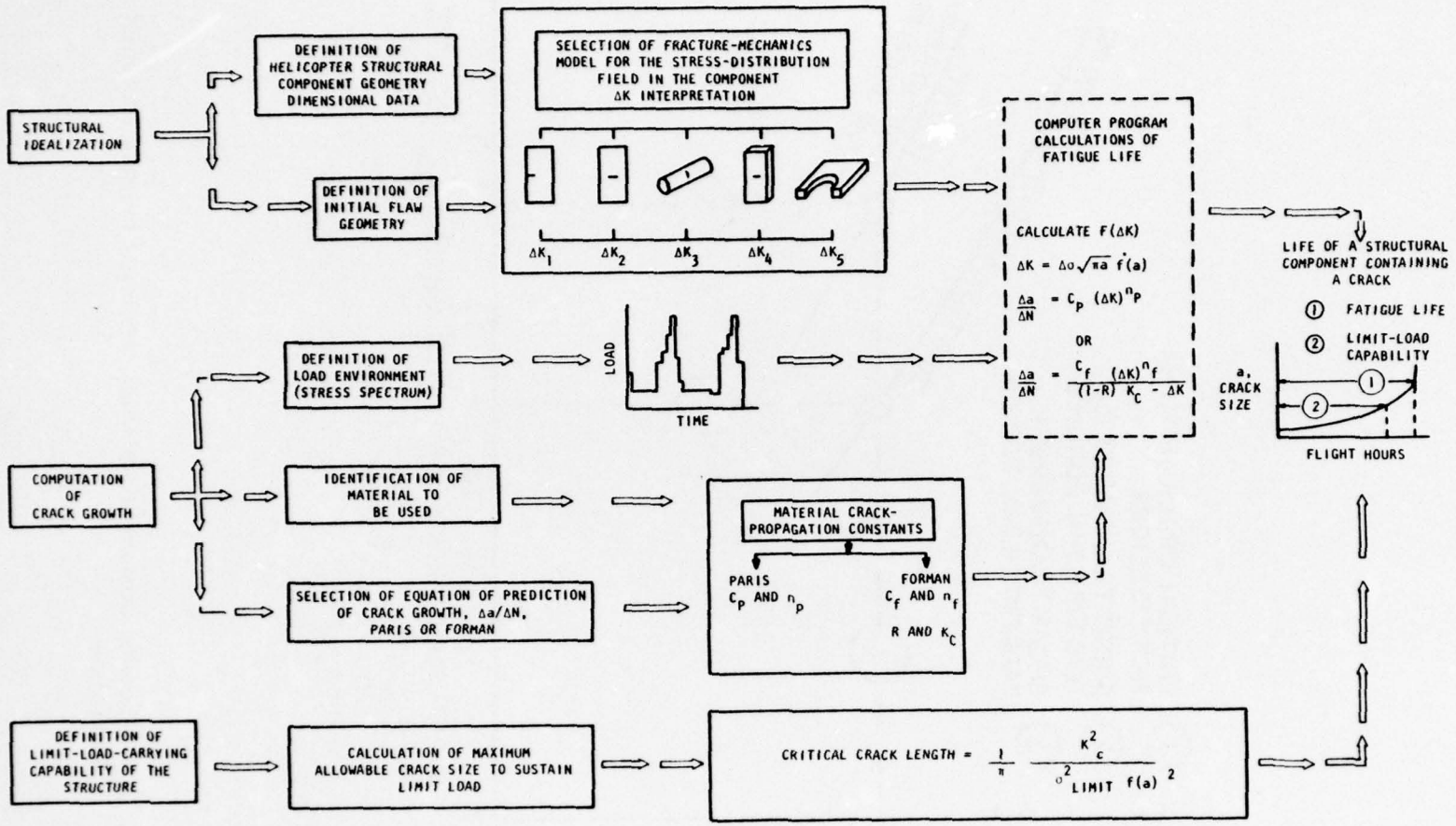



Figure F2. Computation Procedure and Crack-Stress Model for Stress-Intensity Factor.

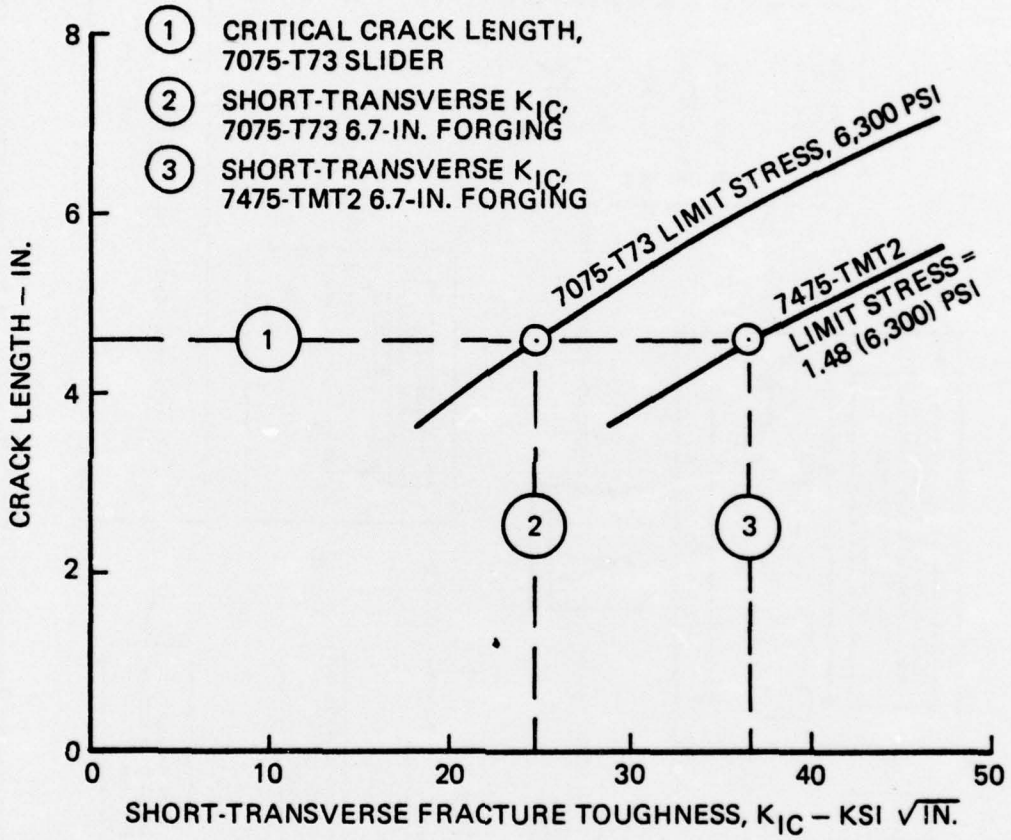



Figure F3. Relationship Between Critical Crack Length and Fracture Toughness of Pitch Slider.

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IMPROVEMENT OF HELICOPTER FORGINGS BY CONTROLLED SOLIDIFICATION & THERMAL-MECHANICAL TREATMENTS(U)

JOSEPH C. ZOLA.

BOEING VERTOL COMPANY, PHILADELPHIA, PA.

UNCLASSIFIED

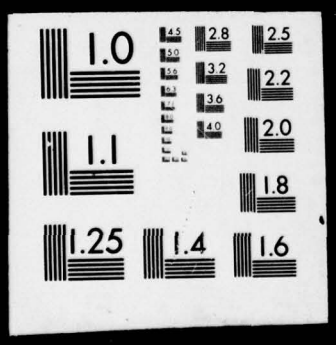
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Cover Page

Form DD 147

P. 97

P. 199

P. 199

P. 199

P. 199

Addition

AD A031357

# ERRATA SHEET - AVSCOM REPORT NO. 76-41

| | |
|---|---|
| Cover Page | Change Contract Number from "A25-74-C-0448" to "DAAA25-74-C-0448" |
| Form DD 1473 | Change 4. Title to "Improvement of Helicopter Forgings By Controlled Solidification and Thermal-Mechanical Treatments" |
| P. 97 | Insert word "and" in last sentence so that statement reads ".... a recrystallized-plus-hot -worked structure, and in .... |
| P. 199 | In first paragraph insert word "and" in first sentence so that paragraph reads "....20 percent better toughness and fatigue ...." |
| P. 199 | In item 1. change "TMT" to "ITMT" |
| P. 199 | In item 3. change "62" to "75" |
| P. 199 | In item 4. change "TMT" to "ITMT" |
| ~~Addition~~ | ~~Distribution List (See attachments)~~ |

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