NDT of COMPOSITES

Seattle, WA, USA • 13–14 May 2013 • Red Lion Hotel

PROGRAM ABSTRACTS

THE AMERICAN SOCIETY FOR NONDESTRUCTIVE TESTING

NDT of Composites
May 13-14, 2013
Red Lion Hotel on 5th Ave.
Seattle, WA, USA

Conference Abstracts
In an effort to keep attendee costs down and to minimize waste, ASNT is going green. Therefore abstracts will not be distributed at this conference.

Abstracts are published as submitted and placed in the order they will be presented at the conference. Some abstracts may not be available.

PROGRAM

Monday May 13, 2013

8:00am
Nondestructive Testing of Fiber Reinforced Composites

Fiber reinforced plastic (FRP) composite materials have migrated over the past several decades into numerous commercial products and high performance industrial applications. Manufacturing techniques are being pushed to keep pace with the required rate of production for these applications. The aerospace industrial sector and in particular commercial aviation has been at the forefront of the development of FRP materials and especially carbon fiber reinforced plastic (CFRP) for the tailored stiffness and high strength to weight ratio that CFRP provides for efficient flight. The Boeing 787 represents one of the most dramatic stories in the development of composite structure design and manufacturing.

Within the continuous quest for efficient structural design and high throughput manufacturing is the requirement for product safety that is assured by proper nondestructive testing and evaluation (NDT/E). NDT/E methods provide the needed vision into the final product form to confirm that the manufacturing process is in control and that the product can perform its mission as-designed. Today NDT/E is challenged to cost-effectively find any critical size features within the highly complex CFRP geometries and return quantitative numbers on the fitness for service both at the time of manufacture and later in-service. As production rates and applications continue to increase the demand for innovative, fast, sensitive and reliable inspection methods and systems will grow as well.

Diane Chong
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9:00am
Ultrasonic Inspection of Composites 101

This paper is a basic introduction to the various inspection methods used on solid composites. The intended audience is for those who have a working knowledge of Ultrasonic inspection, but do not have practical knowledge of composites inspection.

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9:30am

Improving NDI Productivity for Highly-Contoured Composite Parts via Standardized Robotic Platforms

As the prevalence of composite materials in manufacturing increases, innovative methods of performing Non-Destructive Inspection (NDI) of components will need to be developed to keep pace with demand. Increased production requirements and complexity of designs have created a need for trained technicians to interpret increased amounts of test data. ASNT Level 2 & 3 Technicians are in high demand. This paper will compare existing inspection methods with a unique approach to automated NDI that involves integrating commercially available ultrasonic equipment and modern industrial robots. Combining multiple inspection process capabilities into a common pre-engineered standard design that is intended for use on complex surface profiles, enables manufacturers to meet the challenges of more productive low cost inspection processes and improving the productivity of highly trained test technicians.

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10:15am

Integration of Robotics and Surface-Adaptive Phased-Array UT to Achieve Fully Automated Inspection of Complex Composite Parts

Achieving high-speed inspection rates for complex composite parts requires versatile and integrated systems that meet the challenges of automated part handling and NDT for ship sets that can include hundreds of different parts. Cost-effective integrated solutions are presented that are being successfully used to inspect composite parts for fully automated aerospace applications. The most appropriate solution for a given ship set depends on factors that include detection and sizing requirements, the range of sizes and geometries of the parts, the required inspection speed and cost constraints. The challenges of optimizing different technologies and integrating them into a single system are described for a recently implemented industrial solution. Lessons learned from the project are presented both in terms of technology integration and implementation of a new ultrasonic software algorithm. Surface-Adaptive Ultrasound (SAUL) is a very recent advancement in phased-array technology that is being used to overcome inspection challenges that include highly contoured surfaces; parts with small radii such as those often found on blades and stiffeners; rough and irregular surfaces including regions of ply dropoff and lap joints; and parts with varying shape, curvature, and thickness with length. Although vision systems and robots can be used to achieve highly accurate part following, the part-to-part variability that is typically encountered with composites creates problems for automated part and probe positioning, as well as accurate part tracking. This paper demonstrates the performance of a cost-effective inspection solution for complex geometry composites in a high-volume production environment achieved by combining advanced UT technology with industrial robotics and vision technologies.

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10:45am

Portable Ultrasonic Device for NDE of Laminated Composites

In this paper we present a new portable high resolution ultrasonic device designed for imaging and quality examination in laminated structures in composites and their structures. This device features a miniaturized 5 MHz phased array probe with built-in non-contact positioning sensors, and originally developed multi-channel electronics providing visual feedback to an operator. Using proprietary developed advanced imaging algorithms by Tessonics several image strips can be stitched together in real time to facilitate imaging on large samples.

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11:15am

MAUS® V C-Scan Inspection Approaches for Complex Composite Parts

As the use of composite materials in aerospace and space vehicles increases design engineers are taking full advantage of the pliable nature of these materials. With ever increasingly complex shapes and geometries it has become more difficult to inspect these components. With the advent of the Boeing 787 and the Airbus A350 the number of parts designed as complex shapes but also large quantities of parts per ship set. A multi-array approach with individual ultrasonic arrays used to cover each surface of the part is an effective inspection approach. Data collected from the individual arrays is used to build a C-scan map of the full part. Data analysis is performed on the reconstructed data allowing the characterization of defects that extend across multiple part surfaces. This paper discusses concerns presented in the inspection of complex composite parts, describes the multiple array inspection approach and presents several inspection implementations using the MAUS V automated inspection system.

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1:15pm

Probe Tip Tuning Resonates with Composites to Revolutionize Pitch-Catch and Pulse-Echo Technology

Properly tuned probe tips together with a resonant pulse frequency in the material being tested results in deep signal penetration. Because of the resonant frequency and tuned probe tips, input voltages may be reduced substantially without any noticeable loss of penetration. A compounding benefit is a significant reduction in signal to noise ratio. The reduced voltage results in a reduction in voltage induced transducer noise and scrubbing noise. The result is easily detected near-side and far-side dis-bonds and flaws in composites using pitch-catch and pulse-echo technology. This level of detection in composites was previously restricted to resonant probe technology requiring couplant. The resonant tuned probe tip allows for less tedious and invasive testing of composites with equal to or superior results.

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1:45pm

Laser-ultrasonic Inspection of Honeycomb Sandwich Structures

Laser-ultrasonics is an inspection technique that uses lasers to generate and detect ultrasonic waves and is particularly well suited for laminated polymer-matrix composite materials. The results are similar to conventional pulse-echo ultrasonic methods using piezoelectric transducers. The main advantage of laser-ultrasonics is the ability to rapidly inspect complex parts without the constraint of precisely following the surface contour as is the case for conventional ultrasonic methods. High quality signals can be maintained with the laser-based approach at incidence angles up to 45º and within a distance range extending over one foot from the nominal position. This flexibility can improve the inspection throughput by an order of magnitude for composite parts having complex shapes. Although this advantage of laser-ultrasonics for inspecting complex composite parts is well established, another less well known benefit is the large frequency bandwidth of the generated ultrasonic waves. This bandwidth extends from DC to ten's of MHz. Typically, frequencies below 1 MHz are discarded by analog filtering in combination with the response of the systems used to capture and analyze the A-scans. These analog and digital processing methods are comparable to techniques applied to conventional ultrasonic signals and the resulting A-scans therefore appear very similar. However, the low frequency component of the laser-ultrasonic signal, down to 10 kHz, can be exploited to inspect honeycomb sandwich structures. This new approach can detect defects inserted at various depths of honeycomb structures from a single-side inspection by using a reference frequency technique. The reference frequency corresponds to the thickness resonance of a defect-free honeycomb sandwich structure. Signals deviating from this reference frequency indicate the presence of defects and in some cases their depths. This presentation will introduce the technique along with experimental results. Using this new capability, a single laser-ultrasonic system can simultaneously inspect structures containing both solid-laminates and honeycomb sandwich features.

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2:15pm
LaserUT - Production Process Integration

While providing the same fundamental information as a conventional ultrasonics system for composite material inspection, Laser Ultrasonics is still a new technology to most NDI professionals. Its integration with standard production processes provides unique capabilities while presenting a few challenges along the way. After providing a brief overview of how lasers are used to generate and detect ultrasound, this presentation draws on the implementation experience of three different LaserUT® system users to offer a unique perspective on the technology.

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2:45pm
Ultrasound Phased Array Technique for Composite Material Evaluation

Unlike a conventional ultrasound single element transducer, an ultrasound phased array sensor can control and focus acoustic energy to the desired directions and locations. This heightened flexibility and sensitivity is essential for given complex shape of modern composite structures. Despite such promise, understanding and application of ultrasound phased array technique is still challenging due to the anisotropic nature of composite materials, as well as its high acoustic attenuation.
The objective of this paper is to study various NDT techniques for the quantitative evaluation of composite materials, with an emphasis on ultrasound phased array technique. First, mechanical tensile and bending tests were carried out on both carbon fiber and glass fiber composite materials for the material property evaluation. Then X-ray imaging and ultrasound C-scan were applied for the quantitative inspection of various defects in the samples. Finally ultrasound phased array technique was theoretically studied and experimentally applied, the parameters such as ultrasound beam angle and focusing, frequency and material attenuation factors were quantitatively analyzed for the optimization of inspection procedure. The results of ultrasound phased array were compared to other techniques and its limitation was discussed.

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3:30pm

Long Range Ultrasonic Guided Waves in Composite Structures

Composite aerospace structures are becoming larger and more complex. Assessing structural integrity requires independently mechanical integrity assurance of the components. Long range guided wave ultrasonic methods are very effective for the testing of such composite materials structures. This paper will present recent work to assess structural integrity of the directional composite structural elements. Development of new ultrasonic transduction process combined with the advanced data acquisition enables measurements of the composite mechanical defect conditions that are not possible using conventional ultrasonic test approaches. With directional analysis of ultrasonic wave propagation and acoustic wave response in the complex geometry, one can sense and understand mechanical defect conditions. The measurements, using the multi path guide ultrasonic waves, will address corners, joints, hat sections, thickness changes and Pi joints.

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4:00pm

NDE and Damage Prognosis of Composite Wind Turbine Blades

Wind turbine blades made of composite materials have some inherent defects which occur during the manufacturing. There can be many defects in the blade but we will focus on three types of defects: Fiber waviness (Marcel), dry fabric, and uneven adhesive thickness. Structural health monitoring will be performed for the fiber waviness since of the three defects listed above this is most prone to growth. A marcel in itself is not the cause of failure but it nucleates the damage which can eventually cause the ultimate failure of the blade. The objective of this work is to quantify the waviness and monitor the critical marcels using a health monitoring system.

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4:30pm

Shear Horizontal Guided Waves in Laminated Composite Plates Using SH-PWAS

This study presents a comparison between experimental results and predictive model developed for shear horizontal (SH) guided waves excited with shear type piezoelectric wafer active sensor (SH-PWAS). Shear horizontal waves are one type of guided waves like Lamb waves but polarized in horizontal direction, SH wave is preferred in nondestructive evaluation (NDE) because the first SH mode is non-dispersive. SH waves have the advantage of inferring the shear stiffness of adhesive layers in bonded structures; which make it superior in testing multilayered fiber reinforced polymer composites.

The paper starts with a review of the state of the art of excitation SH waves in structures and the use of conventional magnetostrictive transducers. It follows with presenting the piezoelectric wafer active sensor that is polarized in shear horizontal direction. Compared to conventional ultrasonic transducers; piezoelectric transducers are much lighter, inexpensive, they can be used as passive transducers (sensors) andor active (actuators), and they are good candidates for embedded sensors in structures with the limitation of structure integrity considerations. Then, the electro-mechanical impedance of the SH-PWAS transducer is experimentally studied on glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) plates and compared with our predictive models. Pitch-catch experiments are done on aluminum plates to show the non-dispersive nature of SH guided waves, then, experiments are carried on GFRP and CFRP plates. The paper discusses the tuning of the SH-PWAS to excite the structure with optimum frequency to obtain the required mode. Multiphysics finite element modeling on the laminated composites plates is presented. The paper ends with summary, conclusion and suggestion of future work.

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Tuesday May 14, 2013
8:00am
Ultrasonic Inspection of Primary Structure Composite Repairs

With the expanding use of advanced composites as primary aircraft structure the ability to repair this structure is vital to the manufacture and maintenance of these new aircraft. Assuring the quality of these repairs is a crucial step in the repair process.
NDI inspection of composite repairs requires specialized equipment and procedures to find the defects unique to repairs. This presentation will highlight the differences between the NDI inspection procedures required for composite repairs and composite parts fabrication. The presentation will also show the different repair types, defects common to these repairs and how to differentiate between the various flaws.

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8:30am

Acoustic Microscopy Characterization of Composite Adhesive Joints Interfaces

The properties and parameters of adhesive joints are critical for the mechanical performance of complex composite structures used in a wide variety of practical applications. The integrity of the adhesive bonding depends on both cohesive properties of the adhesive material and interfacial interaction between the adhesive and substrate. The interface of the adhesive joint is a complex structure that consists of many micro layers (oxides, primers, adhesive interphase and so on). Reliable inspection of the interfacial region is very important since most failures occur there.

During our research we investigated the quality of the fiber reinforced composite adhesive bonding using acoustic microscopy in a frequency range of 0.5–25 MHz and developed a method for 3D reconstruction of defects both at bonding interfaces and in the bulk of adhesive and composites. High resolution allows us to visualize and monitor the development of micro defects caused by joint deterioration due to water absorption and the aging process. The correlation between microstructure, mechanical properties and acoustic parameters of such adhesive joints was studied and characterized. Both fundamental and applied problems of micro-mechanical properties of the adhesive bond's microstructure were investigated by acoustic microscopy and several other ultrasonic techniques; the obtained data was then compared with the results of traditional light and electron microscopy, X-ray inspection and mechanical tests. The high reliability of ultrasonic inspection methodology was proved by extensive theoretical and experimental research.

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9:00am
Bond Testing and NDTE Technology

This presentation will cover bond testing history and recent NDTE material inspection advancements, Overview of Composites and Bond Types, What are Composites, Materials for Composite Structures, Defects found in Composite Structures and Understanding Bond Testing Technology.

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9:45am
Damage Assessment of Advanced Automotive Composites

As the complexities of composite designs advance so must the ability to inspect these new designs. We will look at the applications and limitations of bond testing and Phased Array Ultrasonic testing.

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10:15am

Quantitative Thermography of Composites Using Temporally Extended Excitation

Application of the Thermographic Signal Reconstruction (TSR) method to each pixel time history in an IR image sequence has been demonstrated to have significant performance advantages over direct viewing of contrast in the IR images by an operator. The logarithmic derivatives obtained by TSR can be used to determine laminate thickness, thermal diffusivity or porosity, as well as flaw depth and composition. Interpretation is based on an instantaneous pulse excitation. However, in many composite applications, pulse excitation may not be appropriate, and sources with longer duration may be preferred. Such sources can be accommodated by adjustment of the TSR algorithm. With appropriate modification, measurement precision and accuracy comparable to pulse results are possible, with the added benefit of higher signal to noise using the longer duration sources. The associated tradeoffs and benefits of pulse vs. extended source excitation will be discussed.

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10:45am

Advances in Thermal Imaging for NDT at General Electric

The Thermographic NDT team at GE has been applying “Large Scale Infrared” methods for the inspection of giant structural composite components. A typical imaging process might cover a complex shaped area 5 ft. x5 ft. in 1 minute including image acquisition and analysis. The single image displayed to the operator is interpreted much like an ultrasonic time-of-flight image and displays flaws present at all depths. We will present an example of a 10-foot Boeing perforated skin nacelle acoustic structure. This item is normally hand-inspected by ultrasound over an 8-hour period. An IR Inspection takes less than ½ hour - mostly handling.

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1:30pm
Composite NDT with Shearography Methods

Shearography NDT has gained wide acceptance for lower cost, high thru put inspection of composites in a wide range of industries including aerospace, marine automotive, and wind energy. Shearography NDT methods are highly capable for the inspection of both solid laminates, honeycomb and foam cored structures. The drive towards lighter weight and lower cost composite aircraft structure has greatly increased the need for innovative NDT technologies with ultra high throughput, non-wetting inspection and real-time data interpretation. LTI shearography systems have been developed and implemented for over 300 aerospace applications. This paper provides a background knowledge of shearography NDT and technical and economic case studies showing important applications of shearography NDT of aerospace, maine and wind energy structures.

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2:00pm
Assessment of Composite Honeycomb Material Using Computed Tomography Techniques

Advanced Computed Tomography (CT) inspection is being utilized at Sandia National Laboratories to verify the integrity of composite honeycomb materials as well as document the location of simulated defects within the material. This advanced inspection method can evaluate ply layers and adhesive interfaces after post computer processing has been performed. Computed tomography (CT) is the optimal technique used to detect cell wall crushing within honeycomb structure and document the size of manufacturing defects. This method can also evaluate each layer of the honeycomb material and determine if disbonds in the adhesive layer have been successfully produced. The detection and analysis techniques used to identify Teflon inserts, epoxy core potting and damage in honeycomb materials will be presented. A review of current equipment capabilities, reference standard development and deployment challenges encountered while scanning the composite honeycomb material will also be discussed.

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2:30pm
In Line CT Inspection of Wind Spar Caps
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No Abstract Available

3:15pm
Textural Analyses and Defectoscopy of CFRP and Preforms by Eddy Current Imaging

By non-contact measuring the electrical properties of carbon fiber distribution and the dielectric properties of the polymer, carbon based materials can be inspected nondestructively. Based on the high-frequency Eddy Current system EddyCus®, structural and hidden defects such as missing carbon fiber bundles, lanes, fringes and angle errors also for hidden layers can be detected. Carbon fiber based materials show a low electrical conductivity, which is sufficient enough to measure deviations in the material by using Eddy Current techniques. To acquire information for process control or quality assurance, the method needs to be robust, nondestructive and economically reasonable priced. Eddy Current methods show a high potential for inline integration due to the absence of couplings e.g. compared to ultrasonic.

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3:45pm

An Eddy-Current Model for Three-Dimensional Nondestructive Evaluation of Advanced Composites

We have developed a rigorous electromagnetic model and an inversion algorithm that are suitable for the three-dimensional quantitative nondestructive evaluation (NDE) of advanced composite materials by using eddy-currents. The approach is based upon Victor Technologies' work in eddy-current NDE of conventional metals. The technical objectives of our research are to determine the feasibility of determining in localized regions the fiber-resin ratio in graphite-epoxy, and to determine more precisely the types of anomalies, whether flaws, delaminations, broken fibers, etc., that can be reconstructed by our inversion method. These objectives are met by: (1) applying rigorous electromagnetic theory to determine a Green's function for a slab of anisotropic composite material, (2) determining the integral relations for the direct and inverse problems using the Green's function just derived, (3) determining suitable numerical algorithms for solving the inverse problem, and (4) writing a computer program to execute the model. We will describe progress in meeting these objectives, as well as validating the model experimentally.

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4:15pm

Electromagnetic Nondestructive Evaluation for Degradation Assessment in Bismaleimide Glass-Fiber Composites

Nondestructive evaluation (NDE) of polymer-matrix structural composites containing fiber reinforcement is presently conducted most commonly using ultrasonic testing, which is well-suited for detection of damage such as delamination and disbonding that arises due to impact. Physical impact, however, is not the only mechanism by which the structural integrity of these composites may be compromised. Environmental degradation, such as may occur due to exposure to excessive heat or ultra-violet (UV) radiation, has been shown to weaken the mechanical properties of many polymers that are used as matrix materials in aerospace composites. The effects of environmental degradation are not readily detected using ultrasonic NDE but often lead to significant changes in the dielectric properties of the polymer matrix, as well as to the mechanical properties. The fact that polymer dielectric and mechanical properties are related raises the possibility of detecting and quantifying loss of mechanical performance indirectly, by using electromagnetic (EM) testing methods to characterize the dielectric properties of the composite. In this paper, the relationship between the dielectric and mechanical properties of thermally-aged bismaleimideglass-fiber structural composites will be presented. Further, the feasibility of capacitive NDE of these composites will be assessed.

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Alternate Presentations
The program schedule is subject to change. In the event of a last minute speaker cancellation or no show, these titles and presentations may be substituted:

Comparative Study of Acoustic and Thermographic Imaging Methods for the Structural Analysis of Composite Materials

Quality control for composite materials involves a number of techniques ranging from bare X- and terahertz radiography to more sophisticated computational techniques directed towards the quantitative estimation of such parameters as mechanical characteristics of a composite structure as well as adhesion of layers, size of cracks, etc.

The work presented outlines the findings in a comparative study of the two methods used for the analysis of carbon-fiber reinforced composites, namely acoustic imaging and thermographic imaging. It was found that though acoustic imaging is capable of producing superior quality high-resolution images, thermography allows for a fast analysis of large size parts and their internal defects and structure.

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NDE of Composites Using Acoustography

This paper will report on recent advancements that have been made toward implementing Acoustography for improving the inspection speed of composite components and structures. Acoustography produces X-ray like, full-field ultrasound images almost instantly, which makes it suitable to meet the growing need for rapid inspection of composite aerospace components and larger elaborate structures, such as hybrid lightweight armor. Successful implementation of this ultrasound inspection approach could provide a fast ultrasonic inspection method, especially for small, complex-geometry aerospace components that can be challenging and time-consuming. We will report progress being made on developing a large field of view (6”x6” to 12”x12”) Acoustography Inspection System for inspecting complex-geometry parts rapidly. Results on a number of candidate parts inspected using Acoustography and standard C-scan will be reported to demonstrate the efficacy and efficiency of Acoustography. In addition, the inspection of a hybrid composite lightweight armor panel with a ceramic core will be presented.

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Evaluating the Detection Sensitivity of Acoustography using a Calibration Standard

The Acoustography method for ultrasonic inspection produces X-ray like, full-field ultrasound images almost instantly, which makes it suitable to meet the growing need for rapid inspection of composite components including complex-geometry components. However, it can only be useful if its detection sensitivity is comparable to the traditional ultrasound method employed for composite inspection. The purpose of this paper is to use a calibration standard with know defect sizes and types to establish the true detection sensitivity of Acoustography. A side-by-side comparison of Acoustography inspection data and that obtained using traditional through-transmission ultrasound will be presented.

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Damage Detection for Aerospace Composites Using Matrix Resins Functionalized with Fluorescent Probe Molecules

Damage detection in aerospace composite parts is difficult because of their opacity and inhomogeneity. Low energy impact damage is especially troublesome because it often leaves no visible surface damage but can cause significant subsurface damage. Ultrasonic C-Scan can detect this damage but requires significant airplane downtime to conduct. This research proposes a method of damage detection based on fluorescent molecular probes with mechanochromic properties. Several molecules were designed and synthesized to be compatible with aerospace matrix resin and coating chemistry, and to exhibit fluorescent behavior that is dependent on local deformation and damage conditions. In a RT cured DGEBA-DETA solid resin, one probe showed strong fluorescent emission color change when samples were compressed. A linear relationship was observed between this change and the strain in the bulk sample. The probe displayed sensitivity to other environmental conditions including temperature and amine-epoxide ratio. The color change of the probe after deformation was not permanent over long periods of time. Probe molecules which are less sensitive to time after deformation and environmental conditions are presently being analyzed.

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Pulse-echo Ultrasonic Testing of Laminated Structures with Significant Acoustic Impedance Mismatch of Layers

The ultrasonic testing of laminated structures such as adhesive bonds in sheet-metal assemblies is a challenging problem due to the large acoustic impedance mismatch between metal and adhesive, as well as the variability in the thickness of metal and adhesive layers. Several ultrasonic techniques have been developed to evaluate adhesive joints, including time and spectral domain methods. Some of these techniques are fundamentally incapable of achieving the lateral resolution needed for the detection of small defects. Others, while achieving high lateral resolution through the use of focused ultrasound waves, suffer from low contrast between sound and defective areas.
To visualize the “adhesiveno adhesive” boundary we proposed the use of a matrix array of small ultrasonic transducers. The reverberating waveforms recorded by the array elements are processed to obtain an informative parameter whose two-dimensional distribution can be presented as a C-scan. Energy of the reflected waveform, normalized with respect to the energy obtained from an area with no adhesive, is a robust parameter for discriminating “adhesiveno-adhesive” regions. Disbonds at the rear adhesive-metal interface cause phase inversion of the reflected response which can estimated by reference waveform subtraction. The proposed techniques have been tested on a set of steel and aluminum samples with varying thickness of the adhesive layer.

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Composite Crew Module Leakage Characterization

NASA's Engineering and Safety Center's Composite Crew Module (CCM)was a rapid prototype program, designed to give cradle-to-grave experience in designing, building, and testing a complex composite structure. From the CCM development program, leakage was identified as one of the primary risk factors that made composites less attractive for a habitable structure than their metallic counterparts. This is because the structure can leak substantially, after impacts at low energy, which could go undetected. Developmental tests were performed to characterize the leak rate through the composite shell system of the CCM in its manufactured state and after post manufacture polymeric liner application. The testing utilized the CCM and composite material coupons. Full-scale CCM leakage tests followed a similar methodology used for qualifying International Space Station (ISS) pressurized elements. Specifically, the CCM was placed in a vacuum chamber and subjected to a pressure differential of approximately one atmosphere with a known helium concentration and the total leak rate was measured with a helium mass spectrometer.

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