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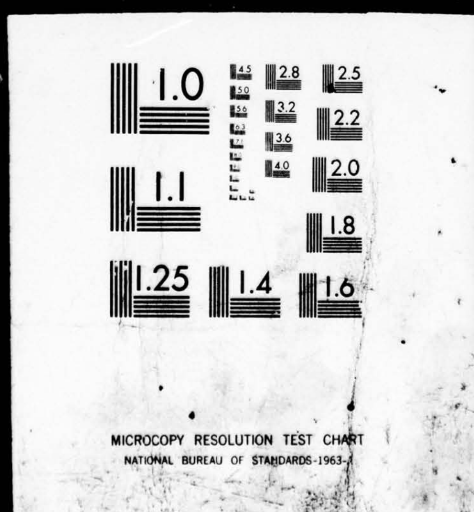

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NONDESTRUCTIVE EVALUATION OF FIBER REINFORCED EPOXY COMPOSITES A STATE-OF-THE-ART SURVEY

G. A. Matzkanin
G. L. Burkhardt
C. M. Teller

SOUTHWEST RESEARCH INSTITUTE
6220 Culebra Road.
P.O. Drawer 28510
San Antonio, Texas 78284

APRIL 1979

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Gary [redacted] L./Burkhardt
Cecil [redacted] M./Teller

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This report contains the essential findings of a comprehensive survey of the state-of-the-art in nondestructive evaluation (NDE) of fiber reinforced epoxy composites with emphasis on the types presently used or planned for use in Army helicopter components. Primary consideration is given to the NDE of glass fiber composites because of its extensive use in the fabrication of advanced helicopter rotor blades with secondary consideration given to the NDE of Kevlar, graphite, and boron reinforced epoxy.

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A computer search of the literature was performed to compile an extensive bibliography of source documents. Pertinent documents were reviewed and NDE results categorized according to NDE methodology and type of composite. For each composite type, tables were developed listing defects and property variations detected by various NDE methods. These tables along with literature references are included in the report. The status of NDE of fiber reinforced epoxy composites with respect to available techniques, ongoing research, and projected future needs is reviewed and summarized. Based on the results of the survey, recommendations are made for advancing the state-of-the-art of the NDE of fiber reinforced epoxy composites to meet practical manufacturing, acceptance, and field inspection needs.

SOUTHWEST RESEARCH INSTITUTE
Post Office Drawer 28510, 6220 Culebra Road
San Antonio, Texas 78284

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By:
G. A. Matzkanin
G. L. Burkhardt
C. M. Teller

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FOREWORD

This report was prepared for the U. S. Army Aviation Research and Development Command (DRDAV-QP). The work reported herein was funded as a separate task under Contract DLA-900-77-C-3733, Modification P00002, Item 0001AB. Technical Monitor for AVRADCOM was Mr. Thomas J. Pojeta.

This NDE state-of-the-art survey was performed under the technical supervision of Dr. Cecil M. Teller, Manager of the NDE Research Section, Instrumentation Research Division. Dr. George A. Matzkanin, Sr. Research Physicist in the NDE Research Section supervised the analysis and organization of the literature survey results and served as principal author of the Final Report. Mr. Gary L. Burkhardt also of the NDE Research Section assisted in structuring the literature search and was responsible for compiling the application tables. Much of the information retrieval and literature searching was performed by Ms. Frances P. Hicks through the Nondestructive Testing Information Analysis Center (NTIAC).

The authors wish to express their appreciation to Mr. Pojeta for providing many helpful comments during the course of the program and for reviewing the report draft prior to final reproduction.

fact, most of the retrieved information relevant to NDE of glass fiber composites was five to ten years old reflecting the interest in this material for rocket motor cases during the late 1960's. The majority of the recent literature retrieved was on NDE of graphite reinforced epoxy reflecting the increasing utilization of this material for primary (load bearing) structures on fixed-wing aircraft.

In analyzing the state-of-the-art with respect to NDE of fiber reinforced epoxy composites, it is apparent that a relatively large gap exists between laboratory methods and those used in the field or in a production environment. In the case of helicopter rotor blades, private communications with several manufacturers revealed that ultrasonics and radiography are used almost exclusively for nondestructive inspection. These two NDE techniques have been applied to production inspection of composite structures for a number of years and have been found to be adequate for providing certain information such as the presence of discrete flaws. However, information on the integrity of the structure with respect to its load bearing capability is not so readily obtainable by these techniques as currently employed.

The results of this survey show that present NDE methods are capable of detecting discrete defects of a size sufficiently large to affect the performance of the structure. Thus, no improvements in the detection sensitivity or resolution seem to be necessary. What is needed, however, are techniques to measure properties, especially those that affect the bulk strength of composites and the strength and fatigue resistance of interlaminar bonds. NDE methods that have received the greatest amount of development thus far for this purpose are ultrasonic velocity measurements of elastic moduli and adhesive bond characteristics, and low frequency damping measurements. Results indicate that both of these approaches show promise for nondestructive evaluation of in-service strength degradation of fiber reinforced epoxy composites.

Environmental damage caused by exposure to hot moist temperatures continues to be a problem. Not only does moisture migrate along the fiber-matrix interface and weaken the interface bond, but it also diffuses through the resin itself. Despite the importance of detecting and quantifying the degree of moisture diffusion together with any resultant damage there is little information available on suitable NDE procedures. One method based on measuring effusing moisture and solving the diffusion equation is currently under development for graphite epoxy composites;[3] however, this method relies on assumptions regarding the reversibility of moisture diffusion which may not apply in general.

EXECUTIVE SUMMARY

The trend towards damage tolerant design philosophy in aerospace vehicles places emphasis on accurate nondestructive evaluation (NDE). Given defects must be found with specified probability and degree of confidence, and once found, they must be characterized in such a way that their effects on structural performance can be determined. Because of the heterogeneous nature of composites, the form of defects is often very different from a metal and the fracture mechanisms are more complex. One result is that the effects of various defects on performance are at present not well understood. The extent to which any combination of defects will prove detrimental is governed by the geometry (including lay-up order) of the structure, the exact location and orientation of the defects, the nature of the applied stress field, and the environment in which a given component is required to operate. On such factors there is a lack of information. From the standpoint of the user of NDE, there is a need to be able to differentiate between defects potentially detrimental to the performance of a structure and those which are not. To achieve this differentiation, it is necessary to ensure good collaboration among design, fabrication, NDE, and mechanical or structural testing groups.

The purpose of this state-of-the-art survey is to provide a review of and a ready reference to the technical literature available and applicable to the nondestructive evaluation of fiber reinforced epoxy composite materials with emphasis on the types presently used or planned for use in Army helicopter components. From this survey recommendations are made by the authors in order to lay the foundation for a comprehensive applications development program roadmap to advance the state-of-the-art to meet practical manufacturing, acceptance, and field inspection needs.

Because of the extensive use of glass fiber reinforced epoxy composites in the fabrication of advanced helicopter rotor blades,[1] and the safety critical nature of this component, the emphasis of this survey is on the NDE of glass fiber composites. Secondary consideration is given to the NDE of Kevlar, graphite, and boron reinforced epoxy because of their utilization in helicopters such as the Black Hawk.[2] The status of NDE of these materials with respect to available techniques, ongoing research, and projected future needs is reviewed and summarized.

Although the literature retrieval performed as part of this state-of-the-art survey was quite comprehensive, little substantive information was found on the NDE of glass fiber helicopter rotor blades. In

Another candidate technique which has been applied for moisture measurement in a variety of materials is nuclear magnetic resonance.[4] Recent instrumentation advancements have indicated the feasibility of measurements on large structures such as helicopter rotor blades.

Several specific recommendations for the inspection of glass/epoxy helicopter rotor blades can be made based on the results of the state-of-the-art survey. Instrumentation technology currently exists for developing automated inspection systems for the ultrasonic and radiographic approaches presently in use. On the basis of laboratory results, thermography and microwave techniques appear promising for the NDE of fiber reinforced epoxy composites. Although additional laboratory investigation is needed, these techniques could probably be developed for practical application in specific circumstances. Effort should continue to be directed toward development of universally accepted reference standards. The progress made in this area in recent years on metals may help in establishing suitable guidelines applicable to composites.

Finally, it is recommended that a workshop devoted to the NDE of composites be held. The last such workshop was held in 1974[5] and resulted in clarifying the role of NDE in the inspection of composites and in a number of suggestions for further method development. Both composite and NDE technologies have advanced considerably since 1974 and thus another workshop in this area would be timely. Such a workshop, in addition to providing the needed interactive communication among the design, fabrication, NDE and mechanical testing groups, would provide a foundation for formulating a program to advance the state-of-the-art of NDE of composites in the most efficient way.

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I. INTRODUCTION

A. Approach

As the first task under this project, the computer retrieval facilities of the Nondestructive Testing Information Analysis Center (NTIAC) located at Southwest Research Institute were used in compiling a bibliography of source documents for this survey. This review covered technical journals, conference proceedings, research reports, and Department of Defense technical reports (unlimited and limited distribution) from 1960 through 1978. Information on current work in progress that has not yet been reported in the technical literature was obtained from Work Unit Summaries and through private conversations with several workers associated with NDE of composites. A list of 56 references from which specific citations are made in the body of the report was developed from a more extensive bibliography containing over 140 references including those related but not specifically applicable to the survey. The details of the literature search task are discussed in Section II. A.

A team of Southwest Research Institute professional staff members was organized to review all retrieved documents to assess relevance to the survey. Abstracts of all documents identified during this search task were given a brief review and each was categorized according to the composite system discussed. Documents providing general background were also identified. The most pertinent documents were thoroughly reviewed and the contents summarized on worksheets according to NDE method(s). Reviewers applied their expertise and knowledge of the state-of-the-art of NDE of composites to assess the capabilities and limitations of each method reviewed. The information summarized on the worksheets was used to write this report.

B. Organization of Report

This report is written for the reader who is generally familiar with composites technology and NDE methodology although several references are given to provide background information. The approach to performing this state-of-the-art survey and organization of this report are presented in Section I. Section II presents the results of the literature search pertinent to NDE of defects and property variations supplemented with introductory information on the NDE techniques themselves. The organization of Section II is by composite type, i.e., type of reinforcement. Section III comprises an assessment of the state-of-the-art for NDE of composites of interest in Army Aviation based on the work reported in the literature. Also included in this section are application tables which provide the reader with a ready reference to the literature. These tables list all referenced documents indicating which NDE techniques have been reported for specific defect and property determinations in composites. Section IV contains a discussion of the application and development efforts needed, as interpreted by these authors, to advance the state-of-the-art in NDE of composites of interest in Army aviation. In Section V is presented a list of conclusions and recommendations and Section VI contains a list of references.

Two appendices are included which should prove useful to the reader. Appendix A contains more detailed descriptions of the NDE methodology than given in Section II. Appendix B is a bibliography containing a comprehensive listing of pertinent articles retrieved through the Defense Documentation Center, NTIAC, and open literature sources.

Throughout the text of this survey, Système International (SI) units are used in accordance with American National Standard (ANSI Z210. 1-1976). However, in the illustrations and tables extracted from referenced papers, measurement units used by the authors are retained and no conversion to SI from English units is provided. For the most part, illustrations taken directly from the source documents have been utilized. Some of these were slightly "touched-up" to improve their quality for reproduction, but in all cases units terminology and captions of the source documents have been retained. In general, tables used in this report were retyped utilizing the format and terminology found in the source documents.

It is hoped that this review will serve as a useful survey of the state-of-the-art in NDE of composites and provide guidance to management for the formulation of a program roadmap to advance this state-of-the-art.

II. NONDESTRUCTIVE EVALUATION OF FIBER REINFORCED EPOXY COMPOSITES -- LITERATURE REVIEW

A. Literature Search Strategy

Several complementary literature searches were conducted in the Nondestructive Testing Information Analysis Center (NTIAC) files, the Defense Documentation Center (DDC) files, and commercial open literature files. In each case the objective was to select a bibliography which would include virtually all the literature on NDE of composites in general, but more specifically on glass, Kevlar, graphite, carbon, and boron fiber reinforced composites. In order to do so, the searches were designed to encompass the broadest range possible commensurate with the retrieval of bibliographies which were of manageable size for manual review.

The NTIAC search strategy is shown in Table I. In the search, one term from each group of terms separated by an "and" must be associated with a document for it to appear as a find. Some terms appear in both groups to assure that any document associated with only that term will be found. No NDE terms appear in this search since all NTIAC documents concern NDE.

An additional search was run in the NTIAC file to retrieve any applicable documents dealing specifically with NDE of helicopter rotor blades without specifically limiting the search to composite materials. The strategy for this search appears in Table II. The "%" that preceeds a term means that the term is truncated, that is, all terms having the same initial letters in the same order will be searched. Thus "% rotor" will search for rotor, rotors, rotor blades, etc.

The strategy for the DDC search is shown in Table III. A different group of terms is used in this search since descriptors in this file differ from those in the NTIAC file in some cases. A broad group of NDE terms is also included. The "%" symbol truncates the term in the same manner as in the NTIAC file. The DDC search excluded all NTIAC documents and all documents concerning carbon-carbon and metal matrix composites since these were not of interest in the survey.

The open literature searches utilized the Lockheed/DIALOG system to search the following files: (1) COMPENDEX (COMPuterized ENgineering inDEX), (2) National Technical Information Service (NTIS), and (3) ISMEC - Mechanical Engineering. The strategy for the open

TABLE I

NTIAC SEARCH

composite materials polymer matrix composites metal matrix composites fiber reinforced composites filament wound construction reinforced plastics reinforcement fibers matrix	and	polymers fiberglass glass plastics foam carbon graphite boron epoxy composite materials polymer matrix composites metal matrix composites fiber reinforced composites filament wound construction reinforced plastics

TABLE II

NTIAC SEARCH ON HELICOPTER ROTOR BLADES

%helicopter	and	%rotor %blade %composite material fiberglass

TABLE III

DDC SEARCH

%composite material		%aramid		%nondestruct
composite structures		%carbon reinforced		ultrasonics
%fiber reinforced		%carbon fiber		%ultrasonic test
matrix materials		%graphite fiber		%eddy current
%carbon reinforced		%graphite reinforced		x ray diffraction
%carbon fiber		graphite composites		%radiogr
%graphite fiber		%glass fiber		%radiometr
%graphite reinforced	and	%glass reinforced	and	visual inspection
graphite composites		fiberglass		%microscop
%glass fiber		%fiberglass reinforced		%electrical resist
%glass reinforced		metal fibers		neutron radiography
fiberglass		metals		interferometry
%fiberglass reinforced		metal		holography
%aramid		%epoxy		acoustic emissions
		%plastic		acoustics
		%polymer		%penetra
		%fiber		%thermogra
		%matrix		liquid crystals
		%filament		microwaves
		%ceramic		acoustooptics
		%polyamide		x rays
		%polyimide		infrared images
		%boron		nuclear magnetic resonance
				nmr
				dielectric

literature searches is shown in Table IV. The "?" after some terms performs truncation. The (w) between multi-word terms is necessary to retrieve those groups of words as a single term.

The literature search results are shown in Table V. Out of a total of 1788 finds, 138 documents were ordered based upon a review of the abstract from each document.

The DDC Work Unit file was also searched to identify any ongoing work of interest to the survey. The same search strategy as for the original DDC search was utilized. Ten projects were identified as potentially applicable to the survey.

B. Fiberglass Reinforced Epoxy Composites

1. Ultrasonics

At the present time, ultrasonics is used extensively for the NDE of most composites, including glass fiber reinforced epoxy structures. Applications of ultrasonics to NDE in the aerospace industry were summarized by Hagemaier in 1974.[7] Although Hagemaier's summary pertains in general to all aerospace materials, much of the discussion was relevant to the inspection of composite structures as well as metal components. Among the various aspects of ultrasonic inspection covered by Hagemaier are the importance of proper selection and use of reference standards. This is especially true in the case of composites. Because of the variables encountered during ultrasonic inspection of composites, reference specimens with known or artificial discontinuities are essential to perform reliable inspection.

Ultrasonic inspection is usually performed by two basic methods: through-transmission whereby the ultrasonic energy passing completely through a part is recorded, or pulse-echo whereby the ultrasonic energy reflected from a discontinuity, or its related effect to the total response is recorded. The characteristics of the ultrasonic signals that may be measured and related to the properties of the material are: attenuation caused by absorption and scattering - sensitive to material structure, density, and composition; and velocity - sensitive to the elastic behavior of the material.

A major problem in the application of ultrasonic methods to the NDE of composite materials is the high attenuation of ultrasonic waves by the material. In glass fiber reinforced epoxy attenuation is produced by absorption in the resin and scattering by the glass fibers. Because of high attenuation in composites, it is

TABLE IV

OPEN LITERATURE SEARCH

GROUP A	GROUP B	GROUP C	GROUP D
Carbon (w) Reinforced	Composite ?	Metal (w) Fiber	Nondestruct ?
Carbon (w) Reinforcement	Fiber (w) Reinforced	Metal (w) Fibers	Ultrasonic ?
Carbon (w) Fiber	Fiber (w) Reinforcement	Metal (w) Matrix	Eddy (w) Current
Carbon (w) Fibers		Boron ?	Eddy (w) Currents
Carbon (w) Phenolic		Aluminum ?	X (w) Ray
Graphite (w) Reinforced		Epoxy ?	Radiograph ?
Graphite (w) Reinforcement		Plastics ?	Radiometr ?
Graphite (w) Fiber		Polymer ?	Visual
Graphite (w) Fibers			Microscop ?
Graphite (w) Composite			Electrical (w) Resistance
Graphite (w) Composites			Electrical (w) Resistivity
Glass (w) Reinforced			Neutron (w) Radiography
Fiberglass ?			Neutron (w) Radiography
Kevlar ?			Interferometry
			Holography (w) interfermetry
			Holography
			Acoustic (w) Emissions
			Acoustic (w) Emission
			Acoustic
			Penetrant
			Thermogra ?
			Liquid (w) Crystal
			Liquid (w) Crystals
			Gamma (w) Ray
			Dielectric
			Nuclear (w) Magnetic (w) Resonance

SEARCH STRATEGY:

(Group A and Group D) or (Group B and Group C and Group D)

TABLE V

LITERATURE SEARCH RESULTS

File	Total Finds	No. of Documents Selected				
		Fiberglass	Kevlar	Graphite	Boron	General*
NTIAC	498	23	2	25	5	5
NTIS	383	9	0	7	1	6
COMPENDEX	596	11 (COMPENDEX and ISMEC combined)	0	7	8	11
ISMEC	28					
DDC	283	6	0	7	0	5
TOTAL	1788	49	2	46	14	27
Total Ordered		138				

*General category pertains to documents with information covering several composite materials.

usually found that flaw detection by the pulse-echo technique is not very efficient compared with a through-transmission approach. This is because the ultrasonic beam must traverse the material twice in the pulse-echo approach and the attenuated echo reflected from a flaw may be obscured by other signals reflected and scattered from glass fibers, etc. Using lower frequencies in order to obtain lower attenuation, results in decreased resolving power. Consequently, for composites it is usually better to use two separate probes in a through-transmission arrangement. In addition, the through-transmission technique has the advantage that it is not as greatly affected by surface contour, surface roughness, or part alignment as the pulse-echo technique.[7] The through-transmission ultrasonic technique is quite successful for locating laminar type defects such as disbonds or delaminations. Disbonds as small as 3.18mm diameter can be detected in fiberglass laminate specimens.[7]

Ultrasonics as well as other NDE techniques were recently evaluated for the inspection of glass reinforced epoxy materials by Førli and Torp.[8] It was stated that the properties of glass reinforced plastic are determined primarily by workmanship during construction. Three factors were found to govern laminate properties other than the properties of the component material:

1. Thickness,
2. Reinforcement fraction and orientation,
3. Quality of laminate (i.e., delaminations, porosity, inclusions, voids, surface cracks, and degree of cure).

Therefore, in assessing the integrity of the composite material, it is important to be able to determine these three factors nondestructively. For the measurement of thickness, Førli and Torp state that pulse-echo ultrasonics is superior to most other methods and allows for one-sided application. Difficulties can be encountered with high damping and laminate inhomogeniety. Broadband transducers may be used with short pulse duration to achieve higher resolution in order to distinguish between glass layer echos and back wall echos. Low pulse intensity due to high internal damping may be overcome somewhat with higher amplification. Accuracy of the method is affected by matrix type and surface roughness. For the nondestructive determination of reinforcement fraction and orientation, ultrasonics has not yet been fully exploited; however, it has been found that the velocity of propagation along fibers is heavily dependent on glass content as shown in Figure 1.[8] For the determination of laminate quality, ultrasonics may be used to detect delaminations, voids, inclusions and porosity clusters.

Fatigue damage in composite materials is a complex phenomenon produced by a combination of interrelated mechanisms such as matrix crazing, delamination, fiber failure, fiber/matrix interfacial bond failure, void growth, and cracking. In fiberglass composites (as well as other reinforcement materials) it has been found that a change in stiffness can occur continuously over a large fraction of fatigue life to fracture.[9] Consequently, measurement of stiffness loss can provide a reliable indication of the structural integrity of the composite component. In laboratory tests of tubular specimens of E-glass/epoxy laminate it was found that ultrasonic C-scans were capable of detecting fatigue induced localized damage after 0.2×10^6 cycles at a maximum stress of 55 MPa and stress ratio $R = 0.1$ when the stiffness loss was 18%. However, a problem encountered with ultrasonic inspection is the noise caused by the scattering and dispersion of the signal by the many interfaces in the composite.

Ultrasonic through-transmission has also been shown to reliably trace accumulation of fatigue damage and predict failure in filament-wound fiberglass reinforced epoxy cylinders.[10] These investigators rejected use of ultrasonic pulse-echo because of high scattering losses from small imperfections which could not be distinguished from noise. The specimens were 6-inch long beams sectioned from cylinders and tested in three point bending. A phenomenological correlation between average and peak magnitude of the ultrasonic attenuation just prior to failure was used to establish an attenuation threshold of failure. It was found that maximum or peak attenuation could not be used as a measure of critical damage which is the accumulated damage level at which failure is eminent. High attenuation indicates either considerable through thickness damage or interlayer cracking, but not low adhesion. On the basis of the ultrasonic attenuation and shear strength measurements, a cumulative damage criterion was derived which is stress independent and interaction free. According to the authors, this criterion makes it possible to predict fatigue life and to determine residual life at intervals of operational life. Agreement between the ultrasonic predictions and actual failure was generally within 10%, with the ultrasonic predictions being conservative. A summary of the results is shown in Table VI.[10]

The question of voids and their effects on the mechanical properties of composites has recently been addressed by Judd and Wright.[11] The experimental evidence shows that the

FIGURE 1. ULTRASONIC PRESSURE WAVE VELOCITY FOR PROPAGATION NORMAL TO FIBERS RANDOMLY DISTRIBUTED IN PROPAGATION DIRECTION FOR A POLYESTER/GLASS LAMINATE (APPROXIMATE CALCULATION)

(From Ref. 8)

TABLE VI

RESIDUAL COMPRESSIVE FATIGUE LIFE RESULTS

Specimen Number	Ultimate Attenuation, db		Fatigue Cycles at Inspection	Predicted Residual Life, percent remaining		Measured Residual Life, percent remaining	Correlation of Predicted and Measured Results	
	Primary	Secondary		Primary Zone	Secondary Zone		Actual - Predicted Life, percent remaining	
148C3	20.32	30.32	4000	24.7	24.7	27.7	3.0	conservative, primary and secondary
150C1	20.93	-	4000	22.5	-	51.2	28.7	conservative, primary
150C3	21.52	19.34	1000	20.3	28.4	22.3	2.0	conservative, primary
							6.1	nonconservative, secondary
152C2	27.24	13.20	2501	- 0.9	14.1	16.5	17.4	conservative, primary
							2.4	conservative, secondary
153C1	20.31	12.10	2501	24.0	55.2	40.8	16.8	conservative, primary
							14.4	nonconservative, secondary
154C1	15.91	15.91	500	41.1	15.91	44.2	3.1	conservative, primary
							3.1	conservative, secondary
154C2	26.12	-	2501	3.3	-	8.9	5.6	conservative, primary
155C4	12.08	-	1000	55.3	-	13.3	42.0	nonconservative, primary
156C3	27.32	27.32	1000	- 1.2	- 1.2	27.2	28.4	conservative, primsty and secondary
159C3	21.89	-	16	18.9	-	5.9	13.0	nonconservative
160C3	32.16	-	13	-19.1	-	8.1	27.2	conservative, primary

(From Ref.10)

presence of voids can reduce the magnitude of the following properties in fiber/resin composites: interlaminar shear strength, longitudinal and transverse flexural strength and modulus, longitudinal and transverse tensile strength and modulus, compressive strength and modulus, fatigue resistance, and high temperature resistance. Interlaminar shear strength has been the property most often determined and available data show that this property decreases by about 7% for each 1% increase in voids up to at least the 4% void content level beyond which the rate of decrease diminishes. Data for the variation of properties other than the interlaminar shear strength are much less extensive; however, the available results indicate that the decrease in the magnitude of these properties with increasing void content is similar to that observed for interlaminar shear strength. This is true for all composites regardless of the resin, fiber or fiber surface treatment used in their fabrication. A variety of theoretical treatments of the effects of voids on the mechanical properties of composites show quite reasonable correlations with experimental results for such properties as interlaminar shear strength, transverse tensile strength, and compressive strength. In general, these theoretical treatments are based on the assumption of either spherical or cylindrical shape voids uniformly distributed throughout the composite.

According to Judd and Wright one of the difficulties in attempting to quantify the influence of voids on the mechanical properties of composites is the absence of a sufficiently accurate method of determining void content. Although all methods presently used for quantitative void content measurement have limitations, one of the most generally useful nondestructive techniques is ultrasonic through-transmission C-scan. This technique is sensitive to voids as well as other defects and is able to interrogate the whole test piece rather than only a small portion. However, the ultrasonic technique must be calibrated by reference to another method such as micrography and hence its overall accuracy cannot be greater than the accuracy of the reference method. This is usually void content ± 0.5% which limits the utility of the ultrasonic technique for low void content, i.e. the 0 to 1% range.

In order to establish some quantitative basis for measuring void content ultrasonically, Martin has derived expressions for ultrasonic attenuation as a function of both void and fiber content.[12] Comparisons between theory and experiment are shown in Figure 2. The ultrasonic attenuation is found to be proportional to the cube of the void radius. Calculated curves can be used in conjunction with attenuation measurements to obtain localized void content and percent volume for composites. Results show that it is best to use the highest frequency possible that will not be totally attenuated for void contents up to 4%

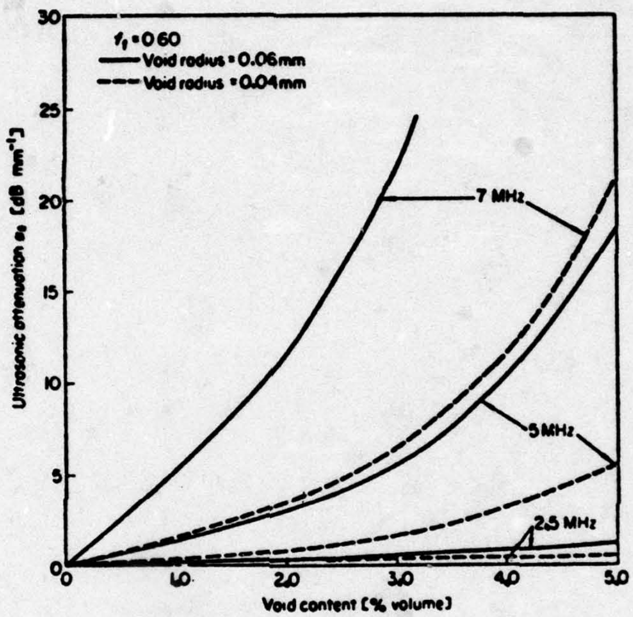


FIGURE 2. ACCORDING TO CALCULATIONS, ULTRASONIC ATTENUATION RISES WITH VOID CONTENT, VOID RADIUS AND ULTRASONIC FREQUENCY FOR UNIDIRECTIONAL GLASS-FIBRE REINFORCED PLASTICS.

(From Ref. 12, published by IPC Science and Technology Press, Ltd., Guildford, Surrey, England.)

by volume. For greater than 4% void content, attentuation is so severe that void content measurement is no longer necessary, since in this case, the composite has an unacceptable porosity.

Ultrasonics has been shown to be useful for the nondestructive evaluation of strength degradation in glass reinforced epoxy as a result of environmental exposure.[13] In this work, ultrasonic attenuation measurements made with a KS 3000 Kramer Modular Flaw Detector were correlated with independently determined mechanical properties. Composite specimens fabricated from E-glass fabric were immersed in hot water at 80°C for periods of 6 hours and 1, 3, and 7 days. After the hot water exposure, the specimens were oven-dried at 80°C for a period of seven days and then tested. Figure 3 shows the relationship obtained between the normalized residual strength and the ultrasonic attenuation. The normalized residual strength is the ratio between the measured strength of an exposed specimen and the respective strength of a control specimen. These data show that after immersion in hot water for a few days, ultrasonic attenuation is a more sensitive indicator of the degree of degradation than the normalized residual strength test method.

2. Radiography

Radiography, especially X-ray radiography, has been used successfully for a number of years for the nondestructive inspection of composite materials. Since the X-ray radiography approach depends on a variation in absorption of the X-ray beam, it is not well suited to detect interlaminar separations in stratified materials unless the beam is directed along the separation.

A number of X-ray radiography inspection approaches for large non-planar structures were evaluated by Maigret and Jube.[14] Among techniques tried for enhancing exposure normal to the specimen surface were fluorescent screens, tomography, treatment of films by contrast correctors, microdensimetric analysis, etc. The only technique which proved useful was to utilize opacifying fluids such as barium oxide. Since this approach requires a defect that is open to the surface in an accessible region, it only applies to very special cases. In addition, use of such fluids may contribute to contamination of the part.

For the radiographic inspection of large diameter parts (15 m radius of curvature), Maigret and Jube described an approach in which the X-ray beam was directed tangential to the curved wall of the part. The large radius of curvature made it necessary to place the X-ray tube as well as the sensitive film remotely from the examined

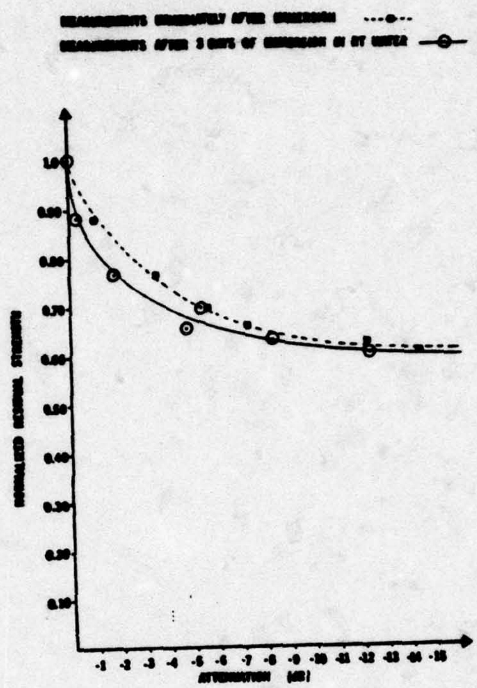


FIGURE 3. CORRELATION CURVE OF NORMALIZED RESIDUAL STRENGTH AND ATTENUATION DATA OF GRP SPECIMENS PREVIOUSLY EXPOSED TO HOT WATER IMMERSION. RT = ROOM TEMPERATURE.

(From Ref. 13, reproduced by permission of The American Society for Testing and Materials, Philadelphia, Pennsylvania) section. This arrangement resulted in several difficulties including the need for a radiance source as sharp as possible to reduce geometrical blur, and a large density variation due to the fact that the quantity of material penetrated varied according to the thickness. For large diameter structures it is necessary to use X-ray sources of 400 kV and even accelerators of several MeV having a focus as thin as possible. Folded films were used to overcome the disadvantage of needing two or three X-ray exposures at different settings in order to remain within the normal density values. Color radiography was also tried but not pursued because of a lack of sharpness and processing complications. It was suggested that televised radioscopy is very useful, since a dynamic observation compensates for some of the loss of definition. In fact Maigret and Jube indicate that defects practically invisible in static observation can be detected on a televised radioscopy channel when a rotating motion is applied to the structure because the human eye is sensitive not only to density variation but also to motion.

Hagemaier, et al. reported X-ray radiography for the nondestructive inspection of glass fiber composites used for aircraft structures.[6] In this work a Picker 50kV X-ray machine with a 0.5 mm effective focal spot and a beryllium window X-ray tube were used. Single emulsion, fine grain film was used to avoid the parallax effect of standard double emulsion film. In application to fiberglass epoxy laminate panels fabricated with known flaws, radiography was found useful to reveal resin-rich and resin-starved areas, porosity, bond joint separations, cracks, fabrication fitup, inclusions, fiber orientation, and crushed honeycomb core. Water intrusion and entrapment in honeycomb aircraft structures were also detected by radiography.

In addition to X-ray radiography, neutron radiography can be useful for engineering evaluation of composite structures. For example, when an adhesively bonded honeycomb specimen is neutron radiographed, the hydrocarbon adhesive becomes very apparent because of its high neutron capture. However, in a feasibility study of neutron radiography for inspection of massive fiberglass composite structures, Youshaw found that neutron radiography was not suitable for practical inspection of such structures.[15] The difficulty is that hydrogen and boron are the two main elements reacting with the neutron beam in these materials (approximately 10% B_2O_3 for "E" glass[16]). The boron constituent of fiberglass severely attenuates neutrons at thermal energies necessitating long exposure times to obtain film darkening. Simultaneously the hydrogen of the binding resin very efficiently scatters neutrons which act to fog the film. Calculations showed that scattering occurs throughout the spectrum of available neutron energies. As a result the obtained neutron radiography images were of poor quality.

Conventional X-ray radiography was performed by Youshaw on 4-inch thick fiberglass test blocks containing intentional defects: 3.2 mm and 6.4 mm voids; 6.4 mm and 12.8 mm delaminations; 6.4 mm steel washer; 6.4 mm steel nut; cored resin 1.6 mm by 6.4 mm by 12.8 mm. Careful radiography revealed all flaws. Although the 3.2 mm voids were only marginally visible in the radiographs, the nuts and washers were quite obvious. Radiography also revealed several bands of low density across the panels. The results of the investigation showed that conventional X-ray radiography may be usefully applied to massive fiberglass structures although some study is necessary to aid in interpretation and evaluation of the film indications.

In an investigation into early fatigue damage detection in composite materials[17] it was found that X-ray radiography using a 23 kV source with a berllium window was not useful for fatigue damage detection. Only very faint indications were observed at seams which were more positively detected with ultrasonic C-scans. No void or crack indications were obtained.

Judd and Wright[11] report that a modified radiographic technique has been described in which samples are first impregnated with molten sulphur and then radiographed using a tungsten target.[18, 19] A stereo pair of radiographs was taken to facilitate examination of the void distribution throughout a sample. It was demonstrated that voids of micron size can be detected although no attempt was made to quantify the measurements. It would depend upon the completeness of filling of the voids with molten sulphur. If it could be established that the impregnation had no significant effect upon mechanical properties or serviceability then this technique would be capable of extension to form the basis of a nondestructive test for fabricated articles.

3. Electromagnetic

Since nonmetallic composites are more or less transparent to microwaves depending on the relationship between the dielectric constant and microwave frequency, the use of microwave testing is obviously promising for nondestructive inspection. Analysis of the basic interactions of microwaves and solid dielectrics shows that most of the defects expected in nonmetallic structures will have an effect upon a microwave beam. In fact the situation is similar to that encountered in ultrasonic testing except that microwaves can traverse empty space (low frequency ultrasonics can also to some extent) and, of course, do not penetrate significantly in electrical conductors (skin depth limitation). The principal difficulty with application of microwaves for NDE is one of equipment and technique.

In 1969 Cribbs reported continuous wave microwave experiments on a 0.91 m length of the cylindrical section of a solid rocket chamber cast with propellant.[20] The chamber was a 6.4 mm thick fiberglass reinforced epoxy composite lined with a 6.4 mm thick rubber insulation. The specimen was fabricated with intentional defects to determine defect sensitivity. Detection of delaminations and separations depends upon the change in reflection coefficient which results from the sharp discontinuity in dielectric constant between air and glass, insulation, or propellant. Experimental results indicated that laminar separations as small as 0.05 mm could be detected. However, the basic difficulty with the continuous wave technique is that neither range nor depth of the defect can be determined.

To provide the capability for depth resolution, a swept frequency microwave approach was developed called the Frequency Domain Interferometer (FDI).[20] This approach combines the characteristics of an interferometer and radar and has the ability to measure distance to a small fraction of a wavelength. In addition, the microwave signal is transmitted into the specimen by means of a horn antenna eliminating the need for machining samples for insertion into a waveguide. Fiberglass/epoxy composite specimens ranging from a fraction of a centimeter thick to over 12 m thick were inspected. It was found that separations down to 0.05 mm thick could be detected and located to an accuracy of 0.25 mm.

The swept frequency microwave approach was used by Plunkett to determine density/porosity variations in bidirectional glass reinforced Narmco 4085/2 test specimens.[21] It was found that go-no go limits could be established, and when the density/porosity fell out of the specified limits, the part would be rejected. The possibility of using swept frequency microwave techniques for production testing was suggested.

Zurbrick performed high frequency (35 gHz) microwave measurements on laminated fabric reinforced plastic specimens.[22] Five resin systems, epoxy, phenolic, polyester, polybenzimidazole, and silicone in glass fabric (181 style) laminates, were nondestructively evaluated. The specimens were intentionally varied in resin content to simulate industrial conditions. Through-transmission microwave measurements were used to determine the dielectric constant of the material by measuring the relative phase shift. The results showed that microwave dielectric measurements in free-space were useful for laminate variability screening; however, Zurbrick suggested that more development should be done to determine the effects of laminate parameters on phase shift and attenuation.

In addition to the high frequency microwave measurements, Zurbrick also reported determination of relative capacitance using a low frequency co-planar dielectric probe technique. The device operated at 1 kHz and projected an electric field into the specimen. The signal from the electric field response was processed and displayed on a meter. Initial measurements with the low frequency dielectric probe indicated the technique to be quite promising for measuring density variations; porosity had no apparent parametric influence on the values obtained. It was suggested by Zurbrick that development was needed to determine the electric field characteristics of stable low-frequency dielectric probe devices in order to fully apply this promising method to organic, non-metallic materials.

Dielectric measurements were also investigated by Smith[23] for the nondestructive evaluation of fiberglass/epoxy specimen panels. The panels were manufactured from four sheets of 2P-181-Volan A glass cloth impregnated with Epon 826-Methane Diamine epoxy resin. Specimens were made with various resin contents and laminating pressures resulting in widely varying thicknesses and different resin glass ratios from panel to panel. A capacitance probe was used to measure the thickness and resin-glass ratio to an accuracy of better than $\pm$ 5%. Results agreed well with those derived from parallel plate capacitor theory.

A one-sided probe arrangement shown in Figure 4 was also investigated by Smith.[23] A graph of the probe output versus panel thickness is shown in Figure 5. Since the output includes the effects of variations in both thickness and dielectric constant, the technique should be used only in a comparative sense. The authors suggest that the approach could be applied in a go-no go system. Advantages of the technique are that the probe is simple mechanically and electrically and the test procedure is straightforward; however, calibration is required. Also the method is not sensitive to voids and surface characteristics and will not detect cracks and delaminations.

Investigations have recently been described by Kovalev, et al. concerning the microwave determination of mechanical strains in glass reinforced plastic.[24,25] The reported work is directed toward developing an understanding of the influence of anisotropic properties of glass reinforced plastics on microwaves. In initial

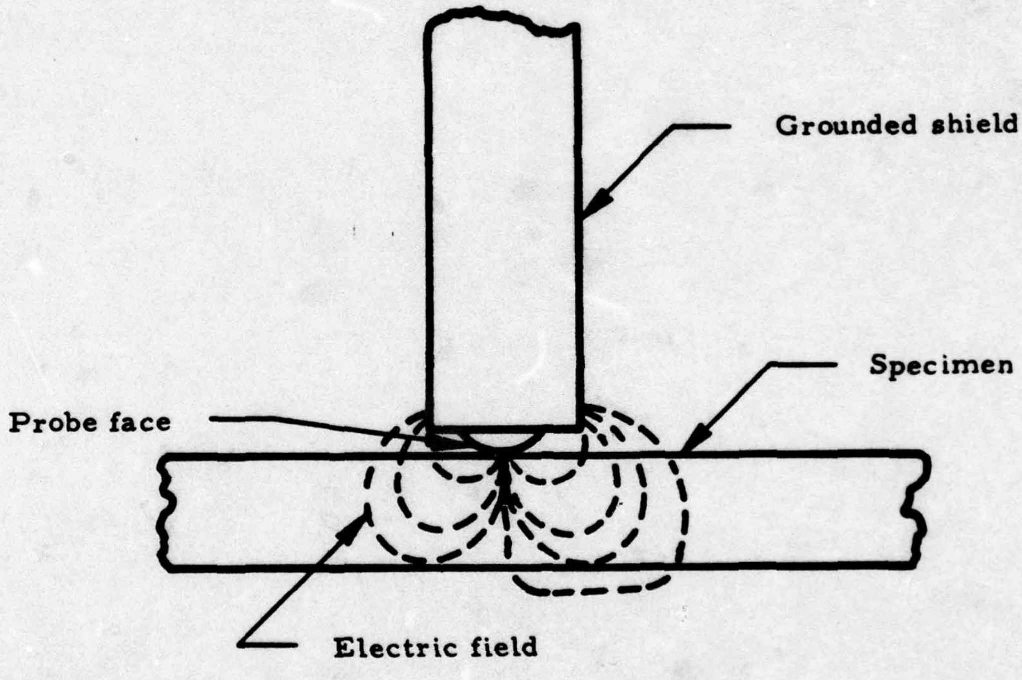


FIGURE 4. GEOMETRY AND ELECTRIC FIELD OF ONE-SIDED TEST.

(From Ref. 23)

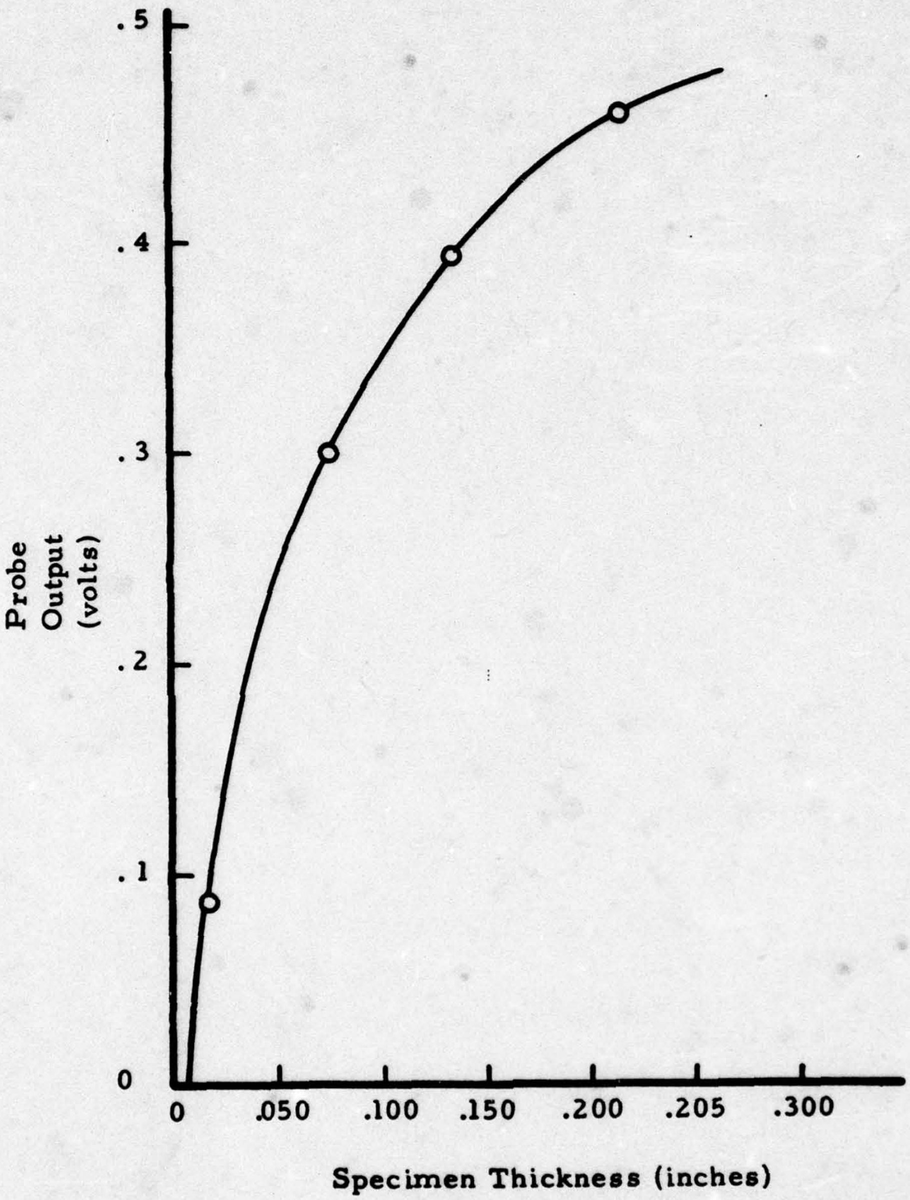


FIGURE 5. DETERMINATION OF LAMINATE THICKNESS BY ONE-SIDED TEST.

(From Ref 23)

work, a quasi-optical analog of a crystal refractometer operating on millimeter waves (4-8 mm) reflected from the investigated specimen was used.[24] It was found that reinforced plastics behave like pseudo-crystalline media with a type of "lattice" formed by interweaving of strands. The direction of the principal axes of electric anisotropy were determined as well as the dielectric constants along the principal axes. The authors indicate that the semi-automatic apparatus can also be used to investigate the dependence of the structure of a glass reinforced plastic on the arrangement of the reinforcing layer, the type of weave, the glass content, the distribution of the resin, etc.

In follow-up work, Kovalev, et al. developed a theoretical basis for the relation between changes in electrical parameters of glass reinforced plastics and mechanical load which displaces the reinforcement fibers.[25] The theoretical model was corroborated by experimental results obtained on glass reinforced plastic tubes loaded by internal pressurization. Dependence of the dielectric constant on deformation was determined using a microwave interferometer adapted for measurements of reflected waves. Measurements were made by comparing the phases of the signals reflected from the investigated tube with the phase of the signal from a standard tube. Results obtained for two directions of the electric field vector are shown in Figure 6. Since the graphs in Figures 6a and 6b have different slopes it is possible to obtain the strain distribution by measuring the dielectric constant with the electric field vector oriented in different directions relative to the fiber directions (directions of the principal axes of anisotropy).

4. Acoustic Emission

Acoustic emission testing of materials generally involves the detection of stress waves produced by deformation or cracking in the material as it is placed under load. Acoustic signals are detected by sensitive transducers placed on the surface of the specimen. Various characteristics of the signals such as the number of pulses, frequency content, and rate of occurrence can be related to the extent of deformation or cracking. As applied to fiberglass composite materials, acoustic emission response has been shown to be related to fiber fracture, ultimate strength of the composite, and manufacturing process changes.

Rotem and Baruch[26] studied the effect of tensile stress on acoustic emission from unidirectional fiber composite specimens of E-glass and epoxy. Upon applying a constant stress, acoustic emissions occurred rapidly at first and then decreased with

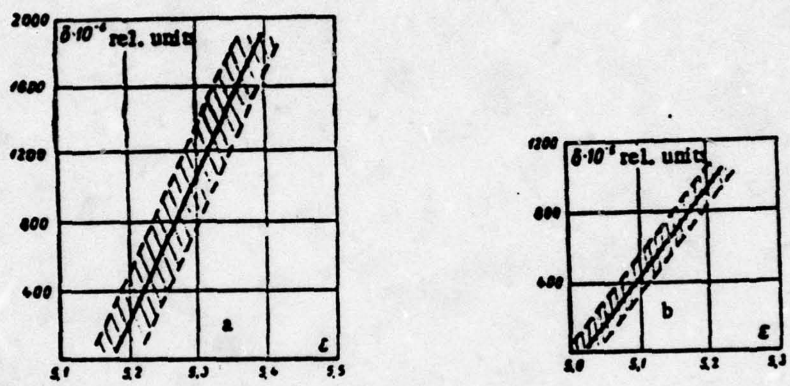


FIGURE 6. RELATION BETWEEN THE DIELECTRIC CONSTANT AND THE DEFORMATION OF THE TUBE MEASURED ALONG THE TANGENT TO THE TUBE CROSS SECTION (a) AND AT AN ANGLE OF 45° TO THE GENERATOR (b).

(From Ref. 25, published by Plenum Publishing Corporation, New York, New York 10011.)

time. This behavior was interpreted in terms of fracture of individual fibers which generate acoustic emissions. Fiber fracture continues at constant load because of the visoelastic nature of the matrix which leads to a redistribution of stresses with time. Figure 7 is a plot of stress, total counts, count rate, and theoretical relative number of fractures versus time for a constant rate of axial tension. Experimental data agree with calculations of fiber fracture behavior. Rotem and Baruch concluded that failure of the material is due to accumulation of fiber fractures which can be detected by acoustic emission.

The relationship of acoustic emissions to glass fiber fracture was also determined by Morais and Green[27] who performed acoustic emission experiments during hydrostatic tests of filament wound glass-reinforced epoxy rocket motor cases. In addition to fiber fracture, glass fiber laminar motion also generated acoustic emissions. These two acoustic emission sources were determined by analyzing amplitude and frequency components of the acoustic emission data and were shown to be significant for establishing structural integrity of the cases. Figure 8 shows characteristics of the data which describe these sources. A relationship was obtained between acoustic emission response and the burst pressure of the chambers as shown in Figure 9. Acoustic emission data taken between 20 to 40 percent of the full hydrotest pressure allowed prediction of the chambers' burst pressure. The acoustic emission response was also shown to be sensitive to detecting manufacturing process changes, e. g. a change in case material and a manufacturing change in mandrel design were both readily detected. Figure 10 shows the acoustic emission responses to the case material change in the upper and middle curves and mandrel change in middle and lower curves.

The relationship between acoustic emissions and ultimate strength of fiberglass was studied by Dethov[28] in experiments on rings (150 mm diameter, 8 mm wall thickness) loaded in compression. Acoustic emission pulse rate was shown to give a quantitative indication of the ultimate load. This was done by loading the test object until the pulse rate exceeded a rejection level determined from a calibration specimen. The ultimate load could then be calculated from appropriate equations. Cleavage defects affect the relationship between load and the acoustic emission pulse rate and could be detected by monitoring the pulse rate as the object was loaded up to 50% of ultimate load.

Rusnak[29] performed an evaluation to determine the feasibility of detecting fatigue crack initiation and growth in helicopter rotor systems under dynamic load. Laboratory tests were conducted first on fatigue bending specimens of S-glass/epoxy composite and

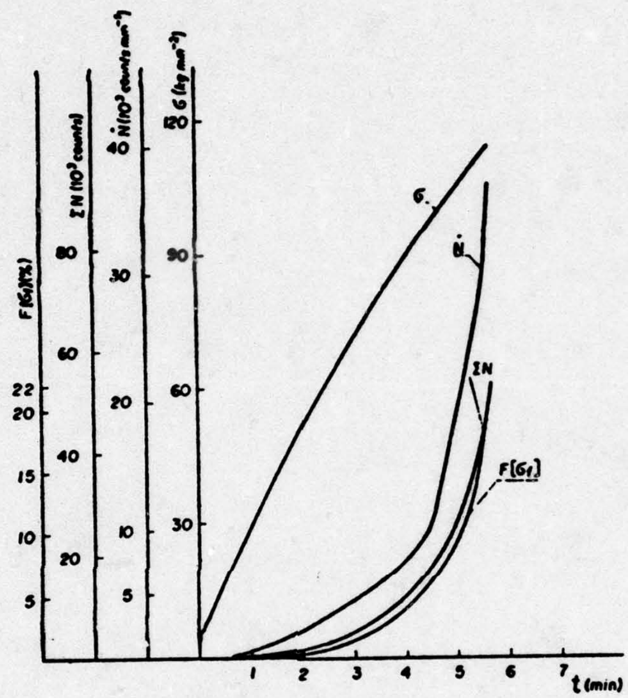
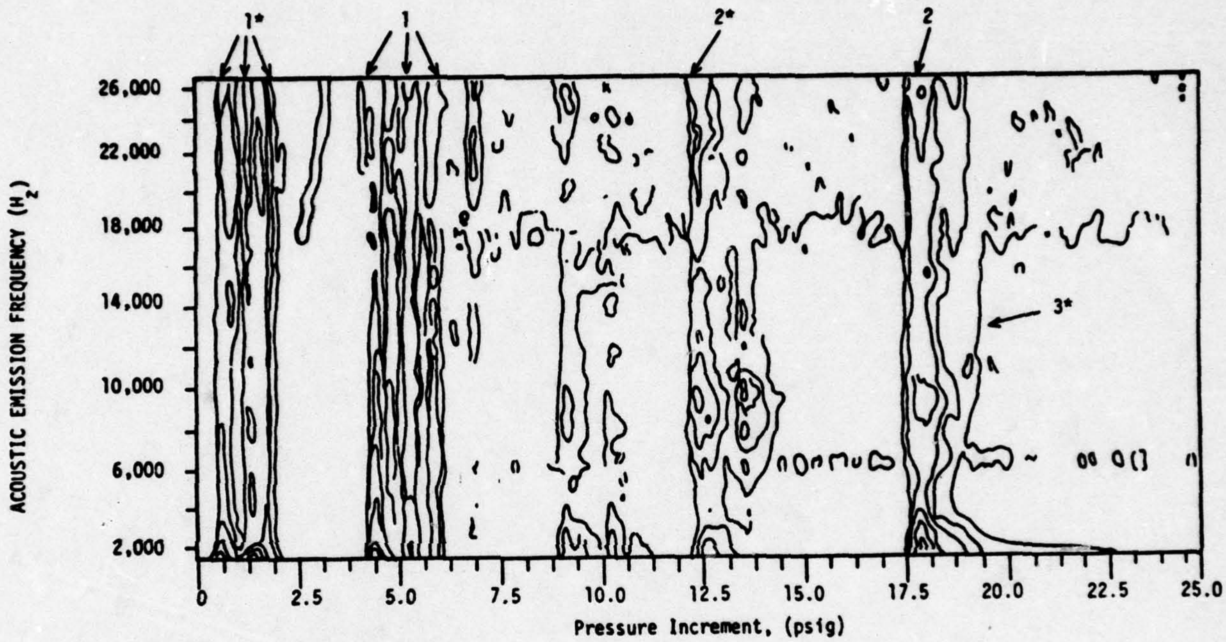


FIGURE 7. STRESS (G), TOTAL COUNTS (Σ N), AND RATE ($\dot{N}$) VERSUS TIME FOR CONSTANT RATE OF AXIAL TENSION OF UNIDIRECTIONAL FIBRE COMPOSITE. THE THEORETICAL RELATIVE NUMBER OF FRACTURES $F[G_f]$, IS ALSO SHOWN.

(From Ref. 26, reproduced by permission of Chapman and Hall Ltd., London, England.)



*NOTES: 1. Filament Failures
2. Interlaminar Shear Failures
3. Amplitude Shown as 6dB (Acceleration Ratio of 2) Between Contours

FIGURE 8. ACOUSTIC EMISSION FREQUENCY VERSUS PRESSURE INCREMENT.

(From Ref. 27, published by American Society for Testing and Materials, Philadelphia, Pennsylvania.)

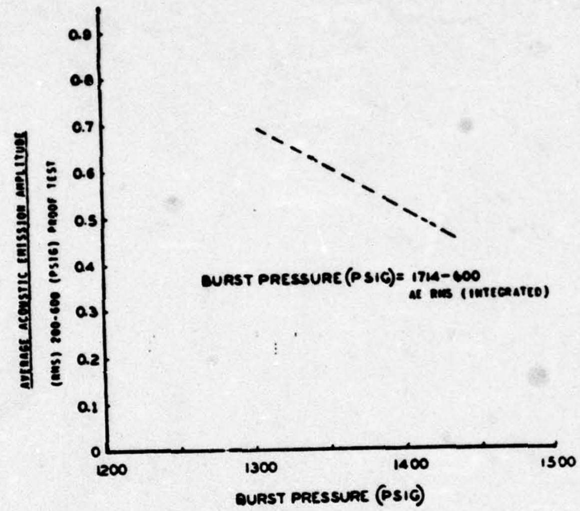


FIGURE 9. INTEGRATED ACOUSTIC EMISSION AMPLITUDE VERSUS CHAMBER BURST PRESSURE.

(From Ref. 27, published by American Society for Testing and Materials, Philadelphia, Pennsylvania.)

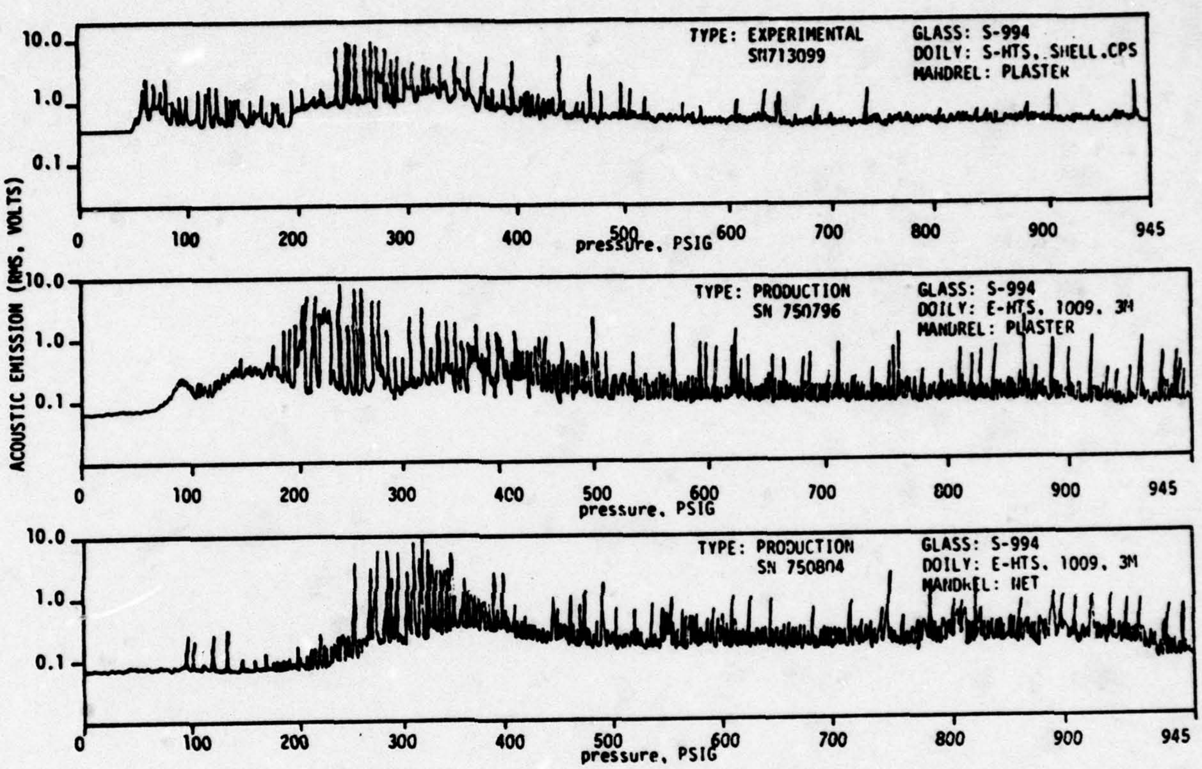


FIGURE 10. ACOUSTIC EMISSION VERSUS PRESSURE FOR EACH OF THREE MOTOR CASES.

(From Ref. 27, published by American Society for Testing and Materials, Philadelphia, Pennsylvania.)

2024-T3 aluminum which are both used as rotor skin materials. Fatigue tests showed that acoustic emission was capable of detecting small cracks in the fatigue samples. Tests were then extended to fatigue testing of inboard and outboard sections of actual rotor blades. The acoustic emission technique was shown to indicate impending blade failure by an increase in count rate which began at 50 to 80% of the blade fatigue life. Although additional testing is needed, the technique holds promise for an onboard (diagnostics) system for detecting impending failure in helicopter rotor systems.

5. Thermal Techniques

Thermal test techniques as applied to fiberglass composites find their widest use in the detection of disbonds or delaminations, although other defects such as inclusions, thickness variations, and fatigue damage have also been detected. Thermal techniques generally respond to differences in heat transmission or absorption caused by different thermal conductivity of defects in the test object. The object is usually heated by an external source while heat transmission or absorption is monitored by a suitable heat detector such as infrared camera or heat sensitive coating painted on the surface.

Maigret and Jube[14] evaluated several thermal sensing techniques for detection of interlaminar defects in fiberglass materials. The sensing methods utilized pyrometers, infrared cameras, and liquid crystals applied to the surface. Thermography by means of an infrared camera was judged to be the most reliable thermal inspection technique. Color thermography, where the temperature differences are displayed as different colors allowed a more quantitative analysis than a black and white presentation.

A thermal image transducer arrangement was used for debond detection by Green.[30] In this technique, heat is applied to the specimen by passing electric current through an electrically conductive layer placed on top of a dielectric layer in contact with the specimen. The temperature in each portion of the conductive layer depends on the local thermal impedance of the specimen which is altered if a defect is present. The temperature of the conductive layer is monitored by a temperature sensitive coating or an infrared camera. This thermal transducer arrangement was tested on bonds formed by cementing fiberglass sheets together with epoxy. The bond line between a 0.79 mm-thick outer wall and a 1.59 mm-thick reinforcing beam could be readily imaged and defects in the bond could be detected. A disbond between an aluminum doubler plate and a fiberglass doubler was also imaged.

Potapov, et al.[31] reported the use of a scanning infrared instrument to detect an artificial lamination-type defect in 7-mm-thick glass-fiber reinforced epoxy. A naturally occurring defect in 30-mm-thick fiberglass casing was also detected. This defect begins as increased porosity and changes to delamination with a separation of 0.1 to 1.5 mm. An artificial defect caused by lack of cementing in a three layer material of foam plastic sandwiched between fiberglass layers was also detected.

Inclusions and thickness variations in Epon 826 resin reinforced with 181 glass cloth were detected by Craig, et al.[32] The thermal device used in these experiments contacted one side of the specimen with a heat source and the opposite side with a heat sink to establish heat flow which was measured with thermocouples. Several specimens were fabricated with artificial inclusions of sawdust, aluminum filings, paper, an aluminum foil stack, Teflon tape, release agent, lamp black, vinyl tape, copper, brass, and steel. Resolution of most inclusions was good and all inclusions except Teflon could be detected. Detection of the thin layer of release agent is important since a defect of this type could easily occur in production. Thickness measurements of specimens showed that thickness could be measured with good resolution up to about 3.30 mm. Error in thickness measurements ranged from ±3.75% for 0.41 mm material to ±16% at 3.30 mm to ±27.1% for 5.33 mm thickness. Although no specific studies were performed, strong indications were obtained that this thermal testing device may also be used for determination of surface finish, resin-glass ratio, and extent of cure.

An alternate form of thermography was used by Nevadunsky, et al.[17] to detect fatigue damage in ±45° E-glass/epoxy laminate during fatigue testing. Localized heating due to fatigue damage was detected by temperature sensitive coatings on the specimens. Specimens subsequently fractured at the area indicated by heating. It was suggested that thermography could be used in this manner as an in-service fatigue damage detection method.

6. Holographic Techniques

Holographic interferometry is useful for composites inspection as a means of locating flaws which cause displacement of the surface when a load is applied.[33] Loading may be mechanical, thermal, or acoustic. Subsurface flaws may be detected as long as they produce a slight change in the movement of the surface. Interference fringes on a hologram of the object show the size and amount of surface displacement and thus indicate defect location.

Grunewald, et al.[33] applied holographic interferometry to defect detection in glass fiber reinforced plastic sheets used for printed circuit boards. Several types of defects were introduced. These included cuts in an upper fabric layer, delaminations, and delaminations in combination with a cut. Specimens were loaded mechanically and by acoustic stimulation. Using mechanical loading, a 25 mm long cut was readily detected in material with two reinforcing layers and with increasing number of layers up to nine. Twelve-mm long delaminations in five and nine layer material could be detected with proper positioning of the specimen under bending load. A cut and a delamination in the same sheet were also readily detected. Overlapping could be detected in a sheet of four layers of reinforcing material. Holographic interferograms of sheets containing air voids showed no indication of this type defect. Tests using acoustic stimulation for loading were not completed; however, it appears that flaws can be detected by this technique if the flaws hinder or prevent development of vibration modes.

Holographic interferometry as a means of detecting fatigue damage and stiffness loss was studied by Nevadunsky, et al.[9,17] The damage accumulated during the fatigue life of an E-glass/epoxy laminate (±45°) specimen was characterized by holographic and ultrasonic C-scan tests and microscopic examinations. The specimen was cycled in an axial mode with a maximum stress of 55 MPa and stress ratio R = 0.1. At 0.05×10^6 stress cycles an increase in fringe lines in the hologram indicated an overall loss in stiffness of 8% as determined by dynamic strain measurements. Ultrasonic C-scans for this number of stress cycles showed no appreciable local defects. The loss of stiffness was believed to be caused by fiber/matrix debonding to which ultrasonics is not sensitive. At 0.2×10^6 cycles, holographic fringes indicated a greater and more localized stiffness loss which was measured as 18%. Ultrasonic inspection at 0.2×10^6 cycles indicated the presence of localized damage caused by concentrations of resin cracks and fiber/matrix debonding. After 0.75×10^6 cycles the fringe pattern indicated an even greater stiffness loss which was determined to be 28%. Ultrasonic C-scans at this number of cycles indicated more damage and resin cracks and fiber/matrix debonds could easily be detected. Additional inspection of a graphite/glass/epoxy specimen showed that local damage under a doubler plate was detected by holography but not by ultrasonic C-scan. The specimen subsequently fractured at this location.

Nevadunsky, et al.[9,17] also compared holographic and speckle interferometry techniques for fatigue damage detection. Holography was determined to be more sensitive for this particular application. Smaller changes in the fringe shapes could be seen with holography than with the speckle interferograms and the speckle interferograms were more difficult to interpret, although this trend may not generally be true. It was suggested that speckle techniques are potentially useful for NDE and should be improved since this method measures in-plane motion (as opposed to out-of-plane motion by holography) which is directly related to stiffness losses in specimens with uniform degradation.

7. Dynamic Properties Measurement

A class of NDE measurements for composites which is aimed at determining the actual strength and stiffness of the material rather than locating discrete flaws has received a considerable amount of attention. These measurements involve determination of dynamic mechanical properties such as elastic modulii and damping coefficients by measuring specimen response to externally introduced vibration. Changes in these mechanical properties have been shown to be related to overall fatigue damage and strength of the material.

A sonic frequency vibration testing technique was applied by Schultz and Warwick(34) to laminated, 3M Scotchply 1002 glass fiber reinforced epoxy beam specimens. The specimens were excited over a variable frequency range and the resonant frequencies and their bandwidths were measured to determine damping ratio and modulus. It was found that a decrease in resonant frequency and increase in damping ratio correlated with fatigue damage due to cracking. Decreases in resonant frequency were small (10% for the most heavily damaged specimens), but increases in damping ratio were much larger, ranging from 10% to 100%. Figure 11 shows changes in damping factor with fatigue time for four specimens. Examinations of the specimens showed that those which had damping ratio changes exhibited significant cracking. Results indicated that sonic frequency vibration testing is promising for nondestructive evaluation of in-service strength and stiffness degradation of fiber-reinforced epoxy structural members. Schultz and Warwick suggested that practical, low cost instruments could be developed for in-service NDE of load-bearing members by periodic measurement of damping ratios.

Sims, et al.(35) used dynamic mechanical measurements in tests for correlation with specimen damage. Vibration resonance, torsional pendulum techniques were used for mechanical property measurements. The torsional pendulum utilizes low frequency and high strains to determine the dynamic shear modulus and damping factor of

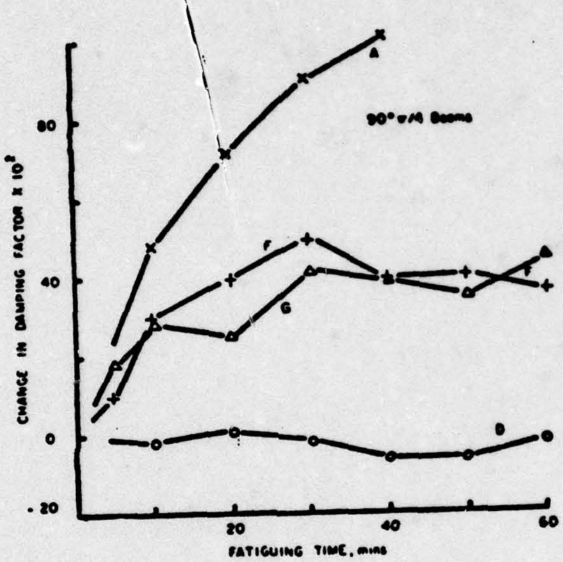


FIGURE 11. INCREASE IN DAMPING RATIO WITH FATIGUING TIME IN 90° — π/4 SPECIMENS.

(From Ref. 34, reproduced courtesy of The Journal of Composite Materials, Technomic Publishing Co., Inc., 265 Post Road West, Westport, Ct. 06880, U.S.A.)

the specimen. Good correlations were obtained between the dynamic properties and crack area in 0°/90° cross-ply glass reinforced plastic laminates. Figure 12 shows the relationship between dynamic properties (presented as tensile modulii times change in damping factor) and crack area for two samples. It was not established if dynamic mechanical measurements can be used for prediction of crack concentration in other geometries since additional work is needed to establish more general correlations between damage and test data. The effect damage has on property degradation also needs to be determined so results can be interpreted more reliably in terms of actual specimen strength.

Adams, et al.[36] also utilized a torsional pendulum to determine damage due to static and fatigue torsional loads. Specimens were fabricated from glass fiber/epoxy (E-glass/DX210). In static tests specimens were incrementally loaded up to and beyond failure in torsion and dynamic property measurements were taken at each load increment. In fatigue tests the specimens were removed from the fatigue machine and dynamic properties measured at stages throughout their fatigue life. Cracking in the specimens was monitored visually. Deterioration of the material due to shear cracks from both static and fatigue testing could be determined by dynamic properties measurement. Figure 13 shows the relationship of dynamic shear modulus damping and crack length as functions of fatigue cycles for one specimen. Generally, the modulus and damping showed permanent and transient changes when progressive cracking took place. Material degradation could be sensed prior to large reductions in stiffness of the material. No simple correlations were obtained between virgin dynamic properties and the load capacity of the material.

Another form of vibration testing which lacks the preciseness of more sophisticated tests is "coin tapping". This technique involves tapping the specimen with a coin or other metallic object and listening to the change in pitch of sound over flawed regions. Nevadunsky, et al.[9, 17] report that coin tapping is a poor indicator of early fatigue damage and that significant defect indications were observed only at areas where damage was easily observed visually. Coin tapping may perform better on larger structures where changes in audible pitch could be greater.

C. Kevlar Reinforced Epoxy Composites

Information on NDE of Kevlar reinforced epoxy composites was extremely limited; only two documents resulting from the literature search contained any relevant NDE material.

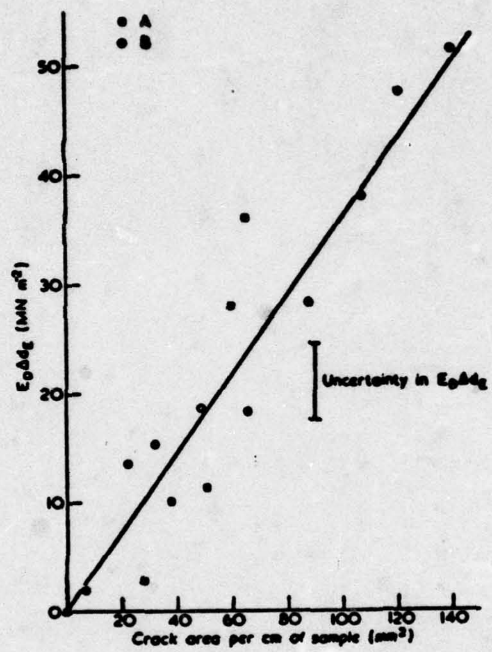


FIGURE 12. DEPENDENCE OF $E_D \Delta d_E$ UPON CRACK AREA FOR 0°/90° LAMINATE SAMPLES.

(From Ref. 35, reproduced by permission of Chapman and Hall Ltd., London, England.)

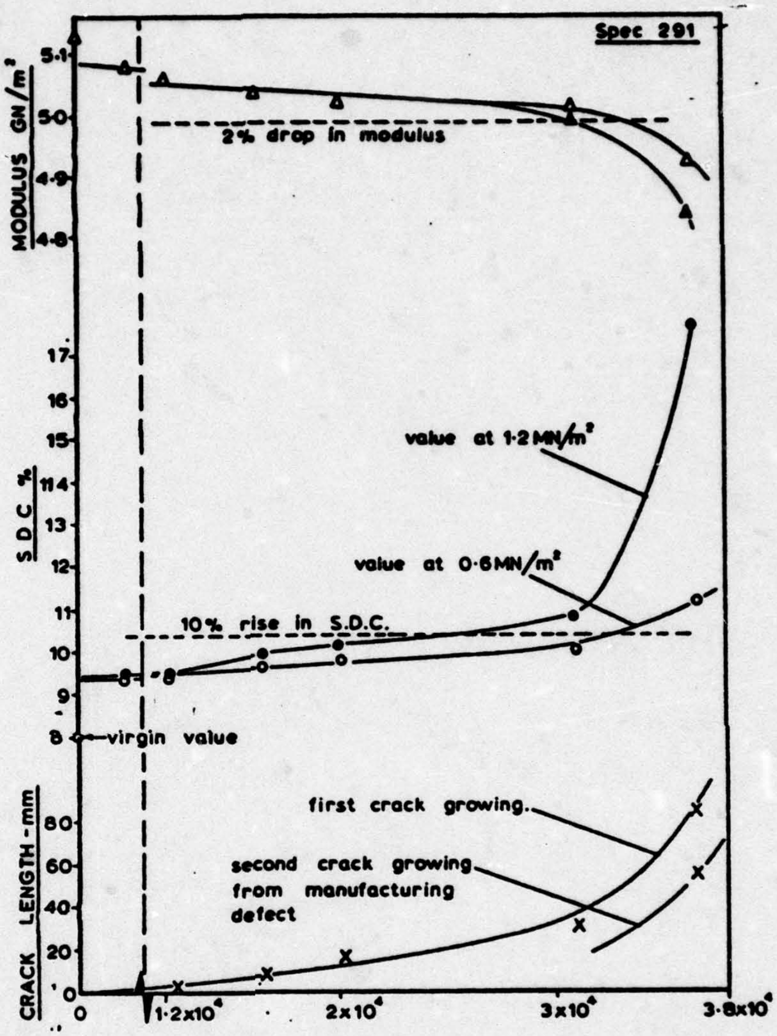


FIGURE 13. VARIATION OF DAMPING, DYNAMIC MODULUS, AND CRACK LENGTH WITH FATIGUE HISTORY OF GLASS FIBER SPECIMEN NO. 291.

(From Ref. 36, published by American Society for Testing and Materials, Philadelphia, Pennsylvania.)

A report by Hamstad and Peterson[37] deals primarily with calibration of a test fixture for acoustic emission monitoring of an aluminum lined spherical Kevlar/epoxy pressure vessel. Experimental data are very limited, but it is reported that both local and global acoustic emission events were detected as vessels were pressurized. Global events could be detected at more than one transducer location while local events could be detected at only one location. The global events appeared to be most closely related to the eventual failure pressure. Techniques to remove local events from the acoustic emission signal were not successful. A series of 17 vessels were proof tested and monitored for acoustic emission but no data were given.

In work by Hamstad and Tatro[38] on acoustic emission from Kevlar 49/epoxy composites only the abstract was published. The time and frequency domains of acoustic emission signals generated during loading of the composites were studied and low frequencies were found to predominate. Effects of composite thickness, transducer type, and load level were also reportedly examined. No data were given in the abstract.

D. Graphite Reinforced Epoxy Composites

As stated in the Executive Summary, the primary thrust of this survey has been on NDE of fiberglass/epoxy composites because of their use in Army helicopter rotor blades. Recent literature, however, on NDE of composites has been largely in the area of graphite reinforced expoxy composites because of the increasing use of this material by the aviation industry (fixed-wing aircraft). To acquaint the reader with the current state-of-the-art on NDE of graphite/epoxy composites in aviation applications, a summary is presented here based on a review of the abstracts of relevant documents.

In a recent publication, a comparative evaluation of potential NDE techniques for inspection of graphite composite aircraft structures is given by Sheldon.[39] Emphasis was placed on application of an acoustic imaging system with a portable X-Y scanner and a flex-arm mechanical hand scanner. Graphite composite structures used in the evaluation were: (1) a wing flap, fuselage bulkhead panel, and a T-38 wing section containing manufacturing flaws; (2) a wing attach trunnion fitting exhibiting a major transverse crack in addition to bearing failure at the lug; (3) an access bay door and several test panels with simulated flaws (precured adhesive discs and foreign object impact damage); (4) a horizontal stabilizer; and (5) a panel mounted in a fatigue test fixture. Each structure was inspected using either ultrasonic resonance, focused image holography, pulse-echo C scan, B scan and 3D scanning techniques. Selected structures were also inspected using a mobile laser holographic system, radiography, Fokker bond tester and a Sondicator.

Acoustic emission techniques were evaluated by Moore for inspecting aerospace components during static and fatigue testing.[40] Components tested included a multilaminated fuselage fitting, a conventional flap attach fitting, the attach lug of a steering component, and outer wing panel test articles. Results are being used to evaluate the applicability of acoustic emission for inspecting production wings scheduled for extensive in-flight testing.

In-service NDE has been conducted by Boeing Company on graphite/epoxy spoilers on 737 transport aircraft and compared with graphite/epoxy material subjected to ground-based environmental exposure.[41] After a total of 766,938 spoiler flight hours and 1,168,090 spoiler landings, there was no evidence of moisture migration into the honeycomb core and no core corrosion based on visual, ultrasonic, and destructive testing. Tests of spoilers removed from flight service and of ground-based exposure specimens after the third year of service continue to indicate modest changes in composite strength properties.

The development of standards and field inspection techniques for the ultrasonic NDE of S-3A graphite/epoxy spoilers was reported by Blosser, et al.[42] Preliminary reference panels were constructed to determine: the best material for producing artificial defects, the minimum detectable defect size, the influence of varying the number of skin plys, the influence of the amount of resin on attenuation properties, and the influence of the amount of bleeder material used on attenuation and physical properties. All reference panels were characterized by radiography, ultrasonic through-transmission (immersion and contact) and ultrasonic pulse-echo methods. Results indicated that ultrasonic through-transmission was a reliable and sensitive method for detecting delaminations or debonds as small as 6.35 mm diameter in the solid laminate areas and 12.70 mm diameter in the honeycomb areas of the composite spoiler. Although through-transmission could locate and define the dimensions of a delamination or debond, it could not provide information on the distance of the defect from the surface of the part.

Nondestructive flight-service evaluation of graphite/epoxy upper aft rudders for the DC-10 aircraft has been recently described by Hagemaier.[43] The rudders will be monitored for a five-year period as part of a program to develop experience and confidence in composite structures through design, fabrication, certification, and flight-service evaluation. Prior to rudder fabrication, laminates and test specimens were manufactured and evaluated. It was found that visual, ultrasonic C-scan, dye penetrant, and 10 to 50 kV X-rays are useful for evaluating these materials for processing defects or cracks and delaminations which are generated by mechanical testing, fatigue testing, or impact damage. Flight-service inspection will be performed using contact pulse-echo ultrasonics or the Fokker bondtester for the detection of delaminations, porosity or voids.

E. Boron Reinforced Epoxy Composites

As in the case of the graphite reinforced composites discussed in the previous section, the summary presented in this section on NDE of boron fiber reinforced epoxy composites is based on a review of only abstracts of selected relevant documents. Thus, the discussion is brief, but should help the reader to become acquainted with the NDE state-of-the-art in this area.

Development and evaluation of an ultrasonic internal velocity measurement technique is reported by Hastings, et al.[44] Results indicate that this method is a practical and useful tool applicable to the evaluation of boron/epoxy laminates used for structural components. For the laminates studied, best results were achieved in the 0 and $\pi/2$ rad directions; unbalanced laminates led to greater errors in the $\pi/4$ rad direction. Measurements made off-angle with respect to the reinforcing filaments were not reliable. Based on interval velocity measurements, correlations were developed for modulus and tensile strength prediction. The internal velocity method proved to be better than tensile tests for predicting modulus (i.e. there was less scatter in the ultrasonic data) and as good as tensile tests for strength determination. Yield strengths could not be correlated because of excessive scatter in the tensile test data.

A report by Schultz[45] is concerned with the development of nondestructive testing techniques for quantitatively evaluating advanced fiber reinforced composites. Boron/epoxy panels having different ply configurations were fabricated and tested for mechanical properties behavior and physical properties characteristics. It was found that useful predictive correlations exist between ultrasonic elastic modulus and mechanical properties. Qualitative agreement was obtained between micro-mechanics theory and the polar modulus determined ultrasonically. The interval velocity technique was shown to have only limited application in determining polar modulus values.

Cooper, et al. reported on the NDE of boron/epoxy structures after aircraft service testing.[46] Rudders fabricated using boron/epoxy skins were flown on operational aircraft and evaluated using a number of NDE methods. Ultrasonics, eddy current, and radiographic methods were shown to be effective for detecting bondline flaws and honeycomb core corrosion.

Acoustic emission experiments were reported for tensile loading of unidirectional boron/epoxy and for aluminum sheets reinforced with unidirectional boron/epoxy.[47] Different prepreg materials are found to have different characteristic acoustic emission patterns. Results from composite-reinforced metal specimens show that early failures are accompanied by a sharp increase in acoustic emission count rate at the knee of the bilinear stress-strain diagram. It is further shown that the count rates are a function of specimen fabrication and that higher total counts do not necessarily correspond to early failures.

Methods of increasing confidence in bonded composite assemblies by upgrading quality assurance procedures were reported by Cook and Hussman.[48] Surface electrical resistivity was identified as a potential quality control tool for titanium cleaning prior to adhesive bonding. Defects in boron/epoxy laminates and boron/epoxy-titanium splice joints could be effectively located by an ultrasonic through-transmission, reflector plate C-scan test. Radiography was found to be most suitable for inspecting substructure, i.e., honeycomb core and edge member-to-core bond lines. The ultrasonic through-transmission system with a focussed search unit and a focussed receiver was found to be the best method of detecting skin-to-honeycomb core unbonds.

TABLE VII

APPLICATION OF NDE METHODS TO FIBERGLASS REINFORCED EPOXY COMPOSITES

Defect/Property Variations	Ultrasonics	Penetrating Radiation	Acoustic Emission	Holography	Thermal	Electromagnetic	Other
Inclusions	10, 12	13, 17			4		Vis-10, 12
Debonds/Delaminations	17, 10, 23, 12, 100	13, 17		16	2, 17, 31, 109	Microwave-97	Vis-12
Voids	19, 29, 101, 12	13, 101		16	28	Microwave-5, 25	LB-28, CD-28, AH-26 Vis-12, 41
Cracking		17					Vib-20, Pen-12
Defects (General)	106						Pen-17, Vis-17
Fatigue Damage	8, 27, 37, 30	8, 30	30, 48	8, 27	30, 8		Pen-8, 30, Coin Tap-8, 27 WAE-30, Vib-110, 20
Resin Rich/Starved Areas	10	17					Vis-17
Uncured Areas	10						Vis-17
Broken Fibers		17	9, 6	16			Vis-17
Fiber Alignment	35	17					Vis-30
Prepreg Folds	10						
Thickness	12				4	Dielectric-1	
Elastic Properties	7, 35, 29	7				Dielectric-7	Vib-30. 110, 3, 20
Volume Fractions	7, 19, 29, 12	7, 5, 12				Dielectric-7, 1 Microwave-12, 29	
Porosity	29, 12				2		
Damping Measurement	39						Vib-30. 110, 3, 20
Density		29. 13				Microwave-97 Dielectric-29	
Strain Measurement						Microwave-33, 34	Percussion-40
Dynamic Behavior			40				
Identification of Material						Dielectric-15	
Strength			9, 36,				Vib-110
Moisture Degradation	21, 22					Dielectric-11	Vis-22

LB-Laser Backscatter
CD-Corona Discharge
AH-Acoustic Holography
WAE-Work Absorption Evaluation
Vib-Vibration
Pen-Penetrant
Vis-Visual

TABLE VIII

APPLICATION OF NDE METHODS TO GRAPHITE FIBER REINFORCED EPOXY COMPOSITES

Defects/Property Variations	Ultrasonics	Penetrating Radiation	Acoustic Emission	Holography	Thermal	Electromagnetic	Other
Inclusions	79, 96	79, 96					
Debonds/Delaminations	72, 79, 17, 96, 74, 56	79			83, 17		Pen-96
Voids	49, 96, 56				83		
Cracking	96	96	65				Pen-96
Defects (General)	59, 56, 77, 84	59, 84, 56	84	59	84, 82, 80		Pen-84, 17, AI-59 Vis-56, 77, 84, 17
Fatigue/Impact Damage	57, 58, 8	57, 61, 8	64, 63, 57, 75	8	58		Pen-8
Resin Variations	79	79, 17					
Cure Variations	79	79					
Fiber Alignment		60, 17					Vis-17
Broken Fibers		17					
Volume Fractions	55	62				Eddy Current-96	
Porosity	55, 79, 96, 56	79, 96					Pen-96
Density	79	79					
Thermal Distortion				69			
Strength	55, 85,	112					
Stress							
Moisture Degradation/Content	50, 68, 54, 52, 53, 51, 81				68, 76, 81	Microwave-52	Vis-53, Dyn Mech Spect-52, 81, NMR-52, Elec Res-73
Reference Standards	79, 74	79, 74					
Resin Chem. Comp							NMR-78
Resin Cure						Dielectric-96	

Vis-Visual
Pen-Pentrant
Elec Res-Electrical Resistance
NMR-nuclear magnetic resonance
Dyn Mech Spect-Dynamic Mechanical Spectroscopy

TABLE IX

APPLICATION OF NDE METHODS TO BORON FIBER REINFORCED EPOXY COMPOSITES

Defects/Property Variations	Ultrasonics	Penetrating Radiation	Acoustic Emission	Thermal	Electromagnetic	Other
Debonds (at interface with adjoining material)	130, 132	130, 132			Eddy Current-130	
Voids	101	101				
Defects (General)	132, 141			139		Acoustic Image-140
Fatigue Damage		135	133, 137	135, 137		
Broken Fibers			136			
Mechanical Properties (including modulus)	129, 128, 134					
Mixture Concentrations		129				
Prepreg Material Variations			131			

make crack detection by means of wave propagation considerably more complicated than in ordinary metals.

These difficulties notwithstanding, ultrasonics is still the most used and accepted NDE technique for inspection of composites; especially for discrete flaws, e.g. delaminations, cracks, inclusions, and voids. The ultrasonic method is also useful for determining property and geometric variations such as porosity, concentration differences, glass content, thickness, and elastic modulus. As pointed out in the previous section, measurement of these properties depends on a change in ultrasonic velocity or attenuation. Recent studies indicate that pulse spectroscopy may offer another way to measure sound fluctuations caused by property variations in different compositions.

Ultrasonic inspection is used extensively by several helicopter manufacturers for inspection of fiberglass rotor blades.[49] For Example, at Boeing-Vertol automatic ultrasonics is used for inspecting the completed blade. Through-transmission is used to scan the blade for defects from the nose of the blade to the trailing edge and to inspect the core for cracks. Bell Helicopter employs ultrasonic through-transmission for inspecting fiberglass rotor blades using reference standards to set up an accept/reject criterion.[49]

B. Radiography

In addition to ultrasonics, the other NDE technique finding significant application in the inspection of composite materials is radiography. Work to date seems to indicate that for fiberglass/epoxy composites, neutron radiography is not suitable due to the dispersion caused by interaction with hydrogen and boron elements. Also, the method has been hampered for production use by the size, cost, and lack of portability of the equipment required. X-ray radiography is much more extensively used for all types of composites. It is a well established production technique, although safety considerations can impose restrictions, and is used to detect broken and misaligned filaments, foreign objects or inclusions in addition to water intrusion and entrapment. Among helicopter manufacturers both Boeing-Vertol and Bell use X-ray radiography for inspection of glass fiber rotor blades. At Boeing-Vertol, image intensification is employed based on an opaque detection yarn in the composite. X-ray scans are used to inspect for overall alignment as well as yarn lay-up, fiber washing and crinkling. X-radiography is also used to inspect the core for lay-up defects and delaminations.[49]

X-ray transmission inspection can be applied successfully for the detection of orientation defects or glass distribution defects in highly loaded filament-wound components. This technique is also capable of detecting large cavities in the rigid expanded plastic cores of thick-walled sandwich materials. These cavities have considerable influence on the stiffness, stability, and insulation behavior especially near the cover layer. With presently available X-ray equipment, it is possible to detect large flaws, air inclusions, and orientation and uniformity fluctuations in plastic composite materials as a function of the material thickness, number of layers, and type of reinforcement.

The X-radiography method will no doubt become increasingly important with further development directed toward improving the detail that can be resolved by suitable choice of film to focus distance, acceleration voltage (i. e., energy level), X-ray film, and exposure time. Also, further development is expected of more sophisticated techniques such as stereo transmission methods, video radioscopy, and tomography.

C. Electromagnetic

Microwave methods have been used in some production applications for thickness measurements and void detection in plastic sandwich structures. As pointed out in the previous section, a swept frequency approach can provide the capability for distance and depth discrimination. Various instrumentation advancements are being made which should provide for more easily used systems of greater versatility. The fundamental work being pursued by Kovalev, et al.[24,25] should help to provide an understanding of the relationship between the unique characteristics of glass reinforced plastics and the electrical parameters affecting microwaves.

Another electromagnetic approach which is promising for measuring concentration variations is the low frequency dielectric probe technique. The simplicity of the approach is attractive, although the results obtained are primarily of a qualitative nature.

D. Acoustic Emission

Acoustic emission has been investigated for microfailure analysis of composites for a number of years. The method is related to fiber fracture, ultimate strength, and manufacturing process changes. Under suitable test conditions acoustic emission analysis can indicate critical stresses in glass fiber reinforced plastic structures before destruction of the laminate. Frequency analysis of the acoustic pulses under favorable conditions can be used to separately determine fiber fracture or interfiber fracture. Most of the work on acoustic emission of composite materials has been research-oriented and performed in various laboratories although limited investigation of acoustic emission has been conducted for on-board diagnostics. As the understanding of the physical mechanisms responsible for the detected phenomena increase and the instrumentation technology improves, the method will no doubt find increasing use in field applications.

E. Thermal Techniques

Research on thermal related NDE techniques for the inspection of composites in recent years has shown that these methods are very promising as a nondestructive inspection tool. Work performed to date has been primarily confined to laboratory investigations with only limited applications reported. The method is able to provide information about the distribution of reinforcement fibers in the matrix material and to detect irreversible processes associated with generated and released thermal energy. Greatest utilization of the technique has been for the detection of disbonds or delaminations although other defects such as inclusions, thickness variations, and fatigue damage have also been detected. Two conditions that limit the sensitivity and therefore the usefulness of the method are:

1. The need for a high coefficient of thermal conductivity of the sheet or laminate material, and

2. The thickness of the facing sheet or laminate.

Despite these restrictions, thermal methods are able to fill needs for which X-ray and ultrasonic testing methods may not be adequate, and therefore merit further development.

F. Holography

Laboratory investigations of holographic interferometry have shown this method capable of detecting certain types of defects, for example stiffness loss associated with fatigue damage, not detected by other methods such as ultrasonics. The method is promising for large scale field application whereby an entire structure must be examined in a short time. Although feasibility of this application has been demonstrated under specialized laboratory conditions, additional difficulties are expected for field or in-service applications which would require development of application specific techniques.

G. Dynamic Measurements

Coin tapping has been an accepted NDE method for a number of years and is still used for indications of gross flaws. However, this method lacks the sensitivity and resolution required in modern technology. Determination of dynamic mechanical properties with more sophisticated approaches such as sonic vibration testing and damping measurements are very promising for providing information on actual strength and stiffness of the material. Results cited in Section II indicate that with suitable effort, practical, low cost instrumentation could be developed for in-service NDE of structural components.

IV. DISCUSSION

A. Recommended Development

Based on the results of the literature search, a summary is presented in Table X of efforts recommended to advance the state-of-the-art of the NDE of fiber reinforced epoxy composites. The intent is to recommend efforts that will result in useful and needed NDE approaches for the user community, on both a short term and long term basis. Three primary areas are identified:

1. In-Service Inspection - includes application of existing technology to improve production and field nondestructive inspection.

2. Laboratory Development - includes techniques that show promise for in-service application, but require further laboratory development. Also included are important inspection problems for which suitable techniques need to be developed.

3. Mechanics of Composites - includes areas requiring laboratory investigation to better understand what parameters and properties need to be measured nondestructively.

1. In-Service Inspection

Included in this group are those efforts and improvements which should result in relatively quick payoff at low risk at least in certain applications. The listed recommendations involve application of existing material testing technology and techniques to specific inspection problems. For example, in the case of rotor blade inspection, instrumentation technology currently exists for upgrading and improving the ultrasonic and radiographic approaches presently in use. Automated inspection systems could be developed to relieve operator reliance and provide signal acquisition and processing capabilities for inspecting large scale systems. Contour following sensor arrangements and computer assistance could be adopted for ultrasonic inspection of complex shapes.[50]

As discussed in Section II.B.2, methods have been under development for improving radiographic inspection procedures. Included are techniques for image enhancement, stereo radiography, and video radiography. Although these may not all be ready for field

TABLE X

RECOMMENDATIONS FOR ADVANCING NDE OF COMPOSITES STATE-OF-THE-ART

In-Service Inspection (Short Term - use existing technology)	Laboratory Development (Long Term with potential application)	Mechanics of Composites
Automated ultrasonics and radiography	Ultrasonic velocity	Failure mechanisms
Articulated ultrasonic sensors for application to complex shapes	Acoustic emission	Composite degradation
Incorporate signal acquisition and processing approaches	Microwave	
Radiography improvements (stereo, video, enhancement)	Low Frequency damping	
Large area field inspection	Thermography	
Development of reference standards	Holography	
	Moisture measurement	

application, they should be considered for the additional development needed to improve radiography state-of-the-art.

Automated radiography systems have also been undergoing recent development and can provide the basis for improved nondestructive inspection for specific applications.(51) A real time radiography system was recently demonstrated for aircraft inspection.(52) This system was developed for maintenance inspection applications and includes features such as portability and high resolution. Although intended for general aircraft application, the system was evaluated on certain aircraft composite structures and H-46 rotor blades which were inspected for corrosion in the spar. It appears that the basic system concepts may be applicable to real time inspection of composite rotor blades.

Also included under the In-Service Inspection group in Table X are development of large-area field inspection capabilities and improved reference standards. One potential approach that should be considered for large-area field inspection is holography. Although there are a number of practical problems to be overcome in using holography for field inspection on a part as large as a rotor blade, laboratory research cited in Section II has shown the method to be useful for inspection of composites and potentially for large scale applications. If holography could be developed for field application it would provide an important and useful procedure for rapid inspection of potentially detrimental conditions such as surface strains.

The need for improved and reliable reference standards was noted in several documents reviewed during the state-of-the-art survey. Because of the complex nature of composites, interpretation of results in terms of specific defects is often difficult and ambiguous. Thus, universally accepted reference standards are needed to allow proper interpretation of results. It appears from the literature survey that little attention has been devoted to this problem in the case of composites whereas universal standards are being developed and accepted for the inspection of metal parts.(53)

2. Laboratory Development

As indicated previously, there does not appear to be a pressing need for improving flaw detection sensitivity and resolution in composites since the critical flaw size is usually large compared to that in homogeneous materials. Development of methods that have the capability of providing information on strength related properties of composites and interlaminar bonds is needed. Methods which are promising for this measurement are ultrasonic velocity, low frequency damping, acoustic emission, and microwave. Laboratory research has been performed on all of these methods for the measurement of strength related properties in composites, but further work is needed to understand the relationship between the measured parameters and the strength of the composite. None of these methods has been explored to any extent with respect to field application, except for acoustic emission. This technique has recently been investigated for in-service detection of fatigue damage in helicopter rotor blades.[29] Tests were performed on dynamically loaded full scale helicopter rotor blade sections and the results demonstrated the feasibility of the approach for in-service inspection, although further verification is needed. According to the investigators, the acoustic emission method offers advantages for detecting rotor system cracks in that it is very sensitive, can simultaneously scan the entire system, and can function as a diagnostic system while the helicopter is operating thus serving to warn pilots before catastrophic failure occurs.

In addition to methods for measuring strength related properties, several other methods offer promise for large scale field inspection of composite systems including thermography and holography. Although only basic laboratory feasibility has been demonstrated in limited special situations, suitable developmental effort in understanding and interpreting the results, and in improving the measurement technique, could result in field applicable approaches for at least obtaining qualitative information. Such approaches are important to provide a rapid and overall field inspection capability resulting in reduced down time and maintenance cost.

Identified in the literature search and in previous surveys[5,54] as an important problem involving composites is environmental degradation. Many reports indicate that exposure of composite structures to temperature and humidity extremes reduces the useable service life and degrades the structural integrity. The moisture degradation problem is especially difficult to resolve because the distribution of moisture throughout the thickness of the material must be measured. The only method currently under development is a moisture diffusion method which depends on measuring effusing moisture and solving the diffusion equation to obtain the moisture distribution throughout the specimen. While this method appears to work in specialized situations, it relies on assumptions regarding the reversibility of moisture diffusion in the material which may not apply in more general circumstances. A candidate for providing the needed moisture information is nuclear magnetic resonance (NMR). This technique has been successfully applied for moisture measurement in a number of different materials and has the advantage of providing a direct measure of the amount of moisture present.[4] In addition, recent instrumentation advancements have established the feasibility of applying NMR to the inspection of large specimens.[55] In one application for which prototype hardware has been constructed, suitcase-size specimens are moved through a large magnet and detection coil on a conveyor belt.[56] Adaptibility of this approach to inspecting rotor blades for moisture ingress or determining characteristic properties of the epoxy matrix should be within the current state-of-the-art.

3. Mechanics of Composites

There is much discussion in the literature regarding a lack of information on the influence of specific defects and flaws on the structural integrity of composites. Thus, from an NDE standpoint, the question arises as to what needs to be measured. The mechanics of composites are very complicated due to the anisotropic and inhomogeneous nature of the material and the fact that the criticality of flaws depends on a large number of parameters such as loading conditions, lamination geometry, flaw location, flaw orientation, and flaw geometry. In determining what specifically needs to be measured nondestructively an understanding of failure mechanisms is necessary. The mechanics community has been devoting increasing attention to these problems in recent years and the failure mechanisms associated with fatigue cracks and voids have been addressed. However, there is still insufficient interaction between the mechanics community and the NDE community in the area of nondestructive evaluation of composites. Thus, a coordinated developmental effort should be directed at defining what types of flaws are important with respect to structural integrity of fiber reinforced epoxy composites and what parameters need to be measured nondestructively in order to assess the criticality of the flaws.

A similar argument can be presented regarding composite degradation. Questions that arise include: What is degradation? What is its relationship to strength? What is its relationship to structural integrity and service life? What properties or parameters need to be measured nondestructively? The answers to these questions involve a coordinated effort between mechanics investigations and NDE measurements and would help to develop a solid foundation for advancing the state-of-the-art of NDE of composites.

B. NDE of Composites Workshop

As the utilization and importance of composite materials in the aviation industry (and other industries) increases, the need arises for improved communication among the various groups involved in the field of composites. From the standpoint of NDE, the relevant groups include the NDE community, the mechanics of composites community, designers, and material fabricators. Since the last workshop devoted exclusively to the NDE of structural composites was held over five years ago (February 1974),[5] and many advancements have taken place in both the areas of NDE technology and composite materials since that time, it seems appropriate that another workshop devoted to this topic would be timely. Such a workshop would enable a direct interchange of ideas and problems among the various groups listed above. Therefore, a recommendation of the authors of this report is that such a workshop be held in order to bring to a focus the various factors associated with NDE of composites and provide guidance in the specific directions that should be pursued to advance the NDE state-of-the-art. To provide the best opportunity for a productive output it might be desirable to limit the scope of such a workshop, for example, to composites used in the aviation industry, or perhaps, just Army aviation composites. It also might be directed to a particular composite type, such as fiberglass, graphite, etc. Regardless of how such a workshop is structured, it should provide the opportunity to approach NDE of composites from the classical problem solving standpoint, that is, starting by identifying the problems that need to be solved rather than starting with assumed "solutions." Information generated by the workshop might be expected to lead to the following program for advancing the state-of-the-art of NDE of composites:

1. State the problems specifically and clearly -- define the requirements.

2. Assess the present state of affairs (utilize state-of-the-art surveys).

3. Establish achievable objectives.

4. Review all possible approaches (existing and proposed; short term and long term).

5. Perform preliminary evaluations of candidates with reasonable chance for success.

6. Select the most promising candidates (short term and long term).

7. Perform required developmental efforts.

8. Evaluate potential for both short term and long term success.

9. Incorporate quick payoff approaches into needed application areas.

10. Continue development of selected candidates for long term payoff.

Although this outline is not definitive, it could be expected that a properly conducted workshop would contribute greatly to providing the needed information by which to formulate a successful program for advancing the state-of-the-art for NDE of fiber reinforced composites.

V. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were reached as a result of this state-of-the-art survey:

1. Much of the recent accessible literature on NDE of fiber reinforced epoxy composites documents work specifically on graphite/epoxy material.

2. Most of the literature relevant to practical applications of NDE to glass/epoxy structures is five to ten years old.

3. Only five documents directly relevant to the NDE of glass/epoxy rotor blades were obtained from the literature search.

4. Ultrasonics and radiography are the only significant NDE methods currently used by manufacturers of glass/epoxy rotor blades.

5. There is a large gap between NDE methods being explored in the laboratory and those sufficiently developed for practical field or production application.

6. The influence of various defects on the performance of composite materials is not well understood.

The following recommendations are made as a result of this state-of-the-art survey:

1. Apply existing automation and signal processing technology to the improvement of nondestructive ultrasonic and radiographic inspection of glass/epoxy rotor blades.

2. Develop universally accepted reliable reference standards for NDE of composites.

3. Pursue development of methods such as ultrasonic velocity, low frequency damping, and microwave that appear promising for providing information on strength related properties of composites and interlaminar bonds.

4. Further explore thermographic and holographic methods for potential application to large component field inspection.

5. Pursue solutions to the problem of moisture measurement in composites by the development of various techniques potentially capable of performing the desired measurement including microwave and nuclear magnetic resonance.

6. With respect to helicopter rotor blade inspection, ensure that relevant NDE documents become part of the accessible literature.

7. Hold a workshop devoted to the NDE of structural composites to provide a framework for developing a program for advancing the state-of-the-art of NDE of composites.

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APPENDIX A

NDE METHODS

In this appendix are presented brief descriptions of NDE methods which have been utilized for the inspection of fiber reinforced composites. While variations of these methods are sometimes used, only the basic principles will be discussed to acquaint the reader with the methodology. The information presented in this section has been extracted in large measure from References A1 and A2 which provide more complete descriptions of these and other NDE techniques.

A. Penetrating Radiation

Penetrating radiation NDE techniques as applied to inspection of fiber reinforced composites include X-ray and neutron radiography; and X-ray and gamma-ray radiometry. X-ray radiography is the most widely used method and consists of illuminating the test specimen with relatively low energy X-rays which penetrate through the specimen and strike photographic film. Variations in specimen thickness and density, or flaws of a different density affect the intensity of the transmitted radiation and show up as variations in contrast on the developed film. A shadowgraph image of the specimen and defects is thus created.

X-ray radiography of fiber reinforced composites is performed using state-of-the-art radiography procedures for materials with low absorption. A small X-ray focal spot size (0.35mm) and a long source-to-film distance gives good sensitivity and resolution of small defects. The use of low power and long exposure times enhances sensitivity and contrast. Extra fine grain film also helps provide sharp images and good resolution.

Neutron radiography is performed in a similar manner to X-ray radiography except that a neutron radiation source is used. This may be a neutron emitting radioactive isotope, nuclear accelerator, or nuclear reactor. Since radiographic film is relatively insensitive to neutrons, the neutrons transmitted through the specimen are made to strike a foil such as indium, gadolinium, or lithium which emits secondary radiation to expose the film.

X-ray and gamma-ray radiometry utilize the same principles as radiography with the exception that the film is replaced with a scintillation detector which can measure much smaller variations in transmitted radiation intensity and thus is more sensitive to defects and density variations. Since the scintillation detector is not an imaging device like film, and only measures radiation intensity, the examination of an entire specimen generally requires measurements to be taken at a number of discrete points.

B. Ultrasonics

Ultrasonic testing involves the propagation of high frequency sound (between 20 kHz and several MHz) through a material. Characteristics of the transmitted or reflected sound are measured to determine material properties or defects. The three most common ultrasonic techniques applied to fiber reinforced composites NDE are ultrasonic velocity, ultrasonic attenuation, and pulse-echo ultrasonics.

Velocity measurements are accomplished by measuring the elapsed time required for an ultrasonic pulse to propagate through the specimen. An ultrasonic transmitting transducer is placed on one side of the specimen and a receiving transducer on the other with alcohol generally used as a couplant between transducer and specimen. A short pulse of longitudinal mode sound is transmitted through the specimen and its propagation time determined by measuring the elapsed time between transmitted and received pulses on an oscilloscope display. The ultrasonic velocity can be calculated from the elapsed propagation time and the measured specimen length. Figure A1 is a diagram of an ultrasonic velocity measurement arrangement.[A3]

Ultrasonic attenuation measurements are also accomplished by a through-transmission technique as shown in Figure A2.[A4] Measurements may be made under immersion conditions to minimize coupling variations which would affect attenuation measurements. An ultrasonic pulse is propagated from the transmitter through the specimen to the receiver. The signal from the receiver is directed through a variable attenuator and displayed on an oscilloscope. The variable attenuator is adjusted to make the signal amplitude from the test specimen the same as that previously obtained from a reference specimen. This value is the relative ultrasonic attenuation of the test specimen compared to a reference specimen.

Ultrasonic pulse-echo measurements are performed with a single transducer which acts alternately as a transmitter and a receiver. Couplant for fiber reinforced composites may be alcohol or an alcohol-water mixture, although for porous surfaces, Teflon tape or other surface sealer such as strippable vinyl may first be applied to the surface and couplant then applied to the tape. A short ultrasonic pulse is introduced

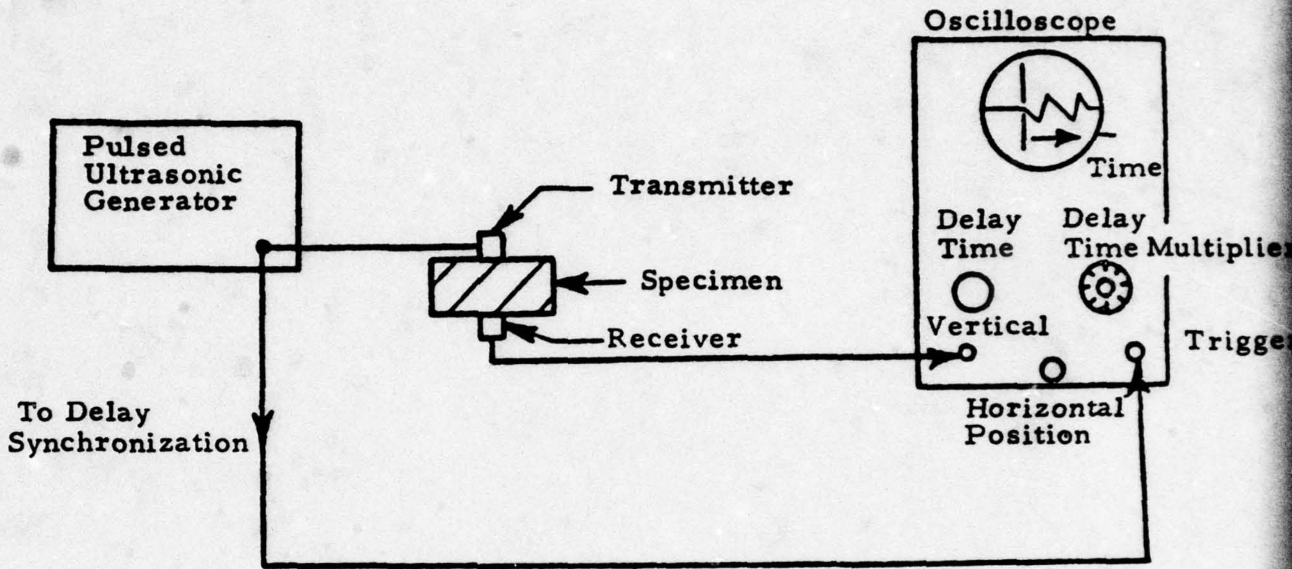

FIGURE A1. BLOCK DIAGRAM OF ULTRASONIC VELOCITY MEASURING APPARATUS

(From Ref. A3)

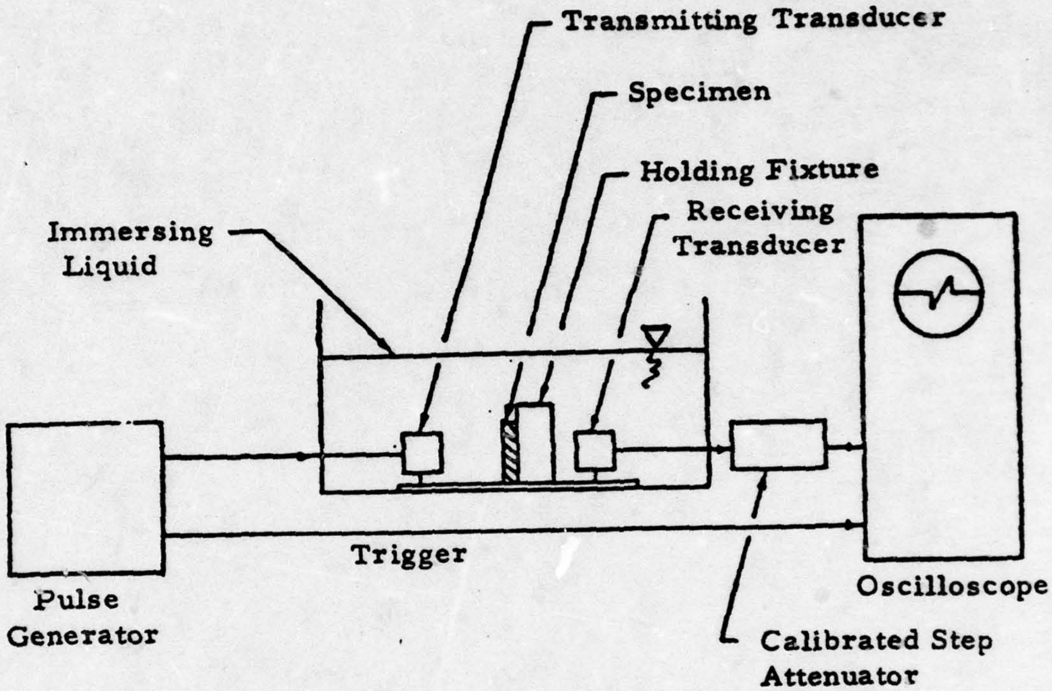

FIGURE A2. ULTRASONIC TRANSMISSION SETUP USING THE PULSED THROUGH-TRANSMISSION TECHNIQUE

(From Ref. A4)

into the specimen and travels through the material. If a defect with a different ultrasonic impedance such as a void or crack is encountered, a portion of the ultrasonic wave is reflected back to the transducer which now acts as a receiver. The reflected pulse is observed on an oscilloscope display and its amplitude may be used to obtain information regarding the size of the defect. The transducer is usually moved to inspect the entire specimen.

C. Microwave Testing

Microwaves are essentially electromagnetic waves in the frequency band 300 MHz to 300 GHz, the velocity and attenuation of which are dependent upon the properties of the medium through which they are propagating. Hence they can be used to determine changes in material properties. In applications for NDE, a microwave generator feeds a transmitting antenna which produces the electromagnetic wave that is incident upon the material to be tested. Both transmission and reflection modes can be used, although for most practical measurements, the reflection mode is found to be most useful. The simplest microwave approach is based on the continuous wave fixed-frequency technique. However, this technique has two drawbacks: (1) the depth of a flaw cannot be determined, and (2) the frequency response of the material being investigated cannot be determined. To overcome these deficiencies a swept-frequency technique may be used in which more complex instrumentation is required than for the fixed-frequency approach (Figure A3).[A5]

D. Acoustic Emission

As a material is placed under stress, plastic deformation or cracking (fiber breakage in the case of composites) produces small stress waves which can be detected as acoustic signals by a sensitive transducer placed on the surface. By the use of suitable instrumentation, these signals may be counted and processed in various ways. Although it is not yet possible to unambiguously characterize individual failure events by the acoustic signals, the number and rate of occurrence of the signals can be related to the extent of deformation or cracking. Although not strictly a nondestructive technique in the usual sense, acoustic emission can play a useful role in revealing whether or not failures have occurred during a structural test. In addition it is sometimes possible to use triangulation techniques to determine something about where a failure event has occurred.

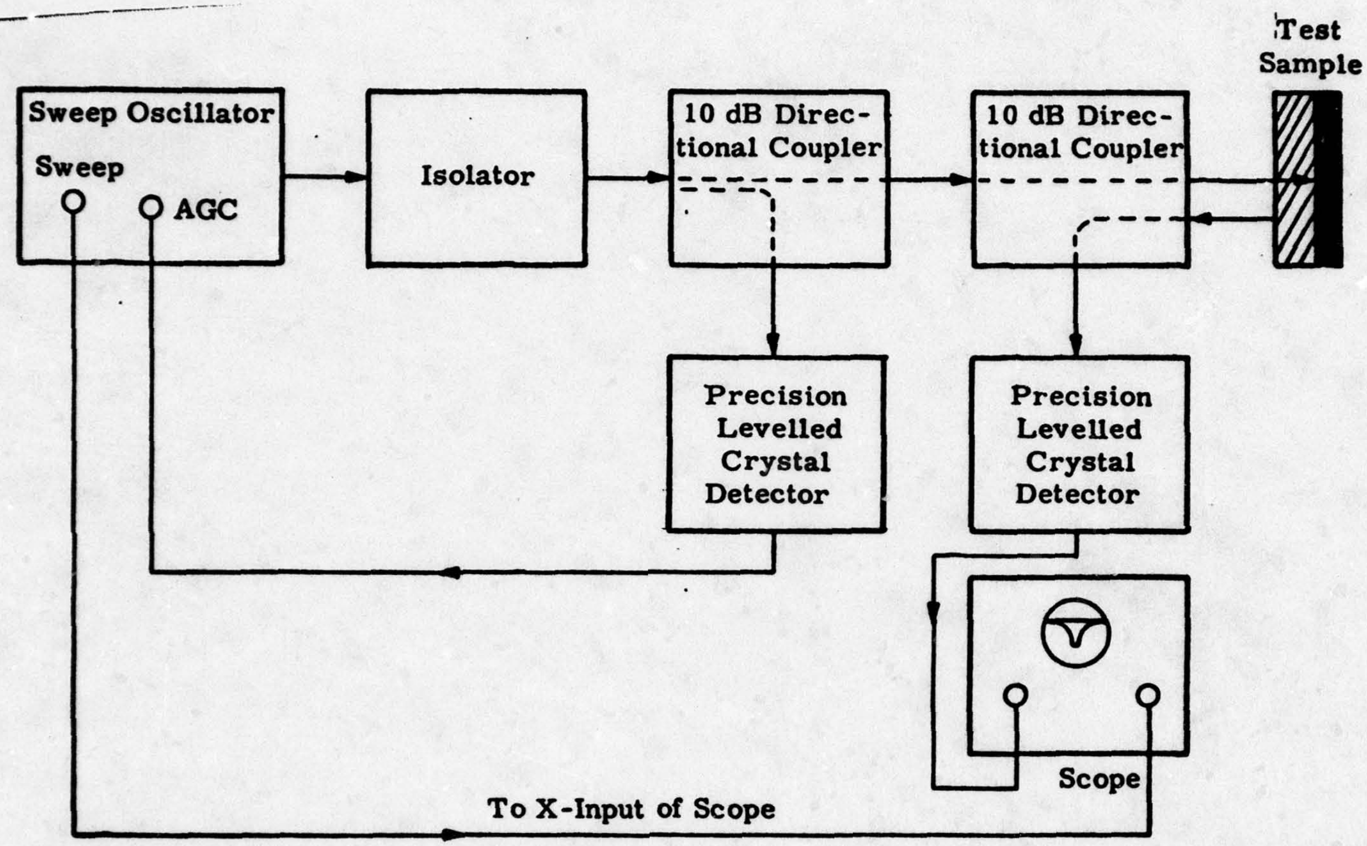

FIGURE A3. MICROWAVE SWEPT FREQUENCY REFLECTOMETER SYSTEM FOR MEASUREMENT OF DENSITY/POROSITY VARIATIONS IN COMPOSITE MATERIALS

(From Ref. A5)

E. Thermography

With this method, normally one side of the specimen is heated uniformly and the opposite side scanned with a heat sensor such as an infrared camera. Areas of different thermal conductivity such as may be caused by a defect show up as hotter or cooler areas on the thermal image. In one variation of this approach, thermal images are detected from one surface by monitoring the time-temperature relationship after injection of a heat pulse.

F. Laser Holography

A hologram is created by the interference pattern of two beams of coherent laser light on photographic film. One beam is a reference beam and the other is reflected from the specimen as shown in Figure A4.[A1] The resultant image on the film (after developing) forms a transmission grating which, when illuminated by a coherent beam of light, diffracts the light so as to reconstruct a three-dimensional image of the specimen. An interferogram is a double exposure hologram which can be used to map very small (half the wavelength of light) strains or deformations of the specimen produced by mechanical or thermal stresses. The same hologram is exposed both before and after the strain-producing action. Strains show up on the developed hologram as interference fringes which map the deformed regions.

G. Dynamic Properties Measurement

Dynamic moduli and associated damping factors can be determined from resonance tests usually performed in the audio frequency range (20 Hz to 20 kHz). The specimen is successively driven into its various natural modes of vibration by a sinisoidal force of constant amplitude and variable frequency. When the driving frequency equals a natural vibrational frequency, a maximum is observed in the vibration amplitude. From the frequency of this resonance peak and the sample dimensions, the real part of the complex dynamic modulus can be determined, and the damping factor determined from the width of the resonance peak. Measurements on several resonance peaks, corresponding to different natural modes of vibration, enable the dynamic moduli and damping factors to be determined over a limited frequency range.

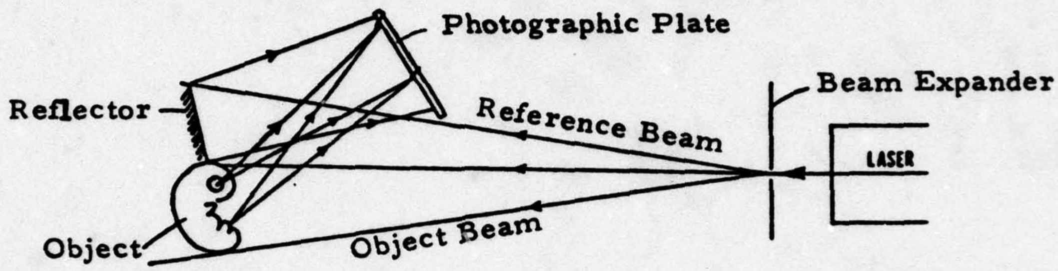

FIGURE A4. BASIC ARRANGEMENT FOR RECORDING A HOLOGRAM

(From Ref. A1)

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1. NTIAC-6152 M

STANFORD UNIV CALIF DEPT OF AERONAUTICS AND ASTRONAUTICS
SMITH, STRETHER
A CAPACITIVE MEASUREMENT SYSTEM FOR THE NONDESTRUCTIVE TESTING OF FIBER GLASS REINFORCED PLASTIC LAMINATES
TECHNICAL REPT.
JAN 69, 33P
USAAVLABS-TR-68-74
SUDAAR-321
DA-44-177-AMC-115(T)
AD-857310

REINFORCED PLASTICS, FIBERGLASS, LAMINATES, FEASIBILITY STUDIES, CAPACITANCE, MEASUREMENT, COMPOSITE MATERIALS, THEORY, THICKNESS

THE FEASIBILITY OF UTILIZING CAPACITIVE MEASUREMENTS FOR THE NONDESTRUCTIVE TESTING OF EPOXY FIBER GLASS COMPOSITES IS DISCUSSED. A SIMPLE THEORY IS DERIVED FROM PARALLEL PLATE CAPACITOR THEORY, AND THE RESULTS ARE PROVEN BY EXPERIMENT. IT IS SHOWN THAT CAPACITIVE MEASUREMENTS CAN BE USED TO ACCURATELY DETERMINE THE THICKNESS AND RESIN-GLASS RATIO WITH AN ESSENTIALLY ONE-SIDED TEST. (AUTHOR)

2. NTIAC-15628

POTAPOV ,A. I. ; RAPOPORT ,D. A. ; KLOPOV,V. D.
A MECHANIZED UNIT FOR INFRARED INSPECTION OF PLASTIC PARTS
PUBLISHED BY CONSULTANTS BUREAU, 227 W. 17TH ST., N. Y. 10011
JAN 78, 04P
AVAILABILITY: PUBLISHED IN SOV. J. NON-DESTR. TEST.; 13, 2; MAR.-APR. 1977; 212-215; 2 REFS. (ENG. TRANS. JAN. 1978)

PLASTICS, MECHANICAL SYSTEMS, INFRARED TESTING, POLYMERS, OPTICAL INSTRUMENTS, QUALITY, GLASS, FIBER REINFORCED COMPOSITES, FOAM

A PRODUCTION OPTICAL UNIT FOR INFRARED NONDESTRUCTIVE TESTING OF THE QUALITY OF POLYMER PARTS OF VARIOUS SHAPES (FLAT, CYLINDRICAL, AND CONICAL) IS PROPOSED. THE RESULTS OF INSPECTION OF SINGLE AND MULTILAYER PARTS OF GLASS-FIBER REINFORCED PLASTIC AND FOAM PLASTIC ARE GIVEN. (AUTHOR)

3. NTIAC-16379

SIMS ,G. D. ; DEAN ,G. D. ; READ ,B. E. ; WESTERN,B. C.
ASSESSMENT OF DAMAGE IN GRP LAMINATES BY STRESS WAVE EMISSION AND DYNAMIC MECHANICAL MEASUREMENTS
PUBLISHED BY CHAPMAN AND HALL; 11 NEW FETTER LANE, LONDON EC4P 4EE
NOV 77, 14P
AVAILABILITY: PUBLISHED IN J. MATER. SCI.; 12, 11; NOVEMBER 1977; 2329-2342; 8 REFS.

ACOUSTIC EMISSIONS, DYNAMIC TESTS, MONITORING, DAMAGE, GLASS, EPOXY, FIBERS, TENSILE TESTS, COMPOSITE MATERIALS, FIBER REINFORCED COMPOSITES, LAMINATES, OPTICAL INSPECTION, COMPONENTS, INSERVICE INSPECTION, LIFE(DURABILITY), INTEGRITY, CRACKS, MICROSTRUCTURE, OPTICAL MICROSCOPES

STRESS WAVE EMISSION (SWE) AND DYNAMIC MECHANICAL METHODS ARE DESCRIBED FOR MONITORING THE DAMAGE INTRODUCED INTO CERTAIN GLASS FIBRE-REINFORCED EPOXY SPECIMENS BY THE APPLICATION OF TENSILE LOAD. FOR ONE PARTICULAR COMPOSITE SYSTEM, A CROSS-PLY LAMINATE, IT WAS POSSIBLE TO MEASURE THE CONCENTRATION OF DAMAGE BY AN INDEPENDENT OPTICAL METHOD AND CORRELATIONS HAVE BEEN FOUND BETWEEN THE SWE AND DYNAMIC MECHANICAL RESULTS AND THE AREA OF CRACKING. IT REMAINS TO BE ESTABLISHED WHETHER THESE CORRELATIONS APPLY TO OTHER REINFORCEMENT GEOMETRIES. THE WORK IS CONSIDERED A FIRST STAGE TOWARDS USING THESE METHODS FOR MONITORING THE INTEGRITY OF A COMPONENT IN SERVICE, FROM WHICH ITS REMAINING LIFE MIGHT BE ASSESSED. (AUTHOR)

4. NTIAC-6985

STANFORD UNIV CALIF DEPT OF AERONAUTICS AND ASTRONAUTICS
CRAIG,J. I. ; SMITH,S. ; HORTON,W. H.
A THERMAL COMPARATOR FOR NONDESTRUCTIVELY EXAMINING FIBER COMPONENTS
FINAL TECHNICAL REPT.
SEP 71, 55P
USAAVLABS-TR-69-27
SUDAAR-319
DA-44-177-AMC-115(T)
AD-733373

*THERMAL EFFECTS, *COMPARATORS, *FIBERS, COMPOSITE MATERIALS, THERMAL TESTING, REINFORCED PLASTICS, THERMAL PROPERTIES, ANOMALIES, DEFECTS(MATERIALS), EFFECTIVENESS, DESIGN, ECONOMICS, COST EFFECTIVENESS, DETECTION, EXPERIMENTAL DATA, FABRICATED DEFECTS, THICKNESS, APPLICATIONS, LABORATORY EQUIPMENT

A NOVEL DEVICE FOR THE NONDESTRUCTIVE TESTING OF GLASS CLOTH/EPOXY COMPOSITES IS DISCUSSED. A THERMAL COMPARATOR IS DESIGNED TO DETECT NONCONFORMITIES IN THE THERMAL PROPERTIES OF THE COMPOSITES. PRINCIPAL ADVANTAGES OF THE INSTRUMENT ARE ITS SIMPLICITY OF DESIGN AND OPERATION AND ITS VERY MODEST COST. A SERIES OF TEST RESULTS FOR METALLIC AND NONMETALLIC INCLUSION DETECTION IS PRESENTED. THE APPLICABILITY TO THICKNESS DETERMINATIONS IS EXAMINED, AND SEVERAL PROMISING USES OF THE DEVICE ARE SUGGESTED. (AUTHOR, MODIFIED-PL)

5. NTIAC-14529 M

SPRINGFIELD ARMORY MASS

FOWLER,K. A. ; HATCH,H. P.

DETECTION OF VOIDS AND INHOMOGENEITIES IN FIBER GLASS REINFORCED PLASTICS BY MICROWAVE AND BETA-RAY BACKSCATTER TECHNIQUES

ALSO INCLUDES APPLICATION OF MICROWAVE AND BETA-RAY BACKSCATTER IN NONDESTRUCTIVE TESTING OF PLASTIC ITEMS

TECHNICAL REPT.

20 MAY 66, 47P

SA-TR19-1519

AD-644419

DETECTION, VOIDS, INHOMOGENEITY, FIBERGLASS, GLASS, REINFORCED PLASTICS, MICROWAVE TESTING, BETA RAYS, BACKSCATTERING, TECHNIQUE, DEFECTS(MATERIALS), RESINS, EXPERIMENTAL DATA

MICROWAVES WERE USED AS A MEANS OF DETECTING VOIDS AND INHOMOGENEITIES IN FIBER GLASS REINFORCED PLASTICS. A NUMBER OF EXPERIMENTS THAT WERE DESIGNED TO EMPIRICALLY ESTABLISH THE LIMITS OF DETECTABILITY OF VARIOUS TYPES OF DEFECTS ARE DESCRIBED. BASED ON THE RESULTS OF THE INVESTIGATION, IT IS POSSIBLE TO DETECT A 1/8-INCH-DIAMETER HOLE IN A 1/4-INCH-THICK PANEL OF FIBER GLASS REINFORCED PLASTIC WITH X-BAND MICROWAVES. HOWEVER, SEVERAL FACTORS SUCH AS SENSITIVITY OF THE SIGNAL AMPLITUDE TO DEFECT LOCATION, TEST-PIECE POSITION, GEOMETRY, AND HOMOGENEITY MAKE INTERPRETATION OF RESULTS DIFFICULT. BETA-RAY BACKSCATTER MEASUREMENTS ARE POTENTIALLY USEFUL AS A MEANS OF DETECTING LOCAL VARIATIONS IN GLASS-TO-RESIN RATIO. THE CONTRIBUTION OF FILLERS AS A THIRD CONSTITUENT IN THE COMPOSITE SYSTEM MUST, HOWEVER, BE CONSIDERED IN ESTABLISHING A RELATION BETWEEN BACKSCATTERING AND GLASS-TO-RESIN RATIOS. (AUTHOR)

6. NTIAC-9339 FFERS AN EXTREMELY PROMISING, PRACTICAL AND

ROTEM ,A. ; BARUCH,J.
DETERMINING THE LOAD-TIME HISTORY OF FIBRE COMPOSITE MATERIALS BY ACOUSTIC EMISSION
9 REFERENCES
1974, 10P
AVAILABILITY: PUBLISHED IN J. OF MATER. SCI.; 9; 1974; 1789-1798

ACOUSTIC EMISSIONS, COMPOSITE MATERIALS, FIBER REINFORCED COMPOSITES, GLASS, EPOXY, VISCOELASTICITY, STRENGTH(MECHANICS), FAILURE, FRACTURE(MECHANICS), STRESSES, THEORY, MATHEMATICAL MODELS

ACOUSTIC EMISSION WAS MONITORED DURING THE AXIAL LOADING OF UNIDIRECTIONAL FIBRE COMPOSITE TENSILE SPECIMENS. THE MATERIAL CONSISTED OF STRONG, BRITTLE FIBRES (E GLASS) EMBEDDED IN A VISCOELASTIC MATRIX (EPOXY). IT WAS FOUND THAT WHEN THE LOAD WAS HELD CONSTANT THE ACOUSTIC EMISSION OUTPUT CONTINUED, BUT AT A DECREASING RATE WITH TIME AT LOAD. AS THE LOAD LEVEL WAS INCREASED, THE ACOUSTIC EMISSION OUTPUT AT LOAD CONTINUED FOR A LONGER PERIOD. IT IS SUGGESTED THAT THE ACOUSTIC EMISSION UNDER CONSTANT LOAD IS A RESULT OF FIBRE FRACTURE WHICH CONTINUES AFTER LOADING CEASES BECAUSE OF THE VISCOELASTIC NATURE OF THE MATRIX WHICH ALLOWS STRESS REDISTRIBUTION WITH TIME. THE EXPERIMENTAL RESULTS FROM ACOUSTIC EMISSION ARE COMPARED WITH COMPUTER CALCULATIONS FOR FIBRE FRACTURE BASED ON THEORETICAL CONSIDERATIONS. GOOD AGREEMENT IS NOTED BETWEEN THE THEORETICAL AND EXPERIMENTAL RESULTS.

7. NTIAC-6577

AVCO GOVERNMENT PRODUCTS GROUP WILMINGTON MASS AVCO SPACE SYSTEMS DIV
ZURBRICK, J. R.
DEVELOPMENT OF NONDESTRUCTIVE TESTS FOR PREDICTING ELASTIC PROPERTIES AND COMPONENT VOLUME FRACTIONS IN REINFORCED PLASTIC COMPOSITE MATERIALS
TECHNICAL REPT. 1 JUL 67-30 JUN 68
FEB 69, 128P
AFML-TR-68-233
AVSSD-094-68-RR
F33615-67-C-1285
AD-851939

*DIELECTRIC PROPERTIES, *ELECTROMAGNETIC TESTING, *COMPOSITE MATERIALS, *ELASTIC PROPERTIES, *ULTRASONIC TESTING, FIBER REINFORCED COMPOSITES, POLYMERS, GLASS, COMPOSITION(PROPERTY), LAMINATES, STRENGTH(MECHANICS), MATHEMATICAL MODELS, RADIOGRAPHY, RADIOMETRY, POLYMER MATRIX COMPOSITES, PHENOLIC, RESINS

THE PRIMARY GOAL IN DEVELOPING NONDESTRUCTIVE TEST METHODS AND TECHNIQUES FOR EVALUATING REINFORCED PLASTICS IS THE ESTABLISHMENT OF A THOROUGH KNOWLEDGE OF THE IMPORTANT MATERIAL-ENERGY INTERACTIONS WHICH OCCUR IN THE COMPOSITE SYSTEM OF INTEREST. THIS HAS BEEN APPLIED TO THE QUANTITATIVE NONDESTRUCTIVE EVALUATION OF THE EPOXY SYSTEM AND GLASS FABRIC REINFORCED LAMINATES CONTAINING SIX RESIN SYSTEMS, EPOXY, PHENOLIC, POLYESTER, POLYBENZIMIDAZOLE, SILICONE, AND POLYIMIDE. (AUTHOR)

8. NTIAC-13602

NEVACUNSKY ,J. J. ; LUCAS ,J. J. ; SALKIND,M. J.
EARLY FATIGUE DAMAGE DETECTION IN COMPOSITE MATERIALS
28 REFERENCES
OCT 75, 15P
AVAILABILITY: PUBLISHED IN J. COMPOSITE MATER.; V.9; OCT 1975; 394-408

COMPOSITE MATERIALS, DETECTION, FATIGUE(MECHANICS), GRAPHITE, GLASS, EPOXY, TEMPERATURE, TORSION, MEASUREMENT, ACOUSTICS, TEST METHODS, MANUAL OPERATION, HOLOGRAPHY, INTERFEROMETRY, ULTRASONIC TESTING, PENETRANTS, X RAYS, PHYSICAL PROPERTIES, RADIOGRAPHY

DETECTION OF EARLY FATIGUE DAMAGE IN COMPOSITE MATERIALS BY NONDESTRUCTIVE INSPECTION (NDI) TECHNIQUES HAS BEEN DEMONSTRATED FOR PLUS OR MINUS 45 DEGREE GLASS/EPOXY, AND PLUS OR MINUS 45 DEGREE/0 DEGREES GRAPHITE/GLASS/EPOXY. DYNAMIC AXIAL MODULUS AND TEMPERATURE WERE MONITORED CONTINUOUSLY WITH A CORRELATION BETWEEN TEMPERATURE RISE AND MODULUS DECREASE OBSERVED. THE MODULUS DECREASE AND TEMPERATURE RISE ARE INDICATIVE OF IRREVERSIBLE DAMAGE IN THESE MATERIALS. TORSIONAL MODULUS MEASUREMENTS AND COIN TAP TESTS WERE PERFORMED AT 0, 1,000,000, 5 X 1,000,000 AND 10 TO THE 7TH POWER CYCLES, ON ALL FATIGUE SPECIMENS. OTHER NDI PROCEDURES INCLUDING HOLOGRAPHIC INTERFEROMETRY , ULTRASONICS, PENETRANT, AND X-RAY RADIOGRAPHY WERE PERFORMED ON TWO SPECIMENS OF EACH MATERIAL TO EVALUATE THEIR EFFECTIVENESS IN DETECTING FATIGUE DAMAGE. ULTRASONICS AND HOLOGRAPHY PROVED TO BE EFFECTIVE; HOWEVER, AT THIS TIME, NO CLEAR QUANTITATIVE CORRELATION BETWEEN STRUCTURAL PROPERTIES AND NDI MEASUREMENTS HAS BEEN DETERMINED. (AUTHOR)

9. NTIAC-11632

MORAIS ,C. F. ; GREEN,A. T.
ESTABLISHING STRUCTURAL INTEGRITY USING ACOUSTIC EMISSION
7 REFERENCES; SEE ALSO NT-11623
JAN 74, 16P
AVAILABILITY: PUBLISHED IN ASTM SP571; JANUARY 1974; 184-199

*EVALUATION, *STRUCTURAL INTEGRITY, *ACOUSTIC EMISSIONS, QUALITY CONTROL, PRODUCTION, PRESSURE VESSELS, ACOUSTICS, HYDROSTATICS, TEST METHODS, DEFECTS(MATERIALS), PROPAGATION, DATA PROCESSING, FIBERGLASS, REINFORCED PLASTICS, GLASS, ULTRASONICS, ULTRASONIC TESTING, METALS, CONCRETE

ACOUSTIC EMISSION TECHNIQUES HAVE ADVANCED FROM LABORATORY USE TO APPLICATIONS SUCH AS ESTABLISHING THE QUALITY OF PRESSURE CONTAINMENT AND MANY OTHER STRUCTURES. THE AUTHORS DISCUSS THE STATISTICAL RELATIONSHIP BETWEEN ACOUSTIC EMISSION DATA AND THE STRUCTURAL INTEGRITY OF A SERIES OF PRODUCTION PRESSURE VESSELS. IN THIS APPLICATION, ACOUSTIC EMISSION DATA OBTAINED FROM THE FIRST 25 PERCENT OF A REQUIRED HYDROPROOF TEST DETERMINED THE BURSTING STRENGTH OF THE VESSEL. ADDITIONAL INFORMATION CONTAINED IN THE DATA IS SHOWN TO ESTABLISH THE MODE OF STRUCTURAL DEGRADATION. AT LEAST SEVEN WAYS OF UTILIZING ACOUSTIC EMISSION DATA TO ESTABLISH THE QUALITY OF PRESSURE VESSELS ARE PRESENTED. USE OF ACOUSTIC EMISSION TECHNIQUES TO DETECT AND LOCATE A GROWING DEFECT IN A STRUCTURE, WHILE UNDER A RELATIVELY SEVERE ENVIRONMENTAL CONDITION, IS PRESENTED. VARIOUS METHODS OF DATA PROCESSING ARE DESCRIBED AND THE RELATIONS TO PARAMETERS WHIC H MAY INDICATE THE DEGREE OF QUALITY OF THE STRUCTURE ARE SHOWN. DATA FROM MATERIALS SUCH AS GLASS-REINFORCED PLASTICS, CONCRETE, GLASS, AND METALLICS ARE PRESENTED. REFERENCES TO LESS WELL KNOWN EFFORTS SHOW THE UNIVERSAL NATURE OF THE TECHNOLOGY. (AUTHOR)

10. NTIAC-7704

BATTELLE COLUMBUS LABS OHIO
GOLIS, M. J. ; MEISTER, R. P. ; CROWE, J. L. ; POSAKONY, G. J.
INVESTIGATION OF TECHNIQUES TO NONDESTRUCTIVELY TEST REINFORCED PLASTIC COMPOSITE PIPE
PREPARED IN COOPERATION WITH BATTELLE PACIFIC NORTHWEST LABS., RICHLAND, WASH. SEE ALSO AD-774 294
FINAL REPT. SEP 73-31 MAR 74
31 MAR 74, 93P
DAAK02-74-C-0008
AD-777014

ULTRASONIC TESTING, PIPES, REINFORCED PLASTICS, COUPLANTS, LIQUIDS, DELAMINATION, INCLUSIONS, C-SCAN, SPECIFICATIONS, LABORATORY EQUIPMENT, LIGHT TRANSMISSION, SCANNING, OPTICS

AN IN-DEPTH STUDY OF TEN NONDESTRUCTIVE TESTING TECHNIQUES HAS SHOWN THAT ULTRASONIC METHODS ARE MOST SUITABLE FOR IN-SPECTING REINFORCED PLASTIC COMPOSITE (RPC) PIPE. BOTH LIQUID-COUPLED AND AIR-COUPLED ULTRASONIC SYSTEMS HAVE BEEN SHOWN TO BE CAPABLE OF DETECTING DELAMINATIONS, INCLUSIONS, AND UNCURED REGIONS IN 14 SPECIALLY PREPARED SECTIONS OF 3-INCH- DIAMETER FIBERGLASS PIPE. PLAN VIEW C-SCANS WERE RECORDED USING BOTH TECHNIQUES. THE LIQUID-COUPLED SYSTEM SHOWED HIGHER RESOLU- TION AND SENSITIVITY TO SMALL-AREA REFLECTIONS. RECOMMENDED INSPECTION SYSTEM SPECIFICATIONS ARE LISTED BASED UPON THE PER-FORMANCE OF LABORATORY EQUIPMENT USED IN THE PROGRAM. (AUTHOR-PL)

AD-A071 973 SOUTHWEST RESEARCH INST SAN ANTONIO TEX F/G 11/4
NONDESTRUCTIVE EVALUATION OF FIBER REINFORCED EPOXY COMPOSITES:--ETC(U)
APR 79 G A MATZKANIN, G L BURKHARDT DLA900-77-C-3733
UNCLASSIFIED SWRI-15-4823-510 USAAVRADCOM-TR-79-24 NL

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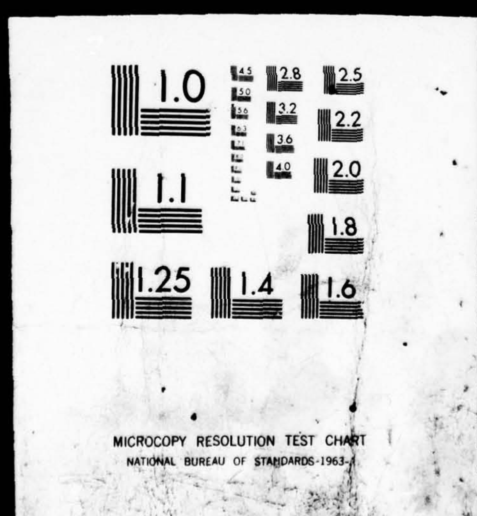

11. NTIAC-13617

DELMONTE, JOHN
MOISTURE PENETRATION INTO COMPOSITES
12 REFERENCES
1975, 13P
AVAILABILITY: PUBLISHED IN MATER. REV. 75; 7TH
NATIONAL SAMPE TECH. CONF.; V. 7; 306-318

COMPOSITE MATERIALS, PLASTICS, REINFORCED PLASTICS, MOISTURE, PENETRATION, INTERFACES, BONDING, LAMINATES, ELECTRICITY, DIELECTRICS

REINFORCED PLASTICS AND COMPOSITES ARE SUSCEPTIBLE TO THE PENETRATION OF MOISTURE ALONG THE INTERFACING OF REINFORCING FILAMENTS AND RESIN MATRIX. TEST MEMBERS ARE BONDED WITH STANDARD EPOXY RESIN SYSTEMS AND ELEMENTS SUCH AS TYPE OF GLASS FABRIC EFFECT OF FILLERS AND SILANE COUPLING AGENTS HAVE BEEN SELECTED AS VARIABLES. CHANGES IN DIELECTRIC DISSIPATION FACTOR ARE REPORTED FOR THE LAMINATE AT SPECIFIC AREAS REMOVED FROM THE AREA OF CONTACT WITH THE MOISTURE. THE CHANGES TAKING PLACE ARE SIGNIFICANT AND SUGGEST GREATER USAGE OF ELECTRICAL PARAMETERS FOR NON-DESTRUCTIVE TESTING. (AUTHOR)

12. NTIAC-14451

FORLI, O.; TORP, S.
NDT OF GLASS FIBER REINFORCED PLASTICS (GRT) (4B2)
SEE ALSO NT-13951
1976, 06P
AVAILABILITY: PUBLISHED IN EIGHTH WORLD CONF. ON
NONDESTR. TEST.; CANNES, FRANCE; 1976

FIBERGLASS, FIBER REINFORCED COMPOSITES, ULTRASONIC TESTING, PULSE ECHO TECHNIQUE, MICROWAVE TESTING, RESONANCE COMPOSITE MATERIALS, LAMINATES, RADIOGRAPHY, X RAYS, EDDY CURRENT INSPECTION, MAGNETIC FIELD TESTING, MICROWAVE TESTING, DIELECTRICS, DELAMINATION

PRESENTATION OF VARIOUS NDT METHODS FOR GRP ADOPTED AND DEVELOPED DURING THE LAST YEARS BY DET NORSKE VERITAS FOR USE BY ITS SURVEYORS. AMONG THE METHODS OUTLINED ARE ULTRASONIC PULSE-ECHO TESTING AND THE USE OF A MICROWAVE RESONANCE METHOD FOR GLASS CONTENT DETERMINATION. (AUTHOR)

13. NTIAC-7340 M

NAVAL ORDNANCE LAB WHITE OAK MD
YOUSHAW, ROBERT A.
NEUTRON RADIOGRAPHY OF MASSIVE FIBERGLASS COMPOSITE STRUCTURES - A FEASIBILITY STUDY
30 JUN 72, 35P
NOLTR-72-78
AD-752457

*FIBERGLASS, *RADIOGRAPHY, NEUTRON RADIOGRAPHY, COMPOSITE MATERIALS, STRUCTURES, FEASIBILITY STUDIES

THE FEASIBILITY OF APPLYING NEUTRON RADIOGRAPHY TO THE INSPECTION OF FIBERGLASS COMPOSITES HAS BEEN STUDIED. IMAGES WERE OF POOR QUALITY, AND VERY LONG EXPOSURE TIMES WERE REQUIRED TO DARKEN THE FILM. THESE EXPERIMENTAL FINDINGS ARE SUPPORTED BY MATHEMATICAL CALCULATIONS FOR THE ATTENUATION OF EACH CONSTITUENT AND FOR THE COMPOSITE MATERIAL FOR FOUR DIFFERENT NEUTRON ENERGIES. FROM CONSIDERATIONS OF THE RATIO OF SCATTER TO CAPTURE FOR NEUTRONS OVER THE ENTIRE RANGE OF AVAILABLE ENERGIES, IT IS CONCLUDED THAT NEUTRON RADIOGRAPHY IS NOT SUITED TO THE INSPECTION OF MASSIVE FIBERGLASS STRUCTURES. IT HAS BEEN SHOWN THAT CONVENTIONAL RADIOGRAPHY CAN BE USEFULLY APPLIED. (AUTHOR, MODIFIED-PL)

14. NTIAC-9203

HOFER ,GERHARD ; GAYER,PETER
NONDESTRUCTIVE DETERMINATION OF GLASS CONTENT AND OF VOIDS IN REINFORCED PLASTICS
9 REFERENCES
JAN 75, 02P
AVAILABILITY: PUBLISHED IN MATERIALPRUFUNG; 17, 1; JAN 75; 17-19

*FIBER REINFORCED COMPOSITES, *GLASS, *RESINS, *POROSITY, *GAMMA RAYS, *RADIOMETRY, COMPOSITE MATERIALS, VOIDS, X RAYS, ATTENUATION, PROCEDURES, ABSORPTION, ACCURACY, RESOLUTION

THERE IS REPORTED A PROCEDURE, BASED ON MEASUREMENT OF ABSORPTION OF HIGH- AND LOW-ENERGY GAMMA QUANTA, FOR NONDESTRUCTIVELY DETERMINING THE GLASS CONTENT AND VOID FRACTION OF GLASS FIBER REINFORCED PLASTICS. THE RESOLUTION AMOUNTS TO 2 SQUARE CENTIMETERS, THE ACCURACY OF GLASS CONTENT DETERMINATION PLUS OR MINUS 0.015, WHICH, FOR AN AVERAGE OF 15 PERCENT GLASS CONTENT, CORRESPONDS TO A RELATIVE DEFECT OF 10 PERCENT. RESOLUTION AND ACCURACY MAY BE IMPROVED FURTHER BY INCREASING THE COST. SINCE THE PROPERTIES (MU, RHO) OF THE PURE COMPONENTS (GLASS, RESIN) MUST BE KNOWN, AND FOR EACH NEW MEASUREMENT ARRANGEMENT THE BUILD-UP FACTOR MUST BE ASCERTAINED, A CONSIDERABLE PRELIMINARY INVESTIGATIN IS NECESSARY IN EACH INDIVIDUAL CASE. FIRST BY SERIAL TESTING OF SIMILAR PARTS, THE TIME REQUIREMENT IS REDUCED TO A FEW MINUTES. IN PRINCIPLE THE VOID FRACTION CAN BE QUANTITATIVELY DETERMINED, ALTHOUGH THIS VALUE IS AFFLICTED WITH A LARGE ERROR (DIFFERENCE BETWEEN TWO LARGE NUMBERS). VOID SIZE AND ARRANGEMENT CANNOT BE DETERMINED, SINCE THE RESOLUTION DOES NOT SUFFICE. A RECORDING OF THROUGH TRANSMISSION OF RADIATION WITH WEAKER X-RADIATION IS FOR THIS RECOMMENDED, ALTHOUGH THE ABSOLUTE VALUE IS NOT GIVEN THEREWITH.

15. NTIAC-16779

YAROSHEK, A. D.
NONDESTRUCTIVE STRUCTURAL IDENTIFICATION OF SEVERAL
ENGINEERING GLASS-PLASTICS
PUBLISHED BY CONSULTANTS BUREAU, 227 W. 17TH ST.,
N. Y., NY 10011
JUL 78, 07P
AVAILABILITY: PUBLISHED IN SOV. J. NONDESTR. TEST.;
13, 5; SEP.-OCT. 1977; 552-558; 7 REFS. (ENG. TRANS.
JULY 1978)

PLASTIC, GLASS, DIELECTRICS, STRUCTURAL MATERIALS,
MECHANICAL PROPERTIES, MATRIX, COMPOSITE MATERIALS,
APPLICATIONS, PHYSICAL PROPERTIES, PERMITTIVITY, POLYMERS,
FIBERS, MATERIAL SELECTION

THE DIELECTRIC CHARACTERISTICS EPSILON AND TAN DELTA OF EIGHT STRUCTURAL VARIATIONS OF ENGINEERING GLASS-PLASTICS WERE MEASURRED OVER THE 50 X 1000 - 50 X 1,000,000 HZ FREQUENCY RANGE, WITH TWO ORTHOGONAL ORIENTATIONS OF THE FORCE LINES OF THE ELECTRIC FIELD. THE RESULTS ARE SHOWN HERE AND THE FEASIBILITY OF USING THESE DATA FOR NONDESTRUCTIVE STRUCTURAL IDENTIFICATION (RECOGNITION) OF THESE MATERIALS IS ESTABLISHED. (AUTHOR)

16. NTIAC-13666

GRUNEWALD ,K. ; FRITZSCH ,W. ; HARNIER ,A. V. ; ROTH,E.
NONDESTRUCTIVE TESTING OF PLASTICS BY MEANS OF
HOLOGRAPHIC INTERFEROMETRY
PUBLISHED BY SOC. OF PLASTIC ENGINEERS, INC.; 656
W. PUTNAM AVE., GREENWICH, CT. 06830
JAN 75, 13P
AVAILABILITY: PUBLISHED IN POLYMER ENG. AND SCIENCE;
15, 1; JANUARY 1975; 16-28; 11 REFS.

INTERFEROMETRIC HOLOGRAPHY, PLASTICS, TESTING, TEST METHODS, FIBERS, DEFORMATION, LOADING, LAMINATES, DEFECTS(MATERIALS), DETECTION, TENSILE STRENGTH, ACOUSTICS;

HOLOGRAPHIC INTERFEROMETRY WAS INVESTIGATED AS A METHOD FOR NONDESTRUCTIVE TESTING OF FLAT SHEETS OF GLASS-FIBER REINFORCED PLASTICS. INITIALLY, THE DEFORMATION BEHAVIOR OF FAULTLESS SHEETS WAS EXAMINED BY MEANS OF HOLOGRAPHIC INTERFEROMETRY. THE INTERFEROGRAMS WHICH RESULTED FROM VARIOUS LOADING CONDITIONS (I.E., TENSILE LOAD, BENDING) WERE COMPARED TO RESULTS OBTAINED MATHEMATICALLY. THE INTERFEROGRAMS OF FAULTLESS SHEETS WERE THEN COMPARED TO THOSE OF DEFECTIVE LAMINATES. BY SUITABLE LOADING OF THE SAMPLES A RANGE OF LAMINATE FAULTS COULD BE READILY AND QUALITATIVELY DETECTED. THE INFLUENCE OF THESE FAULTS ON THE TENSILE STRENGTH WAS EXAMINED. NOT ONLY THE MECHANICAL LOADING OF THE LAMINATES, BUT ALSO AN ACOUSTIC STIMULATION OF THE SHEETS PROVED SUITABLE FOR INTERFEROMETRIC DETECTION OF LAMINATE FAULTS. (AUTHOR)

17. NTIAC-9096

HAGEMAIER ,D. J. ; MCFAUL ,H. J. ; PARKS,J. T.
NONDESTRUCTIVE TESTING TECHNIQUES FOR FIBERGLASS, GRAPHITE FIBER, AND BORON FIBER COMPOSITE AIRCRAFT STRUCTURES
33 REFERENCES
29 OCT 69, 19P
AVAILABILITY: PAPER PRESENTED TO ASTM COMMITTEE D-30; DETROIT, MICH.; 29 OCT 69; 19 PP.

*FIBER REINFORCED COMPOSITES, *AIRCRAFT, *TEST METHODS, COMPOSITE MATERIALS, BORON, GRAPHITE, GLASS, MICROSCOPY, PENETRANTS, ULTRASONIC TESTING, RADIOGRAPHY, THERMOGRAPHY, UNBOND

VARIOUS NONDESTRUCTIVE TEST (NDT) METHODS WERE EVALUATED FOR INSPECTION AND EVALUATION OF BORON, GRAPHITE, AND GLASS-FIBER COMPOSITES FOR AIRCRAFT STRUCTURES. TYPICAL SPECIMENS WERE EVALUATED USING MICROSCOPIC, FLUORESCENT PENETRANT, RADIOGRAPHIC, ULTRASONIC, AND THERMOCHROMIC TEST METHODS. OPTICAL MICROSCOPIC EXAMINATION IS USEFUL FOR DETERMINATION OF FIBER PATTERN FROM THE EDGE OF A PANEL. IT WAS CONCLUDED THAT FLUORESCENT PENETRANT COMBINED WITH MICROSCOPIC EXAMINATION IS A USEFUL TOOL TO DETERMINE SURFACE DEFECTS; RADIOGRAPHY COMBINED WITH MAGNIFIED PHOTOGRAPHY IS AN EXCELLENT METHOD TO DETERMINE FIBER PATTERN, FIBER GAPS, BROKEN FIBERS, CRUSHED CORE, AND RESIN-RICH AREAS; AND ULTRASONIC AND THERMAL METHODS APPEAR TO HAVE MERIT FOR DETERMINING UNBONDED AREAS. THE RESULTS OF A LITERATURE SURVEY CONCERNING NDT OF COMPOSITES ARE PRESENTED IN ABSTRACTED FORM AND INDICATE SIGNIFICANT APPLICATIONS AND LIMITATIONS OF VARIOUS TEST METHODS. THE DIRECTION OF FUTURE NDT RESEARCH AND DEVELOPMENT EFFORTS IS INDICATED.

18. NTIAC-15368

BASLER ,G. ; SCHMEISSER,H.
RADIOMETRIC INSPECTION OF GLASS FIBRE REINFORCED PIPES BY MEANS OF AN IMAGE ANALYZING SYSTEM
PUBLISHED BY VDI-VERLAG GMBH; DUSSELDORF
1977, 05P
AVAILABILITY: PUBLISHED IN MATERIALPRUF.; 19, 9; SEPTEMBER 1977; 361-65

RADIOMETRY, FIBER REINFORCED COMPOSITES, GLASS, EPOXY, PIPES, DEFECTS(MATERIALS), X RAYS, IMAGES, ANALYSIS, TEST EQUIPMENT, DETECTION, MEASUREMENT, ENDOSCOPES, OPTICAL INSTRUMENTS, PROCESSING, IMAGE ANALYSIS, METHODOLOGY, MANUFACTURING, QUALITY CONTROL, QUALITY ASSURANCE

DUE TO THE MANUFACTURING PROCESS, GLASS FIBRE REINFORCED PIPES MADE OF EPOXY GLASS ARE SUBJECT TO STRUCTURAL IRREGULARITIES WHICH MUST BE CONSIDERED DEFECTS UPON EXCEEDING CERTAIN LIMITS AND UNDER CONSIDERATION OF THE REQUIRED COMPRESSIVE STRENGTH. ALSO DAMAGES AND DEFICIENCIES IN PROCESSING CANNOT BE ELIMINATED. BY COMBINING A HIGHLY STABILIZED X-RAY EQUIPMENT, AN IMAGE ANALIZING EQUIPMENT, AND AN ENDOSCOPIC OPTICAL SYSTEM DEFECTS AS DESCRIBED CAN BE DETECTED, CLASSIFIED, AND QUANTIZED. MEASURING ARRAY AND METHODOLOGY, SPECIFICALLY THE MEASURING VALUE EVALUATION ARE DESCRIBED. (AUTHOR)

19. NTIAC-13351

MARTIN,B. G.
ULTRASONIC ATTENUATION DUE TO VOIDS IN FIBRE-REINFORCED PLASTICS
PUBLISHER: IPC SCIENCE AND TECHNOLOGY PRESS, LTD., 32 HIGH ST., GUILDFORD, SURREY, ENGLAND, GU1 3EW
OCT 76, 05P
AVAILABILITY: PUBLISHED IN NON-DESTR. TEST. INT.; 9, 5; OCTOBER 1976; 242-246; 16 REFS.

ULTRASONICS, ATTENUATION, DEFECTS(MATERIALS), FIBER REINFORCED COMPOSITES, PLASTICS, FORMULAS(MATHEMATICS), VISCOELASTICITY, MATERIALS, FIBERS, ISOTROPY, FIBERGLASS, ANISOTROPY, CARBON, EXPERIMENTAL DATA, ACOUSTICS, ULTRASONIC TESTING, NDDT

THE AUTHOR CALCULATES THE ULTRASONIC ATTENUATION DUE TO VOIDS IN FIBRE-REINFORCED VISCOELASTIC MATERIALS AND OBTAINS EXPRESSIONS FOR ULTRASONIC ATTENUATION AS A FUNCTION OF BOTH VOID AND FIBRE CONTENT. HE CONSIDERS BOTH ELASTICALLY ISOTROPIC (FIBREGLASS) AND ANISOTROPIC (CARBON) FIBRES. A COMPARISON OF CALCULATED AND MEASURED VALUES SHOWS QUALITATIVE AGREEMENT. (AUTHOR)

20. NTIAC-13611

ADAMS ,R. D. ; WALTON ,D. ; FLITCROFT ,J. E. ; SHORT,D.
VIBRATION TESTING AS A NONDESTRUCTIVE TEST TOOL FOR COMPOSITE MATERIALS
SEE ALSO NT-13610
1975, 17P
AVAILABILITY: PUBLISHED IN COMPOSITE RELIABILITY; ASTM STP 580; 1975; 159-175

VIBRATION, TESTING, COMPOSITE MATERIALS, FAILURE, FIBER REINFORCED COMPOSITES, MATERIALS, PHYSICAL PROPERTIES, EVALUATION, STATIC TESTS, DYNAMIC TESTS, TORSION, SHEAR, STRESS, RESINS, CRACK PROPAGATION, FATIGUE(MECHANICS)

CERTAIN FAILURES, SUCH AS RESIN BOUND SHEAR CRACKS IN FIBER-REINFORCED MATERIALS GIVE RISE TO LITTLE CHANGE IN ULTRASONIC ATTENUATION OR RADIOGRAPHIC TRANSMISSION BUT CAN RESULT IN SIGNIFICANT REDUCTIONS IN MATERIAL PROPERTIES. A VIBRATION TECHNIQUE IS BEING EVALUATED AS A NONDESTRUCTIVE TEST TOOL UNDER SUCH CONDITIONS. THE WORK DESCRIBED FORMS THE FIRST PART OF THIS EVALUATION PROGRAM AND CONCERNS UNIDIRECTIONAL CARBON AND GLASS FIBER REINFORCED PLASTIC SUBJECTED TO STATIC AND DYNAMIC TORSIONAL LOADING. THE RESULTS AND TECHNIQUES WILL EVENTUALLY BE APPLIED TO COMPLEX COMPOSITE STRUCTURES. IN THE STATIC TORSION TEST PROGRAM, GOOD, VOID-FREE SPECIMENS FAILED AT SHEAR STRESSES OF BETWEEN 52 A

21. NTIAC-14981

MERON ,M. ; BAR-COHEN ,Y. ; ISHAI,O.
NONDESTRUCTIVE EVALUATION OF STRENGTH DEGRADATION IN GLASS-REINFORCED PLASTICS AS A RESULT OF ENVIRONMENTAL EFFECTS
PUBLISHED BY THE AMERICAN SOC. FOR TEST. AND MATER.; 1916 RACE ST., PHILADELPHIA, PA. 19103
SEP 77, 03P
AVAILABILITY: PUBLISHED IN J. TEST. AND EVAL.; 5,5; SEPTEMBER 1977; 394-396; 21 REFS.

DEGRADATION, STRENGTH(MECHANICS), GLASS, PLASTICS, REINFORCED PLASTICS, ENVIRONMENTAL EFFECTS, ULTRASONICS, ULTRASONIC TESTING, ATTENUATION, LAMINATES

DESTRUCTIVE AND NONDESTRUCTIVE TESTS WERE CONDUCTED ON GLASS-REINFORCED PLASTIC SPECIMENS AFTER DEGRADATION BY IMMERSION IN HOT WATER FOR VARIOUS PERIODS. ULTRASONIC ATTENUATION WAS FOUND TO CORRELATE WELL WITH NORMALIZED RESIDUAL STRENGTH DATA OBTAINED FROM DESTRUCTIVE TESTS. (AUTHOR)

22. The Physical Mechanisms Responsible for the Weathering of Epoxy Resins and GFR Epoxy Resins

Bristol Univ (England) H H Wills Physics Lab (393113)

Annual rept. no. 1, Sep 76-Oct 77
AUTHOR: Farrar, N. R.; Turner, T. W.; Ashbee, K. H. G.
E0774J1 Fld: 11D, 20F, 71F, 46C GRAI7809
Oct 77 78p.
Grant: DA-ERO-76-G-068
Project: 1T161102BH57
Task: 00
Monitor: 18

Abstract: The technique of using high intensity light emitting diodes to produce optical images of ultrasonic wave trains has been applied to two aspects of the work. In experiments preliminary to fundamental studies of resin/glass interfaces, the technique has been refined to the stage where clearly resolvable fringes can be reproducibly observed in glass and in epoxy resin, and in experiments to assess the technique's potential as a NDT tool capable of detecting flaws in real composites, ultrasound has been successfully transmitted through composite slabs to give 'readable' fringes in a glass visualising block. Accelerated water exposure tests and natural weathering tests on epoxy resin composites have continued. Chemical analysis has confirmed the impression gained from microstructural examination of fracture surfaces that, even when apparently fully cured, these materials contain unreacted resin and hardener, dissolution of which by diffused water is no doubt partly responsible for generation of the pockets of pressure believed to be the cause of disc-shaped internal cracks. (Author)

Descriptors: *Fiber reinforced composites, *Nondestructive testing, Glass reinforced plastics, Epoxy resins, Weathering, Degradation, Glass, Ultrasonic tests, Stress analysis, Photoelasticity, Light emitting diodes, Optical images, Microstructure, Water, Damage, Cracks, Cracking(Fracturing)

Identifiers: Fiberglass reinforced plastics, Epoxy matrix composites, *Optical measuring instruments, NTISDODXA

AD-A049 796/6ST NTIS Prices: PC A05/MF A01

23. **DETERMINATION OF EFFECTS OF MATERIALS AND PROCESS VARIABLES ON FILAMENT-WOUND STRUCTURES**

Aerojet-General Corp Azusa Calif (000000)

Quarterly progress rept. no. 3, 15 May-15 Aug 64
AUTHOR: Chester, B. E.
1173F1 USGRDR
Sep 64
Rept No: 0827-02-3
Contract: N140 131 75687B X
Project: SF012 01 03 , 6438
Task: 217
See also: AD-602 279.

Abstract: Six additional specimens were fabricated and tested during this report period. Mechanical and physical test data indicated that the values obtained for specific gravity, density, horizontal shear, and modified cylinder shear were the highest to date for specimens fabricated on this program. The calculated void contents were well within the 0.5-vol% range suggested by the technical monitor. The ultrasonic-absorption attenuation values, ranging from 4.3 to 6.4 db/in., which were obtained were also within the customer's suggested range. The attenuation variation was determined to be less than 1 db along the length of the cylinder; the surface reflection losses were determined to be 5.0 db. Microphotographic analysis indicated the structures to be uniform and void free. While the test results described above were excellent, the collapse pressures and the resultant stress levels were lower than expected. The highest value obtained was a pressure of 20,300 psi with a composite stress level at the ID of 112.8 ksi. All test results were below the values previously obtained for the same specimen configuration. These low values are believed to be the result of a combination of high hoop-winding tensions and the use of an internal expansion machining mandrel.

Descriptors: (*FILAMENT WOUND CONSTRUCTION, COMPOSITE MATERIALS), (*COMPOSITE MATERIALS, FILAMENT WOUND (CONSTRUCTION)), REINFORCING MATERIALS, GLASS TEXTILES, NON-DESTRUCTIVE TESTING, HYDROSTATIC PRESSURE, ULTRASONIC RADIATION, SHEAR STRESSES, CYLINDRICAL BODIES, PLASTICS, PHYSICAL PROPERTIES, SUBMARINE HULLS, TEST METHODS, PRESSURE VESSELS, IMPREGNATION, WINDING

AD-605 572 CFSTI Price: PC E01

24. EFFECT OF CYCLE PROFILE ON THE BIAXIAL COMPRESSIVE FATIGUE PERFORMANCE OF FILAMENT WOUND LAMINATES

IIT Research Inst., Chicago, Ill. (175 350)

Technical summary rept.
AUTHOR: Abbott, B. W.; Cornish, R. H.; Cole, C. K.
3573B3 Fld: 11D USGRDR6716
Jan 65 90p
Contract: NObs-90329
Project: IITRI-M6081, SR-007003
Task: 1008
Monitor: 18

Abstract: The results of a program to study the effect of cycle profile on the biaxial compressive fatigue performance of glass reinforced plastics is presented. A description of the materials used, and methods of specimen fabrication and preparation is included. The results of specimen characterization as well as the techniques employed for ultrasonic inspection of the finished specimens are discussed. The results of biaxial compressive fatigue experiments, aimed at (a) establishing the effect of cycle profile, and (b) studying fatigue effects at low stress levels, are presented and discussed. Some observations of fatigue damage sites in unfailed specimens by macroscopic inspection of specimen cross sections is included. A literature review of the effect of frequency on the fatigue strength of metallic materials is presented in an appendix. An analysis of the ultrasonic inspection records obtained during the course of the study is also included as an appendix. (Author)

Descriptors: (*Filament wound construction, Fatigue(Mechanics)), (*Reinforced plastics, Fatigue(Mechanics)), Compressive properties, Non-destructive testing, Ultrasonic radiation, Stresses, Composite materials, Laminated plastics, Pressure vessels, Deep submergence, Epoxy plastics, Structural properties

AD-456 011 CFSTI Price: PC A05

25. EVALUATION OF VOID CONTENT IN EPOXY-GLASS FILAMENT WOUND MATERIAL BY MICROWAVE TESTS

Naval Applied Science Lab Brooklyn N Y (000000)

Technical memo.
161313 USGRDR6513
1965 2p
Rept No: 6188-1-TM-1
Project: SF007 03 04
Task: 1008

Abstract: Several selected samples of epoxy-glass filament wound material were tested in free space by microwave measurement techniques. The purpose of these tests was to seek significant relationships between percentage of void content and dielectric properties for practical application in nondestructive test procedures. The test results revealed that substantial amounts of void content in the test samples caused very small changes in the measured value of dielectric constant. Furthermore, these changes could not be distinguished from the effects of various other factors related to the test. Therefore it was concluded that the free space measurement of dielectric constant was unsatisfactory as in indication of the distributed void content of the subject material. (Author)

Descriptors: (*TEST METHODS, COMPOSITE MATERIALS), (*COMPOSITE MATERIALS, FILAMENT WOUND CONSTRUCTION), (*FILAMENT WOUND CONSTRUCTION, COMPOSITE MATERIALS), (*EPOXY PLASTICS, COMPOSITE MATERIALS), GLASS TEXTILES, DIELECTRIC PROPERTIES, NON-DESTRUCTIVE TESTING, INTERFEROMETERS, MICROWAVE BRIDGES

AD-615 308 CFSTI Price: PC A02

26. A Feasibility Analysis of the Acoustic Holographic Interferometric Concept for Void Detection in Composite Pressure Vessels

Army Missile Command Redstone Arsenal Ala Ground Equipment and Materials Directorate (400406)

Technical rept.
AUTHOR: Fox, Martin D.; Ransom, William F.; Chiang, Fu-Pen; Griffin, Judson R.; Petty, Robert H.
C2362G3 Fld: 14E, 14B, 73D, 82A GRAI7407
Nov 72 46p
Rept No: RL-TR-72-12
Project: DA-1-T-061101-A-91-A

Monitor: 18

Abstract: The purpose of this report is to present the results of a feasibility analysis of an acoustical holographic interferometric concept for the detection of flaws and voids in fiberglass composite pressure vessels. An approach is described which combines interferometry with acoustic holography to produce long wavelength acoustical holographic interferograms. By using ultrasound as the investigating radiation, the potential exists for displacement studies on the interior of normally opaque objects such as composite pressure vessels. The report develops a theory, and suggests some simple means to verify and further investigate acoustic holographic interferometry. (Modified author abstract)

Descriptors: *Nondestructive testing, *Holography, Pressure vessels, Composite materials, Fiberglass, Defects(Materials), Feasibility studies

Identifiers: *Interferometric holography, *Acoustic holography, *Ultrasonic holography, A

AD-773 728/1 NTIS Prices: PC A03/MF A01

27. Static and Fatigue Damage Characterization in Composite Materials

United Technologies Corp Stratford Conn Sikorsky Aircraft Div*Air Force Office of Scientific Research, Bolling AFB, D.C. (323800)

Final rept. Jun 74-Jul 75
AUTHOR: Nevadunsky, Joseph J.; Matusovich, C. J.; Lucas, John J.
C5594C4 Fld: 11D, 1C, 71F, 51C GRAI7601
Aug 75 58p
Rept No: SER-50939
Contract: F44620-73-C-0043
Project: AF-9782
Task: 978205
Monitor: AFOSR-TR-75-1535
See also report dated Sep 74, AD-A001 944.

Abstract: The purpose of the investigation was to characterize two composite laminates. This was accomplished by identifying static and fatigue modes present within the laminates by fractographic and non-destructive tests methods and relating them to stiffness loss. Torsional and axial modulus measurements were employed to quantitatively characterize the materials. Microscopic examinations, both visual and SEM were used to destructively evaluate the failure mechanisms present at various stages of static and fatigue damage. Observations of heat generation, ultrasonics, holographic interferometry, and speckle interferometry were conducted to qualitatively characterize both the failure mechanisms and stiffness loss they cause. This approach is aimed at completely characterizing composite laminates for their structural integrity throughout their static and fatigue lives.

Descriptors: *Composite materials, *Laminates, Static tests, Fatigue tests(Mechanics), Nondestructive testing, Damage, Fiber reinforced composites, Glass reinforced plastics, Fiberglass, Epoxy resins, Carbon fibers, Fatigue(Mechanics), Fracture(Mechanics), Structural properties, Helicopters, Airframes

Identifiers: Epoxy matrix composites, Fiberglass reinforced plastics, Carbon fiber reinforced plastics, Oriented fiber composites, NTISDODAF

AD-A017 632/1ST NTIS Prices: PC A04/MF A01

28. **NONDESTRUCTIVE TESTING FOR VOID CONTENT IN GLASS-FILAMENT-WOUND COMPOSITES**

Naval Research Lab Washington D C (251950)

Final rept.
AUTHOR: Walker, B. E. Jr; Ewing, C. T.; Miller, R. R.
5481E3 Fld: 11D, 13H USGRDR6904
4 Oct 68 19p*
Rept No: NRL-6775
Project: RR-001-01-43

Abstract: Precise nondestructive methods for void determinations on glass-filament-wound composites in the form of rings and ring segments were tested for feasibility, with particular emphasis on the 0- to 3-volume-% void region. Experimental data related to void content are presented for several possibilities - infrared transmission, backscatter from laser transmission, density measurements, and corona discharge inception. The problems associated with these methods are discussed, and the feasibility of a nondestructive test method for void determinations on rings is demonstrated in comparison with destructive void results. (Author)

Descriptors: (*Composite materials, *Non-destructive testing), (*Filament wound construction, Non-destructive testing), Feasibility studies, Glass textiles, Epoxy plastics, Mathematical models, Defects(Materials), Density, Beta particles, Backscattering, Dielectric properties, Infrared transmitters, Lasers, Microwaves, Electrical corona, Mixtures

AD-679 573 CFSTI Prices: PC A02/MF A01

Development of Nondestructive Methods for the Quantitative Evaluation of Glass-Reinforced Plastics

Avco Missiles Space and Electronics Group Lowell Mass Avco Space Systems Div (401 409)

Summary technical rept.. 1 Jul 65-31 May 66
AUTHOR: Zurbrick. J. R.
D1901J2 Fld: 14B d7710
Mar 67 108p
Rept No: AVSSD-0250-66-CR
Contract: AF 33(615)-1705
Project: AF-7360
Task: 736002
Monitor: AFML-TR-66-269
Distribution limitation now removed.

Abstract: Reliability of organic nonmetallic materials for aerospace applications is a serious consideration. Weight and space requirements as well as mechanical properties are important factors in the selection and use of structural components produced from filament wound or laminated fabric reinforced plastics. Applicable nondestructive testing (NDT) techniques can in effect enable end use properties and performance to be predicted with confidence. Five resin systems. epoxy. phenolic. polyester. polybenzimidazole. and silicone. in (181) glass fabric laminates were nondestructively evaluated. They were intentionally varied in resin content to simulate industrial conditions. Correlations were made between a given NDT response and laminate conditions. Gamma radiation gaging using CD 109 was used to measure laminate density. Ultrasonic velocity measurements provided many correlations between physical and mechanical properties for specific resin systems. Experimental moduli were predictable to + or -0.37 X ten to the 6th power psi. Apparent values of both tensile modulus and flexural modulus were affected in the same manner and to the same extent by shear deflections in the resin. between - ply voids. within-ply porosity. and resin content. As a result. it was learned that nondestructive test techniques could be used to clarify material composition/mechanical property uncertainties in reinforced plastics technology. (Author)

Descriptors: (*Nondestructive testing. Glass textiles). (*Laminated plastics. Nondestructive testing). Benzimidazoles. Epoxy resins. Phenols. Polyester plastics. Silicone plastics. Sandwich panels. Tensile properties. Elongation. Elastic properties. Porosity. Defects(Materials). Density. Aging(Materials). Radiography. Radiometers. Ultrasonic radiation. Dielectric properties. Measurement. Statistical processes. Experimental data. Cadmium. Radioactive isotopes. Ultrasonic properties

Identifiers: Benzimidazole polymers. NTISDODXD

AD-815 360/3ST NTIS Prices: PC A06/MF A01

30. Contribution to the Nondestructive Testing of First Irreversible Processes in Glass-Fiber-Reinforced Plastics

Technische Univ., Hanover (West Germany).*Department of Energy. (G131000)
AUTHOR: Buhmann, K. P.
E1513K3 Fld: 11D, 11I, 14B, 94J, 71F GRAI7815
Oct 77 204p
Contract: W-7405-ENG-48
Monitor: 18
Thesis.
Translation of German report.

Abstract: The intent of this paper is to report the following tests: (1) Investigations to determine the deformation-related primary damage limit of uniaxially loaded test specimens made of glass fiber-reinforced unsaturated polyester (GF-UP), epoxy resin (GF-EP), polyamide (GF-PA), polyethylene (GF-PE) and modified polystyrene (GF-SAN). (2) For a broad range of different laminates, limits of application are being determined for nondestructive testing methods such as ultrasonic testing, soft X-ray technique, liquid temperature indicators, infrared radiometry, irreversible work-absorption, evaporation measurements, surface penetrant testing, sound emission analysis. (3) Sound emission analyses, dye penetrant tests and a highly sensitive gas-permeation detection used for thin-walled precision wound tubes made of glass fiber-reinforced epoxy resin and subjected to internal pressure make it possible to compare experimental results with strength theoretical determinations of the cracking limit according to ''laminate fracture analysis'' based on continuum theory. (4) By frequency analysis of individual pulses emitted in the audible range, the possibility of differentiating microscopic fracture processes according to fiber breakage and interfiber breakage (matrix or interface breakage) is being investigated from the standpoint of increasing the reliability of micromechanical analyses and improving predictions of service life and evaluating operational safety. (ERA citation 03:019155)

Descriptors: *Reinforced materials, Epoxides, Fibers, Fracture properties, Glass, Lamellae, Nondestructive testing, Polyethylenes, Polystyrene, Ultrasonic testing

Identifiers: ERDA/360303, ERDA/360403, Translations, West Germany, Reinforced plastics, Fiberglass reinforced plastics, Fiber reinforced composites, NTISDET

UCRL-Trans-11287 NTIS Prices: PC A10/MF A01

31 ID NO.- EI70X148354 048354
High speed thermal image transducer for practical NDT applications
GREEN DR
Pacific Northwest Lab. Richland, Wash
Mater Eval v 28 n 5 May 1970 p 97-102, 110
DESCRIPTORS: (*MATERIALS TESTING, *Nondestructive), (ALUMINUM AND ALLOYS, Fiber Reinforced),
CARD ALERT: 415, 422, 541, 542, 812
A new type of thermal transducer capable of imaging bond defects and thermal property differences within test specimens in a few seconds has been developed. Images of defects in specimens comprising stainless steel bonded to glass, carbon-carbon composites, aluminum honeycomb with aluminum skin, aluminum honeycomb with titanium skin and aluminum honeycomb with fiber glass skin have been produced using this technique. A testing time of 3 sec for a specimen of any size is typical. Panels having areas up to 100 sq in. have been tested in the laboratory. the technique can be applied to test areasof 100 sq ft or so. Dry contact between the transducer and the test specimen is required, but no special preparation of the as-received specimens is needed. 1 ref.

32. 50428 D7605165
PREDICTING THE BREAKDOWN OF GLASS-PLASTICS BY THE SEISMOACOUSTIC METHOD. ANALYSING THE LOADING-RATE CHARACTERISTICS AND THE TEMPERATURE CHARACTERISTICS OF ACOUSTIC EMISSION IN GLASS-PLASTICS UNDER UNIAXIAL TENSION
TUTAN, M.YA.; ADAMOVICH, A.G.
INST. OF POLYMER MECH., ACAD. OF SCI., RIGA, LATVIAN, SSR
MEKH. POLIM. (USSR) VOL.11, NO.2 MARCH-APRIL 1975
Coden: MKPLA6
Trans In: POLYM. MECH. (USA) VOL.11, NO.2 320-1 MARCH-APRIL 1975 Coden: PLYMAQ
Treatment: X
02
(4 Refs)
Descriptors: MECHANICAL STRENGTH; ACOUSTIC EMISSION; COMPOSITE MATERIALS; REINFORCED PLASTICS; FIBRES; GLASS
Identifiers: GLASS REINFORCED PLASTICS; BREAKDOWN PREDICTION ; LOADING RATE CHARACTERISTICS; SEISMOACOUSTIC METHOD; TEMPERATURE CHARACTERISTICS; ACOUSTIC EMISSION; UNIAXIAL TENSION

Section Class Codes: D3260, D3450

33. 52181 D7606918
MICROWAVE DETERMINATION OF THE MECHANICAL STRAINS IN GLASS-REINFORCED PLASTIC ARTICLES. I. INVESTIGATION OF THE ANISOTROPIC PROPERTIES OF GLASS-REINFORCED PLASTICS IN THE MILLIMETER RANGE
KOVALEV, V.P.; KRAMAR, V.K.; BARANOV, G.L.
V.I. UL'YANOV LENINGRAD ELECTRICAL ENGNG. INST., LENINGRAD, USSR
MEKH. POLIM. (USSR) VOL.11, NO.3 533-40 MAY-JUNE 1975 Coden: MKPLA6
Trans In: POLYM. MECH. (USA) VOL.11, NO.3 454-60 MAY-JUNE 1975 Coden: PLYMAQ
Treatment: P
02
(19 Refs)
Descriptors: STRAIN MEASUREMENT; COMPOSITE MATERIALS; FIBRES; GLASS; REINFORCED PLASTICS
Identifiers: GLASS REINFORCED PLASTIC ARTICLES; FREE SPACE METHODS; MILLIMETRE RANGE; DIELECTRIC CONSTANTS; MICROWAVE DETERMINATION; MECHANICAL STRAINS; ANISOTROPIC PROPERTIES
Section Class Codes: D2260, D4370, D3260

34. 57421 D7704670
MICROWAVE DETERMINATION OF THE MECHANICAL STRAINS IN GLASS-REINFORCED PLASTIC ARTICLES. II. INVESTIGATION OF THE RELATION BETWEEN THE MECHANICAL STRAINS AND THE VARIATION OF THE DIELECTRIC CONSTANT IN GLASS-REINFORCED PLASTIC ARTICLES
KOVALEV, V.P.; BARANOV, G.L.; KRAMAR, V.K.
V.I. ULYANOV LENINGRAD ELECTRICAL ENGNG. INST., LENINGRAD, USSR
MEKH. POLIM. (USSR) VOL.11, NO.5 917-22 SEPT.-OCT. 1975 Coden: MKPLA6
Trans In: POLYM. MECH. (USA) VOL.11, NO.5 785-9 SEPT.-OCT. 1975 Coden: PLYMAQ
Treatment: X
02
(6 Refs)
Descriptors: COMPOSITE MATERIALS; PHYSICAL PROPERTIES AND EFFECTS; STRAIN; FIBRES; GLASS; REINFORCED PLASTICS
Identifiers: GLASS REINFORCED PLASTIC ARTICLES; MICROWAVE DETERMINATION; MECHANICAL STRAINS; DIELECTRIC CONSTANT; ELECTRICAL PARAMETERS; MECHANICAL LOAD
Section Class Codes: D3260, D3390

35. ID NO.- EI750640180 540180
CHARACTERISATION OF FIBRE COMPOSITES USING ULTRASONICS.
Dean, G.
Natl Phys Lab, Teddington, Middlesex, Engl
Compos SEM DASH$ Stand Test and Des, Conf Proc, Pap, Natl Phys Lab, Teddington, Engl, Apr 8-9 1974 p 126-130. Publ by IPC Sci and Technol Press, Guildford, Surrey, Engl, 1974
DESCRIPTORS: (*PLASTICS, REINFORCED, *Elasticity), (MATERIALS TESTING, Ultrasonic Applications), (COMPOSITE MATERIALS, Mechanical Properties), GLASS FIBER, MATHEMATICAL TECHNIQUES.
CARD ALERT: 415, 421, 753, 812, 817, 921
An ultrasonic technique is reviewed for determining symmetry and measuring the elastic properties of composite materials. Methods for interpreting data to indicate fiber concentration and defect content in continuous fiber systems and the degree of orientation in short fiber systems are discussed and illustrated with experimental results. 7 refs.

36. ID NO.- EI7711R6067 786067

USING THE ACOUSTIC-EMISSION METHOD TO CHECK THE STRENGTH OF FIBERGLASS RINGS.

Detkov. A. Yu.

All-Union Sci-Res Inst of Nondestr Test. Kishinev. Mold SSR

Sov J Nondestr Test v 12 n 5 Sep-Oct 1976 p 488-493

CODEN: SJNTAB

DESCRIPTORS: (*STRENGTH OF MATERIALS. *Nondestructive Examination).

CARD ALERT: 421. 422

A method is proposed for determining the ultimate loads on rings made of fiberglass by registering and analyzing the acoustic-emission pulses in the high-frequency range. The influence of the loading rate on the parameters of the acoustic-emission pulses is studied. It is shown to be possible to detect cleavage in fiberglass by means of the acoustic emission. A comparison is made between the ultrasonic and the acoustic-emission methods for the prediction of the ultimate loads. 8 refs.

37. ID NO.- EI70X006604 006604

Ultrasonics. Nondestructive technique for predicting residual life of compressively fatigued filament wound composites

COLE CK; ZOISS MH

IIT Research Inst. Chicago. Ill

Soc Aerospace Matl & Process Engrs-Matls and Processes for 70's-SAMPE Nat Symposium. 15th. Apr 29-May 1 1969 p 923-42

DESCRIPTORS: (*MATERIALS TESTING. *Nondestructive). (PLASTICS. Reinforced). (PLASTICS. Mechanical Properties). (MATERIALS TESTING. Residual Stresses). (ULTRASONICS. Measurements).

CARD ALERT: 002. 118. 157

Ability of through transmission ultrasonic testing to determine location and critically of fatigue incuded damage in filament wound fiberglass cylinders is presented: degree of damage. as measured by ultrasonic attenuation. is further correlated to residual life remaining to material: application of this technique to composite. deep submergence multidive vehicles is discussed. 3 refs.

38. ID NO.- EI72X021928 221928

Propagation of stress waves in fiber- reinforced composite rods

TAUCHERT TR; MOON FC

University of Kentucky, Lexington

AIAA J v 9 n 8 Aug 1971 p 1492-8 CODEN: AIAJA

DESCRIPTORS: (*COMPOSITE MATERIALS, *Stresses), STRESSES, STRENGTH OF MATERIALS,

CARD ALERT: 408, 421, 422, 817

The mechanical behavior of fiber- reinforced composite materials subject to dynamic loadings is investigated. The elastic moduli and damping coefficients of glass- epoxy and boron- epoxy beams were determined from the frequencies and bandwidths of their resonances during lateral forced vibrations. Longitudinal stress pulses were generated in the composites by impact of lead pellets fired from a pneumatic rifle. Measured values of the velocity and attenuation of the pulses agree favorably with those based upon the vibration data and thessumption of linear viscoelastic behavior. Results of an exploratory study on the propagation of high-frequency waves in composites using an ultrasonic technique are also reported. 13 refs.

39. ID NO.- EI740846987 446987

INTERNAL DAMPING IN A FIBER-REINFORCED COMPOSITE MATERIAL.

Tauchert, Theodore R.

Univ of Ky, Lexington

J Compos Mater v 8 Apr 1974 p 195-199 CODEN: JCOMBI

DESCRIPTORS: (*COMPOSITE MATERIALS, *Vibrations), (ULTRASONIC WAVES, Absorption), (STRESSES, Analysis),

IDENTIFIERS: STRESS WAVE ATTENUATION

CARD ALERT: 415, 753

This note demonstrates that ultrasonic attenuation measurements may be combined with low frequency vibration data in order to characterize the internal damping over a wide frequency range. Solutions to stress-wave problems of the type considered previously can then be based upon interpolated data rather than less reliable extrapolated information. A simple technique for measuring damping in the ultrasonic frequency range is described, and experimental results are presented for a glass-epoxy composite material. 2 refs.

40. ID NO.- EI72X026565 226565

Study on non- destructive testing method of fiberglass reinforced plastic (FRP) (acoustic method)

FUJII T; MIZUKAWA K; ZAKO M

Osaka City Univ. Japan

Proc 14th Jap Congr on Mater Res. Kyoto. Japan. Sept 1970 (1971) p 115-19

DESCRIPTORS: (*PLASTICS. *Testing).

CARD ALERT: 421. 422. 815

The theory of a percussion method for testing the dynamic behavior of fiber glass reinforced plastics is presented. The testing apparatus and the acoustic and strain gage measurements involved are described briefly. Experimental results obtained are reproduced and discussed.

41. ID NO.- EI71X024570 124570

X- ray eye for quality control

British Plastics v 42 n 9 Sept 1969 p 113

DESCRIPTORS: (*PLASTICS PLANTS. *Production Control). X-RAYS . MATERIALS TESTING APPARATUS.

CARD ALERT: 421. 422. 816. 913

Development of equipment for in- situ nondestructive testing of molded glass fiber reinforced plastic pipes. The x- ray equipment consists of constant potential unit. fitted with a beryllium window 0. 3 mm focus x- ray tube. continuously ratec at 150 kV/3 mA. Shielding is incorporated iwhwith the x- ray unit to limit radiation except in the vicinity of the pipe entry and exit. Marconi Instruments supplied the television equipment. The x- ray tube. screen and TV camera are enclosec in a lead lined cabinet through which the specimen glass fiber tubes pass for inspection.

42. ,DOC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 875 789L 11/9 11/4
NAVAL SHIP RESEARCH AND DEVELOPMENT LAB ANNAPOLIS MD

Nondestructive Ultrasonic Examination of
Epoxy Glass-Reinforced, Filament-Wound,
Cylindrical Deep Submergence Test Models. (U)

DESCRIPTIVE NOTE: Research and development rept.,
OCT 70 57P Hand,W. ;Silvergleit,M. ;
Arcus,G. R. ;
REPT. NO. NSRDL/A-9-32
PROJ: SF51-544-102
TASK: 12402

UNCLASSIFIED REPORT
Distribution: DoD only: others to Commander,
Naval Ship Engineering Center, Attn: SEC-
6101E. Hyattsville, Md. 20782.

DESCRIPTORS: (*REINFORCED PLASTICS, DEEP SUBMERGENCE),
(*EPOXY RESINS, COMPOSITE MATERIALS), FILAMENT WOUND
CONSTRUCTION, NONDESTRUCTIVE TESTING, ULTRASONIC
RADIATION, CYLINDRICAL BODIES, MODELS(SIMULATIONS),
MODEL TESTS, REINFORCING MATERIALS, DEFECTS(MATERIALS),
RECORDING SYSTEMS, SCANNING, AUTOMATION, TRANSDUCERS,
SHIP MODELS, SUBMARINE MODELS, SHIP STRUCTURAL
COMPONENTS, GLASS TEXTILES, ATTENUATION (U)
IDENTIFIERS: C SCAN, C DISPLAYS (U)

43. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 849 284 11/4 13/10
IIT RESEARCH INST CHICAGO ILL

Fabrication Investigations and Biaxial Compressive Fatigue and Creep Evaluations of the ERL-4617 Preimpregnated Fiberglass Composite System.

DESCRIPTIVE NOTE: Rept. for Dec 68-Feb 69,
FEB 69 14P Cole,C. K. ;
REPT. NO. IITRI-D6039-6
CONTRACT: N00024-67-C-5441

UNCLASSIFIED REPORT
Distribution: No Foreign without approval of Commander, Naval Ship Engineering Center, TTN: Code 6101E. Washington, D. C. 20360.

DESCRIPTORS: (*UNDERWATER VEHICLES, CONSTRUCTION MATERIALS), (*COMPOSITE MATERIALS, GLASS TEXTILES), MANUFACTURING, LOADS(FORCES), SHEAR STRESSES, IMPREGNATION, AGING(MATERIALS), FILAMENT WOUND CONSTRUCTION, FATIGUE(MECHANICS), CREEP, CREEP STRENGTH
IDENTIFIERS: ULTRASONIC INSPECTION

This is a progress report delineating process evaluation of fiberglass reinforced plastic construction techniques.

44. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 848 102 11/4 20/11 1/3
AVCO GOVERNMENT PRODUCTS GROUP WILMINGTON MASS AVCO SPACE SYSTEMS DIV

Evaluation of Test Techniques for Advanced Composite Materials. (U)

DESCRIPTIVE NOTE: Technical rept., 10 Jul 67-30 Mar 68,
JUN 68 169P Lenoe,E. M. ;
REPT. NO. AVSSD-0099-68-CR
CONTRACT: F33615-67-C-1719
PROJ: AF-7381
TASK: 738106
MONITOR: AFML TR-68-166-Pt-1

UNCLASSIFIED REPORT

DESCRIPTORS: (*AIRFRAMES, STRUCTURAL PROPERTIES), (*COMPOSITE MATERIALS, TEST METHODS), WHISKERS(CRYSTALS), BORON, ALUMINUM, GLASS TEXTILES, EPOXY RESINS, TENSILE PROPERTIES, COMPRESSIVE PROPERTIES, STRESSES, STRAIN(MECHANICS), SHEAR STRESSES, LAMINATED PLASTICS, NONDESTRUCTIVE TESTING (U)

The report presents a review of tests techniques for plastic and metal matrix advanced composites. The techniques reviewed include tension, flexure, compression, and shear testing of flat laminates at room temperature. A description of the nondestructive test techniques and physical properties evaluation methods are included. (Autnor) (U)

45. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 916 681L 11/4 1/3 13/8
ROCKWELL INTERNATIONAL CORP LOS ANGELES CALIF LOS ANGELES
AIRCRAFT DIV

Advanced Composites Design Guide. Volume
III. Manufacturing. (U)

DESCRIPTIVE NOTE: Rept. for Mar 71-Jan 73,
JAN 73 232P
CONTRACT: F33615-71-C-1362

UNCLASSIFIED REPORT
Distribution limited to U.S. Gov't. agencies only;
Test and Evaluation; Mar 73. Other requests for
this document must be referred to Director, Air Force
Materials Lab.; Attn: LC. Wright-Patterson
AFB, OH 45433.
SUPPLEMENTARY NOTE: Third Edition. See also Volume
4, AD-916 682L.

DESCRIPTORS: (*Composite materials, *Handbooks),
(*Composite structures, Handbooks),
Manufacturing, Fabrication, Quality assurance,
Maintenance, Costs, Aerospace craft, Airframes,
Coding, Fibers, Aluminum, Boron, Beryllium,
Glass, Graphite, Silicon compounds, Carbides,
Tungsten, Epoxy resins, Laminates, Filaments,
Filament wound construction, Matrix materials,
Quality control, Nondestructive testing,
Machining, Specifications (U)
IDENTIFIERS: Design, Borsic composites (U)

UNCLASSIFIED

46. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 860 738L 14/2 7/4
NOTTINGHAM UNIV (ENGLAND) DEPT OF PHYSICS

High-Speed Turbines for Nuclear Magnetic
Resonance Spectroscopy. (U)

DESCRIPTIVE NOTE: Final technical rept. Apr 68-Mar 69,
MAR 69 35P Andrew,E. R. ;Firth,M. ;
Randall,P. J. ;
CONTRACT: DAJA37-68-C-0724

UNCLASSIFIED REPORT
Distribution: USGO: others to Army Research and
Development Group (Europe), APO New York
09757.

DESCRIPTORS: (*NUCLEAR MAGNETIC RESONANCE, *TURBINES),
ROTATION, FLUORIDES, ORGANIC PHOSPHORUS COMPOUNDS, GLASS
TEXTILES, RELAXATION TIME, GREAT BRITAIN (U)
IDENTIFIERS: *FIBERGLASS REINFORCED PLASTICS,
PHOSPHORUS POTASSIUM HEXAFLUORIDE (U)

47. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 913 880L 1/3 11/4
GENERAL DYNAMICS FORT WORTH TEX CONVAIR AEROSPACE DIV

Advanced Composite Technology Fuselage
Program. Volume V. F-5 Mid-Fuselage
Component - Manufacturing. (U)

DESCRIPTIVE NOTE: Technical rept. Jul 70-Aug 72,
APR 73 196P Swazey,E. H. ;Fant,John
A. ;
CONTRACT: F33615-69-C-1494
PROJ: AF-6169CW
MONITOR: AFML TR-71-41-Vol-5

UNCLASSIFIED REPORT
Distribution limited to U.S. Gov't. agencies only;
Test and Evaluation; 17 Oct 73. Other requests for
this document must be referred to Director, Air Force
Materials Lab., Attn: LC. Wright-Patterson
AFB, Ohio 45433.
SUPPLEMENTARY NOTE: See also Volume 6, AD-913
881L.

DESCRIPTORS: (*JET FIGHTERS, FUSELAGES), (*AIRFRAMES,
COMPOSITE MATERIALS), (*FUSELAGES, *COMPOSITE
MATERIALS), MANUFACTURING, MACHINE TOOLS, QUALITY
CONTROL, NONDESTRUCTIVE TESTING, MAINTENANCE, COSTS,
ULTRASONIC RADIATION, ASSEMBLY, GRAPHITE, EPOXY RESINS,
GLASS TEXTILES, BORON, THERMAL EXPANSION, NICKEL ALLOYS,
STEEL, FLAME SPRAYING, CARBON FIBERS, SANDWICH
CONSTRUCTION, MOLDINGS (U)
IDENTIFIERS: F-5 AIRCRAFT (U)

48. **ACOUSTIC EMISSION INVESTIGATION - HELICOPTER ROTOR SYSTEM**

R. M. Rusnak, H. C. Yee, and J. K. Sen
Final Report, Contract DAAJ02-73-C-0066
Report No. USAAMRDL-TR-76-11
November 1976
Prepared by Bendix Research Laboratories, Bendix Center, Southfield, Michigan 48076

49. NTIAC-6984 M

AVCO SYSTEMS DIV WILMINGTON MASS
LENOE,EDWARD M.
EFFECTS OF VOIDS ON MECHANICAL PROPERTIES OF GRAPHITE FIBER COMPOSITES
CONTRACT REPT. 1 MAR 69-30 NOV 70
30 NOV 70, 55P
AVSD-0166-71-RR
N00019-70-C-0242
AD-727236

*DEFECTS(MATERIALS), *MECHANICAL PROPERTIES, *COMPOSITE MATERIALS, GRAPHITE, FIBERS, LAMINATES, ULTRASONIC RADIATION, VELOCITY, METALLOGRAPHY, STRENGTH(MECHANICS), CARBON FIBERS, PLASTICS

THE RESULTS OF AN INVESTIGATION OF THE EFFECT OF VOIDS ON THE MECHANICAL PROPERTIES OF THORNEL 50/EPOXY AND MODMOR II/5206 EPOXY ARE DISCUSSED AND PRESENTED. UNI- DIRECTIONAL, AS WELL AS QUASI-ISOTROPIC, LAMINATES WITH SYMMETRICAL AND NONSYMMETRICAL PLY-TACKING SEQUENCES WERE FABRICATED WITH HIGH AND LOW POROSITY AND SUBSEQUENTLY SUBJECTED TO DETAILED NONDESTRUCTIVE AND DESTRUCTIVE TESTING. LONGITUDINAL AND TRANSVERSE FLEXURE AND TENSION, SHORT BEAM SHEAR, AND TORSION ROD EXPERIMENTS WERE COMPLETED ON THE TWO COMPOSITE SYSTEMS AT 75 AND 250 F. ULTRASONIC COMPRESSION AND SHEAR WAVE VELOCITIES WERE MEASURED AT DISCRETE LOCATIONS ON A SPECIMEN-BY-SPECIMEN BASIS, AND THE OBSERVATIONS CORRELATED WITH OBSERVED MECHANICAL PROPERTIES. AN IN-DEPTH METALLOGRAPHIC CHARACTERIZATION OF VOIDS WAS COMPLETED ON THORNEL 50/EPOXY AND CORRELATION ESTABLISHED FOR NDT -MECHANICAL PROPERTIES AND VOIDS. THESE RELATIONSHIPS WERE USED TO ESTIMATE UPPER AND LOWER BOUNDS ON THE STRENGTH AND STIFFNESS ENVELOPES OF THE UNIDIRECTIONAL AND ANGLE-PLY COMPOSITES. THIS PERMITS EVALUATION OF THE DEGRADATION EFFECTS OF VOIDS ON COMPOSITE PERFORMANCE. (AUTHOR-PL)

50. NTIAC-8997

KAELBLE, DAVID H.
KINETICS OF MOISTURE DEGRADATION IN GRAPHITE-EPOXY COMPOSITES
16 REFERENCES. SEE ALSO NT-8971
NOV 74, 22P
AVAILABILITY: PUBLISHED IN PROC. INTERDISCIPLINARY WORKSHOP FOR QUANTITATIVE FLAW DEFINITION; AFML-TR-74-238; NOV 74; 384-405

*COMPOSITE MATERIALS, *POLYMER MATRIX COMPOSITES, *DEGRADATION, *MOISTURE CONTENT, *ULTRASONIC TESTING, FIBER REINFORCED COMPOSITES, GRAPHITE, EPOXY, MOISTURE, STRENGTH(MECHANICS), FAILURE, LAMINATES, MATHEMATICAL MODELS, DESTRUCTIVE TESTS, VELOCITY, ATTENUATION, CONFERENCES

THE DEGRADING EFFECTS OF MOISTURE ON INTERLAMINAR STRENGTH OF GRAPHITE-EPOXY COMPOSITE LAMINATES WERE STUDIED. ULTRASONIC INSPECTION USING 2.25 MHZ THROUGH-TRANSMISSION C-SCANNING TO DETERMINE SOUND VELOCITY AND ACOUSTIC ABSORPTION COEFFICIENT WAS ACCOMPLISHED. SPECIMENS WERE SUBSEQUENTLY FRACTURED TO DETERMINE STRENGTH AND DESTRUCTIVELY ANALYZED TO DETERMINE MOISUTRE CONTENT. AN ANALYTICAL MODEL IS PRESENTED. ACOUSTIC VELOCITY DID NO SIGNIFICANTLY CORRELATE WITH STRENGTH. ACOUSTIC ATTENUATION, FOR WAVES PROPAGATING PERPENDICULAR TO FIBER PLY ORIENTATION WAS VERY SENSITIVE TO MOISTURE EXPOSURE TIME. ATTENUATION PARALLEL TO FIBER PLYS WAS LESS SIGNIFICANTLY AFFECTED. STUDIES OF DESICCATED SPECIMENS SUPPORT THE CONCLUSION THAT DEGRADATION BY MOISTURE IS IRREVERSIBLE BY DRYING. (NTDSC)

51. NTIAC-13646 M

VERETTE, R. M.
TEMPERATURE/HUMIDITY EFFECTS ON THE STRENGTH OF GRAPHITE/EPOXY LAMINATES
AIAA AIRCRAFT SYSTEMS AND TECH. MEETING, L.A., CALIF., AUG 4-7, 1975, PAPER 75-1011; 8 REFS
1975, 11P
AVAILABILITY: FOR SALE BY AIAA, INC., 750 3RD AVE., N. Y. 10017 (A75-39512)

TEMPERATURE, HUMIDITY, STRENGTH(MECHANICS), GRAPHITE, EPOXY, MOISTURE, ABSORPTION, ACOUSTICS, VELOCITY, ATTENUATION, LAMINATES, AIRCRAFT, DATA, RESIN, FIBERS

THE INFLUENCE OF TEMPERATURE AND HUMIDITY ON THE STRENGTH AND MODULUS OF GRAPHITE/EPOXY IS EXAMINED. THE MECHANICAL PROPERTIES AT SEVERAL TEMPERATURE/HUMIDITY CONDITIONS ARE COMPARED TO BASELINE ROOM TEMPERATURE DRY CONDITIONS. A TECHNIQUE FOR USING A HIGH TEMPERATURE/HIGH HUMIDITY SOAK PRIOR TO TEST TO ACCELERATE ATTAINING A WET CONDITION IS DISCUSSED. INFORMATION IS INCLUDED ON RATES OF MOISTURE ABSORPTION AND DESORPTION, MOISTURE EQUILIBRIUM LEVEL AS A FUNCTION OF INCOMING MATERIAL QUALITY AND PROCESSING VARIABLES, AND INFLUENCE OF SIMULATED SUPERSONIC TEMPERATURE SPIKES ON MOISTURE ABSORPTION. NONDESTRUCTIVE INSPECTION RESULTS (ACOUSTIC VELOCITY AND ATTENUATION) FOR DRY AND SATURATED LAMINATES ARE PRESENTED. STRESSES AND STRAINS AT FAILURE ARE PRESENTED AND REDUCED TO A B-BASIS. DATA FOR UNIDIRECTIONAL LAMINATES ARE GIVEN FOR TENSION, COMPRESSION, AND SHEAR, BOTH PARALLEL AND TRANSVERSE TO THE FIBER DIRECTION. THREE MULTIDIRECTIONAL LAMINATES TYPICAL OF AIRCRAFT CONSTRUCTION ARE ALSO EXAMINED. IN ADDITION, FRACTURE DATA ARE GENERATED AND THE INFLUENCE OF TEMPERATURE AND HUMIDITY IS PRESENTED. THE DATA INDICATE THAT MOISTURE EFFECTS ON RESIN-DOMINATED PROPERTIES AT ELEVATED TEMPERATURES ARE PARTICULARLY DETRIMENTAL. (AUTHOR)

52. NTIAC-14254

KAELBLE, D. H.; DYNES, P. J.
METHODS FOR DETECTING MOISTURE DEGRADATION IN GRAPHITE-EPOXY COMPOSITES
PUBLISHED BY AM. SOC. NONDESTR. TEST.; 3200 RIVERSIDE DR., COLUMBUS, OHIO 43221
APR 77, 06P
AVAILABILITY: PUBLISHED IN MATER. EVAL.; 35, 4; APRIL 1977; 103-108; 8 REFS.

GRAPHITE, EPOXY, COMPOSITE MATERIALS, DETECTION, MOISTURE, DEGRADATION, HIGH TEMPERATURE, FIBERS, LIFE(DURABILITY), MATRIX, PROPERTIES, STRENGTH(MECHANICS), ULTRASONICS, WAVES, VELOCITY, TEST METHODS, BARS, SCANNING, SPECTROSCOPY, PULSES, MICROWAVE TESTING, DYNAMIC TESTS, MECHANICAL TESTING

HYDROTHERMAL TREATMENT (COMBINED HIGH MOISTURE AND TEMPERATURE) OF GRAPHITE FIBER REINFORCED EPOXY MATRIX COMPOSITE PRODUCES IRREVERSIBLE DETERIORATION IN SHEAR STRENGTH LAMBDA (SUB B) AND MODIFIES THE WEIBULL DISTRIBUTION OF SURVIVAL PROBABILITY(S). ANALYSIS OF WATER DIFFUSION KINETICS SHOWS THAT STRENGTH DEGRADATION IS DOMINATED BY THE MATRIX BULK PROPERTIES. ULTRASONIC 2.25 MHZ WAVE VELOCITY TRANSVERSE TO THE FIBER AXIS IS SENSITIVE TO CURRENT MOISTURE CONTENT WHILE ACOUSTIC ATTENUATION ALPHA (SUB L) CORRELATES WITH PRIOR MOISTURE HISTORY AND STRENGTH DEGRADATION. THE HIGH GLASS TRANSITION TEMPERATURE OF THE EPOXY T (SUB G) = 245 DEGREES C RELATIVE TO MAXIMUM MOISTURE EXPOSURE TEMPERATURE T=100 DEGREES C RESTRICTS EXTENSIVE DEGRADATION OF MATRIX AND INTERFACE. ULTRASONIC METHODS ARE APPLIED FOR SCANNING THE EFFECTS OF POSITIONALLY VARIABLE MOISTURE CONTENT AND HYDROTHERMAL DAMAGE IN A COMPOSITE BAR. A NUMBER OF NDE METHODS INCLUDING DYNAMIC MECHANICAL SPECTROSCOPY (1.0-100 HZ), NMR PULSE RELAXATION SPECTROSCOPY, AND MICROWAVE SPECTROSCOPY (2.64 GHZ) ARE SHOWN TO PROVIDE HIGHLY RESOLVED MOISTURE EFFECTS DATA. THE DEVELOPMENT OF COMPOSITE DURABILITY CHARACTERIZATION AND ULTRASONICS SCANNING COUPLED WITH DIRECT MEASUREMENT OF BULK MOISTURE CONTENT APPEARS TO OFFER A VERSATILE NDE METHODOLOGY FOR QUANTITATIVE DETECTION OF HYDROTHERMAL AGING EFFECTS ON LARGE COMPOSITE STRUCTURES. (AUTHOR)

53. NTIAC-15643 M

BOEING COMMERCIAL AIRPLANE CO SEATTLE WASH
STOECKLIN, ROBERT L.
737 GRAPHITE COMPOSITE FLIGHT SPOILER FLIGHT SERVICE EVALUATION
3RD ANNUAL REPT. APR 76-APR 77
AUG 77, 29P
NASA-CR-145207
NAS1-11668
AVAILABILITY: FOR SALE BY NTIS, 5285 PORT ROYAL RD., SPRINGFIELD, VA 22161

GRAPHITE, EPOXY, COMPOSITE MATERIALS, ENVIRONMENTAL EFFECTS, FLIGHT TESTING, SPOILERS, AIRCRAFT, AIRCRAFT EQUIPMENT, VISUAL INSPECTION, ULTRASONIC TESTING, DESTRUCTIVE TESTS, HONEYCOMB STRUCTURES, MOISTURE, CORES, CORROSION, STRENGTH(MECHANICS), SERVICEABILITY, NASA

THE THIRD ANNUAL FLIGHT SERVICE REPORT WAS PREPARED IN COMPLIANCE WITH THE REQUIREMENTS OF CONTRACT NAS1-11668 AND COVERS THE FLIGHT SERVICE EXPERIENCE OF 110 GRAPHITE-EPOXY SPOILERS ON 737 TRANSPORT AIRCRAFT AND RELATED GROUND-BASED ENVIRONMENTAL EXPOSURE ON GRAPHITE-EPOXY MATERIAL SPECIMENS FOR THE PERIOD FROM APRIL 1976 THROUGH APRIL 1977. FOUR SPOILERS HAVE BEEN INSTALLED ON EACH OF 27 AIRCRAFT REPRESENTING SEVEN MAJOR AIRLINES OPERATING THROUGHOUT THE WORLD. A FLIGHT SERVICE EVALUATION PROGRAM OF AT LEAST 5 YEARS IS UNDER WAY. AS OF APRIL 30, 1977, A TOTAL OF 766,938 SPOILER FLIGHT HOURS AND 1,168,090 SPOILER LANDINGS HAD BEEN ACCUMULATED BY THIS FLEET. BASED ON VISUAL, ULTRASONIC, AND DESTRUCTIVE TESTING, THERE HAS BEEN NO EVIDENCE OF MOISURE MIGRATION INTO THE HONEYCOMB CORE AND NO CORE CORROSION. TESTS OF REMOVED SPOILERS AND OF GROUND-BASED EXPOSURE SPECIMENS AFTER THE THRID YEAR OF SERVICE CONTINUE TO INDICATE MODEST CHANGES IN COMPOSITE STRENGTH PROPERTIES. TEN ADVANCED-DESIGN, ALL-COMPOSITE SPOILERS WERE INTRODUCED INTO THE PROGRAM BEGINNING DECEMBER 18, 1975. ALL TEN WERE WITHDRAWN FROM SERVICE IN AUGUST 1976 FOLLOWING AN ADVERSE EXPERIENCE IN WHICH POLYSULFONE SKIN PANELS REACTED TO SKYDROL HYDRAULIC FLUID. REDESIGN OF THE ALL-COMPOSITE SPOILERS IS PLANNED. (AUTHOR)

54. NTIAC-16060

CHANG ,F. H. ; BELL ,J. R. ; CARTER ,H. G. ; YEE,B. G. W. ;

MEASUREMENT OF MOISTURE CONTENT IN ADVANCED COMPOSITES BY AN ULTRASONIC TECHNIQUE
SEE ALSO NT-16087
APR 77, 01P
AVAILABILITY: PUBLISHED IN PROC. 11TH SYMPOSIUM ON NONDESTR. EVAL.; APRIL 20-22, 1977; SAN ANTONIO, TEXAS; P. 6

MEASUREMENT, MOISTURE CONTENT, ULTRASONICS, ULTRASONIC TESTING, COMPOSITE MATERIALS, GRAPHITE, EPOXY, LAMINATES, SPECTROSCOPY, FOURIER TRANSFORMATION, ATTENUATION, EXPERIMENTAL DATA, ABSORPTION, TEMPERATURE EFFECTS, APPLICATIONS, TEST METHODS

AN ULTRASONIC TECHNIQUE HAS BEEN DEVELOPED TO MEASURE THE MOISTURE CONTENT IN GRAPHITE/EPOXY COMPOSITE LAMINATES. THIS TECHNIQUE USES THE PRINCIPLE OF ULTRASONIC SPECTROSCOPY TO OBTAIN THE INTERFERENCE OF SOUND WAVES REFLECTED FROM THE FRONT AND BACK SURFACES OF THE COMPOSITE LAMINATES. THE FREQUENCY SPECTRUM OBTAINED BY A FOURIER TRANSFORM OF THE CONVOLUTED RF SIGNALS IN THE TIME DOMAIN PROVIDES INFORMATION ON THE ULTRASONIC ATTENUATION CHARACTERISTICS OF THE LAMINATES. EXPERIMENTAL RESULTS WERE OBTAINED ON 8-PLY UNIDIRECTIONAL LAMINATES AND CROSS-PLY LAMINATES TREATED UNDER APPROXIMATELY 15 PER CENT INCREASE IN ATTENUATION IN THE FREQUENCY RANGE OF 12 TO 20 MHZ FOR THE LAMINATES WITH APPROXIMATELY 1 PERCENT MOISUTRE ABSORPTION. AT AN ELEVATED TEMPERATURE OF 150 F, THE ULTRASONIC ATTENUATION DIFFERENTIAL WAS INCREASED TO 20 PERCENT. THE EXPERIMENTAL TECHNIQUE AND RESULTS WILL BE PRESENTED ALONG WITH A DISCUSSION ON THE POTENTIAL APPLICATIONS OF THE METHOD. (AUTHOR)

55. NTIAC-10161

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION CLEVELAND
OHIO LEWIS RESEARCH CENTER
VARY ,ALEX ; LARK,RAYMOND F.
CORRELATION OF FIBER COMPOSITE TENSILE STRENGTH WITH THE ULTRASONIC STRESS WAVE FACTOR
TO BE PRESENTED AT ASNT, 1978 SPRING CONFERENCE, NEW ORLEANS, LA; APRIL 3-7, 1978
APR 78, 22P
NASA-TM-78846
AVAILABILITY: APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

TEST METHODS, ULTRASONICS, ULTRASONIC TESTING, ACOUSTICS, STRENGTH(MECHANICS), GRAPHITE, EPOXY, COMPOSITE MATERIALS, FIBERS, RESINS, BONDING, STRESS WAVES, MATRIX, MICROPOROSITY, NASA, PREDICTIONS, FRACTURE(MECHANICS), SHEAR, TENSILE, STRENGTH, TENSILE TESTS, WAVE PROPAGATION, LAMINATES

AN ULTRASONIC-ACOUSTIC TECHNIQUE WAS USED TO INDICATE THE STRENGTH VARIATIONS OF TENSILE SPECIMENS OF A GRAPHITE-EPOXY COMPOSITE. A STRESS WAVE FACTOR WAS DETERMINED AND ITS VALUE WAS FOUND TO DEPEND ON VARIATIONS OF THE FIBER-RESIN BONDING AS WELL AS FIBER ORIENTATION. THE FIBER ORIENTATIONS STUDIED WERE 0 DEGREES (LONGITUDINAL), 10 DEGREES (OFF-AXIS), 90 DEGREES (TRANSVERSE), (0 DEGREES/PLUS OR MINUS 45 DEGREES/0 DEGREES) SYMMETRICAL, AND (PLUS OR MINUS 45 DEGREES) SYMMETRICAL. THE STRESS WAVE FACTOR CAN INDICATE VARIATIONS OF THE TENSILE AND SHEAR STRENGTHS OF COMPOSITE MATERIALS. THE STRESS WAVE FACTOR WAS ALSO FOUND TO BE SENSITIVE TO STRENGTH VARIATIONS ASSOCIATED WITH MICROPOROSITY AND DIFFERENCES IN FIBER-RESIN RATIO. (AUTHOR)

56. NTIAC-16200

HAGEMAIER, D. J.
NDT OF DC-10 GRAPHITE-EPOXY RUDDER
MAY 78, 05P
AVAILABILITY: PUBLISHED IN MATER. EVAL.; 36, 6; MAY 1978; 57-61; 5 REFS.

GRAPHITE, EPOXY, COMPOSITE MATERIALS, AIRCRAFT, AIRCRAFT EQUIPMENT, MANUFACTURING, PRODUCTION, VISUAL INSPECTION, ULTRASONIC TESTING, INSERVICE INSPECTION, PROCEDURES, FLIGHT TESTING, JOINTS, PULSE ECHO TECHNIQUE, BOND TESTING, TEST EQUIPMENT, INSTRUMENTATION, SKIN(STRUCTURAL), THICKNESS;

FLIGHT SERVICE EVALUATION OF GRAPHITE COMPOSITES IS REQUIRED TO DETERMINE THE LONG-TERM BEHAVIOR UNDER ACTUAL SERVICE LOADS AND ENVIRONMENTS. TEN DC-10 RUDDERS WERE PRODUCED IN A PREPRODUCTION MANUFACTURING MODE TO OBTAIN MANUFACTURING COST DATA AND PRODUCTION PROGRESS CURVE TRENDS. THE CULMINATION OF THE PROGRAM WILL BE A MONITORED FIVE-YEAR EXPOSURE OF THE GRAPHITE RUDDERS IN ACTUAL AIRLINE SERVICE. ALL RUDDERS ARE ON A 100 PERCENT INSPECTION PROGRAM DUE TO THE NATURE OF THE FIVE YEAR PROGRAM, AND THE LIMITED NUMBER OF COMPOSITE RUDDERS IN SERVICE. VISUAL AND ULTRASONIC INSPECTIONS OF THE RUDDERS, INSERVICE, ARE DEFINE IN THE DC-10 NONDESTRUCTIVE TESTING MANUAL. THIS PAPER DISCUSSES AND ILLUSTRATES THE INSERVICE INSPECTION PROCEDURES TO BE EMPLOYED BY THE AIRLINE NDT PERSONNEL. (AUTHOR)

57. NTIAC-16322

BAILEY ,C. D. ; FREEMAN ,S. M. ; HAMILTON,J. M.
DETECTION AND EVALUATION OF IMPACT DAMAGE IN GRAPHITE/EPOXY COMPOSITES
SWRI LIBRARY TL698.N38 1977
1977, 23P
AVAILABILITY: PUBLISHED IN MATER. AND PROCESSES IN SERVICE PERFORMANCE; SOC. FOR ADVANCEMENT OF MATER. AND PROCESSING ENG.; 9TH TECH. CONF.; ATLANTA, GA; OCTOBER 1977; 491-503

GRAPHITE, EPOXY, COMPOSITE MATERIALS, IMPACT TESTS, IMPACT RESISTANCE, ULTRASONICS, ULTRASONIC TESTING, X RAYS, FIBERS, ACOUSTIC EMISSIONS, MICROSCOPES, DELAMINATION, PLIES, CRACKS, MECHANICAL PROPERTIES, FATIGUE(MECHANICS), RADIOGRAPHY, MICROSTRUCTURE, FRACTURE(MECHANICS), TENSILE TESTS, FRACTOGRAPHY, PULSE ECHO TECHNIQUE, DAMAGE, CROSS SECTION, OPTICAL EQUIPMENT

TESTS WERE CONDUCTED ON GRAPHITE/EPOXY COMPOSITE TO EVALUATE THE SENSITIVITY TO IMPACT DAMAGE OF ULTRASONIC, ENHANCED X-RAY AND ACOUSTIC EMISSION TECHNIQUES. SPECIMENS WERE SUBJ ECTED TO IMPACTS RANGING FROM 5 TO 50 IN-LBS (.057 TO .57 KG-M) IN ORDER TO DETERMINE THE MINIMUM LEVEL NECESSARY TO CAUSE PLY DELAMINATION AND FIBER BUNDLE FRACTURE. THE DEGREE OF DELAMINATIONN WAS VERIFIED BY MICROSCOPIC EXAMINATIONS OF SECTIONS CUT FROM THE IMPACTED SPOTS. FIBER BUNDLE FRACTURE WAS VERIFIED BY DE-PLYING THE COMPOSITE MATERIAL AND EXAMINING THE INDIVIDUAL PLIES. (AUTHOR)

58. NTIAC-16546 M

VIRGINIA POLYTECHNIC INST AND STATE UNIV BLACKSBURG DEPT
OF ENGINEERING SCIENCE AND MECHANICS
STALNAKER,DAVID O. ; STINCHCOMB,WAYNE W.

AN INVESTIGATION OF EDGE DAMAGE DEVELOPMENT IN
QUASI-ISOTROPIC GRAPHITE EPOXY LAMINATES

INTERIM REPT.
SEP 77, 91P
VPI-E-77-24
F33615-75-C-5119
AD-A045656

ULTRASONICS, PULSE ECHO TECHNIQUE, ULTRASONIC TESTING, COMPOSITE MATERIALS, GRAPHITE, EPOXY, FIBER REINFORCED COMPOSITES, FINITE ELEMENT ANALYSIS, THERMOGRAPHY, THREE DIMENSIONAL, TEST METHODS, LOADS(FORCES), VIBRATION, STRENGTH(MECHANICS), FRACTURE(MECHANICS), STRESS ANALYSIS;

THIS INVESTIGATION DESCRIBES AND DOCUMENTS IN DETAIL THE INITIATION, GROWTH, AND INTERACTIONS OF DAMAGE ALONG THE FREE EDGES OF TWO TYPES OF GRAPHITE/EPOXY FIBER-REINFORCED COMPOSITE LAMINATES. THE DAMAGE IS INITIATED BY TENSILE STATIC LOADING OF FLAT COUPONS FROM EACH TYPE TO THREE DIFFERENT STRESS LEVELS. GROWTH OF THE DAMAGE WAS CAUSED BY TENSION-TENSION FATIGUE LOADING. THE LAMINATES THAT WERE INVESTIGATED DIFFERED ONLY BY STACKING SEQUENCE. THE OBSERVATIONS WERE MADE THROUGH THE USE OF THE REPLICATION TECHNIQUE, A METHOD DEVELOPED FOR THE PURPOSE OF THIS INVESTIGATION. THIS TECHNIQUE ALLOWS FOR THREE-DIMENSIONAL, INSTANTANEOUS RECORDINGS OF THE ENTIRE SPECIMEN EDGE WHILE IT IS UNDER MAXIMUM LOAD. THE RECORDINGS OR IMPRESSIONS CAN BE STUDIED MICROSCOPICALLY AND PHOTOGRAPHED. THIS METHOD PROVIDES FOR DETAIL AND AN OVERALL FIELD OF VISION THAT HAS NOT BEEN OBTAINED IN PREVIOUS STUDIES. THE DAMAGE DEVELOPMENT WAS ALSO MONITORED BY TWO NON-DESTRUCTIVE TECHNIQUES; VIBROTHERMOGRAPHY AND AN ULTRASONIC-PULSE ECHO METHOD.

59. NTIAC-15700

SHELDON, W. H.
COMPARATIVE EVALUATION OF POTENTIAL NDE TECHNIQUES FOR INSPECTION OF ADVANCED COMPOSITE STRUCTURES
PUBLISHED BY THE AM. SOC. NON-DESTR. TEST.; 3200 RIVERSIDE DR., COLUMBUS, OHIO 43221
FEB 78, 06P
AVAILABILITY: PUBLISHED IN MATER. EVAL.; 36, 2; FEBRUARY 1978; 41-46

COMPOSITE MATERIALS, EVALUATION, ACOUSTICAL HOLOGRAPHY, PULSE ECHOES, C-SCAN, ULTRASONICS, RESONANCE, FOCUSING, IMAGES, IMAGING, HOLOGRAPHY, THREE DIMENSIONAL, SCANNING, LASERS, SONIC TESTS, LOW FREQUENCY, RADIOGRAPHY, TEST EQUIPMENT, GRAPHITE, CORES, UNBOND, DETECTION, DEFECTS(MATERIALS), B-SCAN, AIRCRAFT, PORTABLE EQUIPMENT;

THIS PROGRAM SYSTEMATICALLY EVALUATED POTENTIAL NDE TECHNIQUES FOR DETECTION OF FLAWS IN GRAPHITE COMPOSITE AIRCRAFT STRUCTURES. EMPHASIS WAS PUT ON APPLICATION OF AN ACOUSTIC IMAGING SYSTEM WITH A PORTABLE X-Y SCANNER AND A FLEX-ARM MECHANICAL HAND SCANNER. GRAPHITE COMPOSITE STRUCTURES USED IN THIS EVALUATION WERE: (1) A WING FLAP, FUSELAGE BULKHEAD PANEL (24 X 24 X 1 IN.) AND T-38 WING SECTION WHICH HAD FLAWS THAT OCCURRED DURING MANUFACTURING; (2) A WING ATTACH TRUNNION FITTING EXHIBITING A MAJOR TRANSVERSE CRACK IN ADDITION TO BEARING FAILURE AT THE LUG; (3) A WOVEN GRAPHITE COMPOSITE ACCESS BAY DOOR AND SEVERAL TEST PANELS WITH SIMULATED FLAWS (PRECURED ADHESIVE DISCS AND FOREIGN OBJECT IMPACT DAMAGE); (4) A GRAPHITE COMPOSITE HORIZONTAL STABILIZER; AND (5) A GRAPHITE COMPOSITE PANEL MOUNTED IN A FATIGUE TEST FIXTURE. EACH STRUCTURE WAS INSPECTED USING EITHER ULTRASONIC RESONANCE, FOCUSED IMAGE HOLOGRAPHY, PULSE-ECHO C SCAN, B SCAN AND 3D TECHNIQUES. SELECT STRUCTURES WERE ALSO INSPECTED USING A MOBILE LASER HOLOGRAPHIC SYSTEM, RADIOGRAPHY, FOKKER BOND TESTER AND A SONDICATOR. (AUTHOR/NTIAC)

60. NTIAC-16760

CRANE ,R. L. ; CHANG ,F. ; ALLINIKOV,S.
THE USE OF RADIOGRAPHICALLY OPAQUE FIBERS TO AID THE INSPECTION OF COMPOSITES
PUBLISHED BY AM. SOC. NONDESTR. TEST.; 3200 RIVERSIDE DR., COLUMBUS, OH 43221
SEP 78, 03P
AVAILABILITY: PUBLISHED IN MATER. EVAL.; 36, 10; SEPTEMBER 1978; 69-71; 4 REFS.

COMPOSITE MATERIALS, MECHANICAL PROPERTIES, FIBER REINFORCED COMPOSITES, FIBERS, BORON, GRAPHITE, EPOXY, RADIOGRAPHY, SHAPE, FAILURE, INTEGRITY, FLUORESCENT DYES, AUTOMATION, OPTICAL IMAGES, OPACITY, ELECTROOPTICS, PLIES, DEPTH, DAMAGE, NEUTRON RADIOGRAPHY, QUALITY ASSURANCE

SINCE THE MECHANICAL PROPERTIES OF FIBER REINFORCED COMPOSITE MATERIALS ARE DOMINATED BY THE PROPERTIES AND DISTRIBUTION OF THE FIBER CONSTITUENT, THE DETECTION AND MAPPING OF FIBER RELATED FLAWS HAVE A HIGH PRIORITY. IT HAS BEEN SHOWN THAT THE ADDITION OF BORON FIBERS TO THE EDGES OF GRAPHITE-EPOXY PREPREG TAPES FACILITATES THE RADIOGRAPHIC INSPECTION OF THE FINAL SHAPE FOR FIBER DISTRIBUTION RELATED FLAWS. IF THE BORON FIBER USED IN THIS APPLICATION HAS A FAILURE STRAIN EQUAL TO THAT OF THE GRAPHITE FIBER, THEN FIBER INTEGRITY MAY ALSO BE MONITORED. (AUTHOR)

61. NTIAC-13748

CHANG ,F. H. ; GORDON ,D. E. ; RODINI ,B. T. ; MCDANIEL,R. H.

REAL-TIME CHARACTERIZATION OF DAMAGE GROWTH IN GRAPHITE/EPOXY LAMINATES
PUBLISHED BY TECHNOMIC PUBLISHING CO., INC., 265 POST ROAD WEST, WESTPORT, CT 06880
JUL 76, 11P
AVAILABILITY: PUBLISHED IN J. COMPOSITE MATER.; 10; JULY 76; 182-192; 5 REFS.

REAL TIME, DEFECTS(MATERIALS), GROWTH, CHARACTERIZATION, GRAPHITE, EPOXY, LAMINATES, FAILURE, X RAYS, MONITORING, DELAMINATION, TECHNIQUE, STRESSES, DISTRIBUTIONS, COMPOSITE MATERIALS, LOADING, IMAGE ENHANCEMENT

THE DAMAGE GROWTH AND FAILURE MECHANISM IN GRAPHITE/EPOXY COMPOSITE SPECIMENS WERE CHARACTERIZED BY USING A MODIFIED X-RAY NONDESTRUCTIVE EVALUATION (NDE) TECHNIQUE. THE NDE MONITORING WAS CONDUCTED IN REAL-TIME WHILE THE FRACTURE SPECIMENS WERE UNDER TENSILE RAMP LOADING AND CONSTANT AMPLITUDE CYCLIC LOADING. TETRABROMOETHANE (TBE) WAS APPLIED AS AN OPAQUE ADDITIVE AT THE TIPS OF A SLIT IN THE CENTER OF THE SPECIMENS TO ENHANCE THE FLAW IMAGE. DAMAGE INITIATION, GROWTH AND FAILURE MECHANISM WERE OBSERVED FROM SEQUENCES OF X-RAY PICTURES RECORDED DURING TESTING. LIMITED RESULTS INDICATED THAT MATRIX FAILURE APPEARED TO PRECEDE DELAMINATION BETWEEN PLIES IN THE FAILURE MECHANISM STUDY. THE NDE TECHNIQUE ALLOWED THE ACTUAL STRESS REDISTRIBUTIONS IN THE COMPOSITE LAMINATES TO BE OBSERVED. (AUTHOR)

62. .NTIAC-14893

MARTIN, B. G.
AN ANALYSIS OF RADIOGRAPHIC TECHNIQUES FOR MEASURING RESIN CONTENT IN GRAPHITE FIBER REINFORCED EPOXY RESIN COMPOSITES
PUBLISHED BY ASNT, 3200 RIVERSIDE DR., COLUMBUS, OHIO 43221
SEP 77, 05P
AVAILABILITY: PUBLISHED IN MATER. EVAL.; 35, 9; SEPTEMBER 1977; 65-68, 75; 6 REFS.

RADIOGRAPHY, TECHNIQUE, MEASUREMENT, RESINS, X RAYS, GRAPHITE, FIBER REINFORCED COMPOSITES, EPOXY, ANALYSIS, RADIOGRAPHIC FILMS, DENSITY, THERMAL NEUTRONS, GAGING;

AN ANALYSIS WAS MADE OF RADIOGRAPHIC TECHNIQUES FOR MEASURING THE RESIN CONTENT (WEIGHT PERCENT) IN GRAPHITE FIBER REINFORCED EPOXY RESIN COMPOSITES. LOW ENERGY X-RAY AND THERMAL NEUTRON MASS ABSORPTION COEFFICIENTS WERE CALCULATED AS A FUNCTION OF COMPOSITE RESIN CONTENT. SOME MEASUREMENTS OF X-RAY MASS ABSORPTION COEFFICIENTS WERE MADE FOR COMPARISON. IN ADDITION, NEUTRON RADIOGRAPHIC FILM DENSITIES WERE MEASURED AND CALCULATED AS A FUNCTION OF RESIN CONTENT. IT WAS CONCLUDED THAT A THERMAL NEUTRON GAUGING TECHNIQUE SHOWS PROMISE FOR MEASURING COMPOSITE RESIN CONTENT TO WITHIN PLUS OR MINUS 1 WEIGHT PERCENT. (AUTHOR)

63. NTIAC-14320

MOORE, J. A.
ACOUSTIC EMISSION MONITORING OF ADVANCED AEROSPACE COMPONENTS
SEE ALSO NT-14294
1977, 12P
AVAILABILITY: PUBLISHED IN PAPER SUMMARIES, ASNT SPRING CONF., 1977

ACOUSTIC EMISSIONS, MONITORING, AEROSPACE CRAFT, COMPONENTS, STATIC TESTS, FATIGUE(MECHANICS), PLOTTING, GRAPHITE, COMPOSITE MATERIALS, FLIGHT TESTING, WELDS, CARBON, MATERIALS, WELDING, PROOF TESTS, PRODUCTION, FAILURE

THIS PAPER SUMMARIZES THE EFFORTS AT VOUGHT TO MONITOR THE ACOUSTIC EMISSIONS FROM ADVANCED AEROSPACE COMPONENTS DURING STATIC AND FATIGUE TESTING. THE ACOUSTIC EMISSION PLOTS DERIVED FURING FATIGUE TESTING OF A MULTILAMINATED FUSELAGE FITTING, FATIGUE TESTING OF A CONVENTIONAL FLAP ATTACH FITTING, AND STATIC TESTING OF THE ATTACH LUG OF A STEERING COMPONENT ARE REVIEWED. PLOTS WERE OBTAINED DURING FATIGUE TESTING AND STATIC LOADING TO FAILURE OF GRAPHITE COMPOSITE OUTER WING PANEL TEST ARTICLES. THESE DATA WERE USED TO EVALUATE PLOTS FOR PRODUCTION WINGS THAT ARE SCHEDULED FOR EXTENSIVE IN-FLIGHT TESTING. ALSO REVIEWED ARE THE RESULTS OF MONITORING PRESSURE GAS WELDS DURING THE WELDING OPERATION AND DURING PROOF LOAD, PLUS THE RESULTS OF MONITORING FLASH-WELDED CONTROL RODS DURING PROOF LOAD. FINALLY, THE REESULTS FROM MONITORING CARBON-CARRON MATERIALS (SPACE SHUTTLE LEADING EDGE) DURING STATIC LOADING ARE PRESENTED. (AUTHOR)

64. NTIAC-14322

BAILEY, C. D. ; HAMILTON, J. M., JR. ; PLESS, W. M.
ACOUSTIC EMISSION OF IMPACT DAMAGED GRAPHITE-EPOXY COMPOSITES
SEE ALSO NT-14294
1977, 06P
AVAILABILITY: PUBLISHED IN PAPER SUMMARIES, ASNT SPRING CONF., 1977

ACOUSTIC EMISSIONS, GRAPHITE, EPOXY, COMPOSITE MATERIALS, TENSILE TESTS, SPECIMENS(TEST), SOURCES, TECHNIQUE, IMPACT TESTS, FATIGUE(MECHANICS), CYCLIC TEST, TENSILE STRENGTH, POSITION(LOCATION), DETECTION, DAMAGE ASSESSMENT

ACOUSTIC EMISSION SOURCE LOCATION TECHNIQUES WERE USED TO MONITOR AN IMPACT DAMAGED AREA DURING TENSILE TESTS OF GRAPHITE-FIBER REINFORCED EPOXY SPECIMENS. THE SPECIMENS HAD ALSO BEEN FATIGUE CYCLED; SOME HAD BEEN IMPACT DAMAGED PRIOR TO FATIGUE CYCLES AND SOME AFTER THE FATIGUE CYCLES. THE SPECIMENS WERE 16 PLIES AND APPROXIMATELY .088 IN. (2.44 MM) THICK. EIGHT PLIES WERE IN THE ZERO DIRECTION (APPLIED STRESS DIRECTION) AND EIGHT PLIES WERE IN THE PLUS OR MINUS 45 DEGREE DIRECTION. IN ALL ZERO-DIRECTION PLIES, FOUR 1 IN. (25.4 MM) WIDE STRIPS OF GRAPHITE EQUALLY SPACED 2 IN. (50.8 MM) APART, WERE REMOVED AND REPLACED WITH KEVLAR. THE AE DATA GENERATED IN THE IMPACT DAMAGED AREA ARE ANALYZED AS A FUNCTION OF THE FATIGUE CYCLING AND THE ULTIMATE TENSILE STRENGTH. THE RESULTS SHOW THAT THE KAISER EFFECT DOES NOT HOLD TRUE FOR THE IMPACT DAMAGED AREA AND THAT AE TECHNIQUES HAVE EXCELLENT POTENTIAL FOR LOCATING AND ASSESSING THE DAMAGE IN LARGE GRAPHITE-EPOXY COMPOSITE STRUCTURAL COMPONENTS. (AUTHOR)

65. NTIAC-16290 M

VIRGINIA POLYTECHNIC INST AND STATE UNIV BLACKSBURG DEPT OF ENGINEERING SCIENCE AND MECHANICS
RUSSELL ,SAMUEL S. ; HENNEKE,EDMUND G.
SIGNATURE ANALYSIS OF ACOUSTIC EMISSION FROM GRAPHITE-EPOXY COMPOSITES
SEP 77, 84P
VPI-E-77-22
NASA NSG 1238
AVAILABILITY: FOR SALE BY NTIS, 5285 PORT ROYAL RD., SPRINGFIELD, VA 22161 (N77-30179)

ACOUSTIC EMISSIONS, GRAPHITE, EPOXY, SIGNAL ANALYSIS, COMPOSITE MATERIALS, FAILURE MODES, CRACK PROPAGATION, SPECTRUM ANALYSIS, FAILURE, VISUAL INSPECTION, TELEVISION DISPLAY SYSTEMS, OPTICAL MICROSCOPES, LAMINATES

ACOUSTIC EMISSIONS HAVE BEEN MONITORED FOR CRACK EXTENSION ACROSS AND PARALLEL TO THE FIBERS IN A SINGLE PLY AND MULTI-PLY LAMINATES OF GRAPHITE/EPOXY COMPOSITES. SPECTRUM ANALYSIS WAS PERFORMED ON THE TRANSIENT SIGNAL TO ASCERTAIN IF THE FRACTURE MODE COULD BE CHARACTERIZED BY A PARTICULAR SPECTRAL PATTERN. THE SPECIMENS WERE LOADED TO FAILURE QUASI-STATICALLY IN A TENSILE MACHINE. VISUAL OBSERVATIONS WERE MADE VIA EITHER AN OPTICAL MICROSCOPE OR A TELEVISION CAMERA. THE RESULTS INDICATE THAT SEVERAL TYPES OF CHARACTERISTICS IN THE TIME AND FREQUENCY DOMAIN CORRESPOND TO DIFFERENT TYPES OF FAILURE. (AUTHOR)

66. NTIAC-6450 M

AVCO GOVERNMENT PRODUCTS GROUP LOWELL MASS AVCO APPLIED TECHNOLOGY DIV
SCHULTZ, A. W.
THE EFFECT OF VOIDS ON THE MECHANICAL PROPERTIES OF HIGH MODULUS GRAPHITE FIBER/EPOXY-REINFORCED COMPOSITES
CONTRACT REPT. 27 MAY 68-26 AUG 69
26 AUG 69, 112P
AVATD-0153-69-RR
N00019-68-C-0461
AD-860190

*DEFECTS(MATERIALS), *MECHANICAL PROPERTIES, *COMPOSITE MATERIALS, GRAPHITE, FIBERS, EPOXY, REINFORCED PLASTICS, DESTRUCTIVE TESTS, TEST METHODS

NONDESTRUCTIVE TESTS (NDT) WERE USED IN CONJUNCTION WITH PHYSICAL AND MECHANICAL PROPERTIES DESTRUCTIVE TESTS TO (A) DETERMINE THE INFLUENCE OF VOIDS ON THE MECHANICAL PROPERTIES OF THORNEL 50 GRAPHITE FIBER-REINFORCED EPOXY COMPOSITES TESTED IN NORMAL AND HIGH HUMIDITY ENVIRONMENTS; (B) EXAMINE FABRICATION METHODS FOR INTRODUCING VOIDS INTO THESE COMPOSITES; (C) INVESTIGATE METHODS FOR MEASURING VOID CONTENT, WITH EMPHASIS ON NDT TECHNIQUES; AND (D) DETERMINE IF CORRELATIONS EXIST FOR MECHANICAL PROPERTIES AND VOID CONTENT.

67. NTIAC-7263 M

AVCO CORP LOWELL MASS SYSTEMS DIV
OLSTER, ELLIOT F.
EFFECT OF VOIDS ON GRAPHITE FIBER REINFORCED COMPOSITES
FINAL REPT. 1 APR 71-1 JUL 72
01 JUL 72, 162P
N00019-71-C-0305
AD-746560

*DEFECTS(MATERIALS), *FIBER REINFORCED COMPOSITES, *TEST METHODS, GRAPHITE, FIBERS, POROSITY, LAMINATES, MECHANICAL PROPERTIES, EPOXY

POROSITY HAS BEEN ARTIFICIALLY INTRODUCED IN GRAPHITE/EPOXY LAMINATES BY EITHER VARYING THE VOLITALE CONTENT OF THE PREPREG OR BY ALTERING THE PRESSURE DURING CURING. A SERIES OF TECHNIQUES WAS USED TO DETERMINE THE RESULTING POROSITY AND ESTABLISH THE VARIABILITY WITHIN A PANEL. THESE TECHNIQUES INCLUDED DIRECT AND INDIRECT MEASURES OF THE VOID CONTENT AND WERE COMPARED TO STANDARD NON-DESTRUCTIVE TECHNIQUES FOR POROSITY DETECTION. TENSILE, COMPRESSIVE, SHEAR AND FLEXURE PROPERTIES WERE OBTAINED ON UNIDIRECTIONAL AND CROSS PLIED SPECIMENS. THE PROPERTIES SHOWED VARYING SENSITIVITY TO POROSITY, THE HORIZONTAL SHEAR STRENGTH BEING THE MOST SEVERELY DEGRADED OF THOSE PROPERTIES MEASURED. (AUTHOR-PL)

68. NTIAC-11990

KAELBLE, DAVID H.
DETECTION OF HYDROTHERMAL AGING IN COMPOSITE MATERIALS
2 REFERENCES; SEE ALSO NT-11960
DEC 75, 16P
AVAILABILITY: PUBLISHED IN PROC. OF ARPA/AFML REV. OF
QUANT. NDE; DEC 75; 549-564

*COMPOSITE MATERIALS, *ENVIRONMENTAL EFFECTS,
*AGING(MATERIALS), QUANTITATIVE TESTING, MOISTURE,
TEMPERATURE, GRAPHITE, EPOXY, MATHEMATICAL MODELS

THE TERM HYDROTHERMAL, MEANING SEPARATE OR COMBINED CONDITIONS OF HIGH MOISTURE AND TEMPERATURE, DESCRIBES THE COMPLEX PROPERTY DEGREDATION PROCESSES IN TWO GRAPHITE-EPOXY COMPOSITES. IT BECAME EVIDENT IN THIS STUDY THAT IMPORTANT HYDROELASTIC STRESSES DEGRADE COMPOSITE STRENGTH IN MUCH THE SAME FASHION THAT THERMOELASTIC STRESSES DO. IN FACT THE STUDY SHOWS THAT THERE ARE COMPLEX INTERNAL STRESS EFFECTS WITHIN THE COMPOSITE, PROBABLY CONCENTRATED AT THE FIBER-MATRIX INTERFACE, WHICH DEPEND UPON THE DETAILED PRIOR HISTORY OF MOISUTRE-TEMP ERATURE EXPOSURE. THE THREE PARTS OF THIS PROGRAM ARE: 1) PREPARE AND DEGRADE REINFORCED COMPOSITE SPECIMENS WITH VARIED MOISTURE SUSCEPTIBILITY, 2) CHARACTERIZE COMPOSITES BY NDE AND CORRELATE WITH MECHANICAL STRENGTH, 3) DEVELOP A MATHEMATICAL MODEL TO RELATE PHYSICAL PROPERTY MEASUREMENTS WITH MOLECULAR MECHANISMS OF MOISTURE DEGRADATION. (NTIAC)

70. NTIAC-16366 M

CLEVELAND PNEUMATIC CO OH
GIEBER,MYRON J. ; FRICKER,WALTER W.
GRAPHITE COMPOSITE LANDING GEAR COMPONENT -- UPPER DRAG BRACE HARDWARE FOR F-15 AIRCRAFT
FINAL REPT. JUL 75-JAN 77
SEP 77, 154P
AFFDL-TR-77-88
F33615-75-C-3152
AD-A052764

EPOXY, COMPOSITE MATERIALS, GRAPHITE, DESIGN, AIRCRAFT EQUIPMENT, AIRFORCE EQUIPMENT, COSTS, FEASIBILITY STUDIES, FAILURE(MECHANICS), LOADS(FORCES), EVALUATION, WEIGHT, OPTIMIZATION

THIS REPORT SUMMARIZES WORK PERFORMED TO DESIGN, FABRICATE AND TEST A GRAPHITE EPOXY COMPOSITE MATERIAL UPPER DRAG BRACE SUITABLE FOR DIRECT REPLACEMENT OF THE CURRENT TITANIUM UPPER DRAG BRACE FOR THE F-15 AIRCRAFT LANDING GEAR ASSEMBLY. DESIGN, FABRICATION, TEST PROCEDURES, TEST RESULTS, AND FAILURE ANALYSIS ARE PRESENTED IN DETAIL. THE COMPOSITE MATERIAL BRACE FAILED AT LESS THAN DESIGN LOAD. THE PROGRAM ESTABLISHED, AT THE PRESENT TIME, THAT DRAG BRACES AND SIMILAR LANDING GEAR HARDWARE CAN NOT BE SATISFACTORILY FABRICATED FROM GRAPHITE EPOXY MATERIAL FOR USE AS A DIRECT REPLACEMENT OF EXISTING METALLIC HARDWARE IN SOME APPLICATIONS. THE VOLUME AND SHAPE OF AVAILABLE SPACE IN THESE DIRECT REPLACEMENT APPLICATIONS DOES NOT NORMALLY ALLOW THE USE OF OPTIMUM GRAPHITE EPOXY MATERIAL DESIGN AND FABRICATION TECHNIQUES. HOWEVER, AS DEMONSTRATED BY THE SUCCESSFUL DEVELOPMENT OF A GRAPHITE EPOXY SIDE BRACE SUITABLE FOR DIRECT REPLACEMENT OF EXISTING METALLIC HARDWARE ON THE A-37B AIRCRAFT, WEIGHT AND COST SAVING APPLICATIONS TO CURRENT AIRCRAFT ARE FEASIBLE. THEREFORE, EACH POTENTIAL APPLICATION MUST BE INDIVIDUALLY EVALUATED. WORK IS REQUIRED TO IMPROVE ANALYTICAL, FABRICATION AND NONDESTRUCTIVE INSPECTION TECHNIQUES FOR GRAPHITE EPOXY MATERIALS. IT CAN BE REASONABLY EXPECTED THAT CURRENT AND FUTURE EFFORTS BY THE AIR FORCE, INDUSTRY AND THE EDUCATIONAL COMMUNITY, AIMED AT THESE IMPROVEMENTS, WILL INCREASE THE PROFITABLE APPLICATION OF GRAPHITE EPOXY MATERIAL TO LANDING GEAR HARDWARE. (AUTHOR)

69. NTIAC-12099

HSU ,T. R. ; LEWAK,R.
MEASUREMENTS OF THERMAL DISTORTION OF COMPOSITE PLATES BY HOLOGRAPHIC INTERFEROMETRY
11 REFERENCES
MAY 76, 06P
AVAILABILITY: PUBLISHED IN EXP. MECH.; 16, 5; MAY 76; 182-187

*MEASUREMENT, *THERMAL EFFECTS, *DISTORTION, *PLATES, *COMPOSITE MATERIALS, INTERFEROMETRIC HOLOGRAPHY, OPTICS, HOLOGRAPHY, LASERS, DIMENSIONS, GRAPHITE, FIBERS, EPOXY, LAMINATES, MULTIPLE OPERATION, EXPOSURE(GENERAL)

LASER HOLOGRAPHIC-INTERFEROMETRY TECHNIQUE WAS USED TO MEASURE THE DIMENSIONAL CHANGES OF GRAPHITE-FIBRE-EPOXY-RESIN LAMINATED PLATES SUBJECT TO SIGNIFICANT CHANGES OF THERMAL ENVIRONMENT. A MULTIPLE DOUBLE-EXPOSURE SCHEME BASED ON THE PRINCIPLE OF VARYING INCIDENT BEAM ANGLES WAS USED TO RECORD THE INTERFERENCE FRINGES COVERING LARGE TEMPERATURE RANGES ON THE SAME FILM PLATE. THIS FEATURE IS HIGHLY DESIRABLE FOR INDUSTRIAL APPLICATIONS. (AUTHOR)

71. • NTIAC-16666 M

AIR FORCE FLIGHT DYNAMICS LAB WRIGHT-PATTERSON AFB OHIO
DEXTER, PETER F. ; SHUMAKER, GERALD C.
DEVELOPMENT TESTS AND FLIGHT TEST OF GRAPHITE COMPOSITE LANDING GEAR SIDE BRACE ASSEMBLY FOR A-37B AIRCRAFT
FINAL TECHNICAL REPT. 15 MAY 73-15 MAR 77
JUL 77, 59P
AFFDL-TR-77-56
AD-A045761

GRAPHITE, COMPOSITE MATERIALS, FLIGHT TESTS, DEVELOPMENT, AIRCRAFT EQUIPMENT, EPOXY, RESINS, FATIGUE(MECHANICS), LOADS(FORCES), SAMPLING, DATA ACQUISITION, STRESS STRAIN RELATIONS

THIS REPORT DESCRIBES THE SUCCESSFUL DEVELOPMENT, IN-HOUSE TESTING, AND FLIGHT TESTING OF A GRAPHITE/EPOXY SIDE BRACE FOR THE A-37B AIRCRAFT LANDING GEAR. (AUTHOR)

NTIAC-11646 M

DOUGLAS AIRCRAFT CO. LONG BEACH CALIF
LEHMAN, GEORGE M.
DEVELOPMENT OF A GRAPHITE HORIZONTAL STABILIZER
SEE ALSO REPORT DATED JUL 73, AD-768 869
INTERIM TECHNICAL REPT. NO. 6, JUL 73-28 FEB 74
APR 74, 46P
MDC-J6507
N00156-70-C-1321
AD-782646

*GRAPHITE, *FIBER REINFORCED COMPOSITES, *BOND TESTING, AIRCRAFT, AIRFRAMES, STRAIN(MECHANICS), STATIC TESTS, DAMAGE

THE FINAL ASSEMBLY BONDING, NONDESTRUCTIVE INSPECTION, AND STATIC TESTING OF THE SECOND GRAPHITE-EPOXY HORIZONTAL STABILIZER FOR THE A4 SKYHAWK ARE DISCUSSED. THE FIT CHECKS, BONDING TECHNIQUE, AND FOKKER BOND TEST RESULTS FOR THE FINAL ASSEMBLY BOND OF THE UPPER SKIN PANEL ARE DESCRIBED. STRAIN DATA ARE PRESENTED FOR STATIC TESTS IN TWO CRITICAL LOAD CONDITIONS (I.E., MAXIMUM ELEVATOR LOAD AND MAXIMUM STABILIZER LOAD). PREDICTED AND ACTUAL STRAIN PLOTS INDICATING GOOD CORRELATION ARE PRESENTED FOR SELECTED STRAIN GAGES. (AUTHOR-PL)

73. NTIAC-13765 M

MICHIGAN UNIV ANN ARBOR DEPT OF MECHANICAL ENGINEERING
SPRINGER, GEORGE S. ; SHEN, CHI-HUNG
MOISTURE ABSORPTION AND DESORPTION OF COMPOSITE MATERIALS
ANNUAL TECHNICAL REPT. MAR 75-MAR 76
JUN 76, 72P
AFML-TR-76-102
F33615-75-C-5165
AD-A031436

FIBER REINFORCED COMPOSITES, GRAPHITE, MOISTURE CONTENT, WATER, ABSORPTION, COMPOSITE MATERIALS, EPOXY, DIFFUSION, HOMOGENEITY, TEMPERATURE, ELECTRICAL RESISTANCE, HARDNESS, ENVIRONMENTAL TESTS, COMPUTERS, PROCEDURES, DATA

EXPRESSIONS ARE PRESENTED FOR THE MOISTURE DISTRIBUTION AND THE MOISTURE CONTENT AS A FUNCTION OF TIME OF ONE DIMENSIONAL HOMOGENEOUS AND COMPOSITE MATERIALS EXPOSED EITHER ON ONE SIDE OR ON BOTH SIDES TO HUMID AIR OR TO WATER. THE RESULTS APPLY DURING BOTH MOISTURE ABSORPTION AND DESORPTION WHEN THE MOISTURE CONTENT AND THE TEMPERATURE OF THE ENVIRONMENT ARE CONSTANT. TEST PROCEDURES ARE DESCRIBED FOR DETERMINING EXPERIMENTALLY THE VALUES OF THE MOISTURE CONTENT AND THE DIFFUSIVITY OF COMPOSITE MATERIALS. A SERIES OF TESTS USING UNIDIRECTIONAL AND GRAPHITE T-300 FIBERITE 1034 COMPOSITES WERE PERFORMED IN THE TEMPERATURE RANGE 300-425 K WITH THE MATERIAL SUBMERGED BOTH IN MOIST AIR (HUMIDITY 0 TO 100%) AND IN WATER. THE TEST DATA SUPPORT THE ANALYTICAL RESULTS AND PROVIDE THE MOISTURE ABSORPTION AND DESORPTION CHARACTERISTICS OF SUCH COMPOSITES. EXTENSION OF THE RESULTS TO MATERIALS EXPOSED TO TIME VARYING ENVIRONMENTAL CONDITIONS IS INDICATED. ATTEMPTS WERE MADE TO CORRELATE THE MOISTURE CONTENT OF THE MATERIAL WITH (1) CHANGES IN ELECTRIC RESISTANCE AND (2) CHANGES IN THE HARDNESS OF THE MATERIAL. THE LATTER METHOD PROMISES TO PROVIDE AN INDICATION OF THE MOISTURE CONTENT.

74. DIALOG File6: NTIS 64-78/ISS20 (Copr. NTIS) (Item 131 of 383

S-3A Graphite/Epoxy Spoiler Development Program. Volume II

LTV Aerospace Corp Dallas Tex Vought Systems Div (408116)

Final technical rept. Jun 74-Jul 75
AUTHOR: Blosser, E. G.; McGovern, S. A.; Dhonau, O. E.
C7782A2 Fld: 1C, 15A, 11D, 71F, 51C GRAI7626
Jul 75 61p
Rept No: 2-53443/4R-3172-Vol-2
Contract: N62269-73-C-0610
Monitor: NADC-75141-30
See also AD-779 069.

Abstract: After testing of the S-3A Graphite/Epoxy Spoilers was satisfactorily completed, under Contract N62269-73-C-0610, the contracted effort was extended to include the development of NDI standards for the composite spoiler to be included in Volume II. In addition to the fabrication of reference standards for this report, the development of field inspection techniques was pursued using the ultrasonic unit available to Navy inspection personnel. The initial phase of developing NDI standards for the composite spoiler was accomplished through the fabrication and evaluation of eleven experimental Quality Control Defect Specimens (QCDS). These preliminary reference panels were built to investigate the best material for producing built-in defects, the minimum detectable defect size, the influence of varying the number of skin plys, the influence on attenuation properties of the amount of resin in honeycomb cells, and the influence on attenuation and physical properties of the amount of bleeder material used. The final standards were designed utilizing the information gained from the preliminary reference panels. These standards were fabricated in triplicate with two panels to be furnished to the Navy for field use and one panel to be retained by VSD for use in future production inspection. All reference panels were characterized by radiography, ultrasonic through transmission (immersion and contact) and ultrasonic pulse-echo methods.

Descriptors: *Antisubmarine aircraft, *Spoilers, *Ultrasonic inspection, *Honeycomb cores, Carrier based aircraft, Graphite . Epoxy resins, Radiography, Sound transmission, Nondestructive testing, Immersion

Identifiers: S-3A Aircraft, S-3 Aircraft, Epoxy matrix composites, Graphite reinforced composites, Carbon fiber reinforced plastics, NTISDODXA

AD-A031 066/4ST NTIS Prices: PC A04/MF A01

75. **Signature Analysis of Acoustic Emissions from Composites**

Virginia Polytechnic Inst. and State Univ., Blacksburg. Dept. of Engineering Science and Mechanics.

Final Report, 1 Oct. 1975 - 30 Mar. 1978.
AUTHOR: Henneke, E. G. II
E190413 Fld: 11D, 71F STAR1614
19 May 78 79p
Rept No: NASA-CR-145373
Grant: NSG-1238
Monitor: 18

Abstract: Acoustic emission data were obtained from a series of tensile tests on specially designed graphite-epoxy unidirectional laminates. The design was such that the specimens would preferentially fail first by fiber breakage and later by matrix splitting. The AE signals for each of these events was analyzed and some typical results are reported. Patterns characteristic of each failure mechanism were noted for both the time signatures and the corresponding frequency spectra.

Descriptors: *Acoustic emission, *Tensile tests, *Composite materials, Epoxy resins, Graphite, Failure modes, Noise reduction, Signature analysis, Splitting

Identifiers: Laminates, Graphite reinforced composites, Epoxy matrix composites, *Acoustic signatures, NTISNASA

N78-23148/7ST NTIS Prices: PC A05/MF A01

76. **Effects of Moisture in Infrared Thermography of Resin Matrix Composites**

National Aeronautics and Space Administration. Langley Research Center, Langley Station, Va.
AUTHOR: Singh, J. J.; Kantsios, A. G.; Mcerlean, E. A.; Babcock, R. A.; Buckingham, R. D.

E0923A1 Fld: 11D, 7D, 71F, 99A STAR1606
Jan 78 18p
Rept No: NASA-TM-78649
Monitor: 18

Abstract: Several multiply graphite polyimide composite specimens were examined by real-time infrared thermography in order to study the effects of moisture on their thermograms. Heat was injected from one side and IR emission detected on the opposite side using AGA Thermovision System-680. No differences between the thermograms of dry and water containing specimens were detected for defect-free specimens. However, the presence of trapped water in defective specimens modified the thermographic contrast significantly. It is concluded that: (1) IR thermography can be used to detect moisture in defective composites, and (2) because of the possibility of moisture camouflaging defects, IR thermography for subsurface defect detection should be supplemented by other techniques - such as acoustical imaging and X-radiography.

Descriptors: *Composite materials, *Infrared instruments, *Moisture content, Resins, Temperature measuring instruments, Defects, Nondestructive tests, Reliability engineering

Identifiers: *Carbon fiber reinforced plastics, *Thermography, Polyimide matrix composites, Graphite reinforced composites, Test equipment, Defects, NTISNASA

N78-15464/8ST NTIS Prices: PC A02/MF A01

77. Development. Manufacturing. and Test of Graphite-Epoxy Composite Spoilers for Flight Service on 737 Transport Aircraft

Boeing Commercial Airplane Co.. Seattle. Wash.

Final Report.
AUTHOR: Stoecklin. R. L.
D2252C1 Fld: 11D. 1C. 71F. 51C STAR1507
Oct 76 96p
Rept No: NASA-CR-132682

Contract: NAS1-11668
Monitor: 18

Abstract: A total of 114 spoiler units were fabricated in a production shop environment. utilizing three graphite epoxy material systems. Production planning paper was generated for each spoiler unit to completely document each production step of each spoiler unit. The graphite epoxy skins were laid up on production tooling using both mechanical and hand layup techniques. Inspection techniques utilized MRB type assessment in the abscence of quality requirements. Each completed spoiler was subjected to ultrasonic inspection utilizing a multicolor recording system that documented each inspection result. In addition. one static test spoiler was sectioned after the test to examine the adhesive filleting to the honeycomb core. Visual examination of the cured adhesives showed excellent results.

Descriptors: *Boeing 737 aircraft. *Composite materials. *Epoxy compounds. *Graphite. *Spoilers. Control surfaces. Static tests. Transport aircraft

Identifiers: *Carbon fiber reinforced plastics. Graphite reinforced composites. Epoxy matrix composites. Ultrasonic tests. Adhesives. Honeycomb structures. NTISNASA

N77-16023/2ST NTIS Prices: PC A05/MF A01

78. DIALOG File6: NTIS 64-78/ISS20 (Copr. NTIS) (Item 91 of 383

High Performance Composites and Adhesives for V/STOL Aircraft.

Naval Research Lab Washington D C (251950)

Rept. no. 1 (Annual), 1 Jul 75-1 Sep 76
AUTHOR: Bascom, Willard D.; Lockhart, Luther B. Jr
D1721E2 Fld: 11D, 11A, 1C, 71F, 71B, 51C GRAI7709
Dec 76 129
Rept No: NRL-MR-3433
Project: F54593
Task: WF54593201
Monitor: 18

Abstract: An interdisciplinary program has been undertaken to address the composite and adhesive materials requirements of V/STOL aircraft. The primary tasks are to develop and characterize high modulus, high toughness resins with use temperatures of 350 F to 450 F or higher, to develop fabrication technology for newly developed resin matrices for graphite-fiber reinforced composites, to develop composite failure criteria for design optimization and to establish appropriate quality control parameters. The principal accomplishments to date have been to demonstrate (a) the variation in mechanical properties obtainable by the molecular tailoring of polyphthalocyanine resins, (b) the effectiveness of NMR spectroscopy for chemical characterization of resins of complex composition, (c) the viability of resin cure using ionizing radiation, and (d) the development of a unique approach to determining failure criteria for flaw growth in resin matrix composites. (Author)

Descriptors: *Fiber reinforced composites, *Adhesives, *Short takeoff aircraft, *Vertical takeoff aircraft, Carbon fibers, Matrix materials, Polymers, Curing, Ionizing radiation, Nuclear magnetic resonance, Spectroscopy, Chemical analysis, Thermal properties, Mechanical properties, Synthesis(Chemistry), Experimental design, Optimization, Fabrication, Technology, Cracking(Fracturing), Detection, Phthalocyanines, Polyimide resins, Epoxy resins

Identifiers: *Reinforced plastics, Carbon fiber reinforced plastics, NTISDODXA

AD-A035 928/1ST NTIS Prices: PC A07/MF A01

79. The Fabrication. Testing and Delivery of Boron/Epoxy and Graphite/Epoxy Nondestructive Test Standards

Lockheed-Georgia Co.. Marietta.

Final Report.
AUTHOR: Pless. W. M.: Lewis. W. H.
C5115K4 Fld: 11D. 71F. 73 STAR1316
Dec 71 70p
Rept No: NASA-CR-61374. ER-11199
Contract: NAS8-27565
Monitor: 18

Abstract: A description is given of the boron/epoxy and graphite/epoxy nondestructive test standards which were fabricated. tested and delivered to the National Aeronautics and Space Administration. Detailed design drawings of the standards are included to show the general structures and the types and location of simulated defects built into the panels. The panels were laminates with plies laid up in the 0 deg. + or - 45 deg. and 90 deg orientations and containing either titanium substrates or interlayered titanium perforated shims. Panel thickness was incrementally stepped from 2.36 mm (0.093 in.) to 12.7 mm (0.500 in.) for the graphite/epoxy standards. and from 2.36 mm (0.093 in.) to 6.35 mm (0.25 in.) for the boron/epoxy standards except for the panels with interlayered shims which were 2.9 mm (0.113 in.) maximum thickness. The panel internal conditions included defect free regions. resin variations. density/porosity variations. cure variations. delaminations/disbonds at substrate bondlines and between layers. inclusions. and interlayered shims. Ultrasonic pulse echo C-scan and low-kilovoltage X-ray techniques were used to evaluate and verify the internal conditions of the panels. (Author)

Descriptors: *Composite materials. *Nondestructive tests. *Panels. *Standards. Boron. Defects. Epoxy resins. Graphite

Identifiers: NTISNASA

N75-24856/7ST NTIS Prices: PC A04/MF A01

80. DIALOG File6: NTIS 64-78/ISS20 (Copr. NTIS) (Item 110 of 383)

Development of a Non-destructive Inspection Technique for Advanced Composite Materials Using Cholesteric Liquid Crystals

Naval Postgraduate School Monterey Calif (251450)

Master's thesis
AUTHOR: Schaum, Robert Troy
D0403L4 Fld: 11D, 14B, 71F, 94J GRA17703
Sep 76 64p
Monitor: 18

Abstract: A new, relatively simple and inexpensive non-destructive inspection technique for advanced composite materials is proposed and its feasibility is demonstrated. This technique uses encapsulated cholesteric liquid crystals to sense small temperature differences which result from nonuniform heat transfer through composites. Discontinuities in heat transfer evidenced by contrasting surface color patterns indicate material discontinuities, i.e. flaws. Preliminary investigations into the thermal conductivity of a .041 in. thick graphite/epoxy laminated panel in the direction normal to the composite laminae and in the direction parallel to the laminae are described. The coefficients of conductivity in the two directions were found to differ by an order of magnitude. A qualitative test of the technique in locating embedded teflon triangles is reported, and a design for a testing device is proposed. (Author)

Descriptors: *Composite materials, *Nondestructive testing, *Liquid crystals, *Cholesteryl esters, Heat transfer, Encapsulation, Discontinuities, Crystal structure, Crystal defects, Surface properties, Thermal conductivity, Graphited materials, Epoxy laminates, Panels, Experimental design, Experimental data, Steady state, Thermocouples, Steel, Aluminum, Theses

Identifiers: Steel 4130, Stainless steel 17-7 PH, Aluminum alloy 2024, NTISDODXA

AD-A032 322/0ST NTIS Prices: PC A04/MF A01

81. ID NO.- EI780208759 808759

NONDESTRUCTIVE TESTS FOR SHEAR STRENGTH DEGRADATION OF A GRAPHITE-EPOXY COMPOSITE.

Kaelble, D. H.; Dynes, P. J.

Rockwell Int. Thousand Oaks, Calif

ASTM Spec Tech Publ n 617: Compos Mater: Test and Des, 4th Conf, Valley Forge, Pa, May 3-4 1976. Publ by ASTM, Philadelphia, Pa, 1977 p 190-200 CODEN: ASTTA8

DESCRIPTORS: (*COMPOSITE MATERIALS, *Testing), (PLASTICS LAMINATES, Moisture),

IDENTIFIERS: GRAPHITE/EPOXY COMPOSITES, SHEAR STRENGTH TESTING

CARD ALERT: 421, 422, 482, 804, 817

The effects of hydrothermal aging (100 $degree$ C in water) on the shear strength properties of a laminated graphite/epoxy composite were investigated. Fiber surface treatments were employed to produce controlled rates and extents of hydrothermal degradation. A study conducted to develop methods of detecting and identifying the extent and mechanism of hydrothermal aging and its results are described. The degradation state of the fiber matrix interface was detected through correlation of surface energetics analysis, ultrasonic characterization, and moisture take-up. The state of the bulk epoxy was evaluated by differential scanning calorimetry, specific heat measurements, infrared and dynamic mechanical spectroscopy, and thermomechanical analysis. The fiber matrix stress state was delineated by thermal expansivity, dynamic mechanical spectroscopy, and ultrasonic response. 17 refs.

82. ID NO.- EI751279421 579421

NONDESTRUCTIVE TESTING OF LIGHTWEIGHT GRAPHITE-EPOXY SANDWICH PANELS.

Dougherty, T. A.; Epstein, G.; Allinikov, Sidney

Philco-Ford Corp, Palo Alto, Calif

SAMPE Natl Symp and Exhib, 20th, Proc, San Diego, Calif, Apr 29-May 1 1975 p 117-128. Publ by SAMPE (Sci of Adv Mater and Process Eng Ser, v 20), Azusa, Calif, 1975

DESCRIPTORS: (*COMPOSITE MATERIALS, *Mechanical Properties),

CARD ALERT: 415, 421, 817

An investigation of the use of photochromic coatings in nondestructive testing of extremely lightweight honeycomb panels is discussed. These coatings, when used in conjunction with internal pressurization, appear to provide an adequate assessment of internal flaws in structures of this type. 2 refs.

83. ID NO.- EI760962531 662531
THERMOGRAPHIC EVALUATION OF COMPOSITE STRUCTURES.
Kibler, K. G.
Gen Dyn, Fort Worth, Tex
Infrared Inf Exch (IRIE), 2nd Bienn. Proc. St. Louis, Mo. Aug 27-29 1974 p 23-28. Publ by Am Gas Assoc (AGA) Corp. Secaucus, NJ. 1974
DESCRIPTORS: (*PRINTED CIRCUITS, *Testing), THERMOGRAPHY.
CARD ALERT: 703, 713, 742
A varied sampling of representative structures, including bonded aluminum, boron skin-aluminum honeycomb, graphite-epoxy panels, and graphite-to-titanium panels was selected for testing by thermographic nondestructive evaluation techniques. The samples contained known defects such as voids, disbonds, and inserts. No attempt was made to optimize results by using sophisticated test setups and heat injection techniques. The results are discussed.

84. ID NO.- EI71X183095 183095
Nondestructive testing of graphite fiber composite structures
HAGEMAIER DJ: MCFAUL HJ: MOON D
Douglas Aircraft Co. Long Beach, Calif
Mater Eval v 29 n 6 June 1971 p 133-40 CODEN: MAEVA
DESCRIPTORS: (*COMPOSITE MATERIALS, *Testing), (MATERIALS TESTING, Nondestructive).
CARD ALERT: 421, 422, 812
This paper discusses nondestructive testing (NDT) methods and techniques for detection of material and manufacturing anomalies in state- of- the- art graphite composites. Visual, liquid penetrant, radiographic, ultrasonic, sonic, thermal and acoustic- emission NDT methods are used to evaluate graphite fiber composite aircraft specimens and structures. 7 refs.

85. ID NO.- EI780423825 823825
CORRELATION OF ULTRASONIC ATTENUATION AND SHEAR STRENGTH IN GRAPHITE-POLYIMIDE COMPOSITES.
Hayford, D. T.; Henneke, E. G. II; Stinchcomb, W. W.
Va Polytech Inst & State Univ, Blacksburg
J Compos Mater v 11 Oct 1977 p 429-444 CODEN: JCOMBI
DESCRIPTORS: (*COMPOSITE MATERIALS, *Nondestructive Examination), (ULTRASONIC WAVES, Attenuation), PLASTICS LAMINATES.
CARD ALERT: 415, 817, 753
The buffer rod technique for measuring attenuation in thin specimens is modified here to apply to specimens having intermediate thicknesses and high attenuation. The described procedure, which requires only one accessible surface of the material, was used to determine the initial attenuation values of ultrasonic waves in short beam shear specimens of graphite-polyimide composite material. It is shown that there is good correlation between the initial attenuation values and the shear strengths of the specimens determined by the standard short beam shear test method. The modified ultrasonic buffer block technique offers much potential for service as a quantitative, nondestructive, quality assurance test for composite materials. 7 refs.

86. ID NO.- EI740846970 446970
COMPOSITE APPLICATIONS SEM DASHS TODAY'S AIRCRAFT SEM DASHS 2. PRODUCTION METHODS FOR COMPOSITE STRUCTURAL SHAPES.
Van Hamerveld, John; Fogg, Larry D.
Lockheed-Calif Co
SAMPE J v 10 n 2 Mar-Apr 1974 p 6-10 CODEN: SAJUAX

DESCRIPTORS: *COMPOSITE MATERIALS, (AIRCRAFT MATERIALS, Composite Materials), GRAPHITE, EPOXY RESINS, (PLASTICS, REINFORCED, Pultrusion),
CARD ALERT: 415, 482, 652, 816, 817
This two-part series discusses a program to develop a graphite laminate beam-type configuration of a floor support post for commercial aircraft. Part 1 took up design selections, structural analysis methods, material selection and flight test program results. Part II discusses production methods for autoclave molding and pultrusion processes, with cost studies. The discussion is presented under the following headings SEM DASHS design concept and structural analysis studies; material selection; fabrication and tooling methods; production pultrusion process; nondestructive test methods; and manufacturing cost studies. This program has demonstrated that common multi-flanged structural shapes of advanced composites are both feasible and highly effective structurally. Analysis of the fabrication methods to produce structural shapes indicates that the pultrusion process substantially reduced the cost over the autoclave molding process. 6 refs.

87. ID NO.- EI741060987 460987
SPECTRAL ANALYSIS TECHNIQUE OF ULTRASONIC NDT OF ADVANCED COMPOSITE MATERIALS.
Chang, Francis H.; Yee, W. G. W.; Couchman, James C.
Gen Dyn, Fort Worth, Tex
Non-Destr Test (Lond) v 7 n 4 Aug 1974 p 194-198 CODEN: NDETA5
DESCRIPTORS: (*COMPOSITE MATERIALS, *Testing), (ULTRASONIC WAVES, Spectrum Analysis), (MATERIALS TESTING, Nondestructive Testing),
CARD ALERT: 415, 421, 422, 753, 817
The authors describe an ultrasonic-frequency-spectral analysis method of detecting flaws in advanced composite materials. This non-destructive technique depends on the phenomenon of resonance interference of acoustical waves in materials. When the material thickness is an integral multiple of the half wavelength of the sound waves, destructive interference of a return echo by multiple reflections in the material produces anti-resonant dips in the frequency spectrum for the reflected signal. The period of these dips is related to the material thickness normal to the beam path. Delaminations or voids in a plane perpendicular to the direction of propagation of the sound waves may be observed through their characteristic anti-resonant frequencies. Graphite SEM DASHS epoxy composite specimens containing flat-bottom holes and small planar voids were used as examples of the application of this technique. The authors present analytical development, experimental procedures, and spectral analysis results in this paper. 8 refs.

88. AD- 870 162 11/4 11/9 20/11
AVCO CORP LOWELL MASS SYSTEMS DIV

The Effect of Voids on the Mechanical Properties of High Modulus Graphite Fiber/ Epoxy - Reinforced Composites. (U)

DESCRIPTIVE NOTE: Rept. for 26 Aug 69-26 Mar 70,
MAR 70 191P Lenoe,E. M. ;
REPT. NO. AVSD-0170-70-RR
CONTRACT: N00019-69-C-0208

UNCLASSIFIED REPORT

DESCRIPTORS: (*REINFORCED PLASTICS, CARBON FIBERS), (*COMPOSITE MATERIALS, REINFORCED PLASTICS), (*MECHANICAL PROPERTIES, DEFECTS(MATERIALS)), CLASSIFICATION, GRAPHITE, EPOXY RESINS, NONDESTRUCTIVE TESTING, LAMINATED PLASTICS (U)
IDENTIFIERS: *COMPOSITE MATERIALS, *GRAPHITE (U)

The report presents the results of a detailed investigation of various methods of characterizing voids in graphite epoxy composites. The importance of such studies is the necessity to describe voids for our correlation of destructive and non-destructive measurements and in order to apply current theoretical results. Studies of void effects were extended by fabrication of more than forty laminate panels with void fractions ranging up to 11% and for fiber contents varying from 50 to 73 volume percent. Subsequent destructive and non-destructive testing provided correlations with shear, flexure, and compression response. The main contribution here was the isolation of fiber content and void fraction influences and interactions. Of particular interest are the investigations of shear wave phenomena. (Author) (U)

89. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 910 069L 1/3 11/4
DOUGLAS AIRCRAFT CO LONG BEACH CALIF

Composite Wing Conceptual Design. (U)

DESCRIPTIVE NOTE: Final technical rept. 1 Feb 71-17 Jan 73,
MAR 73 317P Nelson,W. D. ;
REPT. NO. MDC-J4381
CONTRACT: F33615-71-C-1340
PROJ: AF-698CW
MONITOR: AFML TR-73-57

UNCLASSIFIED REPORT
Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; Mar 73. Other requests for this document must be referred to Director, Air Force Materials Lab., Attn: LC. Wright-Patterson AFB, Ohio 45433.

DESCRIPTORS: (*SWEPTBACK WINGS, JET TRANSPORT PLANES), (*COMPOSITE MATERIALS, SWEPTBACK WINGS), DESIGN, SHORT TAKEOFF AIRCRAFT, LOADS(FORCES), DIFFERENTIAL EQUATIONS, WEIGHT, MANUFACTURING, COSTS, LAMINATES, LOAD DISTRIBUTION, ADHESIVES, NONDESTRUCTIVE TESTING, QUALITY CONTROL, BORON, EPOXY RESINS, GRAPHITE, TORSION, HONEYCOMB CORES, SANDWICH CONSTRUCTION, BONDING, FUSELAGES, BONDED JOINTS, REDUCTION (U)
IDENTIFIERS: *ADVANCED MEDIUM STOL TRANSPORTS, AMST(ADVANCED MEDIUM STOL TRANSPORT), FILLET BONDING, TRUSS WEB CONSTRUCTION (U)

90. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 891 459L 11/4
AIR FORCE MATERIALS LAB WRIGHT-PATTERSON AFB OHIO

Advanced Composites Management and Planning Review: A Summary. (U)

DESCRIPTIVE NOTE: Technical rept.,
NOV 71 37P Fechek,Frank J. ;
REPT. NO. AFML-TR-71-144

UNCLASSIFIED REPORT
Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; Jun 71. Other requests for this document must be referred to Director, Air Force Materials Lab., Attn: LC. Wright-Patterson AFB, Ohio 45433.
SUPPLEMENTARY NOTE: Papers presented at Seminar on Advanced Composites, 19-22 Jan 71, Point Clear, Ala.

DESCRIPTORS: (*COMPOSITE MATERIALS, SYMPOSIA), ENVIRONMENTAL TESTS, MANAGEMENT PLANNING AND CONTROL, PLANNING, BORON, GRAPHITE, ALUMINUM, REINFORCING MATERIALS, MANUFACTURING, QUALITY CONTROL, DESIGN, CARBON FIBERS, COSTS, AIR FORCE RESEARCH, FILAMENTS, DEGRADATION, FIBERS, AIRFRAMES, HONEYCOMB CORES, SANDWICH CONSTRUCTION, BONDING, NONDESTRUCTIVE TESTING, FLIGHT TESTING, JET FIGHTERS, WINGS, REINFORCED PLAST(U)
IDENTIFIERS: DATA ACQUISITION (U)

AD- 904 039L 21/5 11/4
PRATT AND WHITNEY AIRCRAFT EAST HARTFORD CONN

Advanced Composite Engine Development
Program. Part III. (U)

DESCRIPTIVE NOTE: Final technical rept.,
JUL 72 228P Boll,K. G. ;
REPT. NO. PWA-4474-Pt-3
CONTRACT: F33615-69-C-1651
PROJ: AF-6169CW
MONITOR: AFML TR-72-108-Pt-3

UNCLASSIFIED REPORT
Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; Jul 72. Other requests for this document must be referred to Director, Air Force Materials Lab., Attn: LC. Wright-Patterson AFB, Ohio 45433.
SUPPLEMENTARY NOTE: Prepared in cooperation with Aerojet-General Corp., Azusa, Calif., Structural Composites Industries, Inc., Azusa, Calif. and Hercules, Inc., Magna, Utah. See also Part 1, AD-903 997L.

DESCRIPTORS: (*TURBOFAN ENGINES, *COMPOSITE MATERIALS), (*GAS TURBINE BLADES, COMPOSITE MATERIALS), (*FANS, TURBOFAN ENGINES), POLYAMIDE PLASTICS, HEAT RESISTANT PLASTICS, BORON, GRAPHITE, SYNTHETIC FIBERS, CARBON FIBERS, REINFORCING MATERIALS, MANUFACTURING, AIRFOILS, MACHINE TOOLS, MOLDINGS, BONDING, ENGINE COMPONENTS, VIBRATION, WEIGHT, THICKNESS, NONDESTRUCTIVE TESTING, TEST METHODS, TEST EQUIPMENT, FATIGUE(MECHANICS), ULTRASONIC RADIATION, RADIOGRAPHY, TURBINE STATORS (U)
IDENTIFIERS: ADVANCED COMPOSITE ENGINES, BORON, FIBERS, FAN BLADES, FAN INTERMEDIATE CASES, FAN DISKS, CARBON FIBERS, GRAPHITE, P 13N COMPOSITE MATERIALS, POLYIMIDE PLASTICS, RESIN MATRIX COMPOSITES (U)

AD- 919 165L 11/4 16/4 22/2 13/8
PERKIN-ELMER CORP NORWALK CONN OPTICAL GROUP

Advanced Composite Missile and Space Design Data.

DESCRIPTIVE NOTE: Final technical rept. 1 Jul 72-31 Dec 73,
MAR 74 73P Freund,Norbert P. ;
REPT. NO. PE-11240-41
CONTRACT: F33615-72-C-2033
PROJ: AF-6169CW
MONITOR: AFML TR-74-33

UNCLASSIFIED REPORT
Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; Jan 74. Other requests for this document must be referred to Director, Air Force Materials Lab., Attn: LC. Wright-Patterson AFB, Ohio 45433.

DESCRIPTORS: (*Composite materials, *Aerospace craft), (*Graphite, Composite materials), (*Epoxy resins, Composite materials), (*Mirrors, Manufacturing), Guided missiles, Sandwich construction, Laminates, Honeycomb cores, Aluminum, Lightweight, Spacecraft, Heat shields, Spheres, Precision finishing, Tolerances(Mechanics), Polishes, Processing, Optics, Optical coatings, Metallizing, Mechanical properties, Environmental tests, Thermal expansion, Orientation(Direction), Carbon fibers, Synthetic fibers, Yield strength, Creep, Nondestructive testing, Holography
IDENTIFIERS: Replication

93. DOC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 913 879L 1/3 11/4
GENERAL DYNAMICS FORT WORTH TEX CONVAIR AEROSPACE DIV

Advanced Composite Technology Fuselage
Program. Volume III. F-111 Aft Fuselage
Component - Manufacturing.

DESCRIPTIVE NOTE: Technical rept. Feb 69-Aug 70 on
Phase 1,
NOV 72 242P Swazey,E. H. ;Wennhold,W.
F. ;
CONTRACT: F33615-69-C-1494
MONITOR: AFML TR-71-41-Vol-3

UNCLASSIFIED REPORT
Distribution limited to U.S. Gov't. agencies only;
Test and Evaluation; 17 Oct 73. Other requests for
this document must be referred to Director, Air Force
Materials Lab., Attn: LC. Wright-Patterson
AFB, Ohio 45433.
SUPPLEMENTARY NOTE: See also Volume 2, AD-888 183 and
Volume 5, AD-913 880L.

DESCRIPTORS: (*JET FIGHTERS, FUSELAGES), (*AIRFRAMES,
COMPOSITE MATERIALS), (*FUSELAGES, *COMPOSITE
MATERIALS), MANUFACTURING, MACHINE TOOLS, ALUMINUM,
BORON, DIFFUSION BONDING, BRAZING, GRAPHITE, EPOXY
RESINS, MACHINING, COMPRESSIVE PROPERTIES, MOLDINGS,
NONDESTRUCTIVE TESTING, ASSEMBLY, SANDWICH CONSTRUCTION,
RESISTANCE WELDING, AIRPLANE PANELS, BONDING
IDENTIFIERS: COMPRESSION MOLDING, F-111 AIRCRAFT

95. ACOUSTIC EMISSION SPECTRAL ANALYSIS OF FIBER COMPOSITE FAILURE MECHANISMS

Williams, J. H. Jr. and Egan, D. M.
Materials Evaluation
January 1979

A program to investigate the acoustic emission of graphite fiber polyimide composite failure mechanisms with emphasis on spectral energy analysis is described. A paired-sample t statistical analysis of mean normalized spectral energy distributions provides quantitative discrimination between the acoustic emission from 10°, 90°, and $[\pm 45°, \pm 45°]_s$ specimens. Comparable discrimination is not obtained for 0° specimens.

96. NONDESTRUCTIVE TESTING OF ADVANCED COMPOSITES

Hagemaier, D. J. and Fassbender, R. H.
Douglas Aircraft Company
McDonnell Douglas Corporation
Long Beach, California

The Douglas Aircraft Company of the McDonnell Douglas Corporation has developed a comprehensive background in advanced composite technology through numerous contracted and independently funded research programs. These programs consisted of fabricating selected aircraft structures from glass fiber, boron fiber, and graphite fiber composites. Data generated during nondestructive testing (NDT) of glass, boron, and graphite fiber composite-skin aluminum-core honeycomb specimens, the A-4 boron fiber composite flap assembly, the boron filament composite landing gear strut, and the fiberglass honeycomb box beam assembly were presented to ASTM Committee D-30 in October 1969 (Reference 1). The results of continuing nondestructive testing of graphite/epoxy composites used on the A-4 horizontal stabilizer and flap assembly as well as on static load and fatigue test specimens were presented to the SAE in October 1970 (Reference 2). Finally, results of NDT of the graphite/epoxy composite DC-10 upper aft rudder were presented to the ATA in October 1976 (Reference 3). In this paper, we will discuss the NDT of advanced composite DC-10 structures, e.g., floor beams and struts, vertical stabilizer trailing edge panel, centerline gear drag-brace tube, upper aft rudder, aileron access panel, nose landing gear aft door, and fan cowl door (Figure 1). We will also report on the NDT of the DC-9 rudder trim tab and a study program for a composite wing.

Our comments will concentrate on state-of-the-art NDT methods and the results obtained from the evaluation of fabricated structures.

Douglas Paper 6774

94. AD-B017 191L 11/4 20/5
AIR FORCE FLIGHT DYNAMICS LAB WRIGHT-PATTERSON AFB OHIO

Response of Compression Loaded Graphite Epoxy Laminates to Laser Energy. (U)

DESCRIPTIVE NOTE: Final rept. 1 Jul 75-30 Sep 76,
NOV 76 66P Camburn,Gilbert L. ;Lippert, Jack R. ;Maddux,Gene ;
REPT. NO. AFFDL-TR-76-127
PROJ: 4363
TASK: 01

UNCLASSIFIED REPORT
Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; Sep 76. Other requests for this document must be referred to Director, Air Force Flight Dynamics Lab. Wright-Patterson AFB, Ohio 45433.
SUPPLEMENTARY NOTE: DDC Form 55 not necessary for document request.

DESCRIPTORS: *Fiber reinforced composites, *Laser damage, *Epoxy resins, *Graphite, *Laminates, Heating, Residual stress, Compressive properties, Strength(Mechanics), Test methods, Nondestructive testing, Orientation(Direction) (U)
IDENTIFIERS: PE62201F (U)

The objective of the test program was to determine the response of compression-loaded Graphite Epoxy laminates to 'flood loading' by low intensity laser energy. The test matrix included variations of the laminate orientation ((0)6T, (0/90)2S, and (90/0)2S), incident intensity (118 to 237 w/sq cm), duration of irradiation (0.18 to 0.74 seconds) and prestress (7 to 35 percent of the laminates ultimate lateral compressive strength at room temperature). A total of 42 test specimens was constructed--14 each of the three different laminate orientations. Of the fourteen test specimens for each laminate, two test specimens were used for baseline tests to determine the ultimate lateral compressive strength at room temperature and the remaining twelve test specimens were used in the laser tests. Prior to laser or baseline testing, all test specimens were nondestructively inspected using laser holographic techniques. During the laser tests, the test specimens were prestressed to a desired value and irradiated with a known intensity (U)

97. NTIAC-8954

CONFERENCE ON NDT OF PLASTIC/COMPOSITE STRUCTURES
INDIVIDUAL PAPERS NOT ABSTRACTED BY NTDSC
1969, 01V
AVAILABILITY: AIR FORCE MATERIALS LABORATORY (MAMN);
CONFERENCE ON NDT OF PLASTIC/COMPOSITE STRUCTURES; MAR 69

*COMPOSITE MATERIALS, *TEST METHODS, *CONFERENCES, BOND TESTING, ACOUSTOOPTICAL IMAGING, MICROWAVE TESTING, SOUND, RADIOGRAPHY, STEREORADIOGRAPHY, COMPUTERS, IMAGE PROCESSING, SCHLIEREN PHOTOGRAPHY, HONEYCOMB STRUCTURES, THERMAL TESTING

MAJOR PAPER TOPICS INCLUDE ACOUSTOOPTICAL IMAGING TECHNIQUE, MICROWAVE TESTING, ULTRASONIC INSPECTION OF ADHESIVE BONDS, THERMAL TESTING, ETC. OVERVIEW PAPERS ARE ALSO PRESENTED.

98. NTIAC-16742 M

CALIFORNIA UNIV LIVERMORE LAWRENCE LIVERMORE LAB
HAMSTAD, M. A.
PHILOSOPHY FOR NONDESTRUCTIVE TESTING OF FIBER COMPOSITES
APR 77, 14P
UCID-17454
AVAILABILITY: FOR SALE BY NTIS, SPRINGFIELD, VA 22161

FIBERS, COMPOSITE MATERIALS, PHILOSOPHY, STRESSES, ACOUSTIC EMISSIONS, ULTRASONICS, QUANTITATIVE TESTING, PREDICTIONS, STRENGTH(MECHANICS), DEFECTS(MATERIALS), PERFORMANCE(ENGINEERING), FILAMENT WOUND CONSTRUCTION, CARBON, FIBER REINFORCED COMPOSITES, MECHANICAL PROPERTIES, FAILURE, PLASTICS

A DISCUSSION OF A NONDESTRUCTIVE TESTING PHILOSOPY FOR FIBER COMPOSITES IS PRESENTED. THE POSITION IS TAKEN THAT THE NONDESTRUCTIVE TEST INDICATIONS MUST BE QUANTITATIVELY CORRELATED TO THE REQUIRED ENGINEERING PERFORMANCE PROPERTIES OF THE COMPOSITE ARTICLE. THE CURRENTLY UNKNOWN DEFECT STRUCTURE IN MAY FIBER COMMPOSITES IS DISUCSSED WITH RESPECT TO NONDESTRUCTIVE TESTING. A FEW EXAMPLES FROM THE LITERATURE OF THE ABOVE DESCRIBED QUANTITATIVE NONDESTRUCTIVE TESTING OF FIBER COMPOSITES ARE PRESENTED FROM THE FIELDS OF ACOUSTIC EMISSION AND ULTRASONICS. (AUTHOR)

99. NTIAC-10663

BATTELLE COLUMBUS LABS OHIO METALS AND CERAMICS INFORMATION CENTER
FLECK, J. N.
BIBLIOGRAPHY ON FIBERS AND COMPOSITE MATERIALS--1969-1972
JUL 72, 103P
MCIC-72-09
F33615-71-C-1067
AD-746214
AVAILABILITY: NO COPIES FURNISHED BY DDC. ORDER DIRECTLY FROM NTIS.

*COMPOSITE MATERIALS, *BIBLIOGRAPHIES, *FIBERS, FIBER REINFORCED COMPOSITES, INFORMATION

THE BIBLIOGRAPHY CONTAINS OVER 3000 REFERENCES, INCLUDING TRANSLATED ITEMS FROM JAPAN, WEST GERMANY, U.S.S.R., AND OTHER COUNTRIES AS WELL AS REFERENCES OF ORIGINAL ENGLISH LANGUAGE PUBLICATIONS OF THE UNITED STATES AND UNITED KINGDOM. THE REFERENCES ARE CATEGORIZED BY SPECIFIC FIBER AND MATRIX MATERIALS. IN ADDITION, MANY REFERENCES ARE GROUPED IN THE GENERAL CATEGORIES OF COMPATIBILITY STUDIES, THEORY AND DESIGN, TESTING AND EVALUATION, APPLICATION, AND FABRICATION. A GROUP OF REFERENCES TO GENERAL REVIEW ARTICLES IS INCLUDED. THE REFERENCES REPRESENT THE HOLDINGS OF THE FORMER DEFENSE CERAMIC INFORMATION CENTER (DCIC) PLUS THOSE OF THE FIBERS AND COMPOSITES CENTER (FCIC) AT BATTELLES COLUMBUS LABORATORIES AND MCIC. (AUTHOR)

100. NTIAC-16815

HAGEMAIER, DON
ULTRASONIC APPLICATIONS IN THE AEROSPACE INDUSTRY
PUBLISHED BY SOC. AUTOMOTIVE ENGR.; 400
COMMONWELATH AVE., WARRENDALE, PA 15096
1974, 30P
AVAILABILITY: PUBLISHED IN SAE TRANS.; V. 83; 1974;
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TITANIUM, ALLOYS, AEROSPACE SYSTEMS, AEROSPACE APPLICATIONS, INDUSTRIAL APPLICATIONS, ULTRASONIC TESTING, STATE-OF-THE-ART REVIEWS, STANDARDS, ACCEPTABILITY, METAL, TUBES, PIPES, WELDS, THICKNESS, CORROSION, FIBER REINFORCED COMPOSITES, ADHESIVE BONDS, ACOUSTIC HOLOGRAPHY, MAINTENANCE, ULTRASONIC SPECTROSCOPY, CRITICAL ANGLE, ULTRASONICS, DELTA TECHNIQUE, PULSE ECHO TECHNIQUE

THIS PAPER DISCUSSES STATE-OF-THE-ART ULTRASONIC TESTING AS USED TO INSPECT AND EVALUATE PARTS AND MATERIALS FOR AEROSPACE SYSTEMS. THE PAPER IS DIVIDED INTO FOUR SECTIONS: PURPOSE OF TESTING; BASIC REGUIREMENTS FOR APPLICATION, SUCH AS EQUIPMENT, REFERENCE STANDARDS, AND ACCEPTANCE CRITERIA; STANDARD APPLICATIONS, SUCH AS WROUGHT METAL PRODUCTS, TUBING AND PIPE WELDED ASSEMBLIES, THICKNESS AND CORROSION, FIBER-REINFORCED COMPOSITES, ADHESIVE-BONDED ASSEMBLIES, BRAZED AND DIFFUSION-BONDED ASSEMBLIES, AIRCRAFT MAINTENANCE INSPECTION, ATTENUATION, AND GRAIN-BOUNDARY REFLECTIONS; AND RESEARCH AND DEVELOPMENT APPLICATIONS, SUCH AS THE LIQUID-LEVEL DETECTOR, TITANIUM HYDRIDE DETECTOR, MEASUREMENT OF APPLIED STRESS, ULTRASONIC EXTENSIOMETER, ULTRASONIC MODULUS VERSUS MECHANICAL PROPERTIES FOR FIBER COMPOSITES, ULTRASONIC SPECTROSCOPY, ACOUSTIC HOLOGRAPHY, AND CRITICAL ANGLE REFLECTIVITY. (AUTHOR)

101. NTIAC-15697

JUDD ,N. C. W. ; WRIGHT,W. W.
VOIDS AND THEIR EFFECTS ON THE MECHANICAL PROPERTIES OF COMPOSITES--AN APPRAISAL
PUBLISHED BY SOC. FOR ADVANCEMENT OF MATER. AND RPOC. ENG.; P. O. BOX 613, AZUSA, CA 91702
FEB 78, 05P
AVAILABILITY: PUBLISHED IN SAMPE J.; 14, 1; JANUARY/FEBRUARY 1978; 10-14; 47 REFS.

MECHANICAL PROPERTIES, COMPOSITE MATERIALS, VOIDS, DEFECTS(MATERIALS), FIBERS, RESINS, STRENGTH(MECHANICS), SHEAR, RADIOGRAPHY, ULTRASONIC TESTING, C-SCAN, DESTRUCTIVE TESTS, MICROSCOPES, WATER, ABSORPTION, DENSITY, FORMULAS(MATHEMATICS), QUANTITATIVE TESTING, ACCURACY

BRIEF ACCOUNTS ARE GIVEN OF THE ORIGIN VOIDS IN FIBRE/RESIN COMPOSITES, OF THE AVAILABLE METHODS OF MEASUREMENT OF VOID CONTENT AND OF THE INFLUENCE OF VOIDS ON THE MECHANICAL PROPERTIES OF COMPOSITES. IT IS CONCLUDED THAT, REGARDLESS OF RESIN, FIBRE TYPE, OR FIBRE SURFACE TREATMENT, THE INTERLAMINAR SHEAR STRENGTH OF A COMPOSITE DECREASES BY ABOUT 7 PER CENT FOR EACH 1 PER CENT VOIDS UP TO A TOTAL VOID CONTENT OF ABOUT 4 PER CENT. OTHER MECHANICAL PROPERTIES ARE ALSO AFFECTED, ALTHOUGH NOT TO THE SAME DEGREE, OR EXTENT. (AUTHOR)

102. Ultrasonic Spectrum Analysis for NDT of Layered Composite Materials

Naval Air Development Center Warminster Pa Air Vehicle Technology Dept (407207)

Final rept.
AUTHOR: Scott, William R.
C7245G2 Fld: 14B, 11D, 73A, 71F GRAI7622
31 Dec 75 40p
Rept No: NADC-75324-30
Project: NADC-FR-R022-01-001
Monitor: 18

Abstract: The structural use of advanced composite materials has increased in recent years and a number of problems have arisen associated with assuring the integrity of composite structures. Because ultrasonics has emerged as an important tool for inspecting composite materials, it has become necessary to understand more about the interaction of acoustic waves with composites and what information can be obtained by monitoring this interaction. In this paper a simple model is presented which predicts the ultrasonic frequency spectra for a broad class of layered composite materials having a finite number of laminae. Experimental verification of this model is demonstrated for arrays exhibiting both periodic and aperiodic frequency spectra. The relationship between the spectra of periodic arrays having both finite and infinite numbers of layers is discussed. Important results relating to NDT which have emerged from this study include methods for predicting the results of spectrum analysis studies on layered materials and techniques for mapping small changes in the modulus and thickness of composite materials. Also discussed is the existence of forbidden frequency bands at which ultrasound cannot be transmitted through thick layered composites. (Author)

Descriptors: *Nondestructive testing, *Ultrasonic inspection, *Composite materials, *Laminates, Spectrum analysis, Acoustic waves, Bandstop filters, Interfaces, Pulses, Glass, Water, Boron, Aluminum

Identifiers: Periodic structures, NTISDODXA

AD-A028 856/3ST NTIS Prices: PC A03/MF A01

103. NONDESTRUCTIVE TEST METHODS FOR REINFORCED PLASTIC/COMPOSITE MATERIALS

Aerospace Corp El Segundo Calif Lab Operations (009575)
AUTHOR: Epstein, George
6044E4 Fld: 11D, 13H, 11I USGRDR6912
3 Feb 69 37p*
Rept No: TR-0200(4250-20)-4
Contract: F04701-68-C-0200
Monitor: SAMSO-TR-69-78

Abstract: A review is presented of various methods for nondestructive testing (NDT) of reinforced plastic/composite materials and structures. Visual inspections, ultrasonic methods, sonic methods, radiography, electrical properties, microwave techniques, thermal techniques, and other NDT methods are examined with regard to their characteristics, instrumentation, utility, and limitations. Recent developments are also discussed. (Author)

Descriptors: (*Reinforced plastics, *Non-destructive testing), Reinforcing materials, Visual inspection, Defects(Materials), Laminates, Ultrasonic properties, Rayleigh waves, Crack propagation, Microwaves, Radiography, Electrical properties, Thermal stability

Identifiers: Evaluation

AD-686 466 CFSTI Prices: PC A03/MF A01

104. Research and Development of Nondestructive Testing Techniques for Composites

North American Aviation Inc Los Angeles Calif Los Angeles Div (401 949)

Summary Technical rept. 1 Jul 66-30 Apr 67
AUTHOR: Moore, John F.; Martin, George

D1575C3 Fld: 13H, 11D d7708
Nov 67 142p
Rept No: NA-67-425
Contract: AF 33(615)-2865
Project: AF-7360
Task: 7360
Monitor: AFML-TR-67-166
Distribution limitation now removed.

Abstract: No abstract available.

Descriptors: (*Nondestructive testing, *Composite materials), Filament wound construction, Ultrasonic radiation, Radiography, Probes(Electromagnetic), Reinforcing materials, Fibers, Defects(Materials), Boron, Titanium, Tungsten, Copper, Silicon carbides, Anomalies

Identifiers: Eddy currents, Ultrasonic inspection, NTISCDDXD

AD-825 636/4ST NTIS Prices: PC A07/MF A01

105. Application of Photochromic Coatings for Nondestructive Inspection

Air Force Materials Lab Wright-Patterson AFB Ohio (012320) *

Final technical rept. Jan 69-Jul 70
AUTHOR: Allinikov, Sidney
A1861A3 Fld: 14B, 11C, 73B GRAI7109
Dec 70 61p*
Rept No: AFML-TR-70-246
Project: AF-7381
Task: 738101

Abstract: The application of a photochromic compound to provide a nondestructive inspection (NDI) technique for aerospace materials and structures is discussed. The photochromic compound, incorporated into a paint formulation, is converted from a white to a bright violet color upon a brief irradiation from an ultraviolet source. The colored paint surface is then heated by any suitable means, such as a hot air blower. Heat serves to bleach the paint to the original white color. Defects are disclosed because heat conductivity at the defect site is different from that of the rest of the area under inspection. The defect thus appears as a colored or white area dependent upon the nature of the defect and originating direction of the heat source. Some of the types of defects and kinds of structures to which the NDI paint has been applied are discussed, along with advantages and limitations of the paint. (Author)

Descriptors: (*Non-destructive testing, *Photochromism), Defects(Materials), Thermal conductivity, Paints, Test methods, Spiro compounds, Bonded joints, Composite materials, Laminated plastics

Identifiers:
*Spiro(benzopyran-indoline)/nitro-1'-3'-3'-trimethyl, Dissimilar materials bonding

AD-720 239 NTIS Prices: PC A04/MF A01

106. **Methods for Nondestructive Testing of Composite Materials**

Technische Univ. Hannover (F.R. Germany). (6131000)
AUTHOR: Buhmann, K. P.; Stelling, H. A.; Winkler, T.
C6425C2 Fld: 11D, 14B, 71F ERA0103
1974 50p
Monitor: 18
Translated from Kunststoffe.

Abstract: Nondestructive testing has become increasingly important recently for quality assurance and quality control in regard to the proof of required material properties and irregularities which occur in plastics also, especially composite materials. Nondestructive techniques are discussed which have given satisfactory results for a long time in metal testing, and also newer techniques often used for composite materials. The further development of these methods and their value are illustrated by examples.

Descriptors: (*Reinforced plastics, *Nondestructive testing), (*Plastics, Nondestructive testing), Reviews, Ultrasonic testing

Identifiers: ERDA/360303, ERDA/420500, ERDA/360403, Translations, West Germany, NTISERDA

UCRL-Trans-10938(Pt.1-2) NTIS Prices: PC A03/MF A01

107. Non-Destructive Evaluation of Materials with Cold Neutron Beams

State Univ of New York At Stony Brook Dept of Materials Sciences (401074)
AUTHOR: Herman, Herbert
E143182 Fld: 14B, 94J, 71J, 71F, 71N GRAI7815
Dec 77 164p
Contract: N00019-77-M-0418
Monitor: 18

Abstract: A study is presented on the possibilities of using cold neutrons for non-destructive evaluation (NDE). There are shown to be two sectors where cold neutrons can be effectively employed: (1) cold neutron radiography (CNR); and (2) small-angle neutron scattering (SANS). CNR is an established method of radiography with low energy, long wavelength neutrons, enabling greatly improved contrast and resolution over normal radiographic methods. This improvement will be especially important for hydrogenous materials, for example, contained within thick steel sections (e.g., one mm of plexiglas imbedded between two 7 cm section of steel plates). The main limitations to the use of CNR are portability and expense of the cold neutron source. SANS is actually a scattering method for detecting heterogeneities (10-10,000 A) imbedded within a matrix of different neutron scattering power. SANS has been employed by workers in Italy over a remarkable range of applicability, from predicting failure in nickel-base superalloy turbine blades to a study of debonding of fibers in carbon-carbon fiber composites. Again, as with CNR, applied SANS suffers from the need of a high flux of cold neutrons. The possibilities and limitations of SANS for NDE, with special reference to Naval needs, are examined.

Descriptors: *Neutron radiography, *Neutron scattering, *Nondestructive testing, Metallurgy, Defects(Materials), Microstructure, Alloys, Superalloys, Ceramic materials, Plastics, Hydrogen, Porous materials, Coatings, Cements, Composite materials

Identifiers: Small angle neutron scattering, Small angle neutron scattering, NTISDODXA

AD-A053 073/3ST NTIS Prices: PC A08/MF A01

108. ID NO.- EI72X044151 244151
Inspection system for the non- destructive testing of composites
COMPTON R
Composites v 2 n 3 Sept 1971 p 152-3
DESCRIPTORS: (*COMPOSITE MATERIALS. *Testing). MATERIALS TESTING APPARATUS. (MATERIALS TESTING. Nondestructive). ULTRASONICS. (PLASTICS. Reinforced).
CARD ALERT: 421. 422. 753. 817
A new nondestructive test methods is described which is based on the use of the ultrasonic technique for void detection. Test apparatus developed and its operation techniques are detailed. 1 ref.

109. ID NO.- EI72X034257 234257
Advanced NDT methods for filament wound pressure vessels and composites in general
MAIGRET JP: JUBE G
AERSOPATIALE. Courbevoie. France
Materials '71. SAMPE. 16th Nat Symp and Exhib. Apr 21-23 1971. Soc Aerosp Mater Process Eng. (Sci Advan Mater Process Eng Ser. v 16). 1971 p 123-37
DESCRIPTORS: (*PRESSURE VESSELS. *Plastics). (PLASTICS. Filament Winding). (PRESSURE VESSELS. Testing). X-RAYS. Measurement. (RADIOGRAPHY. X-ray).
CARD ALERT: 421. 619. 817. 932
The quality control of filament wound pressure vessels requires a developxent of methods which can be very useful to laminated and composite materials. The problem of flaw detection can be considered as solved thanks to advanced inspection techniques with x- rays and overall methods such as the thermography process. More difficult. but equally necessary. is the detection of the material aging effect. Microwaves should give interesting future results. This is a survey of existing test procedures. illustrated with x- ray photographs.

110. ID NO.- EI72X033869 233869
Vibration response. A non- destructive test for fatigue crack damage in filament- reinforced composites
SCHULTZ AB: WARWICK DN
Univ of Illinois at Chicago Circle
J Compos Mater v 5 July 1971 p 394-404 CODEN: JCOMB
DESCRIPTORS: (*MATERIALS TESTING. *Nondestructive). (COMPOSITE MATERIALS. Mechanical Properties). (COMPOSITE MATERIALS. Vibrations). (COMPOSITE MATERIALS. Fatigue). (BEAMS AND GIRDERS. Vibrations).
CARD ALERT: 408. 415. 421. 422. 931
Laminated. filament- reinforced epoxy beam specimens were fatigued in vibratory flexure. The complex modulus of the specimens was measured periodically as fatigue crack damage accumulated. Changes in the real and imaginary parts of the modulus correlated with the amount of crack damage. The imaginary part of the modulus changed substantially. Measurement of these vibration response changes shows promise as a means to nondestructively test the structural integrity of filament- reinforced composite structural members. 10 refs.

111. ID NO.- EI70X148871 048871
Testing of fibre- bonded composites
REYNOLDS WN
Atomic Energy Res Estab. Berkshire, England
SPI Reinf Plas/Compos Div. Proc 24th Annu Tech Conf; Washington, DC, Feb 4-7 1969. Sec 14B, 3 p
DESCRIPTORS: *MATERIALS TESTING, (PLASTICS, Reinforced).
CARD ALERT: 421, 816
X- ray and ultrasonic techniques can provide a most detailed picture of composite structure. When combined with the well known ability of these techniques to detect flaws and defects, the value of suggested new developments becomes clear. At a later stage electrical, thermal and optical methods may be prescribed for use in particular situations, but results using these methods normally contain intrinsically less information.

112. ID NO.- EI770105130 705130
STRESS MEASUREMENT IN POLYMERIC MATERIALS BY X-RAY DIFFRACTION.
Barrett, Charles S.; Predecki, Paul
Univ of Denver, Colo
Polym Eng Sci v 16 n 9 Sep 1976 p 602-608 CODEN: PYESAZ
DESCRIPTORS: (*POLYMERS, *Stresses),
CARD ALERT: 815
The method is applicable, when calibrated, to both applied and residual stresses, to stress relaxation studies, to both tensile and compressive stresses, to both interior and surface positions in an object, and to composites of various types as well as to polymers that are substantially homogeneous. In the lower (Hookian) range, strains and stresses in metallic embedded particles increase linearly with applied stresses and strains in the matrix. When applied stresses exceed an apparent yield point, which correlates with the yield strength of the metallic filler, the elastic strains in the particles increase only slightly or even decrease as the matrix strains are increased, and with constant applied strain, the particles reveal changes due to relaxation. 7 refs.

113. 51776 D7606513
POSSIBILITIES OF USING LIGHT PROPAGATION FOR THE NONDESTRUCTIVE TESTING OF REINFORCED PLASTICS
SANDALOV, A.V.; LEIT, V.A.; MEDVEDEV, M.Z.
INST. OF POLYMER MECH., ACAD. OF SCI., RIGA, LATVIAN SSR
MEKH. POLIM. (USSR) VOL.11, NO.3 563-5 MAY-JUNE 1975
Coden: MKPLAG
Trans In: POLYM. MECH. (USA) VOL.11, NO.3 485-7 MAY-JUNE 1975 Coden: PLYMAQ
Treatment: P
02
(11 Refs)
Descriptors: NONDESTRUCTIVE TESTING; REINFORCED PLASTICS; OPTICS; COMPOSITE MATERIALS; TEST EQUIPMENT
Identifiers: LIGHT PROPAGATION; NONDESTRUCTIVE TESTING; REINFORCED PLASTICS; LABORATORY OPTICAL APPARATUS; MEASURING TECHNIQUE
Section Class Codes: D3450, D8500

114. ID NO.- E1771291411 791411
WORLD CONFERENCE ON NONDESTRUCTIVE TESTING. 8TH. SEPTEMBER 9. 1976 SEM DASHS THURSDAY AFTERNOON.
Anon
World Conf on Nondestr Test. 8th. Cannes. Fr. Sep 6-11 1976 Sponsored by World Conf on Nondestr Test. Paris. Fr. 1977 var pagings
DESCRIPTORS: *NONDESTRUCTIVE EXAMINATION. (ULTRASONICS. Measurements). (COMPOSITE MATERIALS. Nonmetallic Matrix Composites).
CARD ALERT: 421. 422. 753. 415. 817
Proceedings of Sections 3F. 3B and 4B include 29 papers on the use of ultrasonic methods of nondestructive testing. comparative studies of various methods of nondestructive testing. and methods of nondestructive testing of composite materials. The papers presented deal with frequency analysis in ultrasonic testing. ultrasonic analysis of rough surfaces. pulse-echo ultrasonic thickness gauging. the attenuation of ultrasonic waves in solids. the effect of heat treatment on ultrasonic wave behavior. determination of grain size from ultrasonic pulse scattering. in-process monitoring of the quality of metallurgical products. the accuracy of equipment used in nondestructive estimation of crack depth. ultrasonic testing of two-layer metals. the crack detection capability of liquid penetrant inspection systems. structural aspects of magnetic-particle crack detectors. properties of inspection media for the magnetic-particle method. nondestructive clearance measurement in closed joints. nondestructive examination of boron/epoxy structures after service testing. nondestructive testing of glass fiber reinforced plastics. assessment of matrix and interface damage in fiber-reinforced composites. radiographic monitoring of plastic materials. acoustic emission testing of a carbon fiber reinforced epoxy pressure vessel. and nondestructive testing of solid propellant rockets by holographic interferometry. In French and English.

115. ID NO.- E1721316074 294073
NONDESTRUCTIVE DETERMINATION OF FATIGUE CRACK DAMAGE IN COMPOSITES USING VIBRATION TESTS.
DiBenedetto. A. T.: Gauchel. J. V.: Thomas. R. L.: Barlow. J. W.
Washington Univ. St. Louis. Mo
J Mater v 7 n 2 Jun 1972 p 211-215
DESCRIPTORS: (*PLASTICS LAMINATES. *Mechanical Properties). LAMINATED PRODUCTS. COMPOSITE MATERIALS. PLASTICS. REINFORCED. MATERIAL TESTING.
CARD ALERT: 415. 421. 817
The results of this investigation show that the vibrational response of a fiber reinforced laminate changes with the formation of cracks and microcavities. Sonic frequency vibration testing shows promise as a means of nondestructively evaluating in-service degradation of strength and stiffness. The vibration response changes correlated in most cases with the visible changes that were attributed to crack damage that occurred during fatiguing. The changes in modulus and damping were large enough to be detected easily. 9 refs.

116. ID NO.- E1721210671 288670
NONDESTRUCTIVE TESTING OF ADVANCED COMPOSITES.
Anderson, Robert T.; DeLacy, Thomas J.
Met Prog v 102 n 2 Aug 1972 p 88-92
DESCRIPTORS: (*COMPOSITE MATERIALS, *Inspection), INSPECTION (MATERIALS TESTING, Nondestructive Testing), ULTRASONICS, RADIOGRAPHY,
CARD ALERT: 415, 422, 753, 913
Radiographic and ultrasonic tests appear most effective for inspecting resin-matrix and metal-matrix composites for improved noise suppression, fracture analysis, detecting open bonds, laminar defects, etc. Test procedures, data analysis and alternative nondestructive testing methods are described.

117. ID NO.- E1751279440 579440
WAVES AND VIBRATIONS IN DIRECTIONALLY REINFORCED COMPOSITES.
Achenbach, J. D.
Northwest Univ, Evanston, Ill
Compos Mater v 2, 1974 p 309-351 CODEN: CMMATBM
DESCRIPTORS: (*COMPOSITE MATERIALS, *Vibrations), PLASTICS, REINFORCED, (METALS AND ALLOYS, Fiber Reinforcement), MECHANICAL WAVES, MATHEMATICAL TECHNIQUES,
CARD ALERT: 415, 421, 531, 817, 921, 931
This paper reviews some aspects of wave motions and vibrations in directionally reinforced composites for small deformations and linear behavior of the constituents. Some of the basic concepts of the motions of elastic continua are briefly reviewed in Appendixes A and B. An investigation of the propagation of mechanical disturbances is of importance for bodies that are subjected to high-rate loads such as are generated by impact or by explosive charges. For a directionally reinforced composite the character of the dynamic response depends on the direction of propagation of the disturbances. For wave motions propagating in the direction of the reinforcements, the reinforcing elements act as waveguides. Mechanical disturbances are subjected to attenuation when propagating in composite materials. The attenuation is effected through geometrical dispersion, and dispersion due to other mechanisms, such as are related to inelastic material behavior, delamination, internal voids and cracks, and crushing of composite constituents. Of the various dispersion mechanisms structural dispersion and dispersion due to inelastic material behavior are analytically treated by using mathematical equations. Experimental results obtained by ultrasonic techniques, sock-tube tests, and flyer-plate impact tests are presented and evaluated by means of equations developed. Refs.

118. ID NO.- E1750854358 554358
OPTICAL METHODS FOR TESTING COMPOSITE MATERIALS.
Daniel. I. M.
Ill Inst of Technol. Chicago
AGARD Conf Proc n 163. 1975. for Meet. Munich. Ger. Oct 13-19 1974. Pap 9. 20 p CODEN: AGCPAV
DESCRIPTORS: (*PLASTICS. REINFORCED. *Deformation). COMPOSITE MATERIALS. Fracture). (STRESSES. Analysis).
CARD ALERT: 815. 817. 408. 421
Optical stress analysis techniques and their application to the study of deformation and fracture of composite materials are described and discussed. These include photoelastic coatings. moire grids. holographic interferometry. and liquid crystals. All these techniques have different advantages and limitations. The selection of any one or more of these depends on each particular application. 44 refs.

119. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 915 592L 1/3 11/4 13/8
MCDONNELL AIRCRAFT CO ST LOUIS MO

Quality Assurance Procedures for Advanced Composite Aircraft Structures. Volume II.

DESCRIPTIVE NOTE: Final rept. Mar 71-Jul 73,
JUL 73 326P Sanders,L. R. ;
CONTRACT: F33615-71-C-1359
PROJ: AF-6169CW
MONITOR: AFML TR-73-162-Vol-2

UNCLASSIFIED REPORT
Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; Jul 73. Other requests for this document must be referred to Director, Air Force Materials Lab., Wright-Patterson AFB, Ohio 45433.
SUPPLEMENTARY NOTE: See also Volume 1, AD-915 591L.

DESCRIPTORS: (*Airframes, Quality assurance), (*Composite structures, Airframes), (*Composite materials, Airframes), Instruction manuals, Laminates, Boron, Honeycomb structures, Epoxy resins, Honeycomb cores, Inspection, Nondestructive testing, Fabrication, Humidity, Defects(Materials), Failure(Mechanics), Repair, Bonded joints, Acceptability, Adhesion, Skin(General), Bonding, Effectiveness

AD-A036 026 11/4 20/6
AUBURN UNIV ALA ENGINEERING EXPERIMENT STATION

Techniques for Flaw Detection in Composite Material Structures.

DESCRIPTIVE NOTE: Final rept. Dec 75-Dec 76,
DEC 76 75P Ranson,W. F. ;Swinson,W. F. ;
REPT. NO. ME-AMC-0467
CONTRACT: DAAH01-76-C-0467

UNCLASSIFIED REPORT

DESCRIPTORS: *Defects(Materials), *Composite materials, *Detection, *Interferometry, *Specular reflection, Fiber reinforced composites, Photography, Shear properties, Cylindrical bodies, Thin walls, Optical interferometers,
IDENTIFIERS: Young's fringes

This study concerns the nondestructive detection and quantification of flaws and voids in thin, cylindrical, fiber reinforced, composite, structures. Three types of flaws were investigated using shearing speckle and single beam speckle interferometry. The theory for each technique and photographs of the fringe patterns are presented. The Young's fringe method of speckle interferometry was used to determine the surface strains in the flaw region and the resulting flaw geometry was presented in graphical form. Shearing speckle interferometry was developed for a qualitative analysis only. The results show that flaws in their fiber reinforced composite structures can be detected and the size determined by either shearing speckle or single beam speckle interferometry. (Author)

121. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 894 884L 14/5 14/2
ROYAL AIRCRAFT ESTABLISHMENT FARNBOROUGH (ENGLAND)

The Use of Radiography in the Nondestructive Testing of Composite Materials.

DESCRIPTIVE NOTE: Technical rept.,
DEC 71 42P Stone,D. E. W. ;
REPT. NO. RAE-TR-71235
MONITOR: DRIC BR-28324

UNCLASSIFIED REPORT

Distribution: DoD and DoD contractors only; others to Britisn M.nistry of Technology via the appropriate channel.

DESCRIPTORS: (*RADIOGRAPHY, COMPOSITE MATERIALS), (*NONDESTRUCTIVE TESTING, RADIOGRAPHY), PENETRATION, CARBON FIBERS, REINFORCED PLASTICS, X RAY PHOTOGRAPHY, GAMMA RAYS, NEUTRONS, TRACER STUDIES, GREAT BRITAIN, MICROPHOTOGRAPHY, DEFECTS(MATERIALS)

122. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 739 780 11/4 11/9
ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT PARIS (FRANCE)

Non-Destructive Testing and Inspection Applied to Composite Materials and Structures,

FEB 72 35P Owston,C. N. ;Jaffe,E. H. ;
REPT. NO. AGARD-R-590

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE: Presented at the AGARD Structures and Materials Panel Meeting (32nd), London, 31 Mar 71. NATO furnished.

DESCRIPTORS: (*COMPOSITE MATERIALS, *NONDESTRUCTIVE TESTING), (*REINFORCED PLASTICS, NONDESTRUCTIVE TESTING), AIRFRAMES, CARBON FIBERS, BORON, QUALITY CONTROL, ULTRASONIC RADIATION, RADIOGRAPHY
IDENTIFIERS: *CARBON FIBER REINFORCED PLASTICS, *FIBER COMPOSITES, ULTRASONIC TESTS, EDDY CURRENT TESTS

The two contributions contained in this report deal with non-destructive testing applied to specimens and structural parts made of composite materials. In the first paper, some aspects of various inspection methods such as ultrasonics, radiography, eddy current and acoustic emission techniques applied to carbon fiber composites are described in connection with a discussion of possible failure mechanisms, especially in fatigue. The second paper shows the possibilities and limitations of NDI applied to the quality control of a primary structural part made of boron composite. (Author-PL)

123. DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. BSM10D

AD- 741 236 11/5
GENERAL ELECTRIC CO PHILADELPHIA PA SPACE DIV

Investigation of electronic Ceramic Fibers for Non-Destructive Evaluation of Advanced Composites. (

DESCRIPTIVE NOTE: Final rept. 16 Feb 71-15 Feb 72,
FEB 72 41P Henry,Edward C. ;
CONTRACT: N00019-71-C-0247

UNCLASSIFIED REPORT

DESCRIPTORS: (*CERAMIC FIBERS, PRODUCTION), (*FERRITES CERAMIC FIBERS), (*NIOBATES, CERAMIC FIBERS), (*NONDESTRUCTIVE TESTING, COMPOSITE MATERIALS), DIELECTRIC PROPERTIES, CRYSTALLIZATION, SODIUM COMPOUNDS, LITHIUM COMPOUNDS, DETECTORS, FERROELECTRIC CRYSTALS, FILAMENTS, MAGNETOSTRICTION, HEAT TREATMENT, DRAWING(FORMING), TENSILE PROPERTIES (U
IDENTIFIERS: LITHIUM NIOBATES, SILICA GLASS, DEVITRIFIED GLASS (U

The objective of this program is to investigate the feasibility of developing and using crystal-bearing filaments as sensors in the NDT of fiber-reinforced plastics and related composites. The fibers or filaments contain crystalline oxidic materials commonly referred to as electronic ceramics. These compositions include soft and hard magnetic ferrites, and ferroelectric potassium sodium niobate and lithium niobate. A study was made of the devitrification behavior of the key compositions, to show the effects of time, temperature, kind of glass and concentration of elctronic ceramic on the exsolution of the active phase. The devitrified filaments were incorporated into composite tile, with an epoxy-novolac matrix. Data are presented for the initial tests of these composites. (Author, modified-PL) (U

124. **FATIGUE MECHANISMS, CHARACTERISATION OF DEFECTS AND THEIR DETECTION IN REINFORCED PLASTICS MATERIALS**
Sturgeon, J. B.
British Journal of NDT
November 1978

When high performance composite materials come into widespread use fatigue failures will almost certainly occur. This paper presents the principal fatigue mechanisms which arise in these materials and also reviews the important role that non-destructive testing techniques have played in not only detecting damage but in determining which mechanisms are present in particular circumstances. No one testing technique is sufficient, by itself, to give all the information desired and some need to be used whilst fatigue testing is in progress; however for inspection of damage after dynamic fatigue loading ultrasonic C-scanning techniques are probably one of the most useful methods, at least as a research tool.

125. NTIAC-16434 M

CALIFORNIA UNIV LIVERMORE LAWRENCE LIVERMORE LAB
HAMSTAD , M. A. ; PETERSON, R. G.
CONSIDERATIONS FOR ACOUSTIC EMISSION MONITORING OF SPHERICAL KEVLAR/EPOXY COMPOSITE PRESSURE VESSELS
MAY 77, 24P
UCRL-79356
AVAILABILITY: FOR SALE BY NTIS, 5285 PORT ROYAL RD., SPRINGFIELD, VA 22161

ACOUSTIC EMISSIONS, MONITORING, EPOXY, COMPOSITE MATERIALS, PRESSURE VESSELS, PREDICTIONS, PRESSURE, FILAMENT WOUND CONSTRUCTION, INSTRUMENTATION, EXPERIMENTAL DATA, DEVELOPMENT, DESIGN, CALIBRATION, TRANSDUCERS, SENSITIVITY, PROOF TESTS

WE ARE CONTINUING TO RESEARCH THE APPLICATIONS OF ACOUSTIC EMISSION TESTING FOR PREDICTING BURST PRESSURE OF FILAMENT-WOUND KEVLAR 49/EPOXY PRESSURE VESSELS. THIS STUDY HAS FOCUSED ON THREE SPECIFIC AREAS. THE FIRST AREA INVOLVES DEVELOPMENT OF AN EXPERIMENTAL TECHNIQUE AND THE PROPER INSTRUMENTATION TO MEASURE THE ENERGY GIVEN OFF BY THE ACOUSTIC EMISSION TRANSDUCER PER ACOUSTIC EMISSION BURST. THE SECOND AREA CONCERNS THE DESIGN OF A TEST FIXTURE IN WHICH TO MOUNT THE COMPOSITE VESSEL SO THAT THE ACOUSTIC EMISSION TRANSDUCERS ARE HELD AGAINST THE OUTER SURFACE OF THE COMPOSITE. INCLUDED IN THIS STUDY AREA IS THE CALIBRATION OF THE ENTIRE TEST SETUP INCLUDING COUPLANT, TRANSDUCER, ELECTRONICS, AND THE INSTRUMENT MEASURING THE ENERGY PER BURST. IN THE THIRD AND FINAL AREA OF THIS STUDY, WE CONSIDER THE NUMBER, LOCATION, AND SENSITIVITY OF THE ACOUSTIC EMISSION TRANSDUCERS USED FOR PROOF TESTING COMPOSITE PRESSURE VESSELS. (AUTHOR)

126. NTIAC-11761

HANSTAD ,M. A. ; TATRO,C. A.
RECENT ADVANCES IN UNDERSTANDING OF ACOUSTIC EMISSION FROM FIBER COMPOSITES AND METALS
ABSTRACT ONLY
1976, 01P
AVAILABILITY: PUBLISHED IN J. ACOUST. SOC. AM.; VOL. 59, SUPPL. NO. 1; SPRING 1976; P S48

*ACOUSTIC EMISSIONS, *FIBER REINFORCED COMPOSITES, *ALUMINUM, FREQUENCY, COMPOSITE MATERIALS, EPOXY, TRANSDUCERS, LOADS(FORCES), FATIGUE(MECHANICS), FRACTURE TOUGHNESS, STRESSES, JASM

THE TIME AND FREQUENCY DOMAINS OF ACOUSTIC EMISSION SIGNALS GENERATED DURING LOADING OF KEVLAR 49/EPOXY COMPOSITES HAVE BEEN STUDIED. THE EFFECTS OF COMPOSITE THICKNESS, TRANSDUCER TYPE, AND LOAD LEVEL HAVE BEEN EXAMINED. RESULTS INDICATE THAT RELATIVELY LOW FREQUENCIES PREDOMINATE. A STUDY OF THE FREQUENCY SPECTRUM OF ACOUSTIC EMISSION SIGNALS GENERATED DURING FATIGUE TESTING OF FRACTURE TOUGHNESS SPECIMENS HAS BEEN COMPLETED. IN PARTICULAR, THE DEPENDENCE OF FREQUENCY ON THE STRESS INTENSITY LEVEL WAS STUDIED. EXTENSIVE TENSION AND COMPRESSION TESTING OF UNFLAWED 7075 AND 2124 ALUMINUM HAS BEEN UNDERTAKEN. AMONG THE RESULTS ARE (I) A CORRELATION BETWEEN FRACTURE TOUGHNESS AND THE ACOUSTIC EMISSION GENERATED DURING A COMPRESSION TEST OF 2124-T851; (II) THE RATE OF ACOUSTIC EMISSION ENERGY SENSED AT STRAINS GREATER THAN 1.5 PERCENT IS MORE THAN TWO ORDERS OF MAGNITUDE GREATER IN TENSION THAN IN SOMPRESSION; AND (III) ACOUSTIC EMISSION CAN EASILY BE USED TO SORT OUT PLATES OF 7075 ALUMINUM WHICH HAVE UNDESIRED 20-60-MICROMETER INCLUSION PARTICLES. (THIS WORK WAS PERFORMED UNDER THE AUSPICES OF THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, UNDER CONTRACT NO. W-7405-ENG-48.) (AUTHOR)

127. **PROCEEDINGS OF THE WORKSHOP ON STRUCTURAL COMPOSITES AND NONDESTRUCTIVE EVALUATION**
National Materials Advisory Board (NAS-NAE)
Prepared for Department of Defense
June 1974
Distributed by National Technical Information Service, U.S. Department of Commerce

AD-781 823

128. NTIAC-13284 M

AVCO CORP LOWELL MASS SYSTEMS DIV
HASTINGS, C. H. ; OLSTER, E. F. ; LOPILATO, S. A.
DEVELOPMENT AND APPLICATION OF NONDESTRUCTIVE METHODS FOR PREDICTING MECHANICAL PROPERTIES OF ADVANCED REINFORCED NONMETALLIC COMPOSITES
FINAL TECHNICAL REPT. 1 JUN 70-30 MAY 73
MAY 73, 96P
AFML-TR-73-157
AVSD-0183-73-CR
F33615-70-C-1526
AD-771774

DEVELOPMENT, APPLICATION, MECHANICAL PROPERTIES, REINFORCED PLASTICS, NONMETALS, COMPOSITE MATERIALS, EVALUATION, ULTRASONIC TESTING, VELOCITY, MEASUREMENT, TECHNIQUE, BORON, EPOXY, LAMINATES, STRUCTURES, MATERIALS, COMPONENTS, CORRELATION, STRENGTH(MECHANICS)

THIS REPORT CONCERNS ITSELF WITH A DETAILED EVALUATION AND DEVELOPMENT OF ULTRASONIC INTERVAL VELOCITY MEASUREMENT TECHNIQUE. RESULTS INDICATE THAT IT IS A PRACTICAL AND POWERFUL TOOL APPLICABLE TO THE EVALUATION OF BORON/EPOXY LAMINATES FOR STRUCTURAL HARDWARE COMPONENTS. BEST RESULTS ARE ACHIEVED IN THE 0 AND 90 DEGREE DIRECTIONS OF THE LAMINATES STUDIED. UNBALANCED LAMINATES LEAD TO GREATER ERRORS IN THE 45 DEGREE DIRECTION. MEASUREMENTS OFF-ANGLE WITH RESPECT TO REINFORCING FILAMENTS DO NOT NOW SEEM TO BE RELIABLE. BASED ON INTERVAL VELOCITY MEASUREMENTS, CORRELATIONS HAVE BEEN DEVELOPED FOR MODULUS CALCULATION AND TENSILE STRENGTH PREDICTION. ACCURACIES APPEAR TO BE BETTER THAN TENSILE TESTS FOR MODULUS (LESS SCATTER) AND AS GOOD AS TENSILE TESTS FOR STRENGTH DETERMINATION. YIELD STRENGTHS DID NOT APPEAR TO BE PREDICTABLE BECAUSE OF EXCESSIVE SCATTER IN THE DENSILE DATA. DEGRADATION OF BORON/EPOXY LAMINATES STUDIED, BECAUSE OF PRIOR TENSILE LOADING DID NOT EXIST. (AUTHOR-PL)

129. NTIAC-6364 M

AVCO GOVERNMENT PRODUCTS GROUP LOWELL MASS AVCO APPLIED TECHNOLOGY DIV
SCHULTZ, ARNOLD W.
THE DEVELOPMENT OF NONDESTRUCTIVE METHODS FOR THE QUANTITATIVE EVALUATION OF ADVANCED REINFORCED PLASTIC COMPOSITES
CONTRACT REPT. 1 AUG 68-31 OCT 69
AUG 70, 165P
AFML-TR-70-20
AVATD-0195-69-RR
F33615-67-C-1285
AD-875229
AVAILABILITY: PUB. IN U.S. NAVY JNL OF UNDERWATER ACOUSTICS, V20N2 P339-35 1 APR 70.

*REINFORCED PLASTICS, *QUANTITATIVE TESTING, PLASTICS, COMPOSITE MATERIALS, GAMMA RAYS, ULTRASONIC RADIATION, EPOXY, CARBON FIBERS, BORON, MECHANICAL PROPERTIES

THIS FINAL REPORT DOCUMENTS THE COMPLETION OF THE FIFTH YEAR OF A CONTINUING STUDY CONCERNED WITH THE DEVELOPMENT OF NONDESTRUCTIVE TESTING TECHNIQUES FOR QUANTITATIVELY EVALUATING ALVANCE FIBER--REINFORCED-PLASTIC-COMPOSITES. FIVE BORON/ EPOXY PANELS, ONE PLAIN-WEAVE CARBON/CARBON PANEL, AND A 3-D QUARTZ/PHENOLIC SSPHERE WERE NONDESTRUCTIVELY AND DESTRUCTIVELY TESTED FOR MECHANICAL PROPERTIES BEHAVIOR AND PHYSICAL PROPERTIES CHARACTERISTICS. IT WAS THE PURPOSE OF THIS PROGRAM TO: (A) ESTABLISH PREDICTIVE CORRELATIONS BETWEEN ULTRASONICALLY-DETERMINED MODULUS VALUES AND DESTRUCTIVELY-MEASURED TENSILE, COMPRESSION, FLEXURE AND SHEAR MODULUS AND STRENGTH VALUES FOR THE 2-D COMPOSITES; (B) RELATE 2- D AND 3-D ULTRASONIC POLAR MODULUS VALUES WITH APREVIOUSLY-DERIVED MICRO-MECHANICS- BASED THEORY FOR GENERATING POLAR MODULUS VALUES; (C) DEMONSTRATE THE FEASIBILITY OF APPLYING A RECENTLY-CONCEIVED 6INTERVAL VELOCITY TECHNIQUE6 TO REINFROCED COMPOSITES; (D) DEMONSTRATE THE CAPABILITY OF A NONDESTRUCTIVE, MULTIPLE-ENERGY, GAMMA- RAY RADIOMETRIC TECHNIQUE FOR PREDICTING MIXTURE CONCENTRATIONS IN BORON/EPOXY COMPOSITES; AND (E) INVESTIGATE THE USE OF WIDTH-AND ACROSS-PLY MEASUREMENTS OF ULTRASONIC VELOCITY FOR PREDICTING THE MECHANICAL MODES OF FAILURE OCCURRING IN COMPOSITE TEST SPECIMENS. (AUTHOR, MODIFIED-PL)

130. NTIAC-14450

COOPER ,T. D. ; HARDY ,G. L. ; FECHEK,F.
NDE OF BORON/EPOXY STRUCTURES AFTER AIRCRAFT SERVICE TESTING (4B1)
5 REFS.; SEE ALSO NT-13951
1976, 06P
AVAILABILITY: PUBLISHED IN EIGHTH WORLD CONF. ON NONDESTR. TEST.; CANNES, FRANCE; 1976

BORON, EPOXY, STRUCTURES, AIRCRAFT, FLIGHT TESTING, RADIOGRAPHY, EDDY CURRENT INSPECTION, THERMAL TESTING, ULTRASONIC TESTING, PENETRANTS, HOLOGRAPHY, OPTICS, ACOUSTIC EMISSIONS, INSERVICE INSPECTION, X RAYS, CORROSION, DEFECTS(MATERIALS), DAMAGE ASSESSMENT, UNBOND, FIBER REINFORCED COMPOSITES

RUDDERS FABRICATED USING BORON/EPOXY SKINS WHICH HAVE BEEN FLOWN ON OPERATIONAL AIRCRAFT HAVE BEEN EVALUATED USING A NUMBER OF NDE METHODS. ULTRASONICS, EDDY CURRENT AND RADIOGRAPHIC METHODS HAVE BEEN SHOWN TO BE EFFECTIVE FOR DETECTING BONDLINE FLAWS AND HONEYCOMB CORE CORROSION. (AUTHOR)

131. NTIAC-8797

HENNEKE,E. G. , II ; HERAKOVICH ,C. T. ; JONES ,G. L. ; RENIERI,M. P.
ACOUSTIC EMISSION FROM COMPOSITE-REINFORCED METALS
JAN 75, 07P
AVAILABILITY: PUBLISHED IN EXP. MECH.; 15, 1; JAN 75; 10-16

*ACOUSTIC EMISSION, *COMPOSITE MATERIALS, ELASTIC WAVES, CRACK PROPAGATION, DEFECTS(MATERIALS), TENSILE STRENGTH, PIEZOELECTRIC TRANSDUCERS, STRESS STRAIN RELATIONS

ACOUSTIC-EMISSION (AE) COUNT RATES ARE PRESENTED FOR TENSILE LOADING OF UNIDIRECTIONAL BORON-EPOXY AND FOR ALUMINUM SHEETS REINFORCED WITH UNIDIRECTIONAL BORON-EPOXY. IT IS SHOWN THAT DIFFERENT PREPREG MATERIALS HAVE DIFFERENT CHARACTERISTIC AE PATTERNS. RESULTS FROM COMPOSITE-REINFORCED METAL SPECIMENS SHOW THAT EARLY FAILURES ARE ACCOMPANIED BY A SHARP INCREASE IN AE COUNT RATE AT THE KNEE OF THE BILINEAR STRESS-STRAIN DIAGRAM. IT IS FURTHER SHOWN THAT THE COUNT RATES ARE A FUNCTION OF SPECIMEN FABRICATION AND THAT HIGHER TOTAL COUNTS DO NOT NECESSARILY CORRESPOND TO EARLY FAILURES.

132. ID NO.- EI741060977 460977
QUALITY CONTROL IN COMPOSITE HARDWARE FABRICATION.
Cook, J. F.; Husman, G. E.
McDonnell Aircr Co. St. Louis, Mo
Compos Mater in Eng Des, Symp, 6th, Proc, Pap, Washington Univ, St. Louis, Mo, May 11-12 1972 p 430-440. Available from ASM, Metals Park, Ohio, 1973
DESCRIPTORS: (*COMPOSITE MATERIALS, *Quality Control), (AIRCRAFT MATERIALS, Nondestructive Testing), (JOINTS, ADHESIVE, Testing), PLASTICS, REINFORCED,
CARD ALERT: 415, 421, 652, 817, 913
Methods of increasing confidence in bonded composite assemblies by upgrading the quality assurance procedures are being studied. Surface electrical resistivity has been identified as a potential quality control tool for titanium cleaning. The capabilities and limitations of presently available nondestructive testing techniques relative to composite empennage hardware have been established. It is shown that surface electrical resistivity exhibits considerable potential as a quality control tool for titanium cleaning prior to adhesive bonding. Defects in boron/epoxy laminates and boron/epoxy-titanium splice joints can be most effectively located by the ultrasonic through transmission reflector plate C-scan test. Radiography is most suitable for inspecting substructure, i. e. , honeycomb core and edge member-to-core bond lines. The ultrasonic through transmission system with a focussed sender and a focussed receiver is the best method of detecting skin-to-honeycomb core unbonds. 1 ref.

133. ID NO.- EI721319058 297056
BROAD RANGE DETECTION OF INCIPIENT FAILURE USING THE ACOUSTIC EMISSION PHENOMENA.
Balderston, H. L.
Boeing Co. Seattle, Wash
ASTM Spec Tech Publ 505, 1972 p 297-317 CODEN: ASTTA8
DESCRIPTORS: (*MATERIALS TESTING, *Nondestructive Testing), (CORROSION, Stress Corrosion Cracking), (MATERIALS, Crack Propagation),
IDENTIFIERS: ACOUSTIC EMISSION
CARD ALERT: 421, 422, 539, 631

The acoustic emission phenomena are employed in the detection of incipient failure in all types of equipment covered in this report. Specifically, the examples chosen are structural, mechanical, pneumatic and hydraulic components, subassemblies, or specimens as applicable. From these examples the broad range incipient failure detection concept based on the acoustic emission phenomena is developed. The experiments covered include detection of incipient failure in bearings, hydraulic assemblies, pneumatic subsystems, stress corrosion in aluminum, ductile tensile failures in carbon steel, 4330M steel, and in boron-epoxy composite material. 7 refs.

134. ID NO.- EI750100915 500915
MEASUREMENT OF THE ELASTIC MODULI OF CONTINUOUS-FILAMENT AND EUTECTIC COMPOSITE MATERIALS.
Sachse. Wolfgang
Cornell Univ. Ithaca. NY
J Compos Mater v 8 n 4 Oct 1974 p 378-390 CODEN: JCOMBI
DESCRIPTORS: (*COMPOSITE MATERIALS. *Elasticity). (MATERIALS TESTING. Nondestructive Testing). (ULTRASONIC WAVES. Transmission).
IDENTIFIERS: ELASTIC MODULI
CARD ALERT: 421. 422. 753
Continuous filaments and eutectic composite materials have been treated as homogeneous and orthotropic and transversely isotropic elastic materials. respectively. in stress analysis problems. Based on these assumptions the elastic moduli of boron-epoxy and Al-Al//3Ni eutectic composite materials are measured using pulse-echo techniques. The shear wave measurements show that the elastic anisotropy assumed for each material is only an approximation. The measurements are also influenced by defects in the fiber arrangement and. in the eutectic composite. by the presence of a solidification substructure. The tangen t modulus c//3//3 is determined from quasi-static compression tests on boron-epoxy specimens whose dimensions were similar to those used for the pulse-echo measurements. 21 refs.

135. ID NO.- EI750422292 522292
MEASUREMENT OF FATIGUE DAMAGE IN COMPOSITE MATERIALS.
Marcus. L. A.: Stinchcomb. W. W.
Va Polytech Inst and State Univ. Blacksburg
Exp Mech v 15 n 2 Feb 1975 p 55-60 CODEN: EXMCAZ
DESCRIPTORS: (*COMPOSITE MATERIALS. *Fatigue). LAMINATED PRODUCTS.
CARD ALERT: 421. 408. 931. 415
Numerical results for the stress state around a circular hole in a boron-epoxy plate under tensile loading are presented. This serves as a model for the initial stress state around the hole during fatigue loading. Comparison is drawn with experimental results for a fatigued specimen obtained from thermography and radiography. Using these results. an interpretation of the effects of the initial stress state on the thermal behavior and on failure initiation is given. This interpretation shows that the circumferential normal stresses are responsible for the initial heat generation and failure initiation in the fatigued specimen. 11 refs.

136. ID NO.- EI72X033840 233840
Acoustic emission studies of boron- epoxy composite
FRITZ-RANDOLPH J: PHILLIPS DC: BEAUMONT PWR: TETELMAN AS
Univ of California. Los Angeles
J Compos Mater v 5 Oct 1971 p 542-52 CODEN: JCOMB
DESCRIPTORS: (*COMPOSITE MATERIALS. *Mechanical Properties). ACOUSTICS.
CARD ALERT: 415. 421. 751. 817. 931
Acoustic emission and stress wave emission are terms used to describe the release of stored acoustic energy from a material when it undergoes plastic deformation. phase transformation. or fracture. This energy is released in discrete pulses characteristic of the process. This note describes how acoustic emission has been correlated with the breaking of fibers during the fracture of a boron- epoxy composite.

137. NTIAC-13658 M

WILLIAMS, R. S.
REAL TIME NONDESTRUCTIVE EVALUATION OF COMPOSITE MATERIALS DURING FATIGUE LOADING
PRESENTED AT ASM, SME, AND ASNT, WESTERN METAL AND TOOL EXPO. AND CONF., LOS ANGELES, CALIF., MAR. 10-13, 1975
1975, 21P
AVAILABILITY: FOR SALE BY TECHNICAL INFORMATION SERVICE, 750 3RD AVE., N. Y. 10017 (A75-31264)

REAL TIME, EVALUATION, COMPOSITE MATERIALS, LOADING, FATIGUE(MECHANICS), EXPERIMENTAL DATA, BORON, EPOXY, ALUMINUM, ACOUSTIC EMISSIONS, DIGITAL SYSTEMS, DATA PROCESSING, CAMERAS, THERMOGRAPHS, CORRELATION, TESTING METHODS, TECHNIQUE

AN NDE SYSTEM THAT EMBODIES THE CONCEPTS OF REAL TIME, STRICTLY PASSIVE NATURE DUE TO THE COMPLEXTY AND DYNAMISM OF THE FATIGUE PROCESS IS DESCRIBED IN DETAIL. VARIOUS EXPERIMENTAL PARAMETERS ARE MONITORED DURING STRAIN-CONTROLLED CYCLIC LOADING OF BORON/EPOXY AND BORON/ALUMINUM COMPOSITES. A GATED ACOUSTIC EMISSION SYSTEM THAT ELIMINATES MOST EXTRANEOUS NOISES IS EMPLOYED. VARIOUS MATERIAL PARAMETERS SUCH AS DAMPING, DYNAMIC COMPLIANCE AND ACOUSTIC EMISSION ARE CONTINUOUSLY MONITORED UTILIZING A DIGITAL DATA ACQUISITION SYSTEM WHICH PROVIDES PROGRAMMABLE CROSS-CORRELATION BETWEEN THESE EXPERIMENTAL MEASUREMENTS. A TIME-RESOLVED VIDEO THERMOGRAPHIC CAMERA IS USED TO PROVIDE A MAP OF THE SURFACE TEMPERATURE DISTRIBUTION DUE TO LOCALIZED THERMAL EMISSIONS CAUSED BY CYCLIC LOADING. CORRELATIONS BETWEEN BOTH STRUCTURAL AND LOCAL DAMAGE AND RESULTING ACOUSTIC EMISSION AND INFRARED HEAT PATTERNS ARE ESTABLISHED. THE GROUNDWORK FOR RESEARCH LEADING TO THE DEVELOPMENT OF TESTING AND INSPECTION TECHNIQUES IS DISCUSSED. (AUTHOR)

138. Non-Destructive Testing and Inspection Applied to Composite Materials and Structures

Advisory Group for Aerospace Research and Development Paris (France) (400043)
AUTHOR: Owston, C. N.; Jaffe, E. H.
A4105H4 Fld: 11D, 11I, 71F, 73B GRA17210
Feb 72 35p
Rept No: AGARD-R-590
Presented at the AGARD Structures and Materials Panel Meeting (32nd), London, 31 Mar 71. NATO furnished.

Abstract: The two contributions contained in the report deal with non-destructive testing applied to specimens and structural parts made of composite materials. In the first paper, some aspects of various inspection methods such as ultrasonics, radiography, eddy current and acoustic emission techniques applied to carbon fibre composites are described in connection with a discussion of possible failure mechanisms, especially in fatigue. The second paper shows the possibilities and limitations of NDI applied to the quality control of a primary structural part made of boron composite. (Author)

Descriptors: (*Composite materials, *Non-destructive testing), (*Reinforced plastics, Non-destructive testing), Airframes, Carbon fibers, Boron, Quality control, Ultrasonic radiation, Radiography

Identifiers: *Fiber composites, *Carbon fiber reinforced plastics, Eddy current tests, Ultrasonic tests

AD-739 780 NTIS Prices: PC A03/MF A01

139. ID NO.- EI71X053681 153681
Practical problems related to the thermal infrared nondestructive testing of a bonded structure
SNEERINGER JW; HACKE KP; ROEHRS RJ
McDonnell Aircraft Co, St Louis, Mo
Mater Eval v 29 n 4 Apr 1971 p 88-92 CODEN: MAEVA
DESCRIPTORS: (*ALUMINUM AND ALLOYS, *Fiber Reinforced), METALS TESTING, Nondestructive), (INFRARED, Devices), AIRCRAFT MANUFACTURE, Bonding),
CARD ALERT: 421, 422, 541, 652
A number of practical problems encountered in the evaluation of a bonded structure, such as, boron composite/aluminum honeycomb sandwich. Included in this discussion are surface effects, such as, emittance and reflectance; internal structural effects, such as, changing cross section in the product, and the effects of instrumentation sensitivity. Images of boron composite/aluminum honeycomb sandwich are presented and discussed to illustrate the problems in evaluating the results. 7 refs.

140. ID NO.- EI761282079 682079
ACOUSTIC IMAGING TECHNIQUES FOR NONDESTRUCTIVE TESTING.-
Waugh, Thomas M.; Kino, Gordon S.; DeSilets, Charles S.;

Fraser, John D.
Stanford Univ, Calif
IEEE Trans Sonics Ultrason v SU SEM DASHS 23 n 5 Sep 1976 p 313-317 CODEN: IESUAU
DESCRIPTORS: (*MATERIALS TESTING, *Nondestructive Testing).
CARD ALERT: 423, 753
A new type of electronically scanned imaging device for nondestructive testing is described. This device uses a 32-element piezoelectric transducer array which can be scanned and focused to give real time images. The scan rates for this system are m**2/min versus m**2/hr for conventional systems. The device has been operated at 2. 5 MHz in both B-scan and transmission modes. This system, when operating in the B-scan mode, gives range and transverse definition of order 2 mm in a field 8 cm wide and 30 cm normal to the array. Images taken with this system of boron fiber reinforced epoxy laminate samples, cylindrical holes in metal-imaged-with shear waves, and quasi three-dimensional images taken with a B-scan system mechanically scanned in the third dimension will be presented. 3 refs.

141. ID NO.- EI71X182633 182633
Ultrasonic inspection of a boron/epoxy- aluminum composite panel
MOOL D; STEPHENSON R
Boeing Co, Seattle, Wash
Mater Eval v 29 n 7 July 1971 p 159-64 CODEN: MAEVA
DESCRIPTORS: (*AIRCRAFT MATERIALS, *Composite Materials), (MATERIALS TESTING, Nondestructive), (ULTRASONICS, Measurement)
CARD ALERT: 415, 421, 422, 652, 751
This investigation was undertaken to determine the inspectability of a boron/epoxy- aluminum panel: the panel consisted of a ten- ply unidirectional boron/epoxy laminate adhesively bonded to aluminum face sheets. The ability of through- transmitted ultrasound to detect and identify defects introduced into a test panel was assessed. 5 refs.

142. EVALUATION OF NONDESTRUCTIVE METHODS OF TESTING GRAPHITE-EPOXY LAMINA

Yee, B.G.W.
Russell, D.R.
Arnett, J.B.
Swint, J.B.
Pickering, J.T.
Ashton, J.H.

Applied Research Laboratory
General Dynamics, Fort Worth Division

August 1970

143. IMMINENT FRACTURE DETECTION IN GRAPHITE/EPOXY USING ACOUSTIC EMISSION

Carlyle, John M.

Experimental Mechanics, May 1978, pp. 191 - 195

An experiment designed to detect incipient failure in graphite/epoxy tensile specimens is described. Tests using eighteen samples of six different graphite/epoxy compositions in six-ply balanced $[0/+45/-45]_s$ laminates indicate that a failure precursor does exist. This precursor takes the form of a sudden reduction in the acoustic-emission output at 99 percent of the ultimate tensile load, and evidence indicates that the reduction is the result of a change in the fundamental failure mechanism. The shape of the acoustic-emission count-rate curve is analyzed and found to correlate well with micro-mechanical fracture activity.

AD-A071 973 SOUTHWEST RESEARCH INST SAN ANTONIO TEX F/G 11/4
NONDESTRUCTIVE EVALUATION OF FIBER REINFORCED EPOXY COMPOSITES:--ETC(U)
APR 79 G A MATZKANIN, G L BURKHARDT DLA900-77-C-3733
UNCLASSIFIED SWRI-15-4823-510 USAAVRADCOM-TR-79-24 NL

3 OF 3
AD A071973

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144. **AN ANALYSIS OF RADIOGRAPHIC TECHNIQUES FOR MEASURING RESIN CONTENT IN GRAPHITE FIBER REINFORCED EPOXY RESIN COMPOSITES**

Martin, B.G.

Materials Evaluation, September 1977

An analysis was made of radiographic techniques for measuring the resin content (weight percent) in graphite fiber reinforced epoxy resin composites. Low energy X-ray and thermal neutron mass absorption coefficients were calculated as a function of composite resin content. Some measurements of X-ray mass absorption coefficients were made for comparison. In addition, neutron radiographic film densities were measured and calculated as a function of resin content. It was concluded that a thermal neutron gauging technique shows promise for measuring composite resin content to within ±1 weight percent.

145. **EDDY CURRENT METHODS FOR THE EXAMINATION OF CARBON FIBRE REINFORCED EPOXY RESINS**

Owston, C.N.

Materials Evaluation, November 1976

The unusual phenomena associated with electrical conduction in non-conducting matrices reinforced with conducting fibres are described and a theory linking fibre volume fraction with the measured electrical properties is derived. The practical details of applying eddy current techniques of nondestructive examination to carbon fibre reinforced polymers are discussed and the results of tests for fibre volume fraction, fibre orientation and cracks in the composite are given.

146. DEVELOPMENT AND APPLICATION OF NONDESTRUCTIVE METHODS FOR PREDICTING MECHANICAL PROPERTIES OF ADVANCED REINFORCED NONMETALLIC COMPOSITES

Schultz, A.W.
AVCO Government Products Group, Systems Division
Air Force Systems Command, Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio

AFML-TR-71-168
June 1, 1970 - April 30, 1971

147. HELICOPTER RELIABILITY TESTING

House, Thomas L.

J. Am. Hel. Soc., Vol. 20, No. 4, pp. 32-41
October 1975

148. FATIGUE PROPERTIES AND TEST PROCEDURES OF GLASS REINFORCED PLASTIC ROTOR BLADES

Jarosch, E.
Stepan, A.

J. Am. Hel. Soc., Vol. 15, No. 1, pp. 33-41.
January 1970

149. A FEASIBILITY STUDY FOR MONITORING SYSTEMS OF FATIGUE DAMAGE TO HELICOPTER COMPONENTS

Johnson, R.B.
Martin, G.L.
Moran, M.S.

Final Report, January 1975
Report No. USAAMRDL-TR-74-92
Contract No. DAAJ02-73-C-0053
ADA006641

150. NON-DESTRUCTIVE INSPECTION OF COMPOSITE MATERIALS FOR AIRCRAFT STRUCTURAL APPLICATIONS

Stone, D.E.W.

AGARD Conference Proceedings No. 234
Non-Destructive Inspection Relationships to Aircraft Design and Materials

Presented at the 45th Meeting of the AGARD Structures and Materials Panel,
Voss, Norway
September 27-28, 1977

151. SOME INSPECTION PROBLEMS OF COMPOSITE MATERIALS

Lovelace, Alan M.
Tsai, Stephen W.

International Journal of Nondestructive Testing, Vol. 2, pp. 355-362 (1971)

Composite materials present special problems in inspection procedures. Concerted effort covering both the fundamental principles and field applications must be further accelerated if composite materials are to become engineering materials. Some of the problems associated with this maturing process are closely tied to the lack of positive inspection techniques. In this paper, the nature of composites and how they are assembled are reviewed from the standpoint of inspection. The advantages and disadvantages of composites from this standpoint will be compared with ordinary metals. Possible solutions of inspection problems will be cited.

152. BIBLIOGRAPHY ON FIBERS AND COMPOSITE MATERIALS - 1969-1972

Fleck, J.N.

July 1972
MCIC-72-09
F33615-71-C-1067