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AN INVESTIGATION OF IMPROPERLY QUENCHED (SOFT) ALUMINUM PLATE.(U)

DEC 79 C L HARMSWORTH , G J PETRAK

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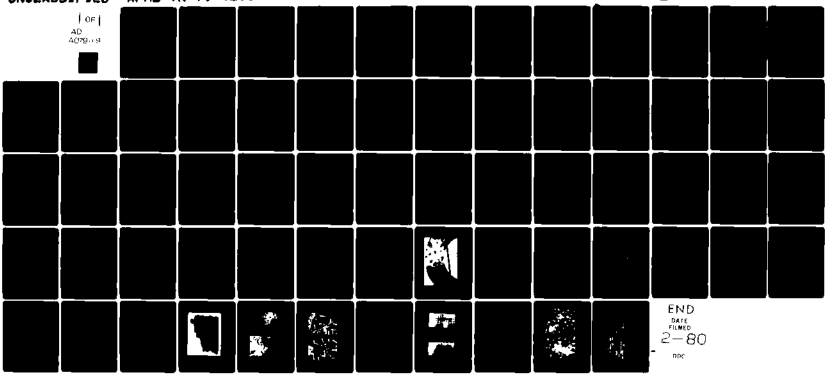

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AN INVESTIGATION OF IMPROPERLY QUENCHED (SOFT) ALUMINUM PLATE

Systems Support Division
Air Force Materials Laboratory

December 1979

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Final Report for Period August 1979 through October 1979

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A program was conducted to evaluate the effects on mechanical properties of a slack (slow) quench on one side of a plate following the solution heat-treatment of high strength aluminum alloys. Seven thick plates, ranging from 1-1/4 to 5-1/2 inches thick, were tested for their tensile properties. Hardness and electrical conductivity readings were taken on all of the specimens to ascertain whether or not recommended limits for these two indicators can accurately identify sub-strength (soft) material. One 5-1/2 inch thick

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plate of 2124-T851 was given a more extensive mechanical property evaluation than the others. On this plate it was observed that the tensile, compression, bearing, strength of elemental joints, and notched fatigue strength at moderately high stress showed a significant reduction in properties. Smooth fatigue, crack growth resistance, fatigue crack growth, and corrosion resistance were not affected by the slack quench.

Other plates of 7000- and 2000-series alloys were also evaluated. A wide range of conductivity and hardness values were correlated with mechanical properties. One 1-1/4 inch plate of 7075-T651 had low tensile properties on both sides, the cause of which is unknown.

Within a given plate, hardness and conductivity measurements did correlate reasonably well with strength variations. Plate-to-plate correlations were less valid.

FOREWORD

This report was prepared by the Materials Integrity Branch (MXA), Systems Support Division, U. S. Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

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This report was submitted by the authors in November 1979.

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SECTION I

BACKGROUND

In June of 1979, black streaks or discoloration were observed in the anodized coating of some aluminum aircraft bulkheads machined from thick 2124-T851 aluminum plate. Subsequent investigation of these plates indicated that they contained soft areas of material with tensile properties well below the aircraft design values. This condition was traced to a slow or delayed quench following the solution heat-treatment. The problem was further narrowed down to material produced in a single production line at the Reynolds Metals Company Plant in Illinois.

Although the problem in quenching was quickly identified and steps were taken to improve future quality, the Air Force and its contractors were very much concerned about material already in the inventory, both in the form of plate stock and machined parts. An inventory check was initiated using electrical conductivity as an indicator (electrical conductivity increases with lower strength).

The check identified a number of plates that indeed contained soft spots. The soft spots varied in surface area and depth and occurred randomly on the bottom surface of the plate. As one of the steps in an attempt to solve this problem, the Air Force Aeronautical Systems Division (ASD) asked the Air Force Materials Laboratory to conduct a test program on a number of these soft plates to: (1) assist ASD in establishing an acceptance-rejection criteria for the suspect plate, and (2) furnish preliminary data for any worst case analysis that may be necessary for parts already installed (and inaccessible) in an aircraft. Steps were taken to obtain typical samples from a number of contractors and the resultant test program is the subject of this report.

Since this concern involved not only the Air Force, but other members of the DoD, NASA, and the FAA, an Interagency Task Group on soft aluminum was formed under the direction of the Defense Logistics Agency to coordinate this and the many other efforts and to ensure the dissemination of all findings from the various investigations to all concerned parties.

During this test program, a number of phrases and identification techniques came into being to describe the "soft" and "normal" material. Many are used in this report. The following terminology list is presented below to aid in understanding the content of this report.

TERMINOLOGY USED TO DESCRIBE SOFT AND NORMAL ALUMINUM

SOFT	NORMAL
Affected	Unaffected
Bottom (plate orientation during quench)	Top
Slack Quenched	Baseline
A (for affected)	B (for baseline)
Improper Quench	

SECTION II

TEST PROGRAM

A total of seven plates of 2000- and 7000-series aluminum alloys were tested as listed in Table 1. Five of these plates had been identified as Reynolds plates containing soft areas as identified by electrical conductivity checks. The plates were selected to represent a range of alloys, tempers, and thicknesses, as well as varying degrees of softness. The remaining two plates, from two other producers, were included to obtain comparative through-the-thickness data. One 5-1/2 inch thick plate was selected for a complete mechanical property investigation as described below. This plate failed the electrical conductivity acceptance criteria by a greater margin than any other plate received. The other six plates were evaluated for their tensile, hardness, and conductivity properties only. Since all of these plates were of finite size and contained limited areas of softness, it was obviously not possible to obtain all of the test samples from areas of maximum softness. Consequently, comparisons of mechanical property effects should be made with respect to the materials' relative degree of softness rather than just a top side versus bottom side comparison.

Within a given plate of material the hardness and electrical conductivity did correlate reasonably well with tensile properties. However, electrical conductivity, in particular, is also affected by chemistry and other processing factors. Consequently, this same correlation is less evident on a plate-to-plate basis. As a result the variance in conductivity within a plate is felt to be a more valid acceptance-rejection criterion than the use of an absolute value for a particular alloy-heat treatment category.

Upon receiving a test plate, both electrical conductivity and hardness profiles were made on the soft surface. The softest areas were identified and specimens were removed from these locations and contiguous areas. Generally, where a through-the-thickness tensile traverse was made, the first specimen in the profile started at the softest area.

For all of the plates, when a specimen was removed from the soft side, a companion specimen was taken from the opposite side of the plate to serve as an index of the baseline properties for the material. All test samples, with the exception of six stress corrosion specimens, were removed from the plates parallel to the plane of the plates. Surface specimens were taken as close to the surface as possible (0.005-0.010 inch cleanup). Every specimen had hardness and conductivity measurements taken on it either before or after it was tested. If the measurements were made after the mechanical property test, the conductivity and hardness were measured in an area that did not experience yielding during the test.

All conductivity measurements were performed with a Nortec NDT-5A instrument having a scale range of 26 to 65% IACS (International Annealed Copper Standard). Test frequency was 60 KHz with a 3/8 inch diameter probe. Two traceable reference standards were used to set up the unit on high and low points of the scale. A 5 minute warm-up time was used prior to checking conductivity. Measurements were made in accordance with the requirements of MIL-STD-1537, "Electrical Conductivity Test for Measurement of Heat Treatment of Aluminum Alloys, Eddy Current Method." At a minimum, all conductivity measurements on the uncut plates were made using a 2 inch square grid pattern. In many cases, smaller grid spacings were used. The instrument was checked for calibration at 2 minute intervals using the reference standards.

Throughout the text, tables, and figures presented in this report numerous references are made to mechanical property specification values ("S" values). These are the values specified in Federal Specification QQA 250 and are primarily used for procurement purposes. Reference is also made to MIL HDBK-5 "A" values, which are design allowables. Generally, the "S" and "A" values are the same, and in the few cases where they may vary, they are so noted in MIL HDBK-5. The electrical conductivity and hardness values listed in the specification column in this report refer to recommended limits published by the Society of Automotive Engineers, Inc., in a draft of an Aerospace Materials Specification, AMS 26GB-1, dated January 1979.

SECTION III

RESULTS AND DISCUSSION

This section is divided into parts representing each of the plates tested. The results and discussions from each of the plates will be summarized in the following section.

2124-T851 Plate, 5-1/2 inch Thick

This particular plate, which had been rough-cut in preparation for machining before the soft spot was discovered, received the greatest amount of mechanical property documentation. The types of tests performed on the plate are shown in Table 1. A description of the specimen configurations used is presented in Table 2, and a photograph of the soft side of the plate is shown in Figure 1. The small, bright, somewhat circular areas are locations where Rockwell B hardness readings were taken. The curved lines are iso-conductivity contours and the rectangles indicate specimen locations. The softest spot in the plate, based on the electrical conductivity (EC) reading of 46% IACS, is located between two hardness readings of R_B=46 and 47. In any direction away from this location the hardness increases and the conductivity decreases. The 24 inch scale in the photo is parallel to the rolling (longitudinal) direction of the original plate. The specimen number and letter designations shown on this soft side surface had an "A" added after them to indicate that the specimens were from the soft "affected" side; specimens removed from the opposite side had a "B" designation to indicate "baseline" material.

The tensile test results for the longitudinal direction are shown in Table 3. Specimens TL-1A, 2A, and 3A, which were located closest to the softness center, had the lowest yield and ultimate strengths. All of the tensile specimens from the affected side of the plate failed to meet the minimum strength requirements for the material, but all specimens from the opposite (baseline) side easily passed the strength requirements. The same is true for the hardness and conductivity data; all readings from the soft side were out of the acceptable range, but those from the normal side of the plates were within specifications. (When two numbers separated by a slash are given for hardness or conductivity, they represent readings taken on two sides of the specimen.)

Similar observations can be made for the transverse tensile data in Table 4. Affected material failed to meet all requirements, and normal (baseline) material met all specifications.

Table 5 presents longitudinal tensile data for specimens stacked through-the-thickness of the plate. Data for two of these specimens were previously shown in Table 3, i.e., data for specimens TL-2-A and TL-2-B. The remaining specimens were equally spaced through-the-thickness between these two specimens. Note that specimen TL-2-A is located very close to, if not at, the softest spot in the plate, as indicated by the hardness and conductivity information shown in Figure 1 and the data in Table 3. The data shown in Table 5 is presented graphically in Figure 2 where the horizonal dashed lines represent specification limits. Note that the ultimate strength, yield strength, and hardness are all below specifications until a depth of approximately four inches into the plate is reached, but the conductivity readings started meeting the recommended range at a depth of a little over one inch. This indicates the proposed conductivity specification may be too high. If the conductivity limit for this particular plate is lowered by one-half percent IACS, to 42%, then the cut-off point of acceptable/unacceptable conductivity data in Figure 2 would be at approximately a 4 inch depth, which is where the other specification limits delineate the acceptable/unacceptable material.

In the figure, all four curves have the same general shape, starting with a flat region near the soft side which extends slightly less than an inch into the plate. This is followed by a sudden rise (fall) leading to a somewhat flat region which gradually changes to a slowly increasing (decreasing) region near four inches in depth. The conclusion can be reached that hardness and conductivity can track strength changes, at least in a given sample of material.

Figures 3 and 4 present yield strength versus hardness and conductivity data, respectively, for all of the longitudinal tensile specimens tested. The hardness specification limit in Figure 3 correlates well with the data trend and yield strength limit, while the conductivity cut-off point in Figure 4 appears to be too high. If the conductivity upper limit for this plate were lowered to 42% IACS, as discussed previously, the cut-off point would correlate with the trend line (not shown) for the data and the yield strength minimum. One should keep in mind that these findings are for one plate of 2124-T851 and additional data from other plates will surely widen the data scatter band.

Compression test results are presented in Table 6. By referring to Figure 1, we see that the two specimens from the soft side of the plate with the lowest strength came from areas very close to the softest area, while the third specimen was from an area away from that location. At the softest area, the compression yield strength is about 50% of the specification limit, while away from this area (approximately 5 inches) the compressive yield strength is sligntly over 60% of the specification limit. Baseline specimens met all specification limits.

Bearing strength data in Table 7 also shows a significant loss in properties. The specimens for these tests were removed some distance away from the softest spot but still indicate a substantial loss, approximately 25%, in properties. Again, baseline data were all within acceptable limits.

Figure 5 and Table 8 document the smooth fatigue data which was generated at two stress levels. A statistical "t" test analysis of the data from the two sides of the plate indicates that there is no difference between the two sides at either of the selected stress levels. Also shown in the figure is a scatter band for literature data generated on similar material. It should be noted, however, that the smooth fatigue samples were not taken from the extremely soft location in the plate which gave the maximum reduction in tensile properties.

Notched fatigue data, which was developed from rectangular specimens with a drilled and reamed centrally located hole, is presented in Figure 6 and Table 9. A statistical "t" test analysis of these data indicate that at the higher stress level (35 KSI) the affected material has inferior properties to those of the baseline material. At the lower stress level (25 KSI) no difference in properties could be proven. The data in Figure 6 and Table 9 are plotted in Figure 7 as conductivity and hardness versus cycles-to-failure for constant maximum stress. Here there are definite trend lines, particularly at the higher stress levels, showing that the softer material has a shorter notched fatigue life.

Crack growth resistance, R-curve data are shown in Figure 8. The data at the lower stress intensities, below approximately 45 KSI $\sqrt{in}$, show there is no difference between the normal and soft material. Above this point the curve for the baseline material starts to turn flat while the trend line for the affected material continues to rise. This observation is predicated on giving some credibility to the technically invalid (by ASTM E24 criteria) data for the soft material. However, it can be stated that no detrimental effects on the crack growth resistance at lower stress intensities occurred and indications are that at higher values the affected material may possess improved resistance.

Fatigue crack growth rate data are shown in Figures 9 and 10. In each figure the data for the affected specimen either appears slightly on the high side of the baseline data or overlaps the baseline data. However, in all cases the data are very close together. The spread in data is no more than would normally be encountered when testing two samples of exactly the same material. It can be concluded that there is very little or no effect of the softness on the fatigue crack growth rate properties over the range tested.

Tensile tests of single lap, high load transfer, fastener specimens were conducted to obtain information on how an actual structure containing the soft aluminum would react. The test curves are reproduced in

Figure 11 and show that the affected material has reduced load-carrying capacity. This is not unexpected, considering the results for the tension, compression, and bearing tests previously presented.

The same configuration single-lap specimen was subjected to constant amplitude fatigue loading to failure, and results are tabulated in Table 10. For two of the three paired tests the affected material had a longer life. From the limited data available it appears there is little difference between the affected and baseline results.

Two types of stress corrosion tests were performed: (1) conventional smooth specimens subjected to constant stress and an alternate immersion 3.5% NaCl solution and (2) precracked compact type fracture mechanics specimens subjected to a continuous 3.5% NaCl solution. Smooth tensile type corrosion specimens were removed from two orientations, longitudinal and short-transverse. Three longitudinal specimens are shown in Figure 1 with an "S" Designation. The short-transverse specimens (not shown) were removed from the area directly next to this location and were numbered 4, 5, and 6. The alternate immersion cycle in the 3.5% NaCl solution consisted of ten minutes immersion and fifty minutes in air. This continued for the duration of the test. Results from these tests are shown in Table 11. The failure lives of both the base and affected material meet or exceed literature data on similar unaffected material. Micrographic examination on the fracture surface did not indicate any excessive intergranular attack or exfoliation. Figure 12 is a photomicrograph of the area around the fracture face of specimen S-4A. The absence of secondary branch cracking, which is associated with stress corrosion cracking, also shows the affected material to be immune to stress corrosion attack.

The compact type corrosion specimens were subjected to constant load in the test environment. Test results (Table 12) indicate the soft material is not stress corrosion sensitive.

There was originally some concern that the soft aluminum condition might be caused in part by an alloy depletion in the ingot. To answer this question, chemical and metallurgical investigations were conducted on the material. Table 13 presents the results of four chemical composition analyses performed on pieces removed from tensile specimens. Specimen TL-2A was located in the softest area and specimen TL-10B was the highest strength tensile specimen tested. These two analyses should, therefore, represent extremes for a composition comparison. There are some minor differences between the two, but these are not enough to cause the significant strength loss observed.

The metallurgical investigation was accomplished on similar soft and normal material. Typical photomicrographs are shown in Figures 13 and 14.

Two primary differences were observed in the microstructures of the 5-1/2 inch thick 2124-T851 plate, as noted below.

1. A difference in the hardening precipitates was observed. Transmission electron microscopy (TEM) was used to examine thin foils from hard and soft areas. It is obvious that in the soft areas the hardening precipitates are very coarse and not as finely distributed. This difference can be explained in terms of a slow quench.

2. An examination using optical microscopy at 100x showed a difference in the degree of grain boundary precipitation between hard and soft areas. The amount of grain boundary phase increases with decreasing hardness. A slow or slack quench could explain this difference in precipitation.

<u>2124-T851 Plate, 2-3/4 inch Thick</u>

Six tensile tests were performed on specimens removed from a 2-3/4 inch thick plate of 2124-T851. The AFML had received a small part of a larger plate that had been rejected because conductivity readings were outside recommended specification limits. Results for the plate are shown in Table 14. None of the soft specimens passed the specification limit for ultimate strength, although specimen 6 was very close; one soft specimen, also number 6, did pass the yield strength specification. The hardness criterion was passed by two of the three affected specimens, while all three were within the recommended electrical conductivity specification range. Specimen number 5, which had a yield strength approximately 20% below the specification value, had a conductivity greater than one percent IACS below the upper limit of the range. In the previous section for the 5-1/2 inch thick plate of the same material, it was noted that a change in the upper conductivity limit of one-half percent IACS would result in a better correlation between the tensile allowables and a conductivity limit. The data in Table 14 for the 2-3/4 inch material do not substantiate that relationship and indicate the need for other criteria. This lack of plate-to-plate consistency in an electrical conductivity to tensile strength correlation has led to the current recommendation of a maximum variation of two percent IACS on any one side of any given plate as an additional criteria.

Typical 2124-T851 Plate, 5 and 5-1/2 inch Thick

Two thick plates of 2124-T851 were obtained from sources other than the producer of the soft aluminum. Stacks of tensile specimens, oriented in the longitudinal direction, were removed from each of the plates to obtain a profile of normal through-the-thickness tensile property variations. Table 15 documents the results of the tensile tests and Figure 15 presents the results from the 5-1/2 inch thick plate in graphical form. Both plates possess the highest strength at their surfaces with decreasing strength toward the mid-thickness. The hardness and conductivity curves in Figure 15 have the same (or inverse) shape as the strength curves, which verifies the supposition that these two indicators can, at least for a given sample, reflect the changes in basic mechanical properties.

2024-T351 Plate, 2 inch Thick

A plate of 2024-T351 with an indicated soft spot, determined by conductivity readings, was given a cursory evaluation for its tensile properties. Three stacks of three specimens were removed from the plate in the softest areas; three specimens from the affected side, three from mid-thickness, and three from the unaffected side for a total of nine specimens. It can be seen from the test results presented in Table 16 that the tensile properties as well as hardness readings were all within specification. However, conductivity readings made on the supposedly affected specimens were both inside and outside the recommended specification range. The higher conductivity reading for these specimens correlated with the readings taken on the plate before the specimens were removed. The most likely reason for these results is that the soft spot was very shallow. This is substantiated by the fact that the range of conductivity readings is much greater for the suspect specimens than for the specimens from the unaffected side and mid-thickness location.

<u>7075-T651 Plate, 1-1/4 inch Thick</u>

The thinnest plate tested in this effort was a 1-1/4 inch thick plate of 7075-T651 shown in Figure 16. At the time, this was one of the thinnest plates which had been identified as being suspect. The sample was mapped for its hardness and conductivity by laying out a two-inch-square grid on the surfaces and determining the hardness and conductivity within each square. (On what was judged to be the unaffected side, only selected spots were checked for conductivity.) Tensile specimens were removed from this plate in two sets. Specimens L-1 through L-10 and X-1 through X-3 (with companion specimens taken from the bottom side) were removed first, along with three mid-thickness specimens located under specimens L-4, -5, and -6. Tables 17 and 18 document the results for the longitudinal and transverse specimens, respectively. The longitudinal ultimate and yield strengths for the specimens removed from what was considered the soft side of the plate were all below specification values. The hardness readings were also below the recommended limit, however, the conductivity readings were all within their recommended range. These findings further indicate that the use of absolute conductivity values alone as an acceptance criterion would not be adequate.

The mid-thickness longitudinal specimens were all above the specification limits for their strength values, but the hardnesses were slightly below the limit. The conductivity was within limits.

Longitudinal tensile test results from specimens removed from what was considered the normal or unaffected side of the plate are scattered above and below specifications. One ultimate strength and four yield strength values were below allowable values while one hardness was below the recommended limit. All conductivity readings were within limits. Specimen L-1B did not meet strength or hardness limits. Referring to Figure 16 it can be seen that this specimen was removed from the normal side of the plate from a location that indicated a hardness of R_B=83, which is below the recommended limit (keep in mind that specimen L-1 shown in the right photograph is the L-1A (affected) specimen and L-1B is directly below, on the Baseline side of the plate). These results indicate the plate has soft areas on both sides, the cause of which is undefined. The longitudinal tensile results discussed in the foregoing are shown in Figure 17 where the most glaring observation is that conductivity readings are all within the recommended range while other properties are both above and below their minimums.

Transverse tensile results are shown in Table 18. Affected specimens failed the strength and hardness limits and baseline specimens passed these limits. All transverse specimens were within the recommended conductivity range.

It was observed previously that soft areas existed on both sides of this particular plate. To further pursue this observation additional specimens were removed from the locations marked L-11 through L-14 shown in Figure 16. Note that the "B" specimens were located on the "normal" side of the plate in an area with hardness as low as R_B=77. Table 19 shows the test results for these specimens. All eight specimens, four from the affected and four from the "normal" side, failed to meet the strength minimums, substantiating the observation that both sides of this plate had soft areas.

Chemical analyses were performed on selected tensile specimens, and results are shown in Table 20. Specimen L-5A had the lowest yield strength and specimen L-10B had the highest yield strength in Table 17. Although there are some differences in the composition it is felt they are not enough to explain the differences in strength. Photomicrographs of the material are shown in Figures 18 and 19. Three primary differences between hard and soft areas were observed in the microstructures of the 1-1/4 inch thick 7075-T651 plate.

A difference in the hardening precipitates was observed. Transmission electron microscopy (TEM) was used to examine thin foils from hard and soft areas. The results are shown in Figure 18. It is obvious that in the soft areas the hardening precipitates are coarser and not as finely dispersed as those in the hard areas. The precipitate morphology in the soft areas is typical of an overaged 7075 microstructure. This difference can be responsible for most, if not all, of the strength loss. The microstructure observed in the soft areas can be explained in terms of a slow quench, since fewer nucleation sites and therefore coarser and more widely spaced precipitates would result.

A difference in the etching behavior of the soft and hard areas is obvious using optical microscopy at 100x, as shown in Figure 19. In the hard areas the grain boundaries are more defined. The soft areas have a "fibrous" appearance of as-wrought plate. This difference may be attributed to electrochemical differences resulting in different etching responses. Electrochemical responses would be the result of residual stress, crystallographic orientation or chemistry variations. It should be noted that these microstructural differences are associated with hard and soft areas irrespective of their location relative to the top or bottom of the plate.

A difference in the constituent particles of the soft and hard areas has been observed. Electron microprobe analysis (EMPA) indicates large constituent particles are Al-Fe-Cu compounds. Some of the constituent particles in the soft area analyzed contain two phases. One phase is similar to constituent particles found throughout the sample. The other phase is significantly higher in Cu and lower in Fe.

It is possible for the two-phase particles to form during solidification of the ingot (liquid state reaction). It is not clear if the difference can be explained in terms of a transformation in the solid state. If a solid state reaction is responsible, the most probable points in processing for it to occur are during the homogenization anneal or during solution heat treatment. Since both of these treatments are soaking operations it is unlikely the gradients in strength would result. The difference in strength could be explained by the high Cu phase only if enough copper is tied up in the compound to prevent it from participating significantly in hardening. However, EMPA indicates there is no difference in Cu content of the matrix of the soft area as compared to the hard area.

<u>7075-T7351 Plate, 4 inch Thick</u>

A four inch thick plate of 7075-T7351 had longitudinal, transverse and a through-the-thickness stack of longitudinal specimens removed from it. The stack of specimens were located directly under a spot that indicated by conductivity to be the softest area in the plate. These specimens were removed every half inch through-the-thickness for a total of eight specimens. The results from the longitudinal and transverse tensile tests are presented in Table 21 and 22, respectively. Ultimate and yield strength values are all above minimum values for 2.5-3.0 inch thick plate material (there are no minimum values for 4 inch 7075-T7351 in MIL-HDBK-5) while the hardness readings are generally above the recommended limits, and the conductivity values are both within and below the recommended range. In no case is the conductivity above the range. In Table 21 two specimens had hardness readings that were below the recommended limit of R_B=78, i.e., specimens P-5A and P-6A. The stack of specimens for obtaining the through-the-thickness tensile property profile was removed below specimen P-5A. Results from these tests are presented in Table 23 and it can be observed that right under the surface where specimen P-5A was removed the strength falls off rapidly and stays low for a rather substantial distance through the plate. Two of the specimens had strength properties that were below the limit values for 2.5-3.0 inch thick material. It should be noted, however, that as product thickness increases, the MIL-HDBK-5 values generally decrease, which means that the tensile data in Table 23 may all meet handbook values if such allowables were available for 4 inch thick plate. Hardness and conductivity readings follow the general trend of the tensile data with some hardness values below recommended limits and some conductivity values below the recommended range.

SECTION IV

SUMMARY

The 5-1/2 inch thick plate of 2124-T851 had a soft spot that extended approximately four inches into the plate. In the affected area the properties that generally exhibited significant degradation were: tensile strength, compression, bearing, and the tensile strength of elemental joints. The notched fatigue strength at a moderately high stress level (35 KSI) also showed a significant loss. Any loss in notched fatigue strength at a lower stress level (25 KSI) and any loss in smooth fatigue properties was less evident and could not be statistically verified. No loss in corrosion related properties, fracture toughness, or fatigue crack growth rate, was observed.

A 2-3/4 inch thick plate of 2124-T851 had a soft area that exhibited a loss in tensile properties that was below specifications but the loss was not as severe as that observed in the 5-1/2 inch sample of the same material.

A plate of 2024-T351, which was determined by conductivity readings to contain a soft spot, exhibited tensile properties that were above specification limits. This ambiguity was attributed to a very shallow area of softness.

The thinnest plate tested was a 1-1/4 inch thick 7075-T651 sample that had soft areas on both surfaces of the plate, the cause of which is undetermined.

Tensile properties on the surface of a 4 inch thick plate of 7075-T7351 were all above handbook values for 2.5-3.0 inch thick material.

Normal (not soft) plates of aluminum exhibit changes in tensile properties at different locations through-the-thickness with the highest strength occurring at the surfaces and the lowest strength generally occurring near mid-thickness. The lower internal strength is reflected in lower specification limits for thicker product forms.

Hardness and conductivity measurements reflect strength variations within a given sample of material, i.e., the hardness goes up as the strength increases, while conductivity decreases with higher strength. It should be obvious that the information in this report represents findings from a very limited number of plates and must be combined with additional data from other sources in establishing appropriate acceptance criteria.

TABLE I

TEST PROGRAM FOR IMPROPERLY QUENCHED (SOFT) ALUMINUM PLATE

ALLOY-HEAT TREAT	THICKNESS (INCH)	PROPERTIES DETERMINED
2124-T851	5-1/2	Tensile
		Tensile, Traverse through Softest Area
		Compression
		Bearing
		R-Curve fracture toughness
		Fatigue, notched and smooth
		Fatigue crack growth
		Simulated structural parts
		Stress corrosion, smooth and K_{Iscc}
		Metallography
		Chemical Analysis
2024-T351	2	Tensile: bottom, mid-thickness, top
2124-T851	2-3/4	Tensile: bottom and top
2124-T851 (ALCOA)	5-1/2	Tensile traverse
2124-T851 (KAISER)	5	Tensile traverse
7075-T651	1-1/4	Tensile: bottom, top, and traverse
		Metallography, Chemical Analysis
7075-T7351	4	Tensile: bottom, top, and traverse

Note: Samples from Alcoa and Kaiser are Identified; all others from Reynolds.

TABLE 2

SPECIMENS USED IN SOFT ALUMINUM STUDY

TYPE TEST	SPECIMEN CONFIGURATION
Tensile	Flat; Gage Section 1/4" X 3/8", Gage Length 2"
Compression	Flat; Rectangular 1/4" X 5/8" X 2.64"
Bearing	Flat; Rectangular .06" X 1-1/2" X 4"; Hole Dia.=1/4", e/d=2.0
Fatigue	
Smooth	Flat; Gage Section 1/4" X 3/8" X 3/4" long
Notched	Flat; Rectangular 1/4" X 1" X 6"; Centrally located Hole 1/4" Dia., Hole was drilled and reamed.
R-curve	Compact Type Fracture Toughness; W=4", B (thickness)=3/8"
Fatigue Crack Growth	Compact Type Fracture Toughness; W=3", B=3/8"
Corrosion	
Smooth	Round; Gage Section 1/4" Dia X 1-1/4" Long
K_{Iscc}	Compact Type Fracture Toughness; W=2.0", B=3/8"
Simulated Structure, Elemental Joint	Flat; Single Lap Fastener Specimen, High Load Transfer 4 each 1/4" non-interference fasteners in lap.

TABLE 3

LONGITUDINAL TENSILE DATA,
2124-T851 5.50" PLATE

	SPEC. NO.	UTS, KSI	YIELD, KSI	ELONG, %	RA, %	HARDNESS, R_B	EC, % IACS*
BOTTOM SIDE (SOFT) LONGITUDINAL	TL-1A	44.5	32.8	8.7	20.6	40/36	46/46
	TL-2A	44.8	33.6	9.1	18.9	48/39	46/46
	TL-3A	44.9	32.7	8.3	23.3	39/36	46/46
	TL-4A	48.9	37.5	7.7	24.6	50/47	45/45
	TL-5A	50.5	38.5	8.5	24.9	48/58	45/44
	TL-6A	49.1	37.4	8.6	19.6	49/47	45/45
	TL-7A	48.4	36.2	8.4	27.2	47/47	45/45
	TL-8A	49.6	37.6	8.5	22.3	47/48	45/45
	TL-9A	49.3	37.1	8.8	24.5	47/49	45/45
	TL-10A	50.9	39.2	8.3	25.2	47/54	45/45
	AVERAGE	48.1	36.3	8.5	23.1	46.2	45.2
	σ n-1	2.43	2.37	0.37	2.70	5.59	0.54
SPECIFICATION		63	54	5	--	74	35.0-42.5
TOP SIDE LONGITUDINAL	TL-1B	69.1	61.3	7.4	20.4	77/74	41/41
	TL-2B	69.6	61.8	7.2	17.7	78/77	41/41
	TL-3B	69.5	61.3	7.7	18.0	75/74	41/41
	TL-4B	68.8	60.8	7.4	12.5	75/74	41/41
	TL-5B	69.6	62.0	7.2	13.1	77/79	41/41
	TL-6B	69.8	61.9	7.1	20.8	79/80	41/41
	TL-7B	69.7	61.8	8.4	17.4	79/80	41/41
	TL-8B	69.5	61.4	6.6	15.6	80/80	41/41
	TL-9B	70.1	62.2	8.1	17.4	80/80	41/41
	TL-10B	70.3	62.1	7.6	18.0	79/79	41/41
	AVERAGE	69.6	61.7	7.5	17.1	77.8	41.0
	σ n-1	0.43	0.44	0.51	2.71	2.26	0.00
SPECIFICATION		63	54	5	--	74	35.0-42.5

* IACS: International Annealed Copper Standard

TABLE 4

TRANSVERSE TENSILE DATA,
2124-T851 5.50" PLATE

	SPEC. NO.	UTS, KSI	YIELD, KSI	ELONG., %	RA, %	HARDNESS, R_B	EC, % IACS
BOTTOM SIDE, SOFT, TRANSVERSE	TT-1A	47.2	31.1	8.2	13.7	53/42	45/45
	TT-2A	44.5	27.3	9.6	20.3	39/38	46/46
	TT-3A	46.3	29.2	9.5	15.3	53/40	45/45
	AVERAGE	46.0	29.2	9.1	16.4	44.2	45.3
SPECIFICATION		63	54	4	--	74	35.0-42.5
TOP SIDE, TRANSVERSE	TT-1B	69.3	61.6	6.9	9.3	77/79	41/41
	TT-2B	69.4	61.7	5.4	8.8	79/78	41/41
	TT-3B	69.1	60.5	7.7	10.1	79/79	41/41
	AVERAGE	69.3	61.3	6.7	9.4	78.5	41.0
SPECIFICATION		63	54	4	--	74	35.0-42.5

TABLE 5

TENSILE TRAVERSE THROUGH 5-1/2"
2124-T851 SLACK-QUENCHED ALUMINUM PLATE

DEPTH FROM SOFT SIDE (")	SPEC NO.	UTS, KSI	YIELD, KSI	HARD., R_B	EC, % IACS
1/8	TL-2-A	44.8	33.6	48/39	45.8
3/4	TL-2-1	44.9	33.8	44/38	45.3
1-1/4	TL-2-2	56.9	48.0	60/64	42.5
1-3/4	TL-2-3	58.5	49.8	65.5	42.4
2-1/4	TL-2-4	59.7	51.4	68.5	42.2
2-3/4	TL-2-5	59.8	51.9	69	42.2
3-1/4	TL-2-6	60.4	50.3	68.5	42.2
3-3/4	TL-2-7	62.4	52.4	70	42.1
4-1/4	TL-2-8	64.6	55.1	74	41.8
4-3/4	TL-2-9	67.8	59.3	77	41.2
5-3/8	TL-2-B	69.6	61.8	77.5	41.0
SPECIFICATION		63	54	74	35.0 - 42.5

TABLE 6

COMPRESSION STRENGTH DATA,
2124-T851 5-1/2" SLACK QUENCHED ALUMINUM PLATE

	SPEC NO.	YIELD, KSI	HARDNESS, R_B	EC, % IACS
BOTTOM SIDE	C-1A	24.7	39.2	45.5
	C-2A	26.0	51.0	45.4
	C-3A	32.1	62.5	44.2
	AVERAGE	27.6	50.9	45.0
TOP SIDE	C-1B	62.9	80.0	40.5
	C-2B	62.3	80.5	40.8
	C-3B	62.0	80.5	40.6
	AVERAGE	62.4	80.3	40.6
SPECIFICATION		51	74	35.0-42.5

TABLE 7

BEARING STRENGTH DATA (E/D=2.0),
2124-T851 5-1/2" SLACK QUENCHED ALUMINUM PLATE

	SPEC NO.	YIELD, KSI	ULT, KSI	HARD., R_B	EC, % IACS
BOTTOM SIDE	BE-1A	71.6	103.0	59-60	43.8
	BE-2A	66.3	102.0	56-56	43.7
	BE-3A	67.0	98.0	55-55	44.2
	AVERAGE	68.3	101.0	56.8	43.9
TOP SIDE	BE-1B	99.6	132.0	76-77	40.7
	BE-2B	97.0	129.0	77-77	40.6
	BE-3B	98.7	131.0	78-77	40.9
	AVERAGE	98.4	130.7	77.0	40.7
SPECIFICATION		93.0	121.0	74	35.0-42.5

TABLE 8

SMOOTH FATIGUE DATA, 2124-T851 5-1/2" SLACK QUENCHED ALUMINUM PLATE

SPEC NO.	MAX STRESS (KSI)	CYCLES TO FAILURE	HARDNESS BEFORE TEST, R_B (AVG)	CONDUCTIVITY, % IACS
FS-1A	45	3.1×10^4	58.5	43.7
FS-1B	45	4.5×10^4	79	40.6
FS-2A	45	3.7×10^4	63	43.8
FS-2B	45	4.4×10^4	79	40.7
FS-3A	32.5	1.4×10^6	68.5	43
FS-3B	32.5	7.8×10^6	81.5	40.9
FS-4A	32.5	2.2×10^6	73	42.5
FS-4B	32.5	3.2×10^5	79.5	40.6
FS-5A	45	5.1×10^4	75	42
FS-5B	45	5.2×10^4	80	40.8
FS-6A	32.5	2.2×10^7	74	42.0
FS-6B*	32.5	1.8×10^5	79	40.7
FS-7A	32.5	6.2×10^5	72	42.6
FS-7B	32.5	3.5×10^5	80	41.0
FS-8A	32.5	5.4×10^6	71	42.3
FS-8B	32.5	3.9×10^6	78	40.9

*FS-6B - Failed in Radius

TABLE 9

NOTCHED (K_t=2.43) FATIGUE DATA 2124-T851 5-1/2" SLACK QUENCHED ALUMINUM PLATE

SPEC NO.	MAX STRESS (KSI)	CYCLES TO FAILURE	HARDNESS BEFORE TEST, R_B (AVG)	CONDUCTIVITY, % IACS
FN-1A	30	1.95×10^4	63	43.6
FN-1B	30	4.2×10^4	79	40.5
FN-2A	35	1.2×10^4	65	43.4
FN-2B	35	2.6×10^4	81	40.5
FN-3A	25	8.3×10^4	68	42.9
FN-3B	25	1.8×10^6	80	40.5
FN-4A	25	1.1×10^5	70	42.4
FN-4B	25	1.0×10^5	80.5	40.6
FN-5A	35	2.0×10^4	73	41.7
FN-5B	35	3.3×10^4	80	40.8
FN-6A	25	6.6×10^4	73.5	41.8
FN-6B	25	7.2×10^4	79.5	41
FN-7A	35	1.6×10^4	70	43
FN-7B	35	2.3×10^4	80	40.7
FN-8A	25	1.4×10^5	70	42.5
FN-8B	25	2.9×10^6	80.5	40.8
FN-TL-1A	35	5.0×10^3	44	45.2
FN-TL-7A	35	5.0×10^3	52	44.9
FN-TL-3A	25	3.0×10^4	46	45.0
FN-TL-8A	25	3.7×10^4	51	44.9

TABLE 10

FASTENER FATIGUE RESULTS
MAX STRESS = 15 KSI (GROSS AREA), R= +0.1, 25 Hz
SINGLE LAP, HIGH LOAD TRANSFER

SPEC. NO.	CYCLES ($x10^3$)	FAILED PORTION	HARD.ON FAILED PORTION, R_B	E.C. (%) ON FAILED PORTION
		BARE FAYING SURFACE		
H-1-B/H-5-B	85.5	H-1-B (F)	79.2	40.9
H-1-A/H-5-A	100.2	H-5-A (F)	69.3	43.1
		EPOXY PRIMER COATING (0.001" thick)		
H-2-B/H-6-B	109.9	H-2-B (F) ?	81.2	41
H-2-A/H-6-A	193.1	H-2-A	61.0	44
H-4-B /H-8-B	197.6	H-4-B	80.2	40.4
H-4-A/H-8-A	87.2	H-4-A	57	43.4

NOTE: (F) Indicates failure due to fretting.

All tests run with "sandwich" type restraint.

TABLE 11

STRESS CORROSION TEST RESULTS FOR 2124-T851 5-1/2" THICK PLATE, CONSTANT STRESS, ALTERNATE IMMERSION

SPEC NO.	ORIENTATION	STRESS (KSI)	STRESS/ YIELD* X 100, %	EXPOSURE TIME, HRS	FAIL YES/NO
S-1A	Longitudinal	45	83	317	YES
S-1B	Longitudinal	45	83	677	NO
S-4A	Short Trans.	45	88	547	YES
S-5B	Short Trans.	45	88	625	YES
S-6A	Short Trans.	45	88	386	YES
S-6B	Short Trans.	45	88	593	YES
S-5A	Short Trans.	38.2	75	600	NO
S-4B	Short Trans.	38.2	75	600	NO

*Yield Strength per MIL-HDBK-5: Longitudinal=54 KSI: Short transverse=51KSI

TABLE 12

STRESS CORROSION TEST RESULTS FROM COMPACT TYPE SPECIMENS,
2124-T851 5-1/2" THICK PLATE,
L-T ORIENTATION, CONTINUOUS IMMERSION

SPEC. NO.	$K_{Initial}$, KSI $\sqrt{In.}$	TIME HR	FAIL/ NO FAIL	HARD., R_B	E.C., %IACS
K-1A	22*	2000 +	No Fail	42	45.6
K-2A				52	45.2
K-1B	22*	2000 +	No Fail	79.5	40.6
K-2B				79.5	40.8

*Based on crack length before test

TABLE 13

CHEMISTRY OF 2124-T851 ALUMINUM PLATE,
5-1/2" THICK
WEIGHT PERCENT

SPEC DESIG.	Zn	Mg	Cu	Cr	Fe	Si	Mn	Ti	Remarks
TL-10A	<.15	1.6	4.3	<.04	.13	.07	.70	.017	High Yield
TL-2A	<.15	1.4	4.1	<.04	.12	.07	.66	.015	Low Yield
TL-10B	<.15	1.6	4.3	<.04	.13	.06	.68	.017	High Yield
TL-2B	<.15	1.6	4.2	<.04	.13	.07	.68	.015	Low Yield

TABLE 14

LONGITUDINAL TENSILE DATA,
2124-T851 PLATE 2-3/4" THICK

	SPEC. NO.	UTS, PSI	YIELD, PSI	ELONG, %	RA, %	HARD., R_B	EC, % IACS
SOFT	2	59,870	52,750	6	12.6	73	40.9
SOFT	5	56,770	47,097	7.7	11.3	74	41.4
SOFT	6	64,012	57,324	8.9	17.2	75	39.8
	AVG	60,217	52,390	7.5	13.7	74	40.7
NORMAL	1	72,020	66,284	8.9	14.9	82	38.5
NORMAL	3	70,063	66,242	9.6	17.2	84	38.6
NORMAL	4	70,512	66,506	8.9	13.3	82	38.6
	AVG	70,865	66,344	9.1	15.1	82.7	38.6
	SPEC	65,000	57,000	6	--	74	35.0-42.5

TABLE 15

LONGITUDINAL TENSILE DATA FROM NORMAL (NOT SOFT) 5-1/2" AND 5" PLATES OF 2124-T851 FROM SOURCES OTHER THAN REYNOLDS

THICK.	DEPTH FROM SURFACE, INCH	SPEC NO.	ULT, KSI	YIELD, KSI	ELONG., %	RA, %	E.C., %IACS	HARDNESS, R_B
5-1/2"	1/8	A5B	73.0	68.0	6.0	24.5	41.5	83-84
	1 7/16	A2	69.1	62.0	7.4	16.7	41.7	80-79
	2 3/4	A3	69.0	61.1	7.3	16.6	42.0	78-79
	4 1/16	A4	68.9	61.8	7.1	17.4	42.0	80-79
	5 3/8	A1T	72.9	68.9	8.5	21.2	41.0	84-84
5"	1/8	K-1T	70.8	65.5	7.8	24.6	41.0-41.0	81.6-79.6
	7/8	K-2	65.5	58.0	7.3	21.6	41.8-41.6	73.4-72.4
	1 3/4	K-3	64.8	56.7	6.5	16.4	41.8-41.9	70.6-69.5
	2 1/2	K-4	64.0	56.6	6.7	14.1	42.0-42.0	73.6-70.9
	3 1/4	K-5	65.1	57.1	7.0	17.2	41.9-41.9	73.0-72.1
	4 1/8	K-6	66.1	58.8	7.7	20.8	41.5-41.6	75.8-76.3
	4 7/8	K-7B	72.2	66.4	7.9	23.9	41.0-40.5	73.8-78.8
	SPECIFICATION		63	54	5		35.0-42.5	74

TABLE 16

LONGITUDINAL TENSILE DATA,
2024-T351 PLATE 2" THICK

SPEC. NO.	UTS, KSI	YIELD, KSI	ELONG, %	RED. AREA, %	HARD., R_B	E.C. % IACS
Base Y-1B	69.9	53.0	13.0	23.6	77-78	30.0-30.4
Y-2B	69.7	53.8	17.7	24.4	77-78	30.1-30.3
Y-3B	69.7	54.1	19.8	24.4	78-79	30.0-30.4
AVG.	69.8	53.6	16.8	24.1		
Middle Y-1M	73.3	57.4	15.5	19.9	77-76	31.0-30.8
Y-2M	73.3	57.0	13.6	16.2	78-77	31.0-31.0
Y-3M	72.9	57.7	13.0	15.3	78-77	31.0-31.0
AVG.	73.2	57.4	14.0	17.3		
Affected Y-1T	65.6	52.1	13.9	23.0	76-73	30.8-33.9
Y-2T	65.7	52.6	12.1	21.2	76-77	30.6-34.0
Y-3T	65.3	52.1	13.0	19.8	72-73	31.0-33.8
AVG.	65.5	52.3	13.0	31.3		
SPECIFICATION	62	47	6	--	63	28.5-32.5

TABLE 17

LONGITUDINAL TENSILE DATA, 7075-T651
1-1/4" IMPROPERLY QUENCHED ALUMINUM PLATE

	SPEC. NO.	UTS, KSI	YIELD, KSI	ELONG., %	RA, %	HARD., R_B	EC, % IACS
BOTTOM SIDE (SOFT) LONGITUDINAL	L-1A	70.0	58.6	10.0	15.9	78.0	34.2
	L-2A	70.0	60.0	8.6	18.8	81.0	34.1
	L-3A	69.8	58.3	11.0	18.5	82.7	33.9
	L-4A	68.8	56.6	10.4	20.2	81.7	34.1
	L-5A	68.6	55.8	11.3	21.1	81.0	34.2
	L-6A	69.1	58.2	10.5	18.8	83.7	33.7
	L-7A	70.7	61.5	7.5	18.6	83.5	33.5
	L-8A	70.7	59.7	10.2	19.4	82.5	33.8
	L-9A	70.2	58.2	11.1	21.6	81.7	34.1
	L-10A	70.3	58.4	11.5	18.4	78.5	33.7
	AVERAGE	69.8	58.5	10.2	19.3	81.4	33.9
	σ n-1	.74	1.62	1.26	1.60	1.92	.25
MID THICKNESS LONGITUDINAL	L-4M	81.0	71.9	10.3	12.2	83.5	33
	L-5M	80.2	71.0	9.3	12.6	82.7	33
	L-6M	80.4	70.6	10.3	14.7	83.0	33
	AVERAGE	80.5	71.2	10.0	13.2	83.1	33
TOP SIDE LONGITUDINAL	L-1B	74.8	64.9	18.1	10.6	82.5	32.5
	L-2B	77.1	70.2	8.6	22.6	84.2	32.2
	L-3B	76.9	67.5	9.3	19.0	84.7	32.0
	L-4B	78.1	69.2	11.5	21.3	85.5	31.9
	L-5B	78.7	69.8	11.6	20.0	85.2	31.5
	L-6B	79.1	70.5	11.6	20.6	85.5	31.8
	L-7B	78.1	68.4	12.6	19.7	86.0	32.0
	L-8B	77.7	68.6	13.2	17.3	86.2	31.9
	L-9B	79.5	70.9	13.4	23.1	88.2	31.3
	L-10B	81.8	75.8	7.2	17.9	85.5	31.1
	AVERAGE	78.2	69.6	11.1	19.2	85.3	31.8
	σ n-1	1.84	2.80	3.03	3.55	1.46	.42
SPECIFICATION		76	69	6	--	84	30.5 - 36

TABLE 18

TRANSVERSE TENSILE DATA,
7075-T651 1-1/4" IMPROPERLY QUENCHED ALUMINUM PLATE

	SPEC. NO.	UTS, KSI	YIELD, KSI	ELONG., %	RA, %	HARD., R_B	E C, % IACS
BOTTOM SIDE	X-1A	71.2	56.8	10.0	17.8	79.0	34
	X-1A	69.9	54.7	9.2	16.5	77.5	34
	X-1A	69.9	54.2	10.6	15.2	79.9	34
	AVERAGE	70.3	55.2	9.9	16.5	78.8	34
TOP SIDE	X-1B	79.6	66.5	9.7	16.1	87.5	31.9
	X-2B	80.2	67.7	9.9	14.6	86.0	32.0
	X-3B	79.8	66.1	9.6	15.7	86.5	31.7
	AVERAGE	79.9	66.8	9.7	15.5	86.7	31.9
SPECIFICATION		75	65	6	--	84	30.5-36

TABLE 19

LONGITUDINAL TENSILE DATA, 7075-T651 1-1/4" THICK PLATE

	SPEC. NO.	UTS, KSI	YIELD, KSI	ELONG., %	R.A., %	HARD., R_B	E.C., % IACS
SOFT SIDE	L-11T	67.3	55.4	10.8	22	81	34.1
	L-12T	72.1	63.0	9.3	20	87	34.1
	L-13T	73.3	63.8	10.0	23	86	32.5
	L-14T	73.2	63.6	12.2	24	85	32.9
	AVERAGE	71.5	61.5	10.6	22	85	33.4
NORMAL SIDE	L-11B	73.4	64.2	7.0	23	83	33.5
	L-12B	72.8	64.7	9.2	20	85	32.5
	L-13B	73.4	64.3	10.4	23	87	32.2
	L-14B	71.2	60.4	11.7	24	85	32.4
	AVERAGE	72.7	63.4	9.6	22	85	32.6
SPECIFICATION		76	69	6	--	84	30.5-36

TABLE 20

CHEMISTRY OF 7075-T651 ALUMINUM PLATE
1-1/4" THICK

WEIGHT PERCENT

SPEC. DESIG.	Zn	Mg	Cu	Cr	Fe	Si	Mn	Ti	B	Remarks
L-5A	5.6	2.7	1.6	.19	.36	.27	.08	.025	.017	Lowest Yield
L-10A	5.8	2.7	1.6	.20	.36	.15	.08	.027	.006	
L-5B	5.8	2.7	1.7	.19	.35	.20	.08	.026	.010	
L-10B	5.9	2.7	1.7	.20	.37	.08	.09	.029	<.002	Highest Yield

TABLE 21

LONGITUDINAL TENSILE DATA, 7075-T7351 4" PLATE

	SPEC. NO.	UTS, KSI	YIELD, KSI	ELONG., %	RA, %	HARDNESS, R_B	E.C., % IACS
BOTTOM SIDE (SOFT) LONGITUDINAL	P-1-A	71.7	60.7	7.9	15.9	78/81	39.2/40.9
	P-2A	70.8	59.5	7.4	15.1	81/79.5	39.2/40.8
	P-3A	70.4	58.6	6.7	11.6	80.5/81.5	39.2/40.2
	P-4A	71.6	60.7	8.4	14.4	81/79	38.8/40.8
	P-5-A	71.2	60.2	8.0	14.9	76/81	39/41.3
	P-6-A	71.9	60.6	7.4	16.6	76/81	39/39.8
	P-7-A	71.7	60.4	7.1	16.0	82/83	38.8/39.3
	P-8-A	71.9	60.5	7.9	13.3	82.5/82.5	38.7/39.8
	P-9-A	71.2	59.6	8.0	14.3	82/82	38.6/40.0
	P-10-A	70.5	58.6	8.4	16.9	80/81	38.8/41.2
	AVERAGE	71.3	59.9	7.7	14.9	80.5	39.6
	σ n-1	0.56	0.82	0.55	2.11	1.97	0.94
SPECIFICATION		*63	*49	--	--	78	40-43
TOP SIDE LONGITUDINAL	P-1-B	73.9	63.3	9.3	13.6	82.5/82	38.7/39.4
	P-2B	73.6	62.8	7.3	14.5	82/83	38.7/39
	P-3-B	73.3	62.3	7.3	16.4	82.5/82	38.7/39.2
	P-4-B	73.5	62.6	8.4	15.6	82/78	38.7/38.8
	P-5-B	73.4	63.1	7.8	14.5	80/83	38.5/38.8
	P-6-B	73.1	62.3	7.4	14.0	79/82	38.7/39
	P-7-B	72.3	61.7	6.9	14.8	82/83	38.7/39
	P-8-B	72.8	61.6	7.0	12.0	82/83	38.7/39
	P-9-B	72.7	62.3	7.4	13.4	82.5/82	38.5/38.9
	P-10-B	72.5	61.3	7.6	16.6	84/83.5	38.5/38.9
	AVERAGE	73.1	62.3	7.6	14.5	82.0	38.8
	σ n-1	0.52	0.65	0.72	1.41	1.45	0.23
SPECIFICATION		*63	*49	--	--	78	40-43

*MIL-HDBK-5 "A" Value for 2.5"-3.0" Plate.

TABLE 22

TRANSVERSE TENSILE DATA, 7075-T7351 4" PLATE

	SPEC. NO.	UTS, KSI.	YIELD, KSI.	ELONG, %	RA, %	HARDNESS, R_B	E.C., % IACS
BOTTOM SIDE (SOFT) TRANSVERSE	G-1-A	69.7	59.0	7.5	17.0	82/83	39/41.4
	G-2-A	71.1	60.3	9.2	17.7	81/81	39/40
	G-3-A	69.8	58.3	9.2	19.1	81/80	39.1/39.5
	G-4-A	69.4	58.6	8.3	18.3	80/80	39.2/39.7
	AVERAGE	70.0	59.1	8.6	18.0	81.0	39.6
	σ n-1	0.75	0.88	0.82	0.89	1.07	0.71
SPECIFICATION		*64	*49	6	--	78	40-43
TOP SIDE TRANSVERSE	G-1-B	72.1	61.7	9.5	19.7	82/83	38.8/39.3
	G-2-B	71.5	61.1	9.0	20.0	83/83	38.7/38.8
	G-3-B	72.0	62.1	9.5	18.0	83/83	38.7/38.9
	G-4-B	72.1	61.8	9.1	26.3	83/83.5	38.7/39.3
	AVERAGE	71.9	61.7	9.3	21.0	82.9	38.8
	σ n-1	0.29	0.42	0.26	3.64	0.42	0.33
SPECIFICATION		*64	*49	6	--	78	40-43

* MIL-HDBK-5 "A" Value for 2.5"-3.0" Plate.

TABLE 23

TENSILE TRAVERSE THROUGH 7075-T7351 4" PLATE

	SPEC. NO.	UTS, KSI	YIELD, KSI	ELONG, %	RA, %	HARDNESS, R_B	E.C., % IACS
BOTTOM SIDE	P-5-A	71.2	60.2	8.0	14.9	76/81	39/41.3
	P-5-1	62.0	48.1	8.0	14.5	72/74	40.0/40.5
	P-5-2	61.6	48.2	7.6	11.8	70/70.5	40.3/40.6
	P-5-3	64.4	52.6	6.3	11.4	74/73	40.3/40.3
	P-5-4	63.7	53.2	6.4	10.0	74/74.5	40.1/40.3
	P-5-5	63.7	50.3	6.6	10.9	74/74	40.0/40.1
	P-5-6	68.4	56.1	7.6	11.4	77/77.5	39.1/39.5
TOP SIDE	P-5-B	73.4	63.1	7.8	14.5	80/83	38.5/38.8
SPECIFICATION		*63	*49	--	--	78	40-43

* MIL-HDBK-5 "A" Value for 2.5"-3.0" Plate.

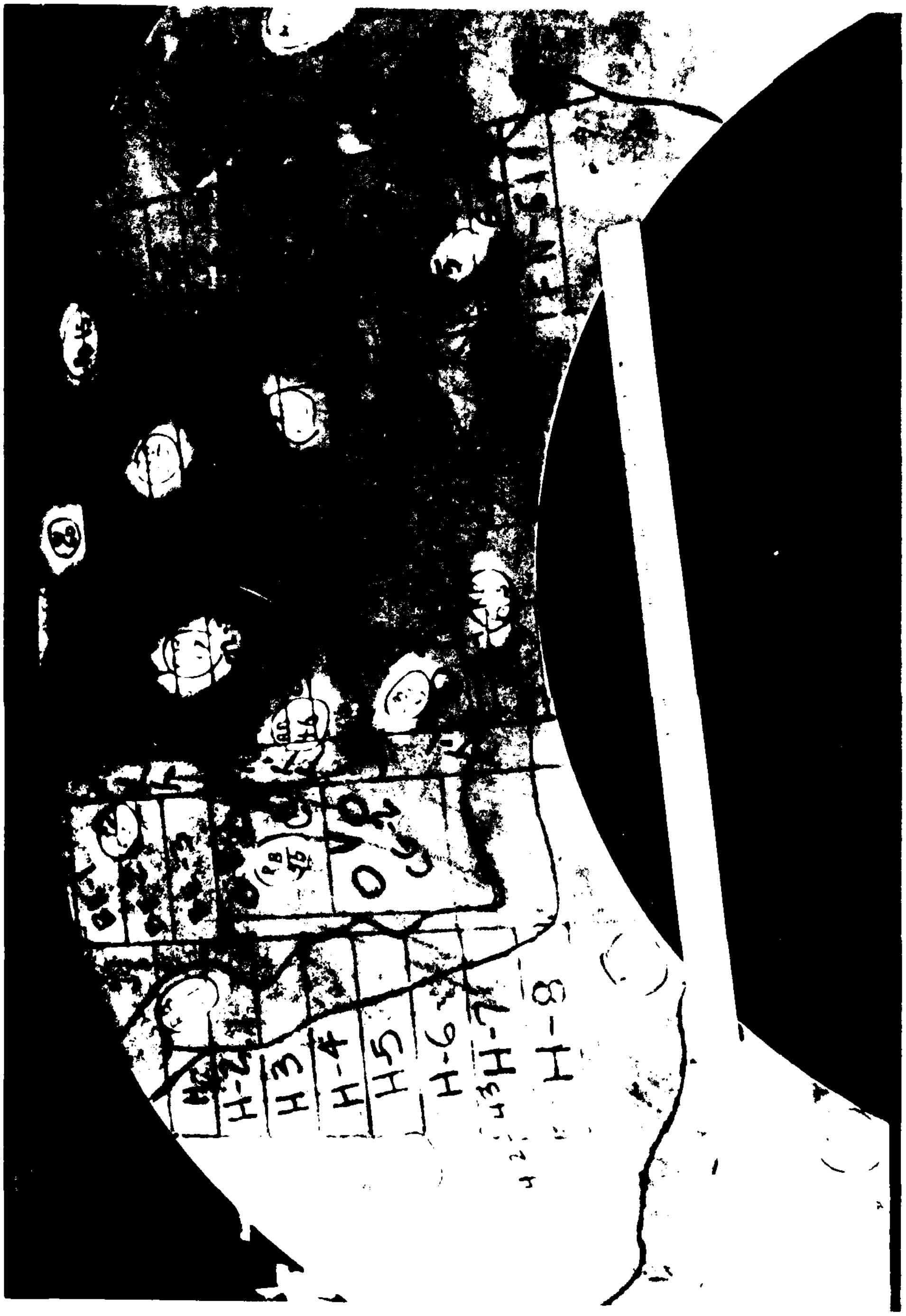


Figure 1. 2124-T851 5 1/2" Plate Showing Test Program Layout. Similar Layout on Opposite Surface

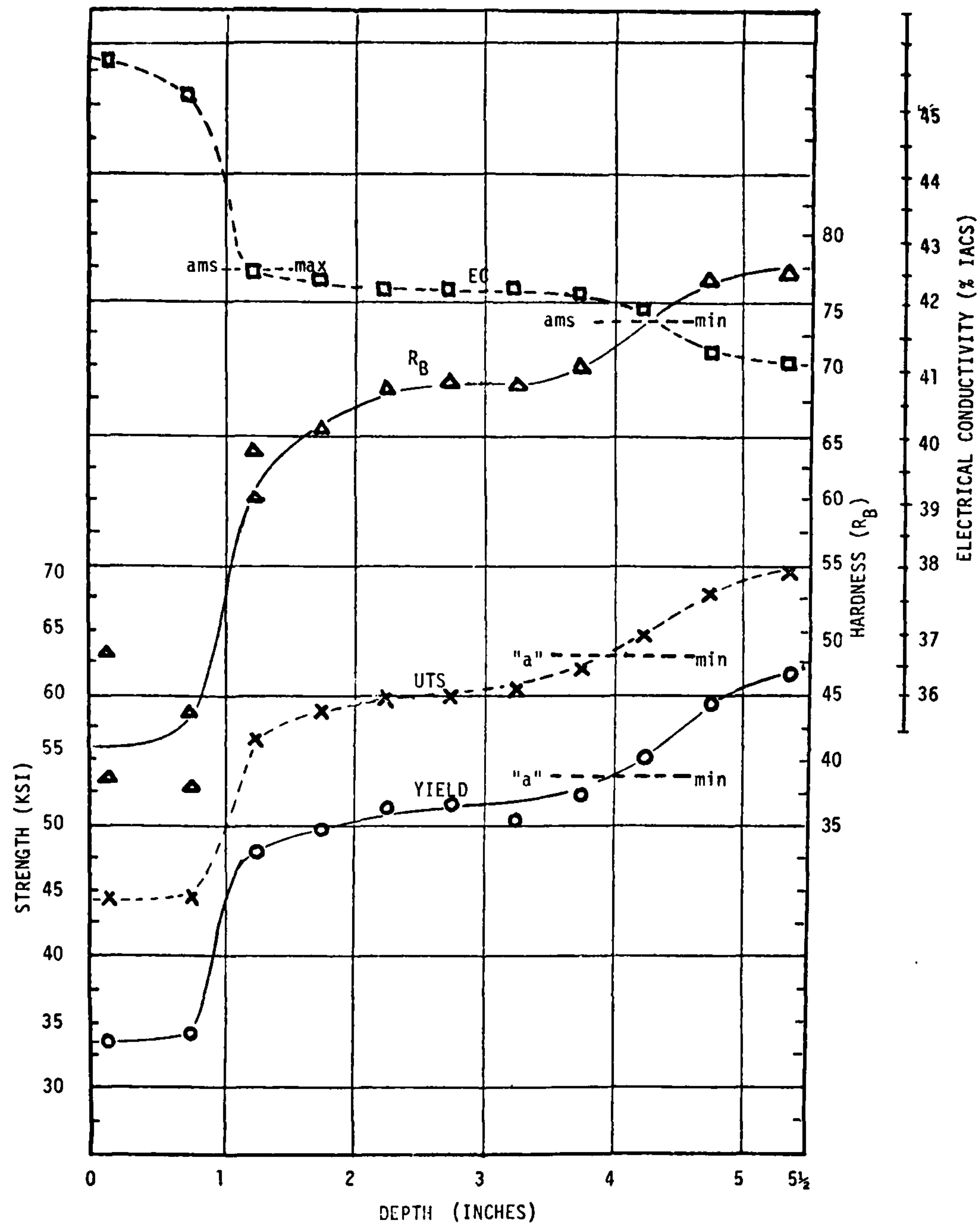


Figure 2. Test Data for 2124-T851 Aluminum Plate 5-1/2" Thick

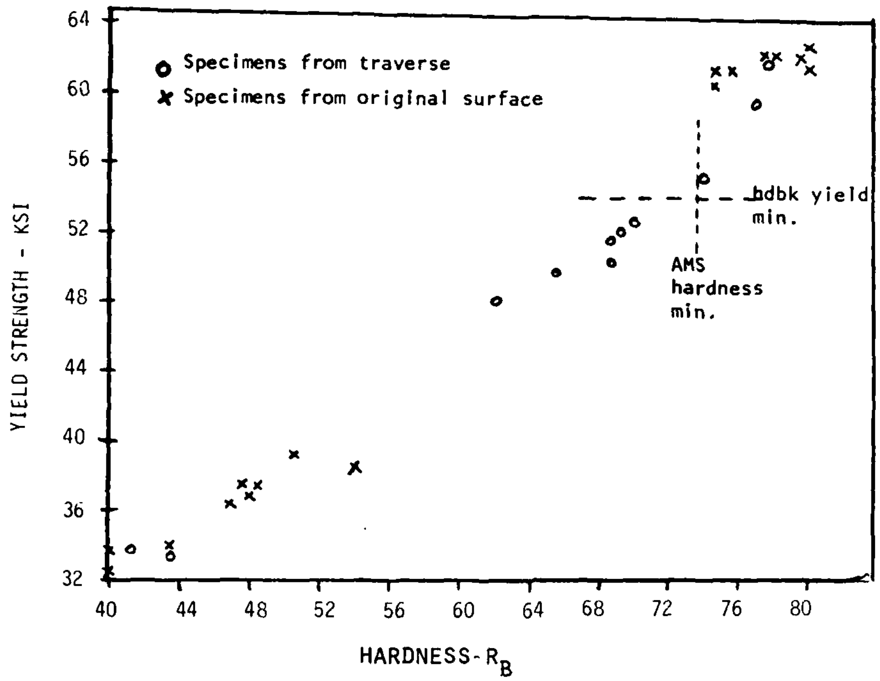


Figure 3. Hardness Versus Yield Strength for 2124-T851 5-1/2" Plate

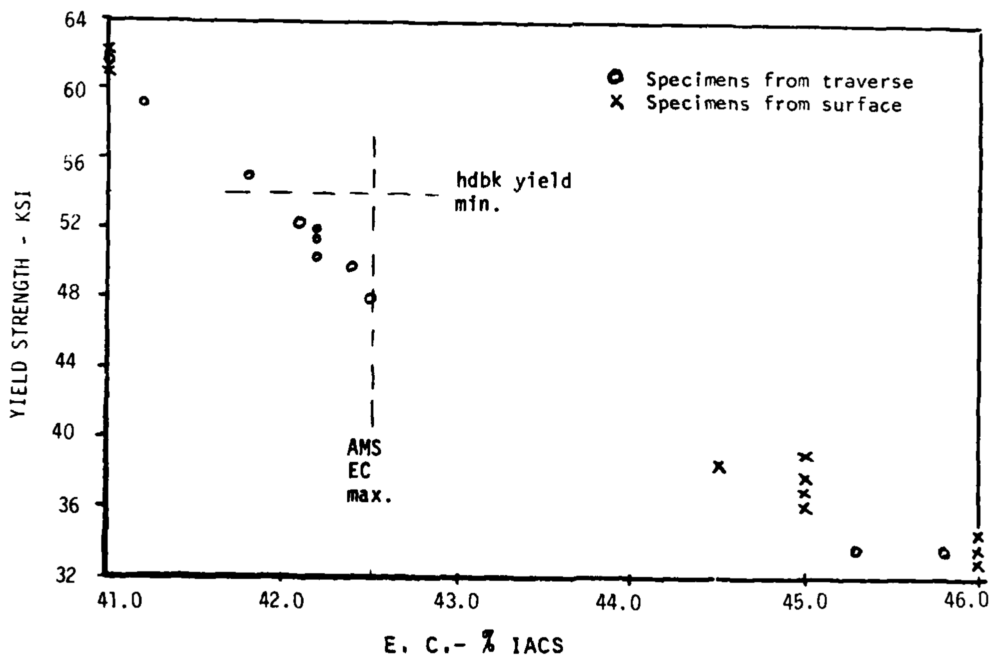


Figure 4. Electrical Conductivity Versus Yield Strength for 2124-T851 5-1/2" Plate

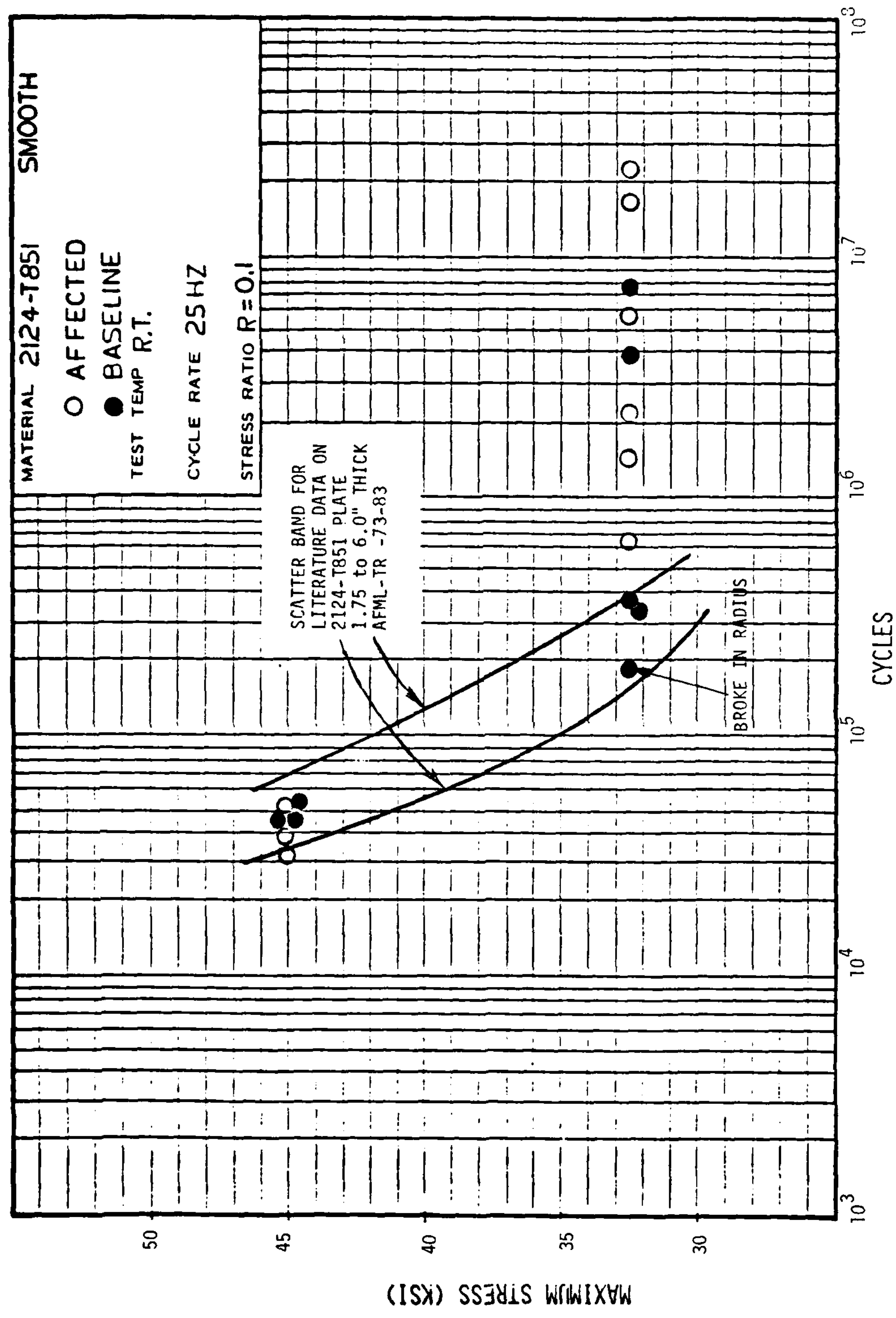


Figure 5. Smooth Fatigue Data for 2124-T851 5-1/2" Plate

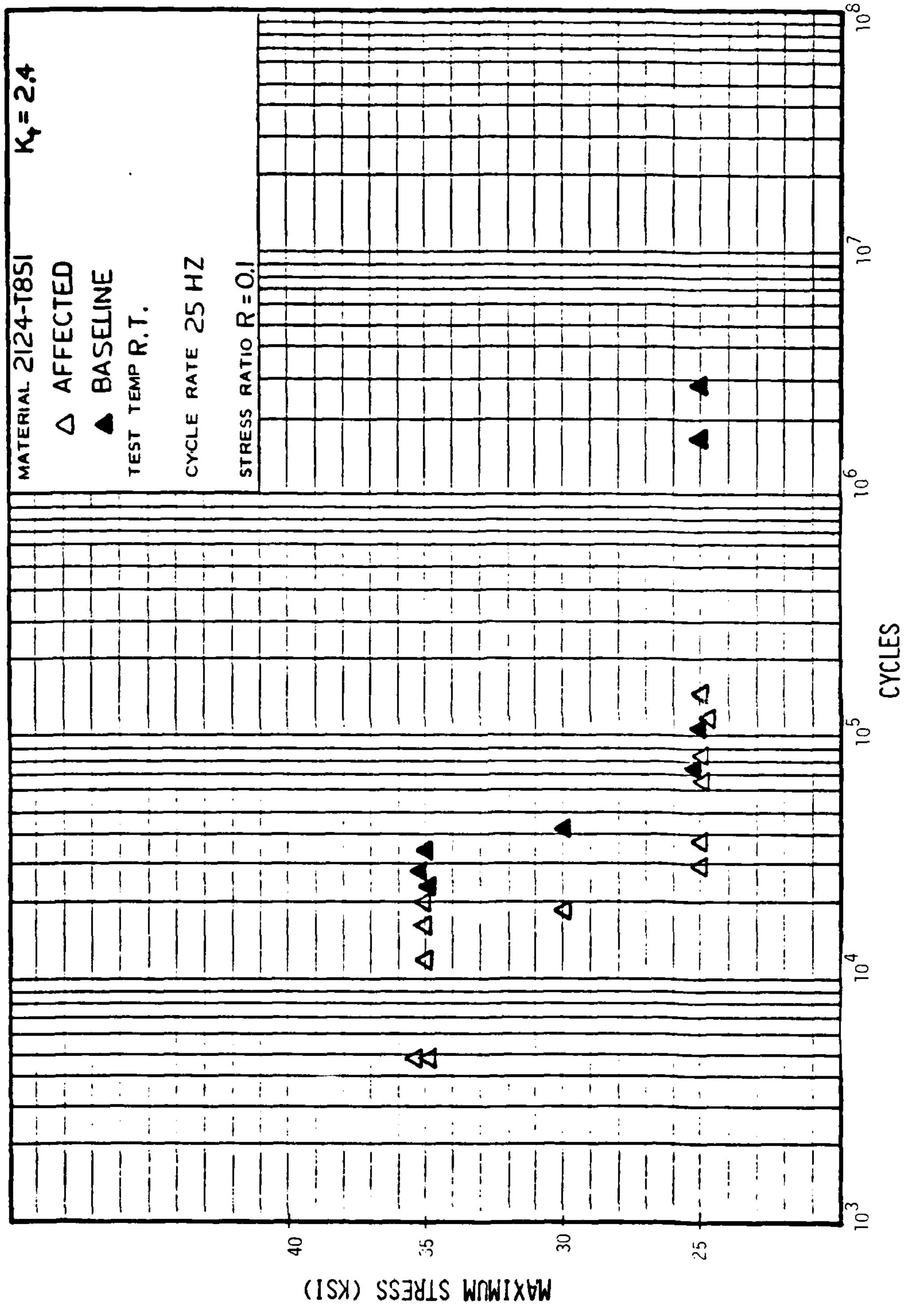


Figure 6. Notched Fatigue Data for 2124-T851 5-1/2" Plate

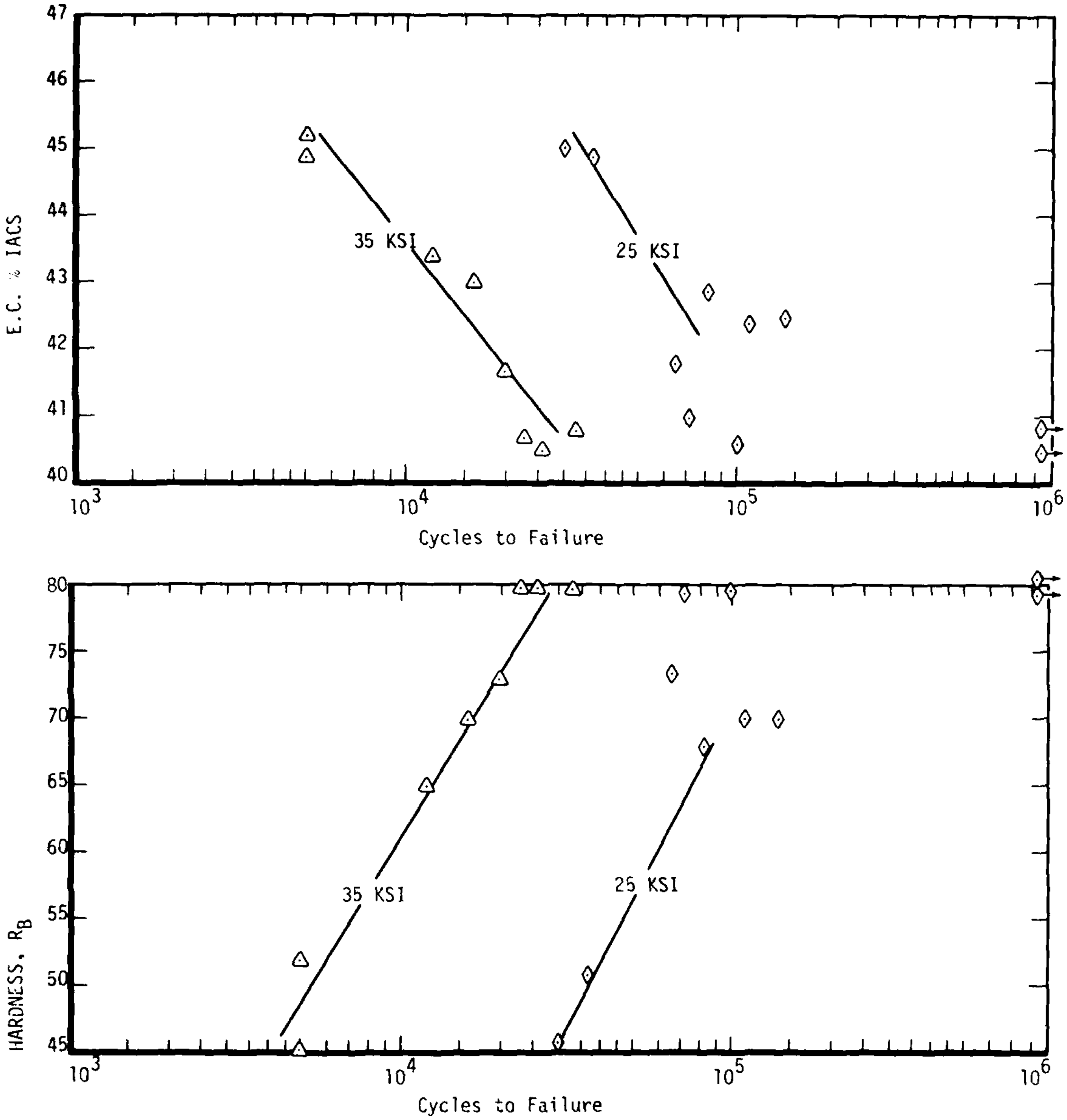


Figure 7. Notched Fatigue Data Showing Relationship Between Conductivity, Hardness, and Fatigue Life of 2124-T851 5-1/2" Plate

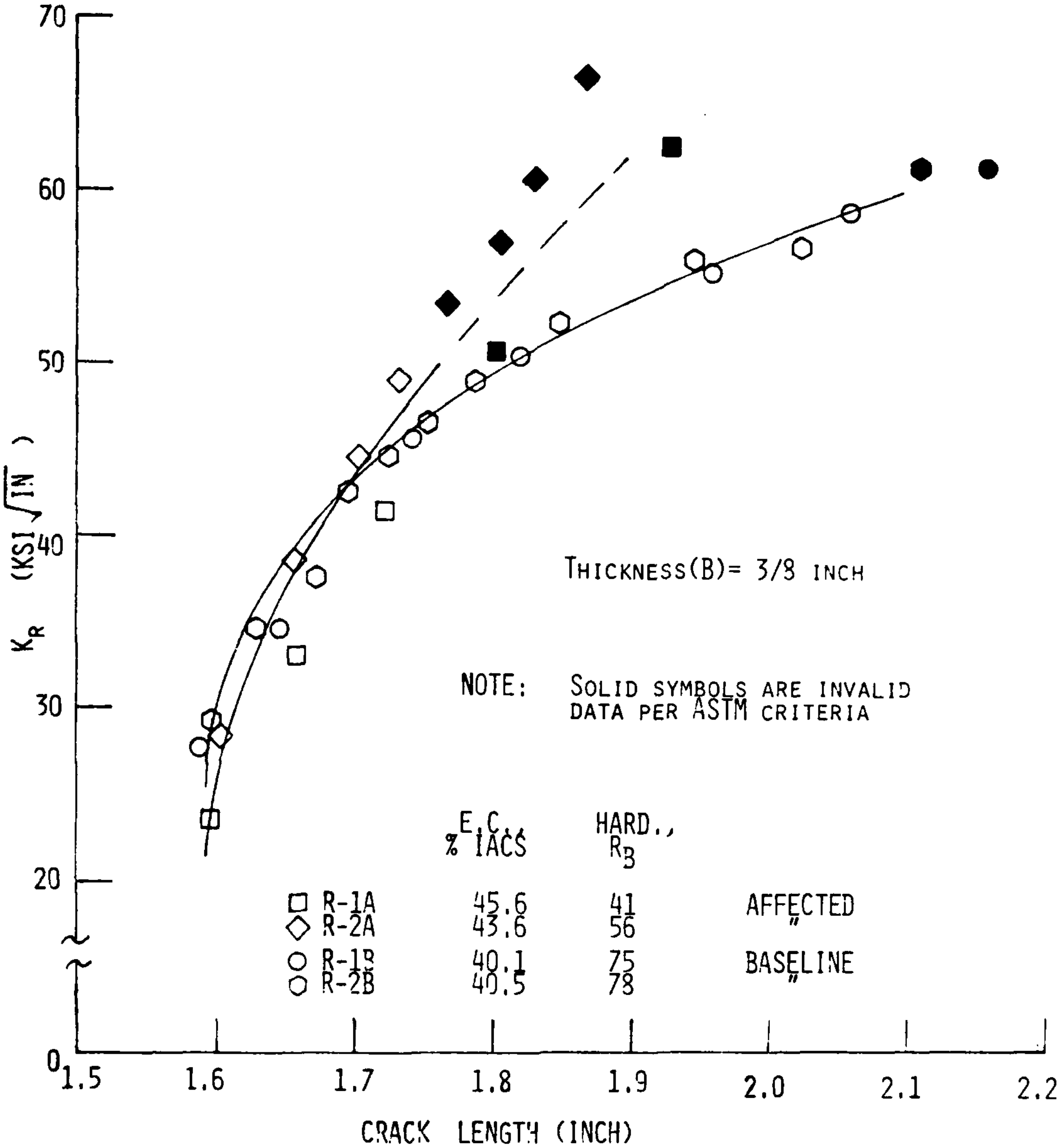


Figure 8. R-Curve Fracture Toughness Data, 2124-T851 5-1/2" Aluminum Plate

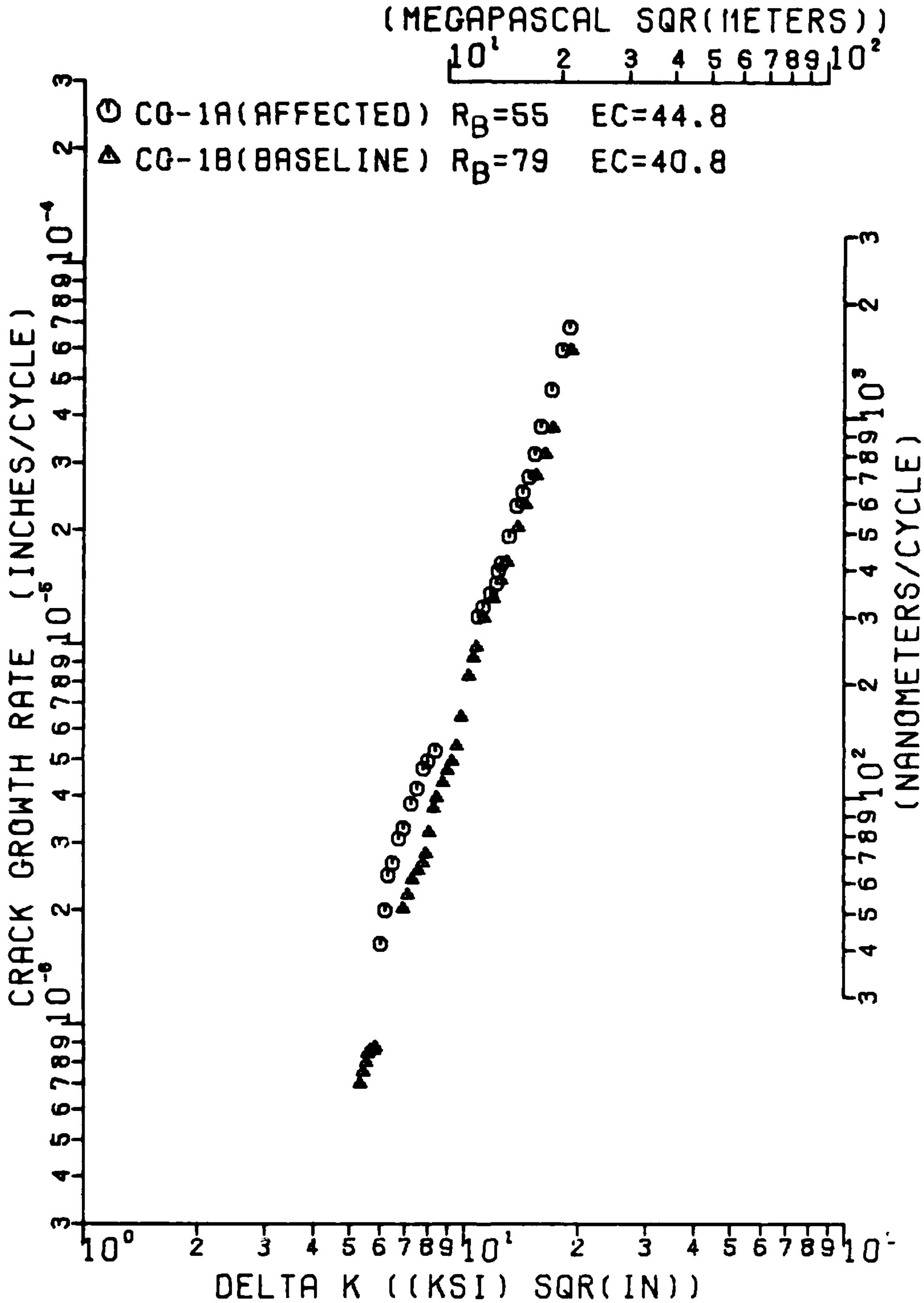


Figure 9. Fatigue Crack Growth Rate Data for 2124-T851 5-1/2" Aluminum Plate

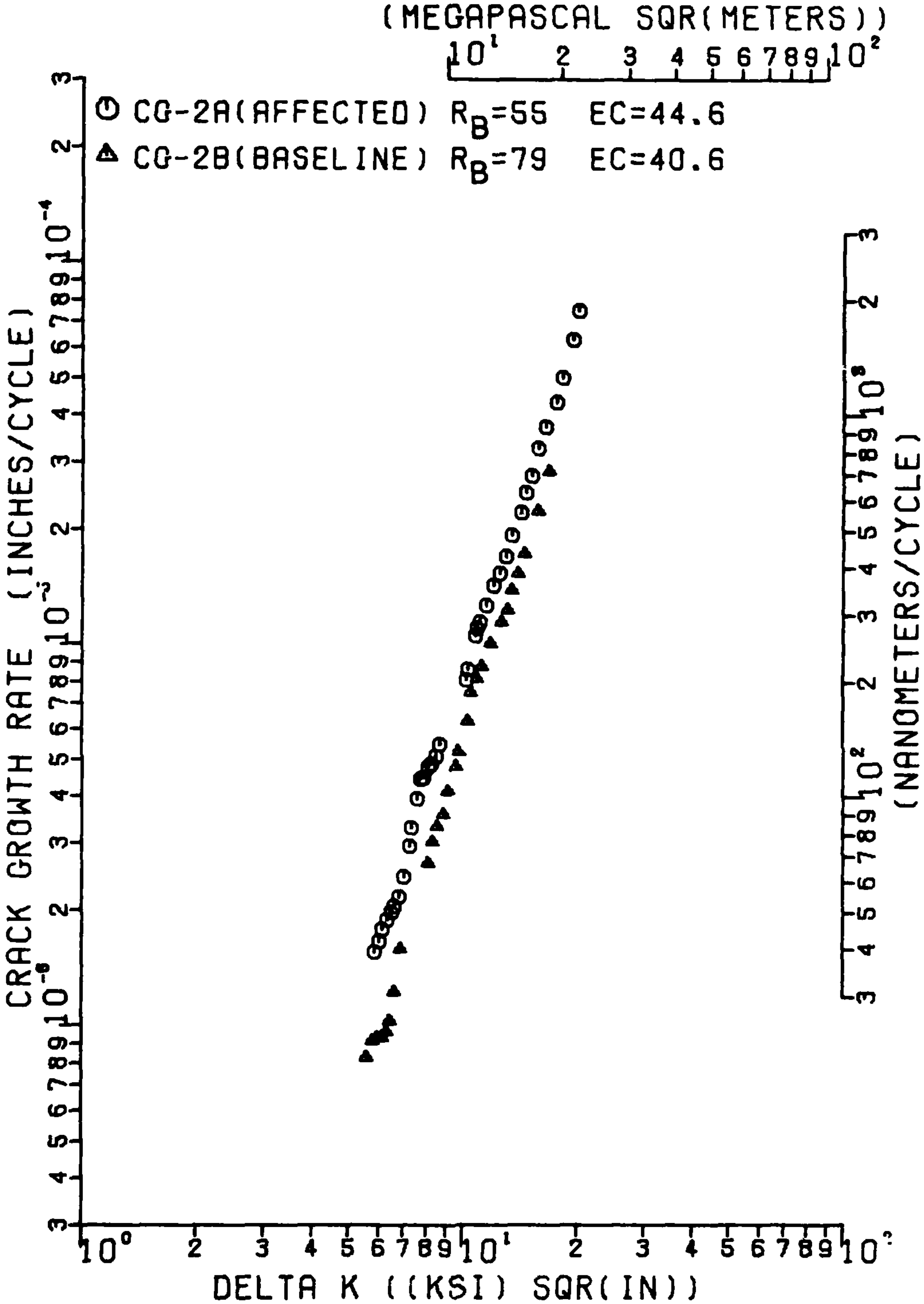


Figure 10. Fatigue Crack Growth Rate Data for 2124-T851 5-1/2" Aluminum Plate

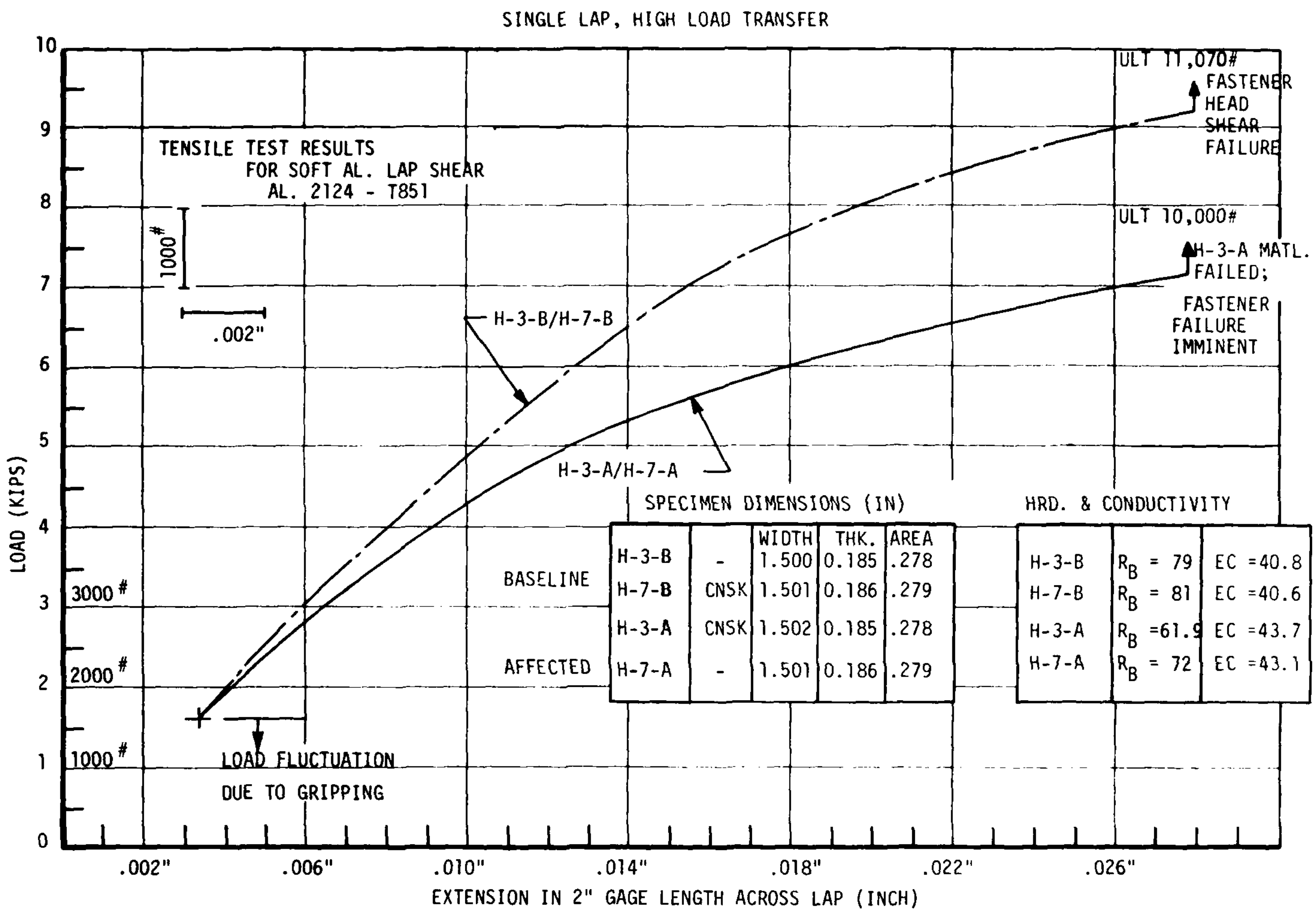
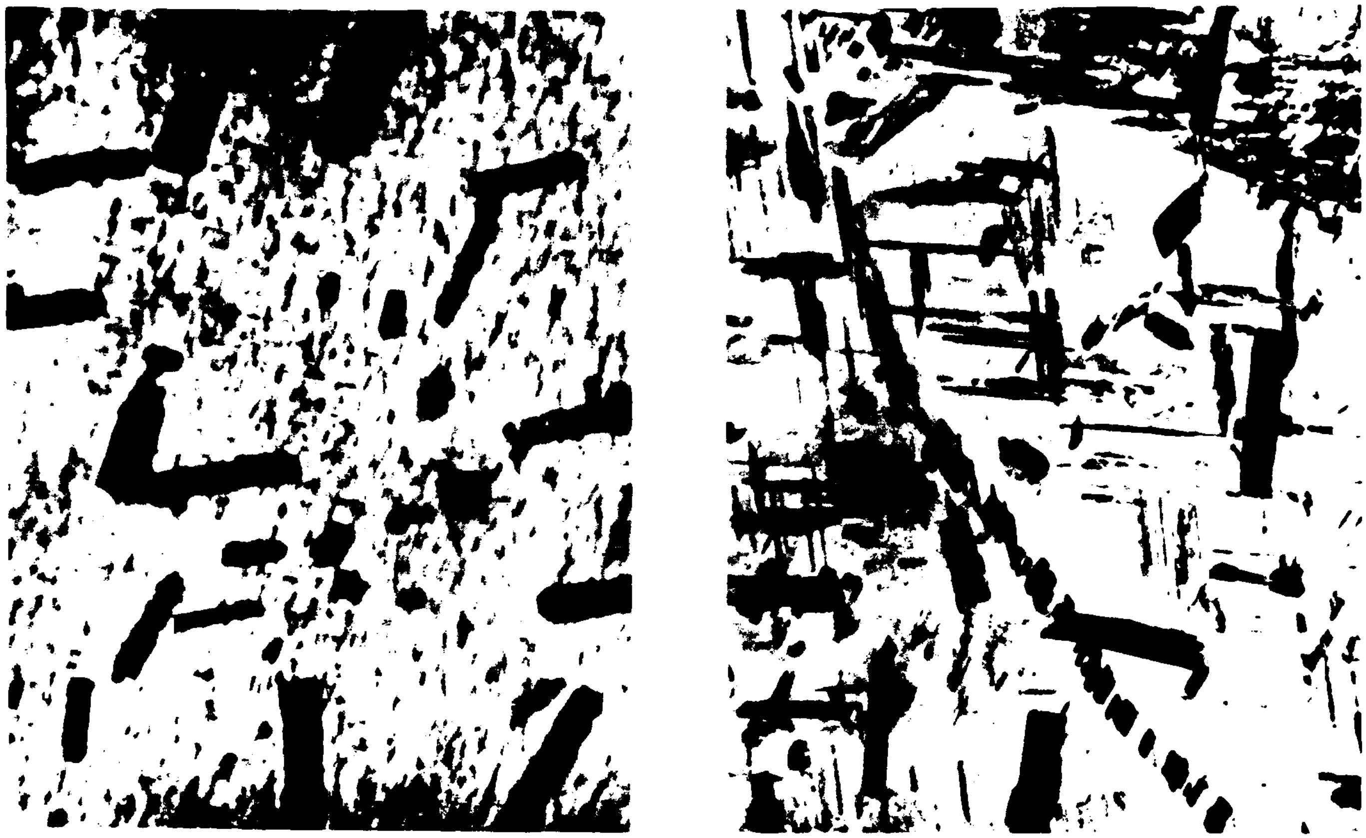


Figure 11. Fastener Tensile Data, Specimens from 2124-T851 5-1/2" Aluminum Plate

Figure 12. Composite Photomicrograph of Area Near Fracture Surface on Affected Stress Corrosion Specimen (Parallel to Long Axis of the Specimen)

Figure 13. Microstructure Taken Near the Surface on Directly Opposite Sides of 2124-T851 5-1/2" Plate. 100X.



BASELINE AFFECTED

Figure 14. Microstructure Near the Surface on Directly Opposite Sides of 2124-T851 5-1/2" Plate. 30,000X

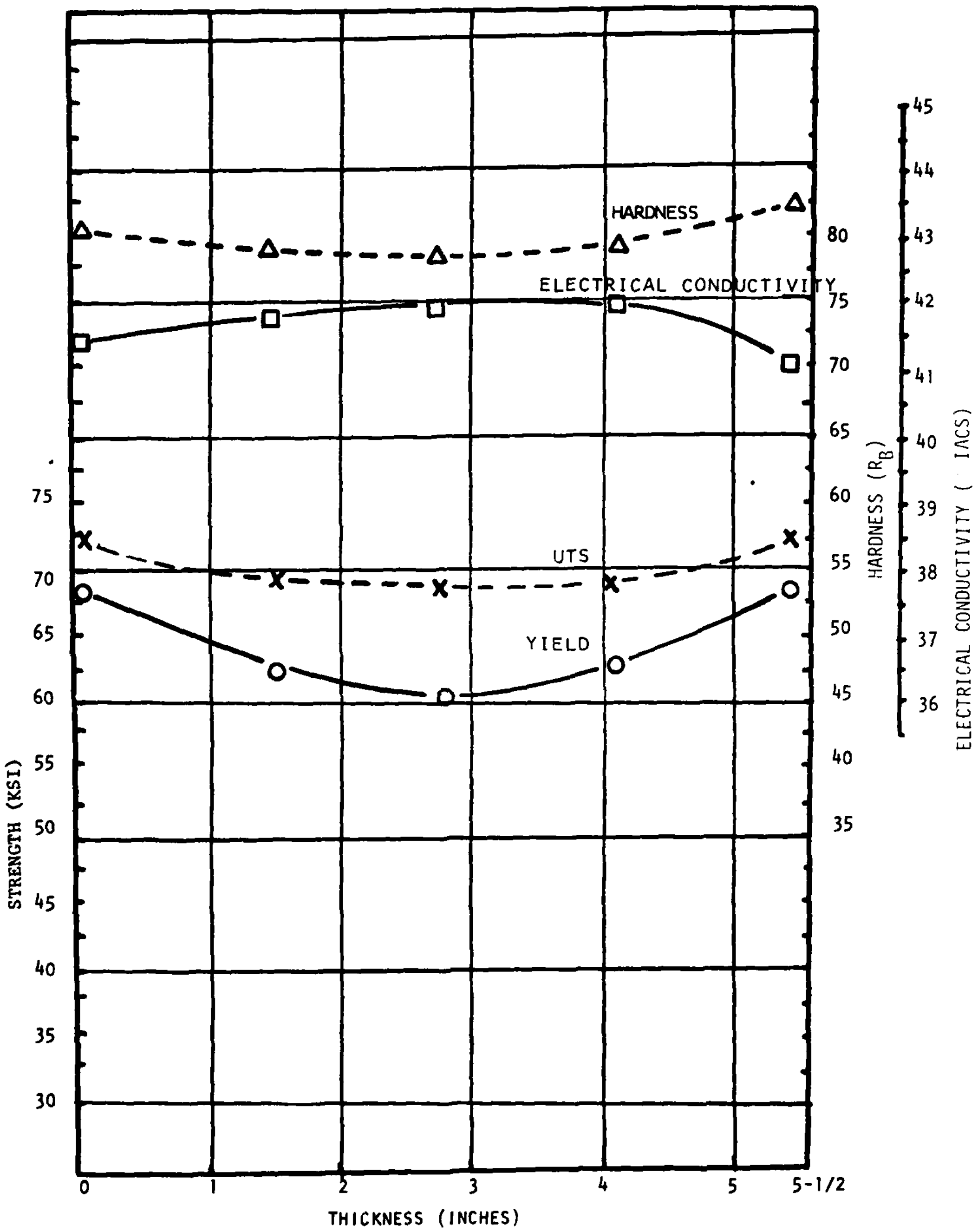


Figure 15. Tensile Data for Normal 2124-T851 Aluminum Plate 5-1/2" Thick

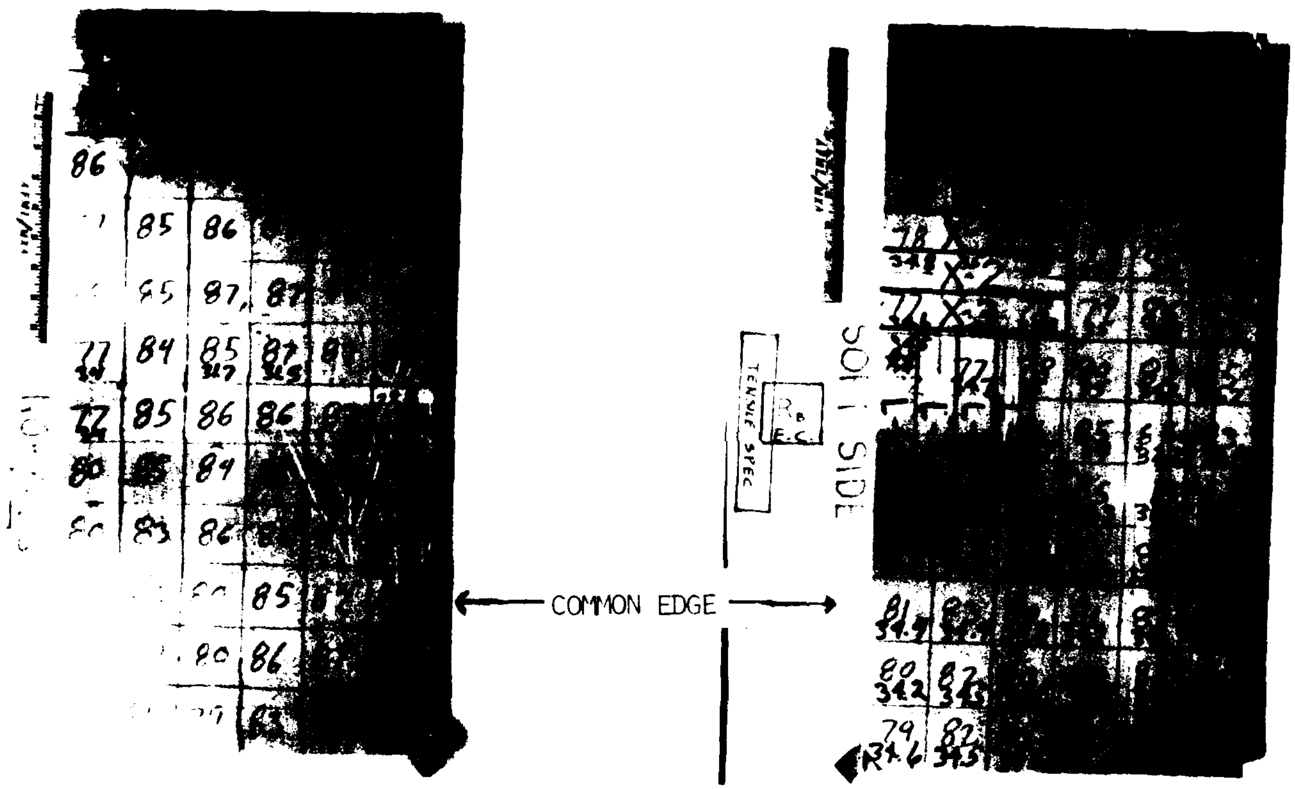


Figure 16. 7075-T651 1-1/4" Plate Showing Tensile Specimen Layout on Soft (Bottom Side). Similar Layout on Top Side

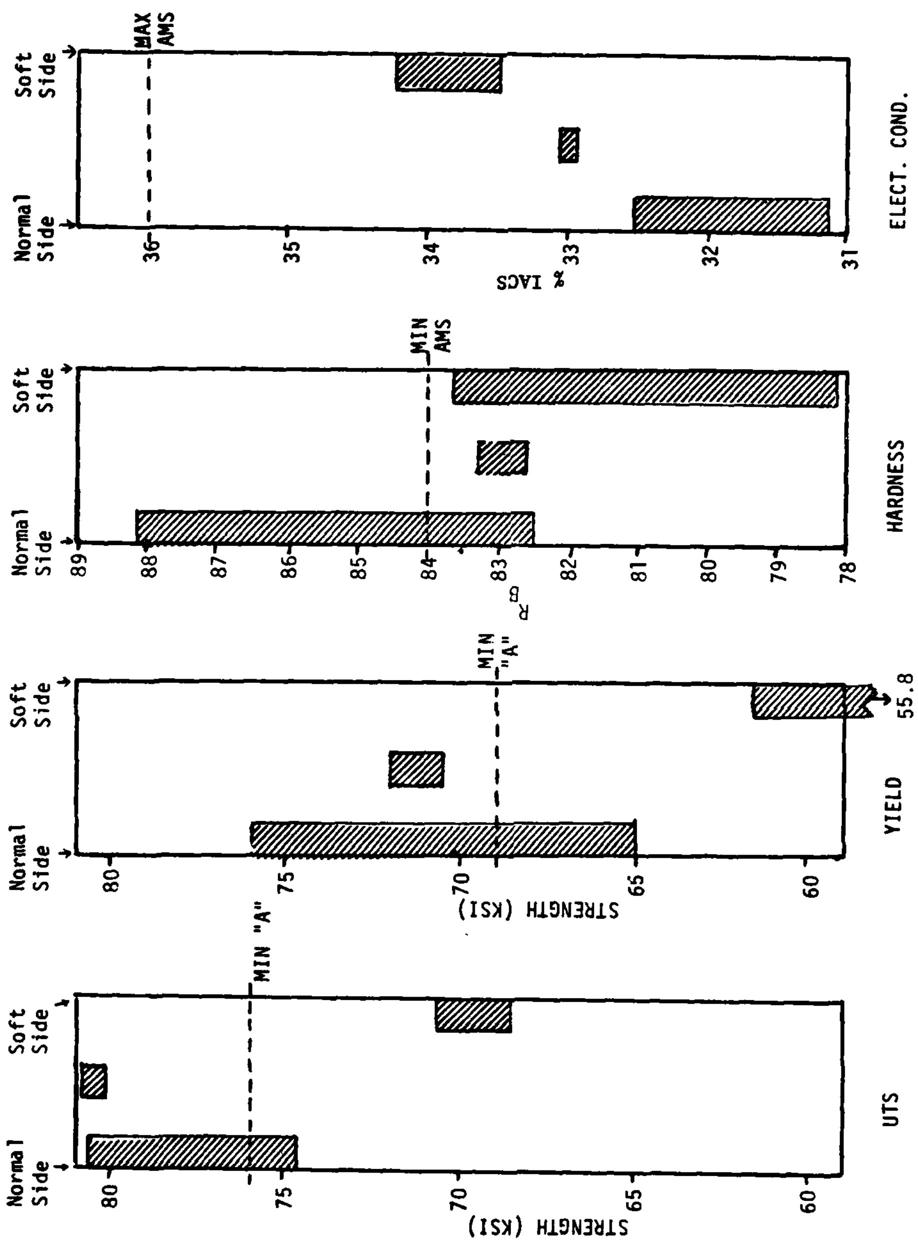
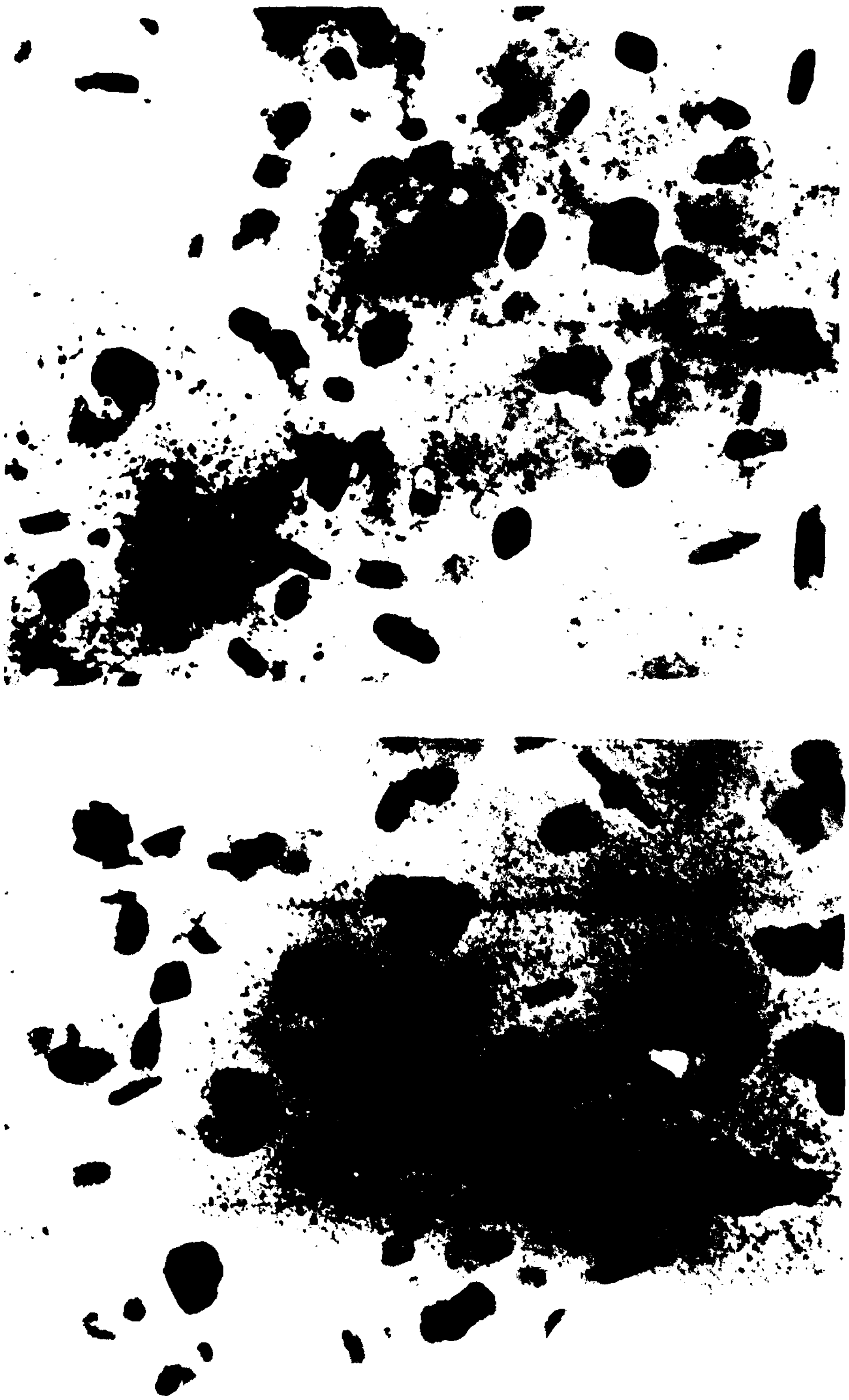
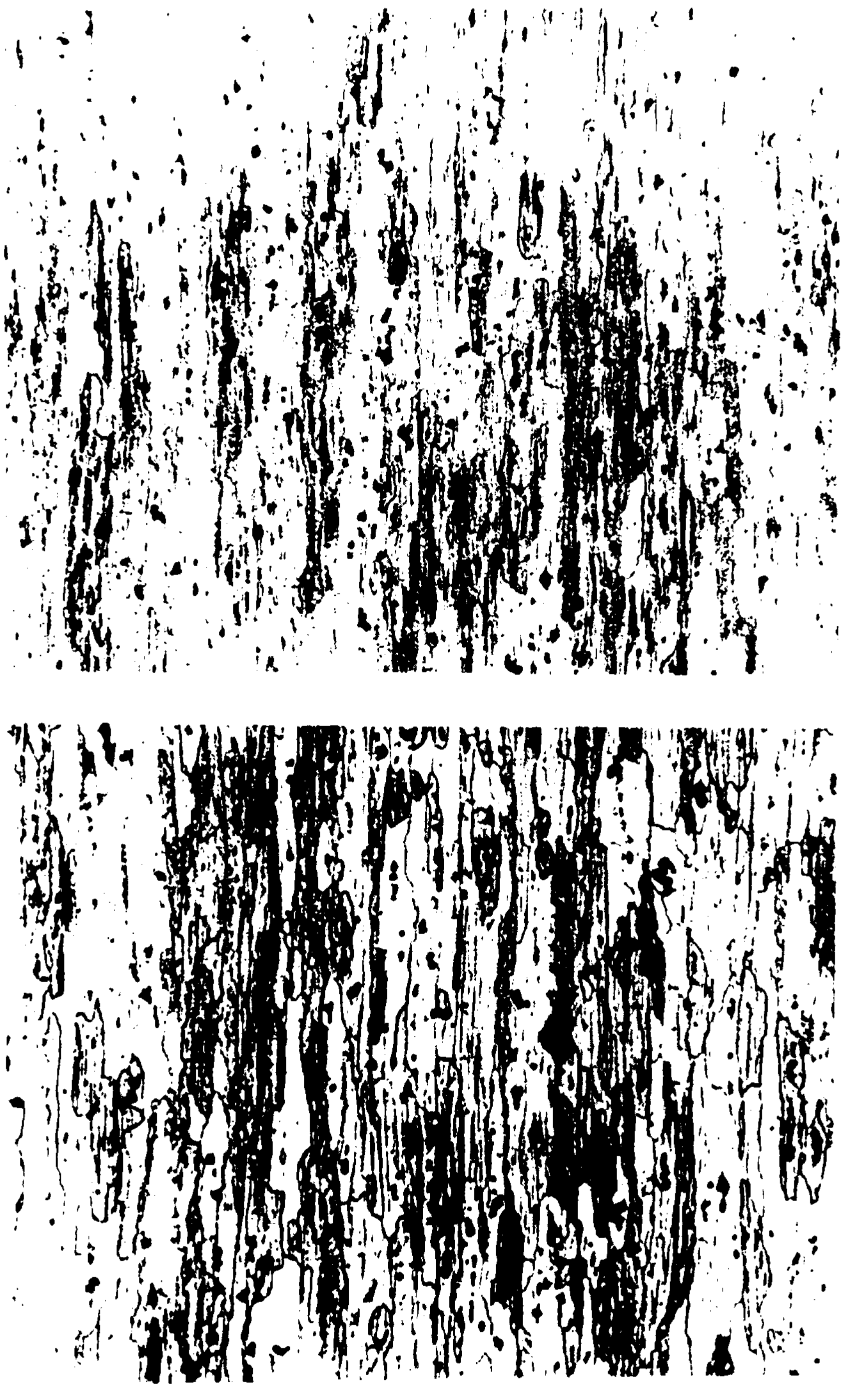


Figure 17. Effect of Slack Quench on Properties of 7075-T651 Aluminum Plate 1-1/4" Thick



BASELINE AFFECTED

Figure 18. Microstructure Near the Surface on Directly Opposite Sides of 7075-T651 1-1/4" Plate. 30,000X



AFFECTED

BASELINE

Figure 19. Microstructure Near the Surface on Directly Opposite Sides of 7075-T651 1-1/4" Plate Taken Perpendicular to the Rolling Plane. 100X

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