N+

NASA Technical Memorandum 82810

Interrelation of Material Microstructure, Ultrasonic Factors, and Fracture Toughness of a Two Phase Titanium Alloy

Alex Vary and David R. Hull
Lewis Research Center
Cleveland, Ohio

Prepared for the
Spring Conference of the American Society for Nondestructive Testing
Boston, Massachusetts, March 22-25, 1982

NASA

Strong incentives also exist for nondestructive methods to evaluate and verify mechanical properties following metallurgical processing steps that affect toughness, strength, and associated properties, ref. 4. Low cost, rapid nondestructive alternatives are needed to supplant destructive tests that by their nature cannot be applied to each finished article or intermediate product. Advanced nondestructive evaluation techniques that are now emerging are needed to ensure that only materials with uniform, acceptable strength and toughness properties serve in critical applications, ref. 5.

Recent studies at Lewis Research Center have demonstrated significant empirical correlations between ultrasonic measurements, fracture toughness, and associated properties of polycrystalline materials, ref. 6. The correlations can be traced to microstructural factors that govern deformation and fracture and that influence ultrasonic stress waves accompanying these processes, ref. 7.

In this paper it will be shown that ultrasonic measurements may go beyond simply the characterization and prediction of mechanical properties. Ultrasonic techniques may, in fact, be used to corroborate and supplement metallurgical, metallographic, and fractographic data for identifying microstructural factors that govern fracture toughness and related properties. Accordingly, this paper has three primary purposes: First, to report empirical correlations between ultrasonic and fracture toughness factors for the two phase titanium alloy Ti-662. Second, to indicate that the empirical correlations reveal the role of an alpha-beta morphology in governing fracture toughness. Third, to show that the empirical correlations conform with a theoretically derived equation.

INTERRELATION OF MATERIAL MICROSTRUCTURE, ULTRASONIC FACTORS, AND FRACTURE TOUGHNESS OF A TWO PHASE TITANIUM ALLOY

By

Alex Vary and David R. Hull

National Aeronautics and Space Administration

Lewis Research Center

Cleveland, Ohio 44135

E-1151

ABSTRACT

This report illuminates the pivotal role of an alpha-beta phase microstructure in governing fracture toughness in a titanium alloy, Ti-662. The interrelation of microstructure and fracture toughness is demonstrated using ultrasonic measurement techniques originally developed for nondestructive evaluation and material property characterization. It is shown that the findings determined from ultrasonic measurements agree with conclusions based on metallurgical, metallographic, and fractographic observations concerning the importance of alpha-beta morphology in controlling fracture toughness in two phase titanium alloys.

INTRODUCTION

There are strong incentives for metallurgical synthesis (tailoring) of microstructures to combine high strength, tensile ductility, and fracture toughness in metals and other materials for advanced heat engines and structures, refs. 1, 2. These incentives prevail where high toughness is often achieved at the expense of high strength as in the case of titanium alloys used in aerospace components, ref. 3. To work around this constraint requires an understanding of factors that govern fracture toughness of titanium and other alloys destined for critical structural applications.

The authors gratefully acknowledge the cooperation and technical assistance given by G. D. Swanson and M. G. Ulitchny of the Kansas City Division of the Bendix Corporation and Dr. C. Hsieh now with Westinghouse Bettis Atomic Power Laboratory in obtaining and mechanically characterizing the material samples used in this study.

EXPERIMENTAL

Material Specimens

The material specimens in this study consisted of a two phase titanium alloy, Ti-6Al-6V-2Sn, that exhibited an alpha-beta Widmanstätten microstructure. The alloy was originally produced for a previous study of fracture behavior as a function of microstructure changes induced by a range of duplex heat treatments, ref. 8. The purpose of the previous study was to identify factors that limit or enhance fracture toughness in alpha-beta titanium alloys.

In the present study seven specimens of the Ti-662 alloy were examined both metallographically and ultrasonically. Each specimen represented a different heat treatment with a successively higher aging temperature. The anneal/age conditions and corresponding mechanical properties for the seven specimens are given in table I where it is seen, that increasing fracture toughness is accompanied by decreasing yield strength, ref. 9.

Each specimen used for ultrasonic and metallographic examinations was a pedigreed piece taken from the remains of a compact tension fracture toughness test specimen, as indicated in fig. 1. This was to ensure that ultrasonic and metallographic measurements were made on samples closely representing material that actually underwent fracture. Therefore, each piece was definitely associated with a known fracture toughness measurement. Each ultrasonic specimen was cut so that its thickness direction was parallel to the general direction of crack propagation in accordance with rules given in ref. 6. The ultrasonic specimens were 0.5 centimeters thick and 2 centimeters square.

Representative photomicrographs of the seven material samples at two magnifications appear in figs. 2(a) through 2(g). There are three distinct levels of microstructure, typified by the diagram in fig. 3: (1) a polygonal "grain" structure containing (2) a subgrain structure or "colonies" consisting of (3) alpha plateletes in a beta matrix. Mean representative dimensions measured by ASTM intercept methods, ref. 10, or by an image analyzer are given in table II for each level of microstructure in the seven specimens. The polygonal grain size is identical to the beta grain size prior to precipitation of the alpha-beta Widmanstätten substructure. The alloy chemistry for the Ti-662 specimens is given in table III.

Ultrasonic Measurements

Ultrasonic measurement methods that were used are desribed in refs. 6, 12, and 13. A block diagram of the ultrasonic signal acquisition and data processing system appears in fig. 4. As indicated in fig. 4, a broadband ultrasonic pulser-receiver evokes a series of back echoes in the material specimen. The first two of these echoes (B1 & B2) are digitized and analyzed by Fourier transformation. Resultant amplitude spectra of the two echoes are sufficient to derive a functional relation between attenuation coefficient, α, and frequency, f, where α is taken as (ref. 11),

$$\alpha = cf^{m} \tag{1}$$

The quantities c and m are constants that define the attenuation properties of the material specimens. These two material constants characterize the material microstructure over the frequency range of interest. This frequency range covers wavelengths for which Rayleigh scattering prevails, i.e., wavelengths greater than, or equal to a characteristic grain size, refs. 14, 15.

THEORETICAL

Putting α in the form of eq. (1) allows one to calculate the derivative,

$$\beta_\delta = \left.\frac{d\alpha}{df}\right|_{f_\delta} = mc\left(\frac{v_\ell}{\delta}\right)^{(m-1)} \qquad (2)$$

where, v_ℓ is longitudinal velocity in the material and $f_\delta = v_\ell/\delta$. The quantity δ is a characteristic or critical dimension of the micro-structural factor that governs the material fracture toughness (refs. 7, 8). When this quantity is used to determine β_δ, the empirical data should conform to the relation derived in ref. 7 between toughness and ultrasonically measured quantities,

$$(K_{Ic}/\sigma_y)^2 = M\,(v_\ell\beta_\delta/m)^{0.5} \qquad (3)$$

Here, K_{Ic} is plane strain fracture toughness and σ_y is 0.2 percent offset yield strength. Both these material properties are destructively measured, table I. The ratio $(K_{Ic}/\sigma_y)^2$ or "characteristic length" is an alternative index of fracture toughness, refs. 16, 17. This "characteristic length" corresponds to the radius of the plastic zone that develops just ahead of a critically stressed crack prior to catastrophic crack extension. The coefficient M in eq. (3) is an empirical constant for a given set of material specimens, i.e., all seven Ti-662 specimens in the present case. The quantity m is the exponent on f in eq. (1).

It will be shown that the relation in eq. (3) applies to the Ti-662 specimens provided that the critical microstructural feature is correctly identified and its dimension for each specimen is assigned to δ. In the case of the Ti-662 there are the three previously mentioned microstructural features: grains, colonies, and platelets (see fig. 3) each with its own characteristic dimension. The question to be answered is which of these features exerts the greatest influence on toughness while agreeing with the relation in eq. (3).

RESULTS

An example of computer documentation of attenuation and associated data for one of the Ti-662 specimens appears in fig. 5. Typical attenuation vs. frequency curves for the Ti-662 specimens appear in fig. 6 while table IV contains all the ultrasonically determined quantities needed to characterize the specimens for the purpose of this report, e.g., velocity v_ℓ, attenuation constants c and m, etc.

The question posed in the previous section can be answered by use of the material properties in table I, the microstructure dimensions in table II, and the ultrasonic measurements in table IV. Figs. 7(a) through 7(d) show correlations between the fracture toughness index $(K_{Ic}/\sigma_y)^2$ and the ultrasonic factor $v_\ell \beta_\delta / m$ based, in turn, on the grain, colony, alpha, and beta dimension given in table II. Each figure exhibits an empirical correlation that can, to a different degree, be used to rank the specimen materials according to fracture toughness. However, only the alpha and beta based correlations in figs. 7(c) and 7(d) exhibit strong trends.

The beta phase correlation in fig. 7(d) conforms best with the predicted relation, eq. (3). Using the beta phase thickness from table II to evaluate β_δ gives the regression analysis based relation,

$$(K_{Ic}/\sigma_y)^2 = 7.63\times10^{-4}\ (v_\ell\,\beta_\delta/m)^{0.56} \tag{4}$$

The exponent on $v_\ell\beta_\delta/m$ agrees closely with that in eq. (3) and the goodness-of-fit correlation coefficient for eq. (4) is 0.998. This suggests that the beta phase matrix has a primary role in governing fracture toughness. The correlation based on alpha platelet thickness in fig. 7(c) is also significant but the correlation coefficient is less than that for the beta correlation in fig. 7(d), i.e., 0.977 vs. 0.998.

These findings show that empirical correlations (e.g., eq. 4) will agree with the theoretically derived relation (eq. 3) based on the stress wave interaction concept (ref. 7 & DISCUSSION) provided microstructural factors critical to fracture toughness are identified.

DISCUSSION

Photo-optical and scanning electron techniques are standard tools for analyzing catastrophic crack growth and for inferring the roles of various microstructural factors during fracture. Photomicrographs of a set of material specimens when arranged in order of decreasing grain or phase boundary spacing may actually rank the materials according to fracture toughness. However, photomicrographs do not necessarily reveal which microstructural features influence toughness. The experimental results presented herein illustrate how ultrasonic measurements can supplement photo and electron-optical techniques and thus aid in identifying and characterizing microstructural factors governing fracture toughness.

Based on photomicroscopy and fractography, previous investigators have concluded that the alpha phase in Ti-662 and similar alloys is pivotal during fracturing. Their evidence indicates that alpha type, size, aspect ratio, distribution, and spacing are factors in determining fracture toughness, refs. 1,3. For example, acircular alpha platelets as opposed to equiaxed alpha have been associated with higher degrees of fracture toughness, ref. 2. It has also been observed that fracture toughness improves as the "mean free path" between primary alpha platelets decreases, ref. 3.

In Widmanstätten alpha-beta titanium alloys cracking often proceeds along the alpha-aged beta interface or grain boundary alpha. Alternatively, if the Widmanstätten alpha thickness is comparable to that of the grain boundary alpha, the crack path may alternate between the two types of alpha, ref. 1. Beta heat treatment tends to improve fracture toughness of alpha-beta alloys. This leads to a high incidence of crack deviation for intergranular fracture and to a combination of crack deviation and arrest for transgranular fracture, ref. 2.

The previous findings cited above confirm the pivotal nature of the alpha and beta phases in Ti-662 independently uncovered by the ultrasonic approach described herein. According to both metallographic and ultrasonic analyses, the best combinations of strength and fracture toughness occur in alpha-beta titanium alloys with very fine microstructures. The ultrasonic correlations differ in attributing somewhat more significance to the beta matrix phase as opposed to the alpha. This is not inconsistent with the observations of previous investigators concerning the importance of alpha platelets and the alpha-aged interface in governing fracture properties. Crack nucleation in the beta phase (inferrable from the data given herein) does not preclude the crack path trajectories relative to the alpha particles observed by previous investigators.

From the fractographic viewpoint greater crack tortuousness due to acircular alpha particles correlates with high fracture toughness. From the ultrasonic viewpoint smaller beta matrix thickness corresponds to higher attenuation and hence higher values for the toughness index. Clearly, these alpha-beta correlations are not mutually exclusive but represent complementary factors governing toughness.

Estimates of ultrasonic attenuation in the alpha and beta phases were made by measurements on representative sheet samples that approximated their chemistries. Attenuation in the beta sample was greater than in the alpha sample by a factor >10 in the stochastic regime, ref. 15, according to the estimates. It is inferred, therefore, that more stress wave energy would be absorbed in the beta phase given an identical alpha thickness. This tentative evidence suggests that the beta phase is more susceptible to crack nucleation due to stress wave interactions that induce dislocation motions and pile-ups. This is supported by the observation that the beta phase has significantly higher dislocation density than the alpha, ref. 8.

According to the stress wave interaction concept, spontaneous ultrasonic stress waves that arise during catastrophic crack growth actively promote a cascading of microcrack nucleation processes at the crack front. This wave interaction may be described in terms of Rayleigh and stochastic scatter attenuation. Stochastic scatter attenuation predominates where ultrasonic wavelengths are less than the scatterer size, refs. 14, 15. The scatterer may be a metallurgical phase, subgrain, or grain. The scatterer absorbs an increasingly higher proportion of the stress wave energy at the smaller wavelengths (higher ultrasonic frequencies). This energy loss reappears as dislocation motion and heat. The dislocation movements are assumed to lead to the nucleation and microcracking processes mentioned above. The experimental results presented herein confirm the predicted relation of eq. 3 which was derived from a theoretical model based on the stress wave interaction concept and the previously stated assumption (refs. 7, 11).

CONCLUSION

The potential of ultrasonic nondestructive material evaluation for verification and measurement of fracture toughness has been demonstrated. Herein, this was accomplished by showing the existence of strong correlations between ultrasonic attenuation factors and an index of fracture toughness for the two phase titanium alloy Ti-662. A metallurgical foundation for the correlations was discussed and it was indicated that the correlations conform with a theoretically predicted relation. Analysis of the ultrasonic results indicate that in addition to mechanical property evaluation, ultrasonic techniques can supplement metallurgical techniques for identifying microstructural factors that influence fracture toughness.

REFERENCES

1. M. A. Greenfield, C. M. Pierce, and J. A. Hall, "The Effect of Microstructure on the Control of Mechanical Properties in Alpha-Beta Titanium Alloys," Titanium Science and Technology, Volume 1, 1973, p. 1731-1743, Plenum Press, New York, N.Y.
2. D. H. Rogers, "The Effects of Microstructure and Composition of the Fracture Toughness of Titanium Alloys," ibid, p. 1719-1730.
3. H. Margolin, M. A. Greenfield, and I. Greenhut, "Yield Strength, Microstructure, and Fracture Toughness," ibid, p. 1709-1718.

4. "Rapid, Inexpensive Tests for Determining Fracture Toughness," NMAB-328, National Materials Advisory Board, National Research Council, National Academy of Sciences, Washington, D.C. (1976) (AD-A047934).

5. A. Vary, "Ultrasonic Measurement of Material Properties," Research Techniques in Nondestructive Testing, Volume IV, 1980, p. 159-204, Academic Press, London.

6. A. Vary, "Correlations Among Ultrasonic Propagation Factors and Fracture Toughness Properties of Metallic Materials," Materials Evaluation, Vol. 36, No. 7, June 1978, p. 55-64.

7. A. Vary, "Correlation Between Ultrasonic and Fracture Toughness Factors in Metallic Materials," Fracture Mechanics, ASTM STP 677, 1979, p. 563-578, American Society for Testing and Materials, Philadelphia, Pa.

8. M. G. Ulitchny, H. J. Rack, and D. B. Dawson, "Mechanical and Microstructural Properties Characterization of Heat-Treated Beta-Extruded Ti-6Al-6V-2Sn," Toughness and Fracture Behavior of Titanium, ASTM STP 651, 1978, p. 17-42, American Society for Testing and Materials, Philadelphia, Pa.

9. C. N. Freed, "A Comparison of Fracture Toughness Parameters for Titanium Alloys," Engineering Fracture Mechanics, Volume 1, 1968, p. 178-189, Pergamon Press, London.

10. 1973 Annual Book of ASTM Standards, Part 31, 1973, p. 422, American Society for Testing and Materials, Philadelphia, Pa.

11. A. Vary, "Concepts and Techniques for Ultrasonic Evaluation of Material Mechanical Properties," Mechanics of Nondestructive Testing, 1980, p. 123-1[illegible], Plenum Publishing, New York, N.Y.

12. A. Vary, "Computer Signal Processing for Ultrasonic Attenuation and Velocity Measurements for Material Property Characterization," Proceedings of the Twelfth Symposium on Nondestructive Evaluation, 1979, p. 33-46, American Society for Nondestructive Testing, Columbus, Oh.

13. E. P. Papadakis, "Ultrasonic Velocity and Attenuation Measurement Methods with Scientific and Industrial Applications," Physical Acoustics - Principles and Methods, Volume 12, 1976, p. 277-374, Academic Press, New York, N.Y.

14. S. Serabian, "Frequency and Grain Size Dependency of Ultrasonic Attenuation in Polycrystalline Materials," British Journal of Non-Destructive Testing, Vol. 22, No. 2, 1980, p. 69-77.

15. K. Goebbles, "Structure Analysis By Scattered Ultrasonic Radiation," Research Techniques in Nondestructive Testing, Volume 4, 1980, p. 87-157, Academic Press, London.

16. G. T. Hahn, M. F. Kanninen, and A. R. Rosenfeld, "Fracture Toughness of Materials," Annual Reviews of Materials Science, 1972, p. 381-404, Annual Reviews, Inc., Palo Alto, Ca.

17. R. W. Hertzberg, Deformation and Fracture Mechanics of Engineering Materials, 1976, p. 270-277, John Wiley a Sons, New York, N.Y.

TABLE I. - ROOM TEMPERATURE MECHANICAL PROPERTY CHARACTERISTICS

Specimen[a]	Aging temperature,[b] K	Hardness HRC[c]	Hardness HKN[d]	Yield strength,[e] σ_y, MPa	Fracture toughness,[f] K_{Ic}, $MPa\sqrt{m}$	Characteristic length factor (g), $(K_{Ic}/\sigma_y)^2$ mm
89	673	44	440	1170	34.7	0.88
91	723	45	420	1138	39.2	1.19
93	773	43	390	1150	47.9	1.73
95	823	42	381	1103	60.0	2.96
97	873	40	372	1048	70.4	4.51
109	923	37	337	931	81.4	7.64
111	973	35	322	870	90.5	10.8

[a]Density of each specimen was 4.52 gm/cc.

[b]All specimens solution treated at 1123 K for 1 hour, water quenched, aged 8 hours, and air cooled.

[c]Rockwell "C" hardness, average of 3 measurements.

[d]Knoop hardness, 500 gram load, average of 9 measurements.

[e]Yield strength measured at 0.2 percent elongation, ASTM E8-69.

[f]Plain strain, all tests valid per ASTM E399-74.

[g]Characteristic length factor, an alternative index of fracture toughness, refs. 16 and 17.

TABLE II. - DIMENSIONS OF MICROSTRUCTURAL FEATURES

Specimen	Prior beta[a] grain size, μm	Colony[b] size, μm	Alpha platelet[c] thickness, μm	Beta matrix[d] thickness, μm
89	213	56	0.87	0.98
91	220	59	0.75	0.86
93	289	54	0.88	0.98
95	229	47	0.73	0.73
97	210	57	0.72	0.70
109	226	58	0.84	0.56
111	201	53	1.08	0.57

[a]Mean size of polygonal grains measured by ASTM intercept method, ref. 10.

[b]Mean size of colony within grains measured by ASTM intercept method, ref. 10.

[c]Mean thickness of alpha platelet measured by image analyzer.

[d]Mean thickness of beta matrix measured by image analyzer.

TABLE III. - CHEMICAL ANALYSIS OF Ti-6Al-6V-2Sn MASTER HEAT

Element	Ti	Al	V	Sn	Cu	Fe	O_2	C	N_2
Weight percent	balance	5.8	5.8	2.1	0.77	0.75	0.15	0.02	0.01

TABLE IV. - ULTRASONIC CHARACTERISTICS OF Ti-6Al-6V-2Sn SPECIMENS

Specimen	Velocity[a] v_ℓ, cm/μs	Attenuation[b] parameters, $c\times10^6$	m	Attenuation factors[c] β_δ, μs/cm	$(v_\ell\ \beta_\delta/m)$
89	0.610	237.5	2.06	4.96	1.47
91	0.612	161.6	2.12	6.70	1.92
93	0.612	106.7	2.26	14.9	3.99
95	0.612	89.9	2.37	46.9	12.1
97	0.610	35.1	2.54	107.	24.3
109	0.609	31.3	2.62	271.	62.6
111	0.607	16.0	2.75	477.	105.

[a]Longitudinal wave velocity was measured at a center frequency of approximately 50 MHz.

[b]Attenuation versus frequency characteristic curve parameters, where $\alpha = cf^m$ (see Eq. (1)).

[c]Attenuation factor, $\beta_\delta = mc(v_\ell/\delta)^{m-1}$, δ = beta matrix thickness (see Eq. (2)).

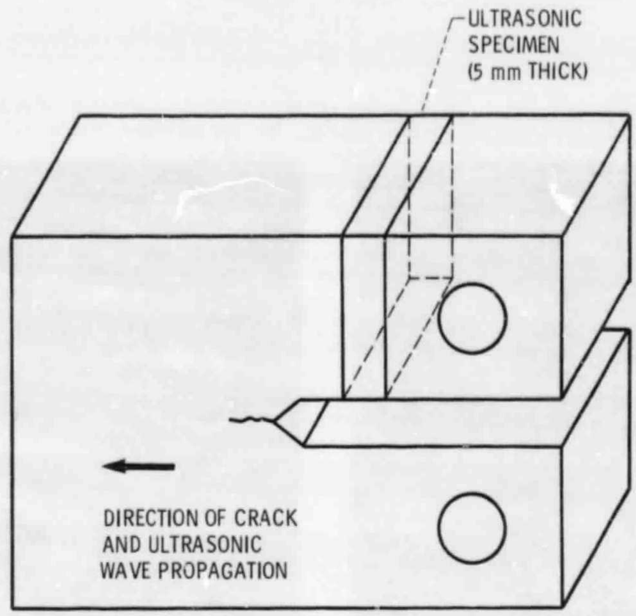
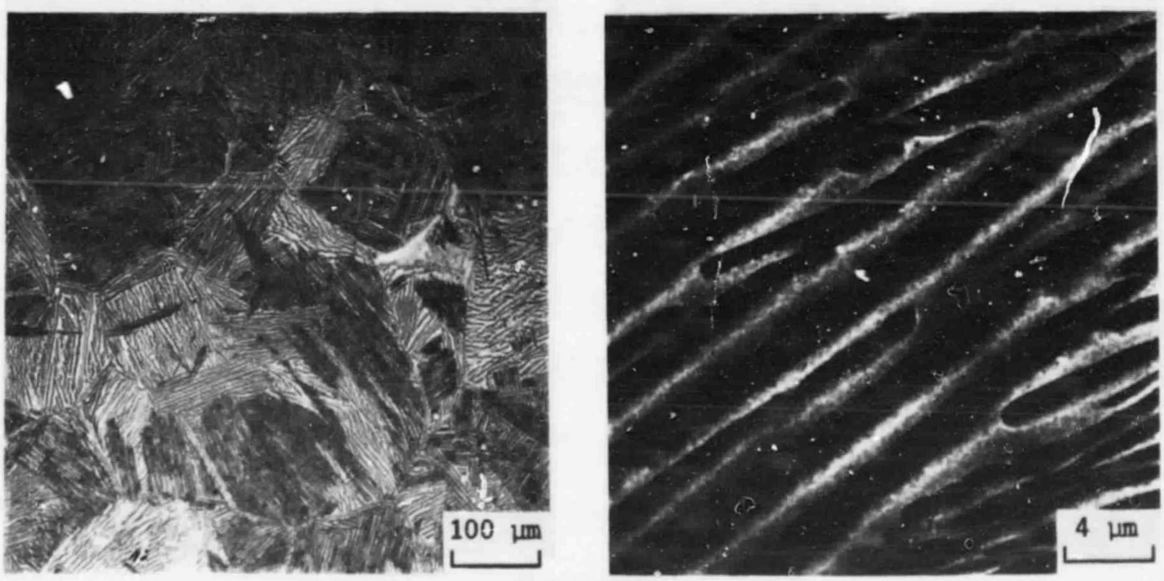
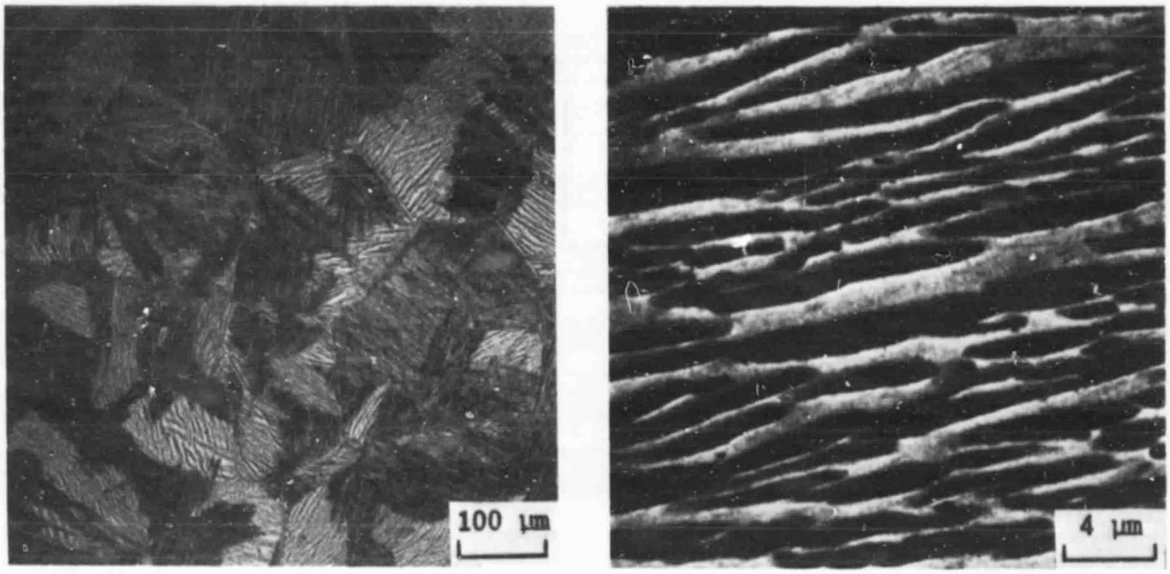


Figure 1. - Excision of ultrasonic specimen from compact tension fracture toughness specimen.

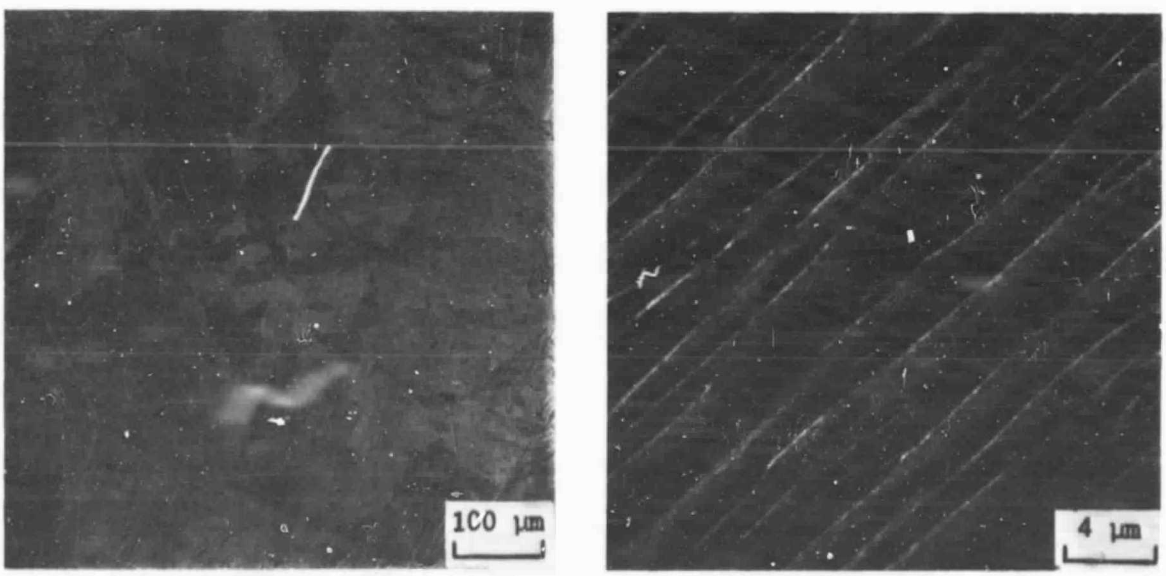


(a) SPECIMEN 89.

Figure 2. - Representative photomicrographs of Ti-6Al-6V-2Sn specimens. Original magnifications were X120 (left) and X3000 (right). Optical photomicrographs (left) illustrate the equiaxed prior beta grains outlined by a continuous layer of primary alpha. Scanning electron photomicrographs (right) detail the interior structure of the grains revealing the Widmanstätten alpha (black) separated by the beta matrix (white).
Etchant: Kroll's reagent (15 HF + 30 HNO_3 + 50 H_2O).

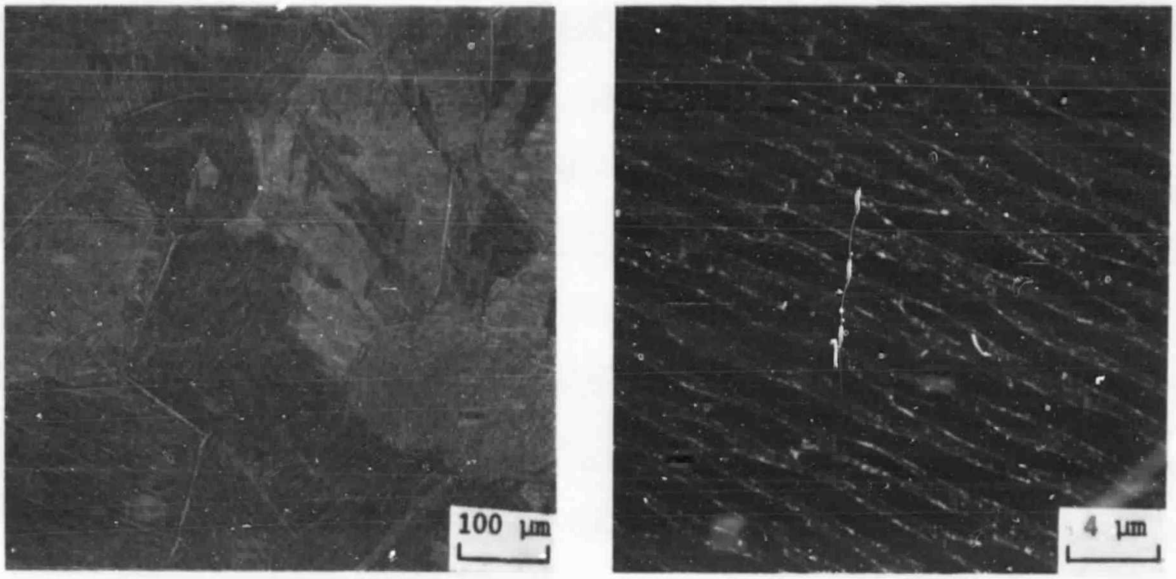


(b) SPECIMEN 91.

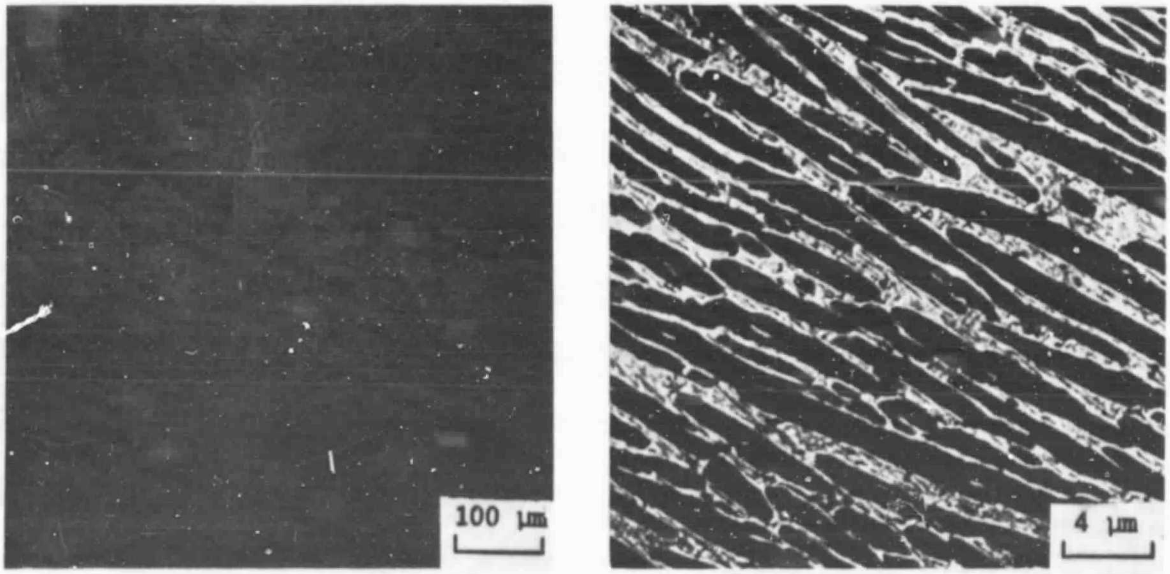


(c) SPECIMEN 93.

Figure 2. Continued.

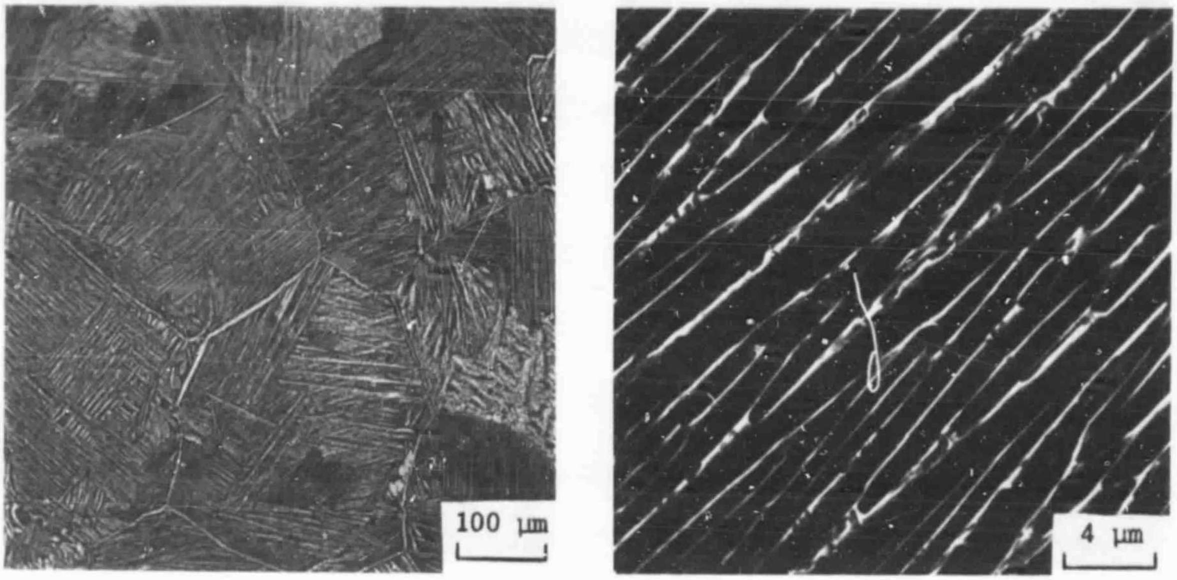


(d) SPECIMEN 95.

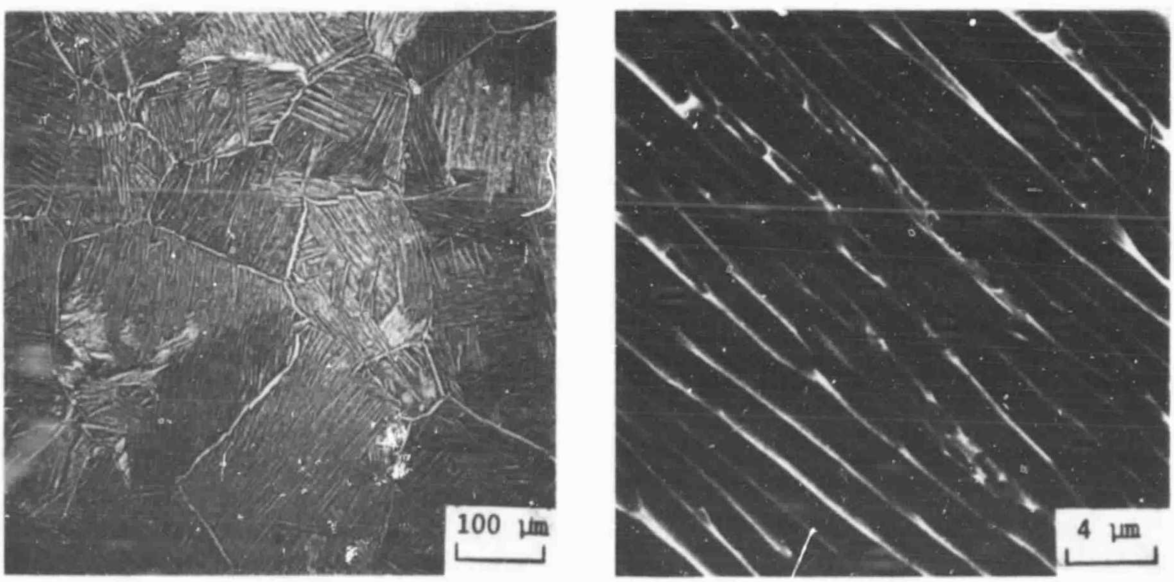


(e) SPECIMEN 97.

Figure 2. - Continued.



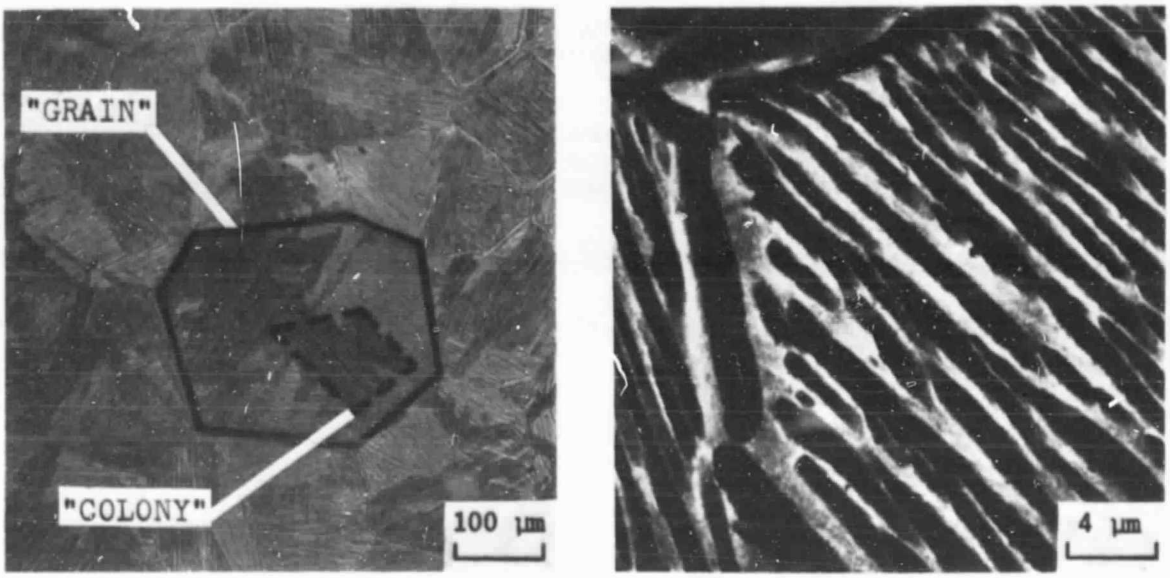
(f) SPECIMEN 109.



(g) SPECIMEN 111.

Figure 2. - Concluded.

ORIGINAL PAGE IS
OF POOR QUALITY



(a) Typical grain/subgrain structure.

(b) Typical Widmanstätten substructure.

Figure 3. - Identification of three distinct levels of microstructure. (a) Optical photomicrograph illustrates a polygonal "grain" containing a subgrain structure, "colony", which in turn consists of alpha "platelets" in a beta matrix. (b) Scanning electron photomicrograph detailing Widmanstätten alpha (black) in the beta matrix (white).

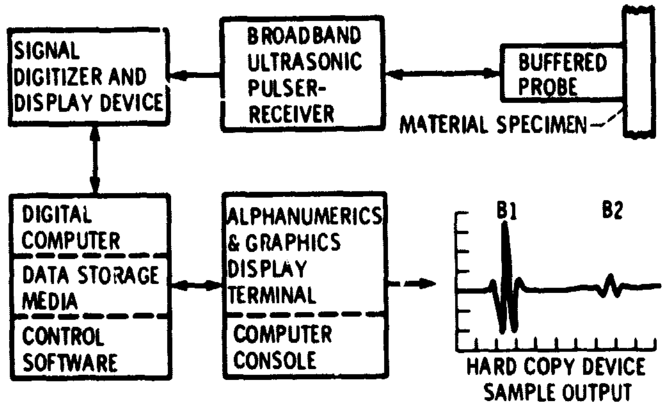


Figure 4. - Block diagram of computer system for ultrasonic signal acquisition and processing for pulse-echo velocity and attenuation measurement. Details of the computer system are described in ref. 12.

DATE: 14-DEC-81 (10: 16: 12) ATTENUATION VS FREQUENCY CURVE, 'AFC'

SPECIMEN: 95
MATERIAL: TI 662

THICKNESS (ST) = .5014 CM
DENSITY (DN) = 4.521 G/CC
GRAIN SIZE (GS) = .73 UM

VELOCITY (VL) = .612469 CM/US
CENTER FREQUENCY (CF) = 38 MHZ

ARC PARAMETERS:
LOW LIMIT = 38 MHZ
(RCV) = .306423
(M) = 2.4
(C) = 6.30446E-05
(FIT) = .999975

AFC PARAMETERS:
(BA) = .0426643
(BD) = 47.1112
(VLX BD) = 28.8541
(VLX BD)/(M) = 12.0226

TRANSDUCER = 50 MHZ
TYPE: LONGITUDINAL
COUPLANT: GLYCERINE
PULSER RECEIVER: 75 MHZ

NOTES: TYPICAL DATA FILE: TEMP. D04

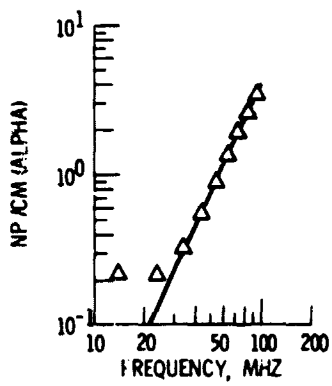


Figure 5. - Sample computer documentation of an attenuation measurement and associated data for Ti-6Al-6V-2Sn specimen 95. Details of the attenuation and velocity measurements are described in refs. 6, 7, and 12. Triangles represent raw data, solid line is the attenuation curve corrected for diffraction effects seen at the low frequencies.

ORIGINAL PAGE IS
OF POOR QUALITY

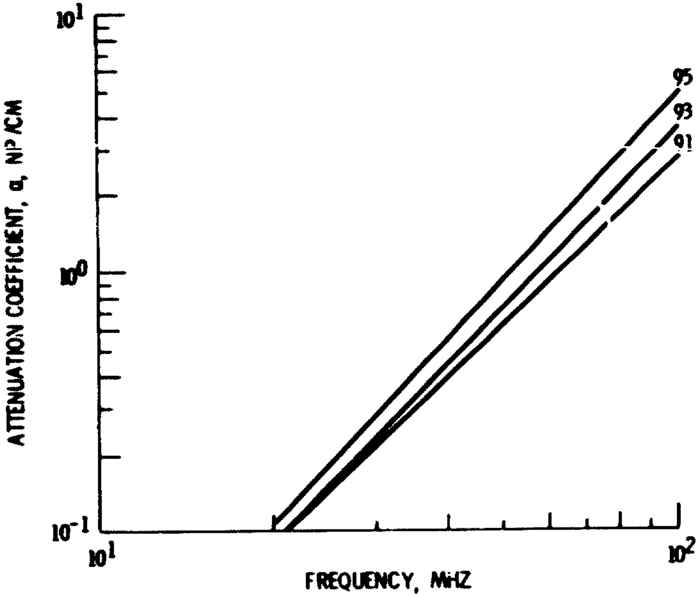
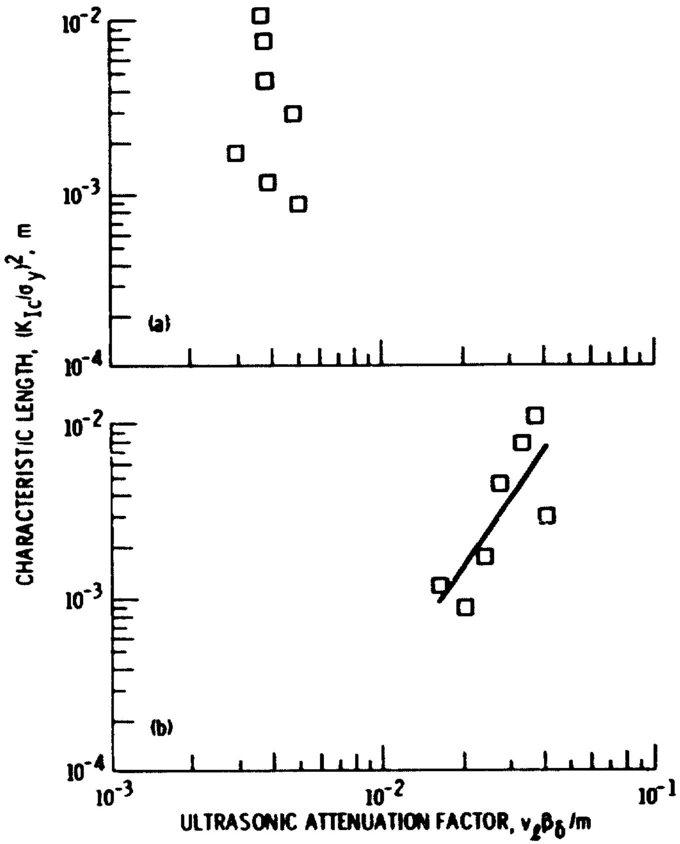


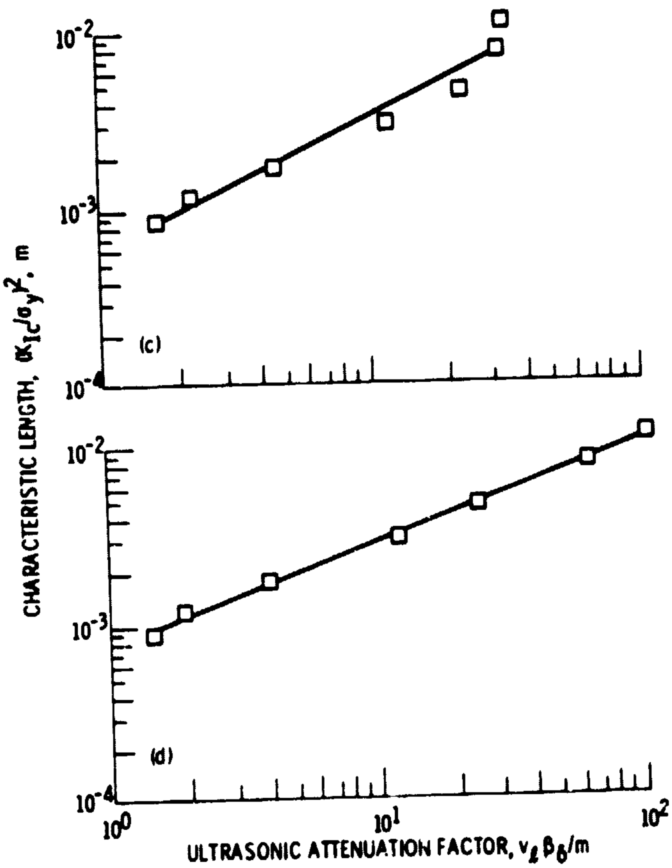
Figure 6. - Attenuation coefficient versus frequency curves for three typical Ti-6Al-6V-2Sn specimens: 91, 93, and 95. Linear regression was used to calculate c and m values for the equation, $\alpha = cf^m$. The values, c and m, are given in table IV for all seven specimens.



(a) δ - Prior beta grain size. (Equation indeterminate) Correlation of coefficient - -0.291.

(b) δ - Colony size. $(K_{Ic}/\sigma_y)^2 = 10.9\,(v_\ell\beta_\delta/m)^{2.27}$. Correlation of coefficient - 0.788.

Figure 7. - Correlation of ultrasonic attenuation factor, $v_\ell\beta_\delta/m$, and fracture toughness characteristic length factor, $(K_{Ic}/\sigma_y)^2$, for Ti-6Al-6V-2Sn. The quantity, β_δ, as defined in eq. (2), was calculated for four microstructural dimensions: (a) prior beta grain size, (b) colony size, (c) alpha platelet thickness and (d) beta matrix thickness. Theory (ref. 7) predicts that the correlation should be; $(K_{Ic}/\sigma_y)^2 = M(v_\ell\beta_\delta/m)^{0.5}$, where M is an empirical constant for a given set of specimens. For (a) the equation is indeterminate because of the low correlation coefficient. The best correlation and agreement with the predicted equation occurs for (d) the beta matrix thickness.



(c) δ - Alpha platelet. $(K_{Ic}/\sigma_y)^2 = 5.91\times10^{-4}\,(v_\ell\beta_\delta/m)^{0.73}$. Correlation of coefficient = 0.977.

(d) δ - Beta matrix. $(K_{Ic}/\sigma_y)^2 = 7.63\times10^{-4}\,(v_\ell\beta_\delta/m)^{0.56}$. Correlation of coefficient = 0.998.

Figure 7. - Concluded.

ORIGINAL PAGE IS
OF POOR QUALITY

1. Report No. NASA TM-82810	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle INTERRELATION OF MATERIAL MICROSTRUCTURE, ULTRASONIC FACTORS, AND FRACTURE TOUGHNESS OF A TWO PHASE TITANIUM ALLOY		5. Report Date 6. Performing Organization Code 505-33-22
7. Author(s) Alex Vary and David R. Hull		8. Performing Organization Report No. E-1151 10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No. 13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes Prepared for the Spring Conference of the American Society for Nondestructive Testing, Boston, Massachusetts, March 22-25, 1982.		

16. Abstract

This report illuminates the pivotal role of an alpha-beta phase microstructure in governing fracture toughness in a titanium alloy, Ti-662. The interrelation of microstructure and fracture toughness is demonstrated using ultrasonic measurement techniques originally developed for nondestructive evaluation and material property characterization. It is shown that the findings determined from ultrasonic measurements agree with conclusions based on metallurgical, metallographic, and fractographic observations concerning the importance of alpha-beta morphology in controlling fracture toughness in two phase titanium alloys.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Ultrasonics; Nondestructive testing; Fracture toughness; Metals; Microstructure	Unclassified - unlimited STAR Category 38

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161