NASA Contractor Report 3179

Ultrasonic Attenuation as an Indicator of Fatigue Life of Graphite/Epoxy Fiber Composite

James H. Williams, Jr., and Beth Doll

GRANT NSG-3210
DECEMBER 1979

NASA

NASA Contractor Report 3179

Ultrasonic Attenuation as an Indicator of Fatigue Life of Graphite/Epoxy Fiber Composite

James H. Williams, Jr., and Beth Doll
Massachusetts Institute of Technology
Cambridge, Massachusetts

Prepared for
Lewis Research Center
under Grant NSG-3210

NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1979

INTRODUCTION

Microscopic imperfections in graphite fiber epoxy composites may be introduced during both fabrication and service. The tendency of graphite fiber composites to fail in a quasi-brittle mode (as defined by the absence of a substantial nonlinear region in the stress-strain curve) makes these composites more sensitive than many metals to microscopic imperfections. In fatigue, failure has been described as being "like sudden death; that is, the fatigue failure occurs without any visible evidence of damage" [1]. Thus, any means of nondestructively monitoring fatigue damage or predicting fatigue behavior of graphite fiber composites is likely to enhance their effective use. The purpose of this report is to present the results of an experimental study to investigate the ultrasonic attenuation and velocity as a function of the fatigue state of a graphite fiber composite subjected to transfiber compression-compression loading.

Fatigue of Composites

Papers on fatigue of composites deal with a broad range of topics including damage initiation and growth [2-5]; and the effects on fatigue behavior of holes [5-8], loading frequency [6], notches [7,9-12], environment [6,13-15], compression loading [9,16,17], compression load excursion [18], and fabrication [19-22].

The majority of fatigue research has been on tension-tension fatigue of fiber-controlled specimens. However, in an attempt to develop a fatigue failure theory, Sims and Brodon [23] dealt specifically with situations in which the matrix contributes significantly to fatigue strength. Also, Hashin and Rotem [24] proposed a fatigue failure criterion which in part is expressed in terms of data obtained by fatiguing off-axis unidirectional specimens. Bevan [8] found that $[\pm 45/\pm 45/0/0]_s$ graphite epoxy laminates in compression or tension fatigue sustained 80% of their static strength for 10^6 cycles while $[\pm 45/\pm 45/90/90]_s$ laminates sustained only about 60% of their static strength for 10^6 cycles. He concluded that this percentage difference was due to the matrix - controlled failure of the latter laminates. Other attempts to relate static and fatigue strengths include investigations by Ryder and Walker [18] who noted that residual static strength degraded rapidly due to fatigue cycling; Awerbuch and Hahn [1] who observed that static strength decreased rapidly immediately before fatigue failure in unidirectional graphite epoxy composites; and Porter [25] who found that for a range of flaw types, there exists a relationship between initial static strength and fatigue strength.

NDE of Fatigue Damage and Ultrasonics in Composites

Adams et al. [26-29] have stated that changes in lower structural natural frequencies can be used to locate and roughly quantify damage. Also, Schultz and Warwick [30] found a correlation between the amount of fatigue damage and the imaginary part of the composite complex modulus. On the other hand, by observing changes in dynamic mechanical properties, Nielsen [31] was not able to detect fatigue damage in various filled polymers.

Based on the hypothesis that wave propagation efficiency is affected by microstructure and microflaws, Vary et al. [32-34] have proposed an ultrasonic quantity called the stress wave factor which has been positively correlated with the tensile strength and the interlaminar shear strength of graphite fiber composites. In testing graphite fiber polyimide composites, Hayford et al. [35] correlated the initial attenuation and the shear strength.

To our knowledge, there has been no work reported on the relationship between ultrasonic parameters and the fatigue state of fiber reinforced composites. In fact, very little has been done in this area for any material. Truell and Hikata [36] monitored attenuation changes as a function of the number of fatigue cycles on various aluminum alloys. They concluded that the form of the attenuation-fatigue cycles curve depended on the magnitude of the stress, the cyclic frequency, and the mode of loading. Unfortunately, there was no apparent attempt to correlate the attenuation with the S-N curves of the various alloys. However, they were able to deduce some general trends, the primary observation being that an increase in attenuation always occurred prior to cyclic failure. The point at which this increased attenuation occurred varied from 30% to approximately 100% of the failure cycles.

EXPERIMENTS

Material

The specimens were unidirectional Hercules AS/3501-6 graphite fiber epoxy composites. In order to introduce a range in the properties of the specimens, two laminates were fabricated with slightly different procedures. The Hercules fabrication specifications [37] prescribe the following temperatures: (1) a precure temperature of 135°C during which pressure is applied; (2) a cure temperature of 177°C; and (3) a postcure temperature of 177°C with no pressure. One laminate (No. 1) was fabricated according to these specifications with the single exception that the precure temperature was 149°C, 14°C higher than the specified temperature. A second laminate (No. 2) was fabricated exactly in accordance with the specifications.

Attenuation, Velocity and Fatigue Tests

The experiments consisted of alternately compression-compression (C-C) fatiguing specimens and measuring their narrow band longitudinal wave group velocity and attenuation properties. The velocity and attenuation measurements were typically made at intervals of 3×10^4 fatigue cycles. The specimens are sketched in Fig. 1 where the principal directions are indicated. The attenuation and velocity measurements were recorded at four narrow band center frequencies: 0.5 MHz, 1.0 MHz, 1.5 MHz and 2.0 MHz.

The specimens were subjected to sinusoidal compression-compression fatigue along the x_2 direction with a peak-to-peak stress amplitude of σ_{max} to $\frac{\sigma_{max}}{2}$. Tests were conducted for σ_{max} at $0.2\sigma_f$, $0.4\sigma_f$, $0.6\sigma_f$ and $0.8\sigma_f$ where σ_f was the prefatigued static compressive fracture stress. The value of σ_f used in computing the fatigue stress levels always corresponded to the value of σ_f for the laminate from which the specimen was machined. All tests were conducted at a loading frequency of 30 Hz.

Equipment

A schematic of the through-transmission attenuation and velocity measuring experimental system is shown in Fig. 2.† The transducers were Acoustic Emission Technology (AET) FC-500 transducers and the couplant was AET SC-6 resin. The peak-to-peak input voltage was 100 volts. A pressure of 2.5×10^5 N/m^2 (36 psi) was applied to the transducer-specimen interface. As reported in [38], this pressure exceeded the "saturation pressure", which is defined as the minimum transducer-specimen interface pressure which results in the maximum output signal amplitude, all other parameters being held constant. The compression fatigue testing was conducted on a Baldwin Model SF-1U Universal Fatigue Machine.

†More details of this system are given in [38].

RESULTS AND DISCUSSION

Laminate No. 1, as identified above, had a prefatigued static compressive fracture stress of 145 MN/m^2 and laminate No. 2 had a prefatigued static compressive fracture stress of 180 MN/m^2. Thus, the 14°C change in the precure temperature produced a significant effect on the prefatigued static compressive fracture stress.

Nine specimens were randomly selected from laminate No. 1 and three each were tested at $0.2\sigma_f$, $0.4\sigma_f$ and $0.6\sigma_f$, respectively. The group velocity was frequency-independent and was substantially the same for all the specimens (2.4×10^3 m/sec, whereas the attenuation was frequency-dependent and varied significantly (to be discussed below) from specimen to specimen. Despite these differences, no change in either the attenuation or the group velocity of individual specimens was revealed up to 10^6 cycles where the tests were discontinued. Also, no fatigue fractures occurred and no material degradation was visible under microscopic examination.

Twelve additional specimens from laminate No. 1 and three specimens from laminate No. 2 were randomly selected and tested at $0.8\sigma_f$. As in the tests described above, the group velocity again remained constant at 2.4×10^3 m/sec. In general, the attenuation of individual specimens at the four monitored frequencies increased by 5% to 10% of their respective prefatigued values which is defined as "initial attenuation". This increase in attenuation, which tended to be larger for specimens with higher initial attenuation, often occurred within the first 50% of the fatigue life; however, no distinct trend was observed. Fig. 3 is a plot of the attenuation at 2.0 MHz versus fatigue cycles for the specimens from laminate No. 1. Attenuation versus fatigue cycles curves for 0.5 MHz, 1.0 MHz and 1.5 MHz display similar trends and are given in [39]. It appears from these curves that the changes in attenuation do not provide a precursor of fracture.

The initial attenuation, cycles to fatigue fracture, static fracture stress and fabrication data for specimens tested at $0.8\sigma_f$ are summarized in the Table below. For laminate No. 1 the specimens are ordered in accordance with the number of fatigue cycles to fracture. None of the specimens from laminate No. 2 failed where in accordance with [9], the fatigue limit was defined as 5×10^6 cycles. (However, as noted in the Table, one of the specimens was returned to the fatigue machine and subsequently failed at 30.2×10^6 cycles.) In addition to the difference in σ_f for laminates No. 1 and No. 2 cited earlier, the differences in the initial attenuation values for the two laminates are considerable.

The inverse relationship between prefatigued fracture stress and initial attenuation described in [35] is consistent with the data in the Table. Further, there appears to be a correlation between initial attenuation and cycles to fracture. And, the correlation improves with increasing wave frequency. At ultrasonic frequencies of 1.5 MHz and 2.0 MHz, there appear to be "upper cutoff" initial attenuation values (~5.8 neper/cm at 1.5 MHz and

~9.4 neper/cm at 2.0 MHz), above which failure occurred either during the static preload or before the dynamic load had reached its steady-state value during the acceleration period (~2000 cycles) of the fatigue loading. The "upper cut-off" value of ~9.4 neper/cm is apparent in Fig. 4 where the initial attenuation at 2 MHz versus cycles to failure for specimens from laminate No. 1 only is plotted. The initial attenuation at 2 MHz versus cycles to failure for specimens from laminates No. 1 and 2 is plotted in Fig. 5. Fig. 5 further suggests the existence of a "lower cut-off" value of attenuation, below which specimens may be screened for survival to the fatigue limit.

CONCLUSIONS

Hercules AS/3501-6 graphite fiber epoxy composites were alternately compression-compression fatigued and monitored using ultrasonic longitudinal waves. A small change (14°C) in the pre-cure temperature resulted in significant changes in the prefatigued static compressive fracture stress σ_f, the initial attenuation and the number of cycles to failure at $\sigma_{max} = 0.8\sigma_f$. The correlation between prefatigued static fracture stress and initial attenuation found in [35] is supported by the data obtained here. No changes in attenuation or velocity as well as no fatigue fractures occurred for specimens fatigued to 10^6 cycles at maximum stress levels at or below $0.6\sigma_f$.

During C-C fatigue when $\sigma_{max} = 0.8\sigma_f$, there is generally a 5% to 10% increase in attenuation; however, this increase does not appear to be a fracture precursor. It is important to note that the attenuation measurements were intermittent at about 3×10^4 cycle intervals and that the possibility of an attenuation precursor within a few cycles of failure cannot be discounted. The initial attenuation at 1.5 MHz and 2.0 MHz appears to be a good indicator of the relative survivability in the fatigue environment. There appear to be ultrasonic frequency-dependent "upper cut-off" attenuation values which define a minimal fatigue life and "lower cut-off" attenuation values which define a fatigue life limit.

REFERENCES

1. Johnathon Awerbuch and H. T. Hahn, "Fatigue and Proof-Testing of Unidirectional Graphite Epoxy Composites", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 248-266.

2. D. P. Kendall, "Mechanisms of Fatigue Crack Growth in Boron Aluminum Laminates", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 47-56.

3. B. Harris, "Fatigue and Accumulation of Damage in Reinforced Plastics", Composites, Vol. 8, No. 4, October 1977, pp. 214-220.

4. E. W. Smith and K. J. Pascoe, "The Role of Shear Deformation in the Fatigue Failure of a Glass-Fibre Reinforced Composite", Composites, Vol. 8, No. 4, October 1977, pp. 214-220.

5. G. L. Roderick and K. D. Whitcomb, "Fatigue Damage of Notched Boron Epoxy Laminates under Constant Amplitude Loading", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 73-88.

6. K. L. Reifsnider, W. W. Stinchcomb, and T. K. O'Brien, "Frequency Effects on a Stiffness-Based Fatigue Failure Criterion in Flawed Composite Specimens", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 171-184.

7. J. B. Sturgeon, "Fatigue of Multi-directional Carbon Fiber-Reinforced Plastics", Composites, Vol. 8, No. 4, October 1977, pp. 221-226.

8. L. G. Bevan, "Axial and Short Beam Shear Fatigue Properties of CFRP laminates", Composites, Vol. 8, No. 4, October 1977, pp. 227-232.

9. S. V. Ramani and D. P. Williams, "Notched and Unnotched Fatigue Behavior of Angle-Ply Graphite Epoxy Composites", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 27-46.

10. S. V. Kulkarni, P. V. McLaughlin, Jr., R. B. Pipes, and B. W. Rosen, "Fatigue of Notched Fiber Composite Laminates: Analytical and Experimental Evaluation", Composite Materials: Testing and Design (Fourth Conference), ASTM STP 617, American Society for Testing and Materials, 1976.

11. R. Papirno, "Fatigue Fracture Initiation in Notched Graphite-Epoxy Specimens", Journal of Composite Materials, Vol. 10 January 1977, pp. 41-50.

12. W. S. Carswell, "Fatigue Damage in Notched Composites", Composites, Vol. 8, No. 4, October 1977, pp. 251-254.

13. K. E. Hofer, Jr., L. C. Bennett, and M. Stander, "Effects of Moisture and Fatigue on the Residual Mechanical Properties of S-Glass Graphite Epoxy Hybrid Composites", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 103-122.

14. G. P. Sendeckyj, H. K. Stalnaker, and R. A. Kleismit, "Effects of Temperature on Fatigue Response of Surface Notched $[(0/\pm 45/0)_s]_3$ Graphite Epoxy Laminate", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 123-140.

15. M. B. Kasen, R. E. Schramm, and D. T. Read, "Fatigue of Composites at Cryogenic Temperatures", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 141-151.

16. D. Schütz and J. J. Genharz, "Fatigue Strength of a Fiber-Reinforced Material," Composites, Vol. 8, No. 4, October 1977, pp. 245-250.

17. R. W. Walter, R. W. Johnson, R. R. June, J. E. McCarthy, "Designing for Integrity in Long Life Composite Aircraft Structures", Fatigue of Filamentary Composite Materials, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 228-247.

18. J. T. Ryder and E. K. Walker, Effect of Compression on Fatigue Properties of a Quasi-Isotropic Graphite Epoxy Composite", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 3-26.

19. R. L. Mehan, "Fabrication and Mechanical Properties of Sapphire Whisler-Aluminum Composites", Journal of Composite Materials, Vol. 4, January 1970, pp. 90-101.

20. J. R. Eisenmann, B. E. Kaminski, D. L. Reed, and D. J. Wilkins, "Toward Reliable Composites: An Examination of Design Methodology", Journal of Composite Materials, Vol. 7, July 1973, pp. 298-308.

21. S. J. Harris and R. E. Lee, "Effect of Fibre Spacing on the Fatigue Behavior of Metal Matrix Composites", Composites, Vol. 5, No. 2, March 1974, pp. 101-106.

22. C. T. Sun and G. L. Roderick, "Improvement of Fatigue Life of Boron Epoxy Laminates by Heat Treatment Under Load", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 89-102.

23. D. F. Sims and V. H. Brodon, "Fatigue Behavior of Composites Under Different Loading Modes", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 185-205.

24. Z. Hashin and A. Rotem, "A Fatigue Failure Criterion for Fiber Reinforced Materials", Journal of Composite Materials, Vol. 7, October 1973, pp. 448-464.

25. T. R. Porter, "Evaluation of Flawed Composite Structure Under Static and Cyclic Loading", Fatigue of Filamentary Composite Materials, ASTM STP 636, K. L. Reifsnider and K. N. Lauraitis, Eds., American Society for Testing and Materials, 1977, pp. 152-170.

26. R. D. Adams, D. Walton, J. E. Flitcroft, and D. Short, "Vibration Testing as a Non-Destructive Test Tool for Composite Materials", Composite Reliability, ASTM STP 580, American Society for Testing and Materials, 1975, pp. 159-175.

27. R. D. Adams, P. Cawley, C. J. Pye and B. J. Stone, "A Vibration Technique for Non-Destructively Assessing the Integrity of Structures:, Journal of Mechanical Engineering Science, Vol. 20 1978, pp. 93-100.

28. P. Cawley and R. D. Adams, "The Location of Defects in Structures from Measurements of Natural Frequencies" (Submitted to Journal of Strain Analysis).

29. P. Cawley and R. D. Adams, "A Vibration Technique for Non-Destructive Testing of Fiber Composite Structures", Journal of Composite Materials, Vol. 13, April 1979, pp. 161-173.

30. A. B. Schultz and David N. Warwick, "Vibration Response: A Non-Destructive Test for Fatigue Crack Damage in Filament-Reinforced Composites", Journal of Composite Materials, Vol. 5, July 1971, pp. 394-404.

31. L. E. Nielsen, "Fatigue Behavior of Some Filled Polymers", Journal of Composite Materials, Vol. 5, April 1975, pp. 149-156.

32. A. Vary and K. J. Bowles, "Ultrasonic Evaluation of the Strength of Unidirectional Graphite Polyimide Composites", NASA TM X-73646, April 1977.

33. A. Vary and K. J. Bowles, "Use of an Ultrasonic-Acoustic Technique for Nondestructive Evaluation for Fiber Composite Strength," NASA TM-73813, February 1978.

34. A. Vary and R. F. Lark, "Correlation of Fiber Composite Tensile Strength with the Ultrasonic Stress Wave Factor", NASA TM-78846, April 1978.

35. D. T. Hayford, E. G. Henneke, II, and W. W. Stinchcomb, "The Correlation of Ultrasonic Attenuation and Shear Strength in Graphite Polyimide Composites", Journal of Composite Materials, Vol. 11, October 1977, pp. 429-444.

36. R. Truell and A. Hikata, "Fatigue and Ultrasonic Attenuation", Symposium on Nondestructive Testing, ASTM STP 213, American Society for Testing Materials, 1957, pp. 63-69.

37. Hercules Incorporated Systems Group, "Preparation of Laminate Test Specimens from Graphite Prepreg", HD-SG-2-6005C, September 15, 1976.

38. James H. Williams, Jr., Hamid Nayeb-Hashemi, and Samson S. Lee, "Ultrasonic Attenuation and Velocity in AS/3501-6 Graphite/Epoxy Fiber Composite," NASA CR-3180, 1979.

39. B. Doll, "Ultrasonic Attenuation as a Method of Nondestructive Evaluation of Graphite Epoxy Composites Undergoing Compression-Compression Fatigue", S.B. Thesis, Department of Mechanical Engineering, M.I.T., May 1979.

TABLE Summary of Initial Attenuation, Fatigue, Static Fracture Stress, and Fabrication Data for Specimens Tested in C-C Fatigue at $0.8\sigma_f$

	Specimen Number	Initial Attenuation (neper/cm) 0.5 MHz	1.0 MHz	1.5 MHz	2.0 MHz	C-C Cycles to Fracture @ $\sigma_{max} = 0.8\sigma_f$ (10^4 Cycles)	Prefatigued Static Compressive Fracture Stress σ_f	Fabrication Procedure
Laminate No. 1	101	1.62	3.47	7.37	11.42	0	$\sigma_f = 145 \frac{MN}{m^2}$ (21,000 psi)	Laminate fabricated in accordance with [37] except the precure temperature was 149°C (300°F) instead of the specified temperature 135°C (275°F).
	102	1.53	2.91	6.13	9.65	0		
	103	1.40	2.80	6.17	9.83	0.1		
	104	1.44	3.25	6.69	10.74	0.3		
	105	1.44	3.03	6.46	9.83	1.1		
	106	1.44	2.69	5.64	9.09	2.7		
	107	1.40	2.74	5.73	9.14	3.1		
	108	1.25	2.41	5.68	9.14	6.0		
	109	1.36	2.74	5.44	8.84	13.1		
	110	1.57	2.85	5.56	8.84	13.9		
	111	1.32	2.56	5.18	8.58	20.4		
	112	1.22	2.22	4.72	7.56	24.4		
Laminate No. 2	201	0.625	0.882	1.45	2.22	500.0*	$\sigma_f = 180 \frac{MN}{m^2}$ (26,1000 psi)	Laminate fabricated completely in accordance with [37].
	202	0.690	0.941	1.70	2.65	500.0*		
	203	0.700	0.941	1.86	2.78	500.0*		

*Specimen did not fail; test stopped at 5×10^6 cycles. Postfatigued attenuation values were:
Specimen 202 - 1.00 (1.0 MHz), 1.80 (1.5 MHz), 2.82 (2.0 MHz)
Specimen 203 - .99 (1.0 MHz), 1.94 (1.5 MHz), 2.92 (2.0 MHz).
Specimen 202 was subsequently retested and failed at a total of 30.2×10^6 cycles.

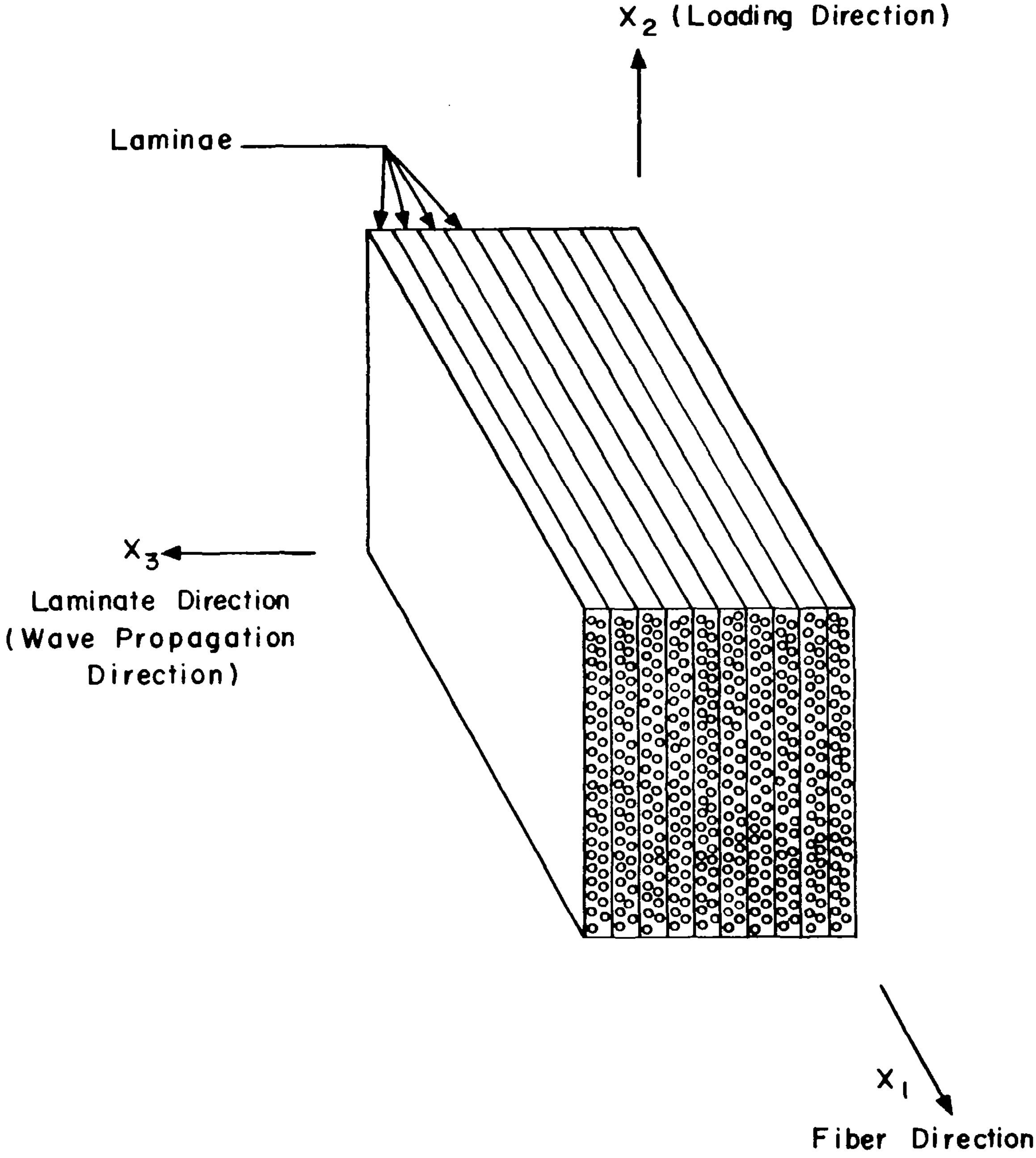

Fig. 1 Schematic of unidirectional graphite epoxy composite laminate showing principal directions.

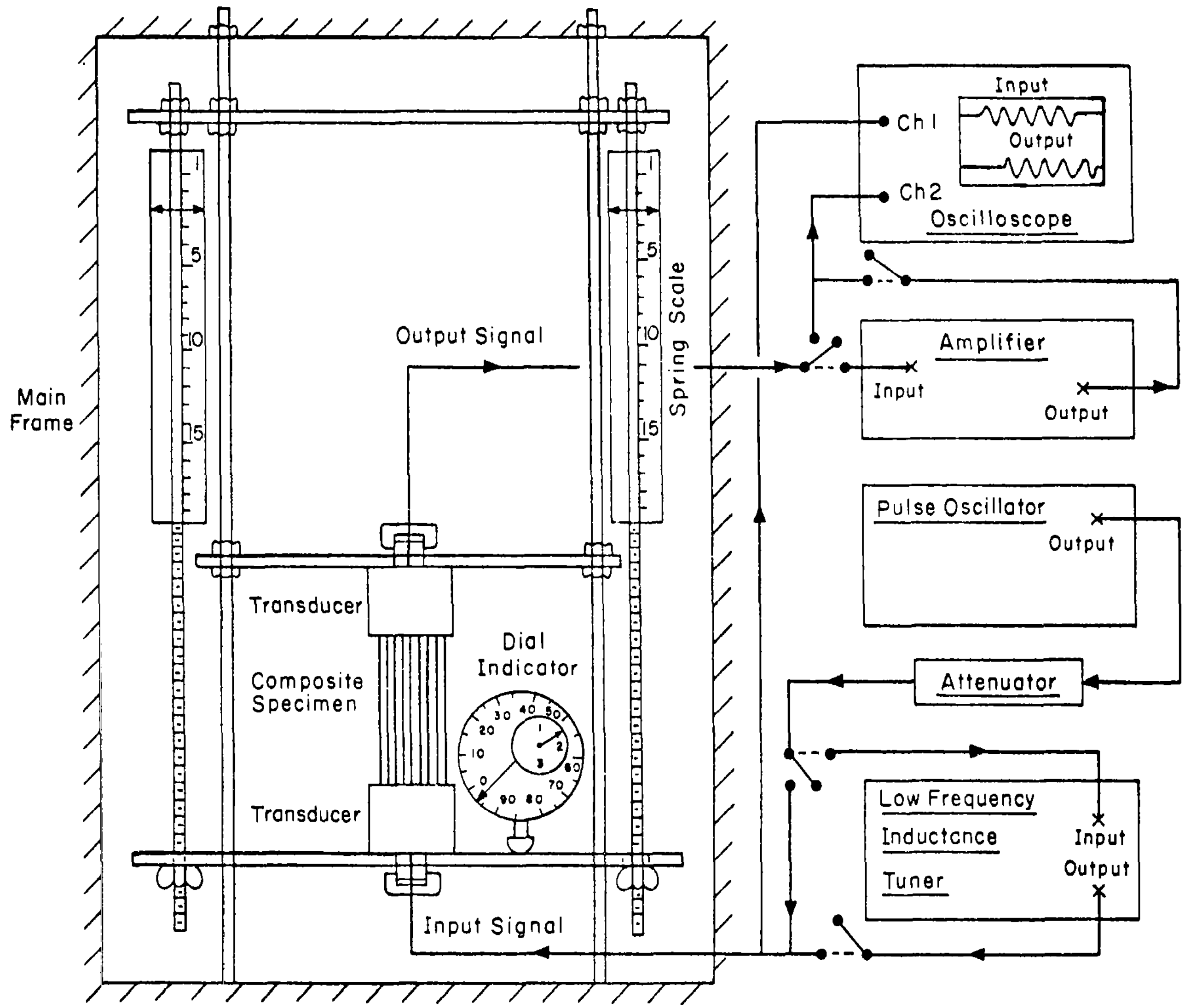

Fig. 2 Schematic of attenuation and velocity measuring experimental system.

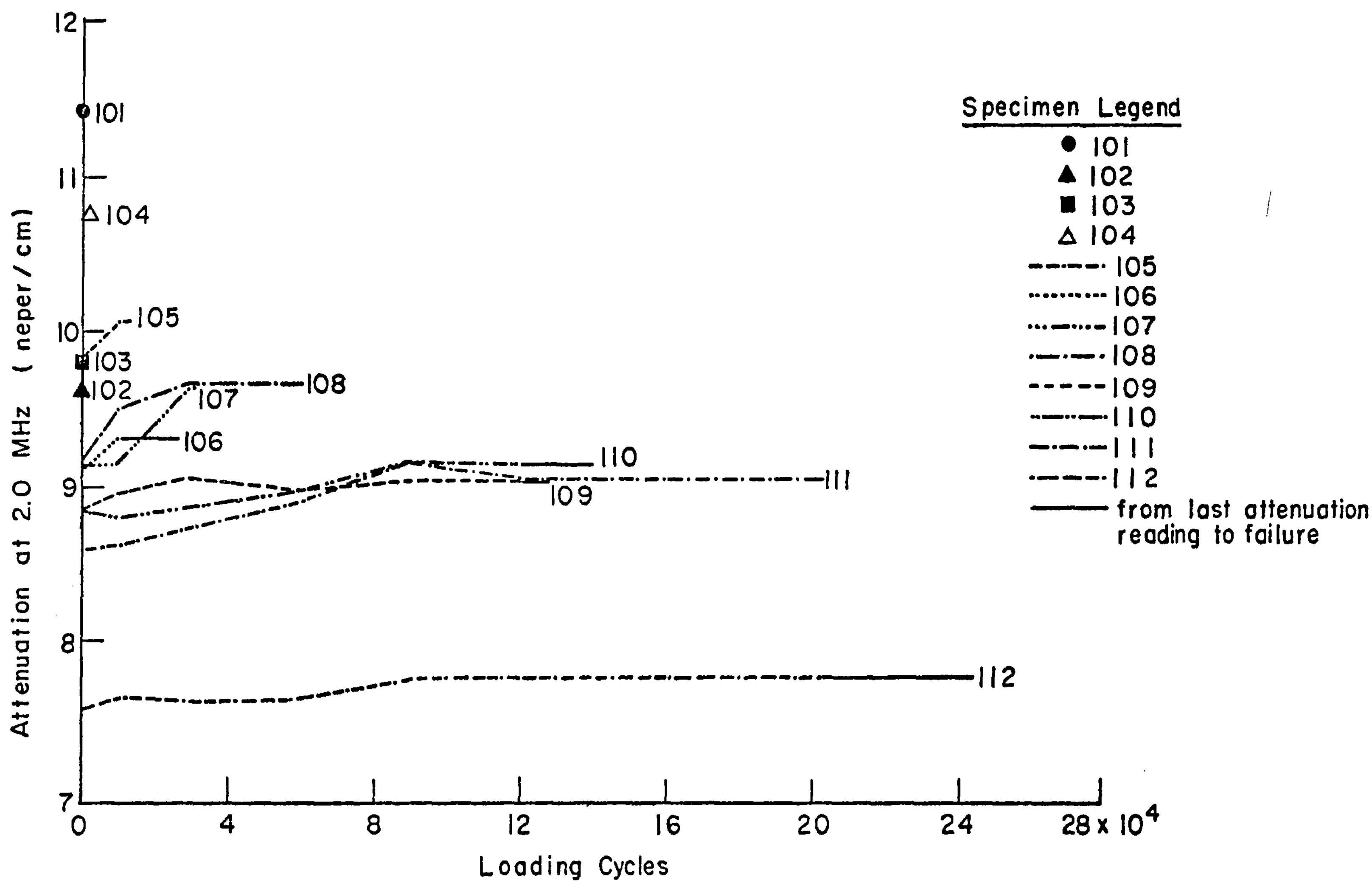

Fig. 3 Attenuation at 2.0 MHz versus loading cycles for transfiber compression-compression fatigue of laminate No. 1 specimens at $\sigma_{max} = 0.8\ \sigma_f$.

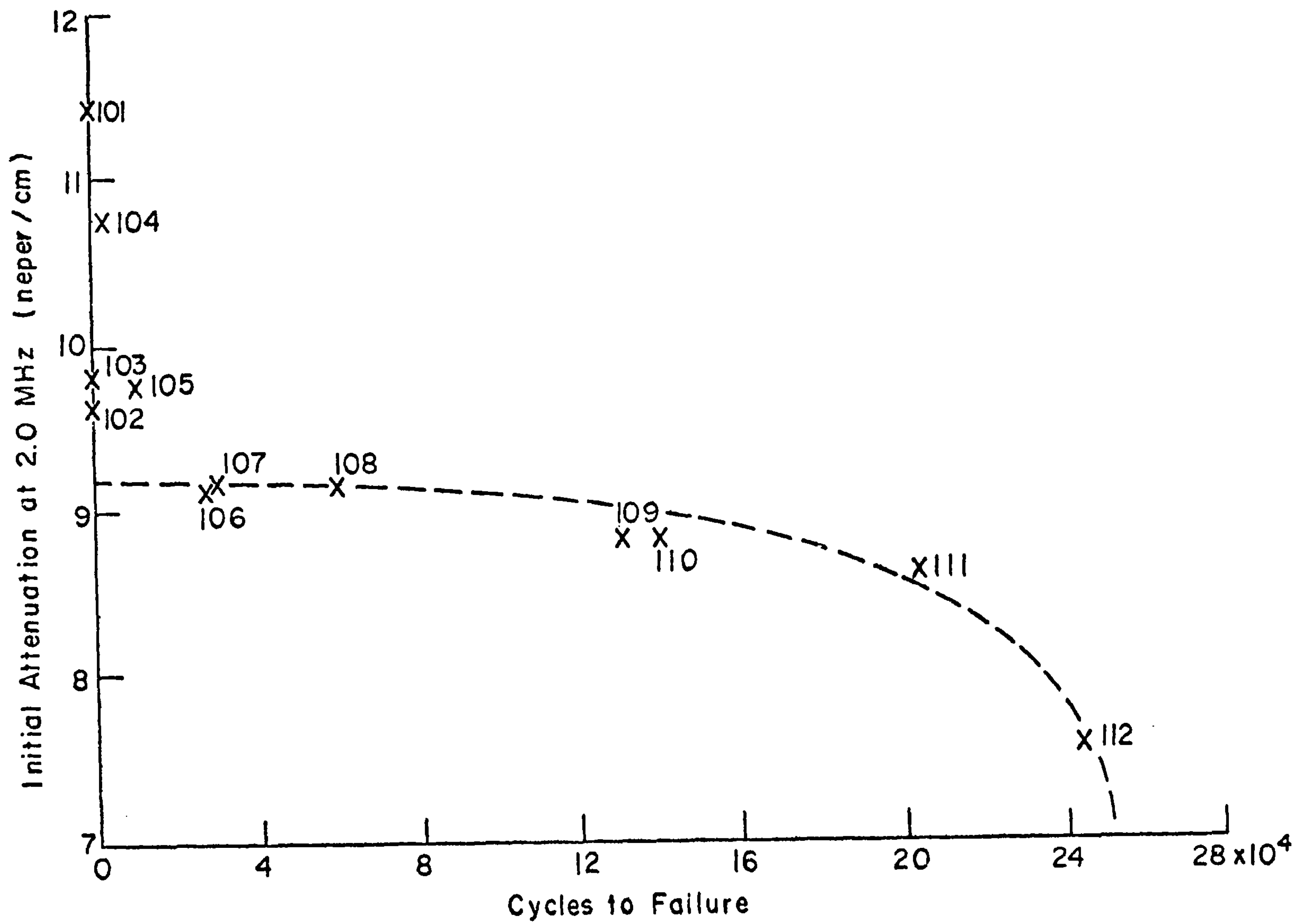

Fig. 4 Initial attenuation at 2.0 MHz versus cycles to failure for transfiber compression-compression fatigue of laminate No. 1 specimens at $\sigma_{max} = 0.8\ \sigma_f$.

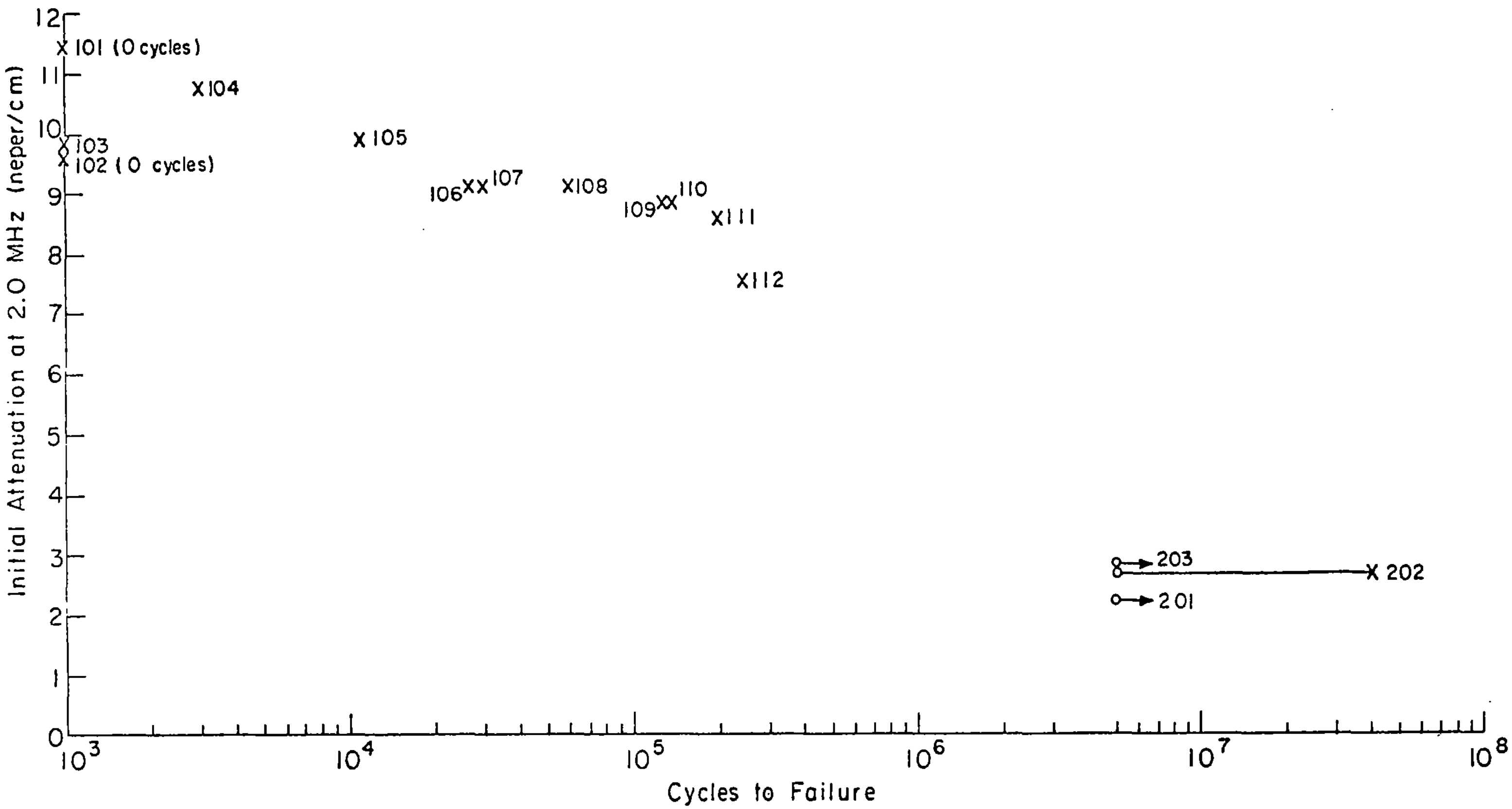

Fig. 5 Attenuation at 2.0 MHz versus cycles to failure for transfiber compression-compression fatigue of laminates No. 1 and 2 specimens at $\sigma_{max} = 0.8\ \sigma_f$.

1. Report No. NASA CR-3179	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ULTRASONIC ATTENUATION AS AN INDICATOR OF FATIGUE LIFE OF GRAPHITE/EPOXY FIBER COMPOSITE		5. Report Date December 1979
		6. Performing Organization Code
7. Author(s) James H. Williams, Jr., and Beth Doll		8. Performing Organization Report No. None
		10. Work Unit No.
9. Performing Organization Name and Address Massachusetts Institute of Technology Cambridge, Massachusetts 02139		11. Contract or Grant No. NSG-3210
		13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Final report. Project Manager, Alex Vary, Materials and Structures Division, NASA Lewis Research Center, Cleveland, Ohio 44135.

16. Abstract

The narrow band ultrasonic longitudinal wave velocity and attenuation were measured as a function of the transfiber compression-compression fatigue of unidirectional graphite/epoxy composites. No change in velocity was detected at any point in fatigue life. For specimens fatigued at 80% of static strength, there was generally a 5% to 10% increase in attenuation, however, this increase does not appear to be a satisfactory indicator of fatigue life. On the other hand, there appears to be a correlation between initial attenuation (measured prior to cycling) and cycles to fracture. Initial attenuation as measured at 1.5 MHz and 2.0 MHz appears to be a good indicator of relative fatigue life.

17. Key Words (Suggested by Author(s)) Composite materials; Ultrasonic testing; Fatigue testing; Ultrasonic attenuation; Nondestructive evaluation	18. Distribution Statement 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	20	A02

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

NASA-Langley, 1979