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14th International Symposium on Nondestructive Characterization of Materials
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The NASA Engineering and Safety Center was charted in the wake of the Space Shuttle Columbia accident to serve as an Agency-wide technical resource focused on engineering excellence. The objective of the NESC is to improve safety by performing in-depth independent engineering assessments, testing, and analysis to uncover technical vulnerabilities and to determine appropriate preventative and corrective actions. Critical to the NESC are teams of experts in a number of core disciplines including nondestructive evaluation (NDE). These teams, designated Technical Discipline Teams (TDTs), draw upon the best engineering expertise from across NASA and also include partnerships with other government agencies, national laboratories, universities and industry. An overview of the NESC NDE TDT will be presented along with a review how the TDT has helped to resolve safety critical inspection concerns for the Space Shuttle, International Space Station (ISS), and a variety of launch vehicles and unmanned spacecraft.

Keywords: Structural Health Monitoring, aerospace, NDT-wide,
Solid woven carbon fiber reinforced plastic (CFRP) consists of more than one material constituent. At the macroscopic level, each material is distinguishable and can be characterized by several destructive tests. Computed Tomography (CT) inspection is being deployed to verify the integrity of the composite material structure and analyze the bonding mechanism. Composites also contain voids and micro-cracks within the fiber and polymeric binder. The wide range of materials, processing and configurations used in composite fabrication are in constant need of new inspection methods. This paper describes the techniques used to evaluate ply layers and adhesive interfaces after performing CT inspection coupled with computer processing. A review of current equipment capabilities and deployment challenges encountered while scanning composite materials will also be discussed. Finally, a summary of the detection and analysis techniques developed to identify: bonding materials, lack of bonding at the laminate-to-laminate interface, porosity levels within a solid laminate and polymer starvation are presented. This paper is declared a work of the U.S. Government and is not subject to copyright protection in the United States. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

**Keywords:** Composites,
be due to the presence of soluble sizing being used. The investigated samples showed a substantial difference in signal yield, signal-deca,y, with $T2^*$ values clearly depending on moisture content. Based on these results further research is ongoing in order to assess progress and direction of water uptake depending on fiber-sizing, fiber-content and orientation.

Keywords: Composites, aerospace, Other Methods, NDT-wide, gfrp, epoxy, mri, moisture

10:15 - 10:40

5 NDC of Resins, Carbon Fiber Fabrics, Preforms and Consolidated CFRPs by HF Radio Wave Techniques

Henning HEUER $^1$, Martin SCHULZE $^1$, Matthias POOCH $^1$, Simone GÄBLER $^2$

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Eddy current testing is well established for non-destructive testing of electrical conductive materials. The development of radio frequency (RF) eddy current technology with frequency ranges up to 100 MHz made it possible to extend the classical fields of application even towards less conductive materials like CFRP. It turns out that RF eddy current technology on CFRP generates a growing number of valuable information for comprehensive material diagnostic. Both permittivity and conductivity of CFRP influence the complex impedance measured with RF eddy current devices. The electrical conductivity contains information about fiber texture like orientations, gaps or undulations in a multilayered material. The permittivity characterization influenced by dielectric properties allows the determination of local curing defects on CFRP e.g. hot spots, thermal impacts or polymer degradation. An explanation for that effect is seen in the measurement frequency range and the capacitive structure of the carbon rovings. Using radio wave frequencies for testing, the effect of displacement currents cannot be neglected anymore. The capacitive structures formed by the carbon rovings is supposed to further strengthen the dielectric influences on eddy current measurement signal. Due to electrical field effects, also nonconductive materials like resins can be inspected by RF techniques. Maxwell's equations, FEM simulations and experimental research are applied to support this hypothesis. An industrial high-frequency eddy current (HFEC) device is used to measure the change of dielectric properties during the curing process of the epoxy resin L20. The measurement results are in good agreement with the expected behavior of the parameters relative permittivity and tan $\delta$ during cure. Using a capacitive reference device, similar characteristics regarding the change of the complex permittivity of the resin can be observed. In addition HFEC imaging results on PMMA are presented, discussed and compared to capacitive imaging. HFEC permittivity mapping benefits from a high spatial resolution with a sensitivity and penetration depth that is at least comparable to those of capacitive imaging technology. The paper close with an introduction to robot based systems for radio frequency imaging on real 3d structures.

Keywords: eddy currents, Composites, aerospace, Electromagnetic Testing (ET), NDT-wide, CFRP Characterization, Testing, Process monitoring, Eddy Current, Radio Frequency

10:40 - 11:05

6 Eddy Current Method for Measuring Composite Facesheet Thickness Through Cork

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The authors were presented with a need to measure the spatial thickness variation of a composite facesheet for the honeycomb sandwich material used to construct a large cylindrical structure. The measurements were needed to insure structural integrity. The facesheet of interest was covered with a thickness of cork that precluded the use of ultrasonic methods. To address this particular need, a novel eddy current technique was developed and successfully applied so that the costly and time-consuming need to remove the cork was averted. The technique will be described with details including a discussion of the sensor design, calibration
Composite materials have seen an increased use in aerospace in recent years and it is expected that this trend will continue due to the benefits of reduced weight, increased strength, and other factors. Ongoing work at NASA involves the investigation of the large-scale use of composites for spacecraft structures (SLS components, Orion Composite Crew Module, etc). NASA is also involved in work to enable the use of composites in advanced aircraft structures through the Advanced Composites Project (ACP). In both areas (space and aeronautics) there is a need for new nondestructive evaluation and materials characterization techniques that are appropriate for characterizing composite materials. This paper will present an overview of NASA’s needs for characterizing aerospace composites, including a description of planned and ongoing work under ACP for the detection of composite defects such as fiber waviness, reduced bond strength, delamination damage, and microcracking. The research approaches include investigation of angle array, guided wave, and phase sensitive ultrasonic methods. The use of ultrasonic simulation tools for optimizing and developing methods will also be discussed.

Keywords: Ultrasonic Testing (UT), composite, characterization, nondestructive evaluation, ultrasonic

Optical Distortion Evaluation in Large Area Windows using Interferometry

It’s important that imagery seen through large area windows, such as those used on space vehicles, not be substantially distorted. This presentation will start by discussing the ANSI definition of window distortion and the corresponding image projection technique used to measure it. An argument will be given that Schlieren imaging yields the same measurement as the ANSI image projection methods so that it can be used as a surrogate for the purposes of comparison with an alternative measurement approach, namely optical interferometry. Optical interferometry provides a direct measurement of the optical path length function through the window, but this data is measured over multiple small sub-apertures of the window. We will discuss how multiple sub-aperture interferometric measurements can be stitched together and then mathematically processed in order to obtain a high resolution map of the window distortion. This method will be compared to the Schlieren method highlighting the relative advantages of both methods. Specific window images will be presented showing and comparing fringe patterns, Schlieren imagery, optical path length functions, and the corresponding distortion mappings. Selected features in these windows corresponding to manufacturing issues, stress, and damage will be shown, indicating the relative performance of these techniques in detecting and quantifying the effect of various window anomalies.

Keywords: Visual and Optical Testing (VT/OT), Distortion, Interferometry, Optical Windows
Composite characterization using laser Doppler vibrometry and multi-frequency wavenumber analysis
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NASA has recognized the need for better characterization of composite materials to support advances in aeronautics and the next generation of space exploration vehicles. An area of related research is the evaluation of impact induced delaminations. Presented is a non-contact method of measuring the ply depth of impact delamination damage in a composite through use of a Scanning Laser Doppler Vibrometer (SLDV), multi-frequency wavenumber analysis, and a wavenumber-ply correlation algorithm. A single acquisition of a chirp excited lamb wavefield in an impacted composite is post-processed into a numerous single frequency excitation wavefields through a deconvolution process. A spatially windowed wavenumber analysis then extracts local wavenumbers from the wavefield, which are then correlated to theoretical dispersion curves for ply depth determination. SLDV based methods to characterize as-manufactured composite variation using wavefield analysis will also be discussed.

Keywords: Other Methods, NASA, Wavenumber, Composites, scanning laser doppler vibrometer

Subharmonic oscillations and chaos in dynamic atomic force microscopy
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The increasing use of dynamic atomic force microscopy (d-AFM) for nanoscale materials characterization demands a deeper understanding of the cantilever dynamics influencing scan stability, predictability, and image quality. Model development is critical to such understanding. Renormalization of the equations governing d-AFM provides an interpretation of cantilever dynamics as a single spring and mass system with frequency dependent cantilever stiffness and damping parameters. The renormalized model is sufficiently robust to predict the experimentally observed splitting of the free-space cantilever resonance into multiple resonances upon cantilever-sample contact. Central to the model is the representation of the cantilever-sample interaction force as a polynomial expansion with coefficients $F_{ij}$ ($i,j = 0, 1, 2, ...$) that account for the effective interaction stiffness parameter and the cantilever-to-sample energy transfer. Application of the Melnikov method to the model equation is shown to predict a homoclinic bifurcation of the Smale horseshoe type leading to a cascade of period doublings with increasing cantilever drive amplitude culminating in chaos and loss of image quality. The threshold value of the drive amplitude necessary to initiate subharmonic generation depends on the cantilever drive frequency, the effective damping coefficient, and the nonlinearity of the cantilever-sample interaction force. For parameter values leading to drive amplitudes below threshold for homoclinic bifurcation other bifurcation scenarios can occur, some of which lead to chaos.

Keywords: Other Methods, atomic force microscopy, image quality, subharmonic oscillations, chaos

High-Resolution Microwave and Millimeter Wave SAR Imaging of Rubber with Voids and Delamination

Microwave
Tuesday 23. Jun 14:30 - 16:10
Chair: Joseph T. Case, Kristen M. Donnell
Sierra Ballroom

14:30 - 14:55

High-Resolution Microwave and Millimeter Wave SAR Imaging of Rubber with Voids and Delamination
Rubber is used in many critical and non-critical environments and applications including the power generation industry and utilities. Rubber is a complex dielectric material with significantly diverse chemical properties that directly influence the mechanical properties of rubber-made structures. Structures and components made of rubber also expected to have long service life. However, in-service conditions (i.e., environmental exposure, chemical attack, mechanical stresses, physical damage, etc.) can significantly reduce their useful service life. Given the criticality of some environments in which they are used, periodic health monitoring of these structures and components becomes a necessity. In such cases practical constraints such as the ability to detect interior flaws or degradation from the outside of the structure, accuracy of measurements as they relate to identifying specific damage and speed of measurements (to name a few) become critically important. Microwave and millimeter wave nondestructive evaluation (NDE) and imaging techniques are very well suited for inspection of rubber materials since they are in the family of dielectric materials. Recent advance in materials characterization and imaging techniques in these regimes have brought upon a flurry of activities. Advance synthetic aperture radar (SAR) imaging techniques, specifically designed for nondestructive testing purposes render images with 3D resolution in the few mm range. These techniques can also produce images very rapidly. This paper presents the results of an investigation in evaluating the efficacy and limitations of these imaging techniques for detecting and evaluating small and differently-shaped voids in rubber sheets. In addition similar measurements are conducted on a delaminated rubber sheet to detect the delamination and moisture permeation into the delaminated layers. A discussion of the foundation of these techniques, as well as the influence of frequency and other measurement parameters will be discussed as well.

Keywords: Other Methods, Microwaves, Millimeter Waves, SAR Imaging, Materials Characterization

Advances in Dielectric Property and Thickness Evaluation of Layered Composite Structures using Open-Ended Waveguides

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Layered composite structures are being increasingly used in a host of critical applications (e.g., aircraft radomes, chemical storage tanks and pipes). Microwave and millimeter wave techniques can be used in a number of distinct ways to evaluate the dielectric properties and thickness of composite structures. One robust method involves radiation of an open-ended rectangular waveguide into such structures. Owing to a full-wave forward electromagnetic model capable of describing the reflection properties of the structure, one may subsequently deduce the mentioned characteristics by using an iterative recalculation technique. In recent years, this method has been improved by the development of a specifically-designed rounded waveguide flange that mimics the infinite ground plane considered by the model. In this work, two advances have been made to benefit the overall technique: advanced numerical evaluation of the forward electromagnetic model and the reduction of complexity in the iterative recalculation technique. The forward electromagnetic model is an accurate mathematical derivation. However, great care must be taken to ensure that the output of the numerical integration within the model is accurate and efficient. In particular, singularities may occur within the integration domain when low loss layers are considered. To this end, the numerical integration was significantly improved, using automatic segmentation of the integration domain, to ensure the proper treatment of singularities. Regarding the second advancement, the iterative recalculation technique was reworked to include relationships between layers. For example, some layers in a stratified media may be known to have the same - yet still unknown
Microwave nondestructive testing techniques have been widely used to evaluate and characterize inherent properties of a diverse array of materials. More specifically, various material properties of cement-based materials have been extensively examined in this regime. For instance, microwave dielectric constant measurements have shown great potential in identification and monitoring of alkali-silica reaction (ASR) formation in concrete. During ASR, reactive minerals present in some aggregates react with alkalis in the presence of moisture to produce a potentially expansive gel product. Current laboratory test methods for assessment of the potential of material combinations to produce damaging ASR have been criticized for numerous reasons, including poor correlation with field performance. The concrete prism test, ASTM C1293, is considered among the more reliable laboratory test methods for assessment of potential for ASR, but this test requires the addition of sodium hydroxide (i.e., NaOH) to the mix water in order to accelerate the ASR gel formation. The use of high alkali cement in combination with NaOH in the mix water alters the pore solution concentration. While this is intended to change the rate of the ASR reaction, unintended changes in the rate of cement hydration and the nature and structure of the hydrated cement paste may also occur. In this paper, the influence of the NaOH addition is examined through microwave nondestructive dielectric constant measurements. For this purpose, two different sets of mortar samples, one with and the other without NaOH but both containing an alkali-reactive aggregate, were cast and cured at hot and humid conditions. The corresponding dielectric constants were measured temporally at S-band (i.e., 2.6 – 3.95 GHz). The difference between the measurement results may be attributed to the additional alkali, as NaOH in the samples. The measurement results can be further investigated in order to correlate and/or corroborate the petrographic examination conducted on the same samples after conclusion of the experiment.

Keywords: Other Methods, Electromagnetic Testing (ET), microwave measurements, dielectric constant, ASR gel, concrete, hydration kinetics

Ruggedized Compact Microwave Probes for Mapping Material Properties of Structures
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Microwave properties of dielectric and magnetic materials can be obtained non-destructively in a laboratory setting with a free-space focused beam device. However, while a focused beam system exhibits good accuracy, it is far from portable and may be impractical for use in a manufacturing environment. Instead, a portable and rugged microwave sensor is of interest for characterization of larger structures that don’t easily fit within the geometry of a laboratory system. Such a sensor could be used in either a factory or field setting to measure microwave relevant materials and components (e.g. antenna arrays, radomes, electromagnetic
interference shielding, etc). Additionally such a sensor could find utility in detecting defects in dielectric composite structures. This paper describes a new microwave probe design that is optimized to interrogate a small area of a material or component, and determine reflection or transmission properties in the 2 to 20 GHz range. Consisting of a computationally designed antenna embedded within a shaped, solid polymer rod, this probe is ruggedized for use in harsh environments and is optimized to have a standoff of 10 to 100 mm from the material under test. Additionally, this paper describes the integration of this probe with industrial robots to spatially map the dielectric properties of flat or curved structures. Example measurements are shown of a multilayer structure of dielectric and conductive constituents, where a two-dimensional map shows spatially-dependent microwave properties. In addition to qualitative measurement of material variations, dielectric permittivity and conductivity of the structure under test are inverted from the measured transmission or reflection properties through a transmission line model. Similarly, magnetic materials used in electromagnetic interference (EMI) suppression are measured with this probe, demonstrating its potential for characterizing a wide range of materials in a manufacturing setting. Finally, a hand-held version of this probe is also demonstrated showing its potential as a sensor for diagnosing microwave material properties in an ad-hoc field setting.

Keywords: Electromagnetic Testing (ET), transmission, reflection, probe, microwave

Guided Waves
Tuesday 23. Jun 16:25 - 18:05
Chair: David Moore
Sierra Ballroom

16:25 - 16:50
15
Wavelet spectral finite element modeling of guided wave propagation in lap joints for bondline assessment
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Adhesive bonding of structural components has gained significant attention in the last few decades due to the advantages that it offers over conventional mechanical fastening techniques. Major advantages of adhesive bonding include its longer fatigue life, light weight, ability to join thin and dissimilar components, low manufacturing cost, and good vibration and damping properties compared to other mechanical joining techniques. Nondestructive inspection plays a key role in assuring the integrity of adhesive bonded joints during manufacturing and operation. In this work, ultrasonic guided wave propagation in adhesively bonded lap joints is studied using wavelet spectral finite element (WSFE) method. The adherands used in the study are considered as shear deformable beams/plates with corresponding degrees of freedom describing in-plane and out-of-plane displacements. Partial differential equations (PDEs), governing the wave motion of adherands, are derived using Hamilton’s principle. Adhesive layer is assumed to be a linearly distributed shear and transverse normal springs. The governing PDEs are coupled due to the presence of the adhesive layer, making it very complex to solve in time domain. The WSFE method is used for solving the differential equations. In WSFE the governing PDEs are transformed by approximating time, and for the plate case one spatial dimension, using Daubechies compactly supported scaling functions. The resulting ordinary differential equations (ODEs) have derivatives with respect to one spatial dimension only. These ODEs are solved exactly by assuming a harmonic solution in the transformed domain. The WSFE model is validated with conventional finite element simulations performed using commercial finite element software ABAQUS. Examples are provided to demonstrate the utility of the model in order to understand complex nature of guided wave propagation mechanism through adhesive bonded lap joints. Numerical and experimental studies are conducted to examine multiple guided wave modes that are present in bonded beams. Numerical examples suggest changes in higher order modes of group/phase velocity dispersion diagrams depending on the bondline thickness and/or strength. Particular attention will be paid to verify it experimentally and perhaps to exploit
the features in order to evaluate bondline property variations.

Keywords: Structural Health Monitoring, Composites, aerospace, non-contact ultrasound, NDT-wide, Guided waves, bonded joints, spectral finite element method

16:50 - 17:15

16

Characteristics of electromagnetic acoustic Lamb wave based on finite element analysis method

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The electromagnetic acoustic Lamb wave, because of the advantages with the rapid detection rate and sensitive to defects, is widely used in non-destructive testing of thin sheet. Because of the design parameters of electromagnetic acoustic transducer, mode selection of plate wave, estimation of Lamb wave detection range are all concerned with the characteristics of Lamb wave, therefore, it is necessary to study the directivity of sound field, multi-mode characteristics and dispersion characteristics of Lamb wave. In this paper, the directivity of sound field, Phase velocity, group velocity and displacement amplitude of Lamb wave are study based on finite element analysis method. The results show that, for 1mm aluminum, there is only A0 and S0 modes in 0-1MHz excitation frequency. These two modes have the strong sound field in the acoustic axis direction, and the sound field radiation angle of A0 mode is less than it of S0 mode. When the excitation frequency is less than 0.180MHz, there is only A0 mode, and when the excitation frequency at 0.08MHz displacement amplitude of A0 mode is largest. When the excitation frequency is greater than 0.45MHz, the displacement amplitude of S0 mode is increasing, and larger than the A0 mode. When the excitation frequency 0.64MHz, the displacement amplitude of A0 mode is minimum, and the displacement amplitude S0 mode is largest. Appropriate to increase the amplitude of a mode shift, while reducing displacement amplitude of another mode, to achieve the excitation of a single mode Lamb wave. To study the characteristics of Lamb waves by the finite element method, it is helpful to the Optimization of transducer parameters, the choice of Lamb wave modes and providing optimal excitation frequency, and it has an important applications prospect in terms of electromagnetic acoustic NDT.

Keywords: Ultrasonic Testing (UT), NDT-wide, NDT, EMAT, Lamb wave, finite element

17:15 - 17:40

17

Ultrasonic Guided Waves NDE

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Ultrasonic guided waves are more complex and harder to interpret than conventional ultrasonic methods. Guided waves use is feasible in many difficult NDE applications. Materials and structural integrity can be tested in geometrically complex components and in difficult to get to areas using advanced guided wave methodologies. Supported by modeling and signal processing algorithms, guided wave methods can be effectively developed for the demanding full part cross-section testing of, for example, railway track or aircraft structures. This paper will review recent work in ultrasonic guided modes testing, including novel ultrasonic transduction process and advanced data acquisition. These developments enable measurements of the mechanical defect conditions, structural integrity, material degradation and materials properties that are not possible using conventional ultrasonic test approaches.

Keywords: Composites, non-contact ultrasound, Ultrasonic Testing (UT), Ultrasonic, guided wave, composites
The State-of-the Art Innovative Technologies for Non Destructive Analysis of the Fine Art Objects And the Cultural and Historical Heritage

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Continuous innovations in advanced High Resolution Imaging Technologies and Methods have caused unique applications for non-destructive investigations of surface and subsurface microstructures in the conservation of cultural and environmental heritage. It became a preferred approach even in cases where microanalysis sampling is permitted. The synergy between experts in science and culture will lead to continuous development and adjustments of new innovative scientific methods, their applications in the field of preservation, reconstruction and diagnostics of museum, and archeological objects. High-resolution imaging diagnostic, in particular, is powerful and significant methods that can bring a revolution in the usual study and conservation processes of art-objects. There is an ancient saying that “A picture is worth a thousand words”. Never this is truer than when it is applied to nondestructive characterization of materials of various natures. It is also true that it was the very first nondestructive test when after God created the universe he stopped and “saw that it was good”. It may be difficult for modern research scientists and engineers to believe, but visual inspection is still the nondestructive testing technique most often used in practical applications. The goal of this invited talk is to introduce advanced acoustic imaging technique, UV, X-ray, Infrared and Thermo-imaging approaches, which have been recently developed and successfully applied as NDT technique in the industrial sector. In that presentation we will demonstrate the most recent results in the field of Nondestructive Investigations and Diagnostics of Cultural and Environmental Heritage. We strongly believe that this advanced and efficient technical approaches will benefit art collection community as a whole, and further emphasize scientist’s contribution to the world cultural and historical heritage as well.

Keywords: Other Methods,

Ultrasonic nondestructive evaluation in holmium monopnictides

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We present a detailed theoretical investigation of elastic and ultrasonic properties of rare-earth compounds HoX (X: N, P, As and Bi) with NaCl structure (B1 type) in the temperature range of 0-500K. The second- and third- order elastic constants (SOEC and TOEC) are obtained using an electrostatic and the Born repulsive potentials up to second nearest neighbors. The elastic constants help in understanding the anharmonic and nonlinear properties of the chosen material as shown by the variations in hardness. The hardness for HoX is calculated using the semi-empirical microscopic model and is an important parameter for measuring the material’s resistance to penetration, deformation, etc. The deviation of Cauchy relation from unity is seen to be fairly small. SOECs and TOECs are used to evaluate various mechanical and thermal
parameters which give knowledge about the performance of HoX. Mechanical properties such as Young’s modulus, bulk modulus, shear modulus, Zener anisotropy factor, Poisson’s ratio, etc. are also calculated. The compounds under study are found to be brittle in nature. Further, we have computed the thermal properties such as thermal conductivity, Debye temperature, specific heat, etc.; which plays a significant role in quality control in material producing industries. The ultrasonic attenuation due to phonon-phonon interaction, thermoplastic mechanism and dislocation damping along the three crystallographic directions of propagation, viz. [100], [110] and [111] for longitudinal and shear modes of propagation has also been evaluated in the present study. The major cause for lattice imperfection is the damping due to screw and edge dislocations. Obtained results are discussed with available findings.

Keywords: Ultrasonic Testing (UT), Elastic constants, hardness, Young’s modulus, ultrasonic attenuation, dislocation damping

09:25 - 09:50

20 Non-Destructive Characterization of Materials by Combining Electrical Testing and Imaging Methods with Scattering Methods
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Scattering methods such as small angle x-ray (SAXS) and small angle neutron scattering(SANS) are excellent methods for characterization of materials at many different length scales, ranging from sub-nm up to the micron scale. They have the added benefit that the obtained results are statistically significant since the data is obtained throughout the volume of the sample and is not confined to a small sampling region as it would be with high resolution transmission electron microscopy (TEM) for example. The main requirements are that the sample needs to show enough contrast between the scattering objects of interest and that the equipment used (beamline used, energy used, detectors used) is able to probe the desired scattering species. There are a number of user facilities all over the world that one can use to establish the baseline behavior of a given material which can then be coupled to results obtained from imaging methods for corroboration of the size and shape of the features modeled and with electrical testing for detailed quality control and monitoring of changes with exposure to temperature, humidity, optical pumping and/or mechanical loading. In this talk, a summary of results from several material systems studied by combined scattering, imaging and electrical methods will be presented. Examples will include in-situ monitoring of the growth of reinforcing precipitates in a nickel base superalloy as a function of time and temperature, in-situ densification of porous ceramic material as a function of applied pressure and temperature. Additionally, determination of the pore volume and average size and shape of pores in thermal barrier coatings and highly porous silica gels will be described. Finally, determination of the dimensions of nanoparticle aggregate structures that formed percolating paths in insulator-conductor nanocomposite materials will be accompanied by percolating curves, conductive AFM images as well as simulated and measured ac impedance spectroscopy spectra. If time permits, film thickness and chemical composition data on nanoparticulate films deposited by layer by layer assembly and characterized by neutron reflectometry, atomic force microscopy and quartz crystal microbalance will also be presented.

Keywords: Other Methods, Visual and Optical Testing (VT/OT), Electromagnetic Testing (ET), small angle scattering, impedance spectroscopy, resistivity, current AFM

09:50 - 10:15

21 Study of Structural Foam Core Used in Aerospace Laminate Construction
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Closed cell, polymethacrylimide foam is widely used as a core material in sandwich structures for aerospace components. The integrity of these structures is typically assessed using ultrasonic methods (UT). Past investigations have correlated the attenuation of UT
transmission with variations in foam cell size and a reduction in shear strength with acoustic attenuation, implying a correlation between strength and cell size. With the goal of assessing how foam parameters (bulk density, cell diameter, wall size) influence strength, this study was undertaken to investigate the strength/cell size correlation in non-laminated bare foam, as well as strength impacts due to cell distortion induced by the thermal forming process in co-cured graphite/epoxy laminate panels for curved structures.

Keywords: Composites, aerospace, Ultrasonic Testing (UT), ultrasonic testing, composites, foam core

10:15 - 10:40

An Experimental Study of Prestress Force Effects on Nonlinear Ultrasonic Characteristics of Concrete Beams
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This research presents a preliminary experimental research work for evaluating the prestress force effects in the prestressed concrete beams. Nonlinear ultrasonic method was applied during static loading of two concrete beams in the context of the nonlinear acoustic response of concrete. At each load step, the nonlinear ultrasonic characteristics were measured using two kinds of ultrasonic transducers. As the results, the nonlinearity parameter was computed at each load step, which has been known to sensitively represent inherent discontinuities in concrete. It was found that the nonlinearity parameter was decreased with increasing the prestress force which can be explained by strengthening phenomenon of the inherent discontinuities in concrete. Based on the experimental results, prestress force effects can be properly represented by the nonlinear ultrasonic method.

Keywords: Ultrasonic Testing (UT), Prestress force, concrete beam, nonlinear ultrasonic method, non-destructive evaluation, higher-harmonics generation

10:40 - 11:05

Ultrasonic Scattering Measurements of Grain Size in Nickel and Titanium Alloys
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The grain size of metal alloys is one of the key material properties that control mechanical strength. The grain size is carefully manipulated during processing to create the desired mechanical properties and reliability in a final component. Traditional metallographic grain size measurements are destructive, time consuming, and labor intensive. In addition they only sample a small region of a component and cannot be performed on every component. Ultrasonic scattering measurements are excellent at probing metal microstructures and providing a quantitative measurement of grain size if appropriate measurement methods and theories exist. However, the ultrasonic backscattering can only be used if the measurement provides the same backscattering coefficient predicted from wave propagation theories and if the measurement is independent of the ultrasonic system used. We developed a software tool that unifies the entire process including the data collection, backscattering coefficient calculation, theoretical predictions, grain size calculation and visualization. We tested the tool on nickel super alloys including IN718, Waspaloy, Udimet 720, and Rene 88. We also measured the grain size in an alloy 10 disk with grain sizes ranging from ~8 microns in the bore to ~30 microns at the rim designed to alleviate fatigue and creep respectively. Our results compared favorably with traditional metallography agreeing to within 2 microns for some nickel alloys. We are now developing methods to characterize the elongated grains in the complex microstructures created by additive manufactured methods as well as titanium alloys.
This tool provides the NDE and materials community the ability to quickly map the grain size, test various theories and to predict the measured backscattering coefficient in one software platform.

Keywords: aerospace, Ultrasonic Testing (UT), ultrasound, scattering, grain size, microstructure, turbine disk

Nonlinear NDE
Wednesday 24. Jun 12:35 - 14:15
Chair: Igor Solodov
Sierra Ballroom

12:35 - 13:00

Advantages and drawbacks of nonlinear acoustic NDE methods
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Over the last two decades, studies of nonlinear acoustic effects in engineering materials have steadily intensified. Numerous nonlinear static and dynamic observations demonstrated that the macroscopic nonlinearity in a material is highly dependent on the amount of micro-inhomogeneous imperfections (defects) that exist within the material that leads to high sensitivity of nonlinear material properties to defect presence. This paper gives a brief review of Nonlinear Acoustic NDE (NA NDE) methods and pays specific attention to their drawbacks that limit their practical applications. Historically, the first applications of the nonlinear acoustic technique for material characterization used measurements of the second harmonic generated by the nonlinear distortion of a primarily sinusoidal acoustic wave propagating in a medium with defects. The first test of this method was conducted in 1979 by Dr. Buck's team. Later it was realized that harmonic generation is not the best way to implement the effective NA NDE. The other nonlinear techniques are based on the modulation of ultrasound by vibrations and on time amplitude dependence of the mode resonance peak. Due to the use of resonant modes, these methods need much less acoustic power than the travelling-wave methods used before. Later Time Reversal Acoustic and Slow Dynamics methods were investigated for NDE applications. In these studies, it was found that nonlinear methods are more sensitive to damage-related structural alterations than any known method based on the measurements of linear parameters such as wave speed and attenuation. Despite the high sensitivity of the nonlinear acoustic methods, they were not moved to practical applications due to the following drawbacks: • NA NDE methods are very sensitive to other sources of nonlinearity usually produced by various contacts including contacts between ultrasonic sensors and tested parts and interfaces between various elements of tested parts. • The NA NDE technique is more complicated in comparison with standard ultrasonic methods and their applications might require highly trained NDE technicians. • The majority of the NA NDE methods can detect crack presence, but cannot localize them. A review of NA NDE methods that may be used for crack localization are presented in this paper.

Keywords: Ultrasonic Testing (UT), Nonlinear acoustic

13:00 - 13:25

Absolute Measurement and Relative Measurement of Ultrasonic Nonlinear Parameter
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The second- and third-order ultrasonic nonlinear parameters, $\beta$ and $\gamma$ have been studied for the evaluation of material degradation, which are defined by $(8*A_2)/(k^2*x*A_1^2)$ and $(32*A_3)/(k^4*x^2*A_1^3)$, respectively, where $A_1$, $A_2$, $A_3$ are the displacement amplitudes of fundamental, second-order, and third-order harmonics, $k$ is the wave number and $x$ is the propagation distance. These parameters are called the absolute parameter, and it is generally difficult to be measured due to very small displacement amplitude of harmonic
component, so that the relative form has been widely used. The relative parameter is a ratio of the nonlinear parameter measured at a condition to the nonlinear parameter measured at a reference condition, which is convenient when comparing the nonlinear parameters relatively. Moreover, it does not require the precise displacement measurement since it is not dependent on the detection method as long as the measurement system is kept in consistent and the detected signal amplitude is linearly proportional to the actual displacement amplitude of the wave. However, the relative ultrasonic nonlinear parameter has never been verified in comparison with absolute ultrasonic nonlinear parameter. Therefore, in this study, the absolute ultrasonic nonlinear parameters and the relative ultrasonic nonlinear parameters were measured up to third-order for two different materials, fused silica and Al6061-T6 and it was experimentally verified that the ratio of absolute parameters is identical to the relative parameter. In the absolute measurement, piezoelectric detection method was adopted. In the experiments, first, the theoretical relationship between second- and third-order parameter was confirmed, and then the ratio of absolute parameters in fused silica to those in Al6061-T6 and the relative parameter obtained from fused silica and Al6061-T6 was compared respectively in second- and third order. The results showed that the ratio of absolute ultrasonic nonlinear parameters and the relative ultrasonic nonlinear parameter was almost same. --- This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (NRF-2013M2A2A9043241).

Keywords: Structural Health Monitoring, Ultrasonic Testing (UT), NDT-wide, Relative ultrasonic nonlinear parameter, Absolute ultrasonic nonlinear parameter, Fused silica, Al6061-T6

13:25 - 13:50
26
Non-destructive characterization of XB2 (X= V, Nb and Ta) transition metal diborides
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The elastic properties, acoustic properties and mechanical properties of the group VB transition metal diborides like VB2, NbB2 and TaB2 have been studied along unique axis at room temperature. The second- and third order elastic constants (SOEC & TOEC) have been calculated for these diborides using Lennard–Jones potential model. The velocities VL and VS2 increases with the angle from the unique axis and VS1 have maximum at 450 with unique axis of the crystal. The inconsistent behaviour of angle dependent velocities is associated to the action of second order elastic constants. Debye average sound velocities of these compounds are increasing with the angle and has maximum at 550 with unique axis at room temperature. Hence when a sound wave travels at 550 with unique axis of these materials, then the average sound velocity is found to be maximum. The mechanical properties of VB2 are better than TaB2, because VB2 has low ultrasonic attenuation comparison than TaB2. The diborides are good electrical conductors; they are attractive for the same types of applications as other hard refractory materials such as in composite and in hard coating. Traditional applications of such materials are based on their interesting combination of mechanical and transport properties. Keywords: Ultrasonic Testing (UT), NDT-wide, Elastic properties, VB transition metal diborides, thermal conductivity, ultrasonic properties

13:50 - 14:15
27
Highly-sensitive defect-selective imaging via linear and nonlinear resonances of defects
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The efficiency of interaction between ultrasonic wave and a defect is a crucial factor, which determines sensitivity of any ultrasound-related NDT methodology. In this context, the role of ultrasound frequency is usually evaluated as “to be high enough” to overcome diffraction limit defined by the ratio of the defect size and the ultrasonic wavelength. However, such an answer to the question “What is an optimal frequency for wave-defect interaction?” is not always
correct. In fact, inclusion of the defect leads to a local drop of rigidity for a certain mass of the material and therefore manifests in a particular characteristic frequency of the defect. A frequency match between the driving ultrasonic wave and this characteristic frequency provides a Local Defect Resonance (LDR) and results in efficient energy pumping from the wave into the defect. In this paper, such a selective ultrasonic activation of defects is suggested to enhance acoustic, optical and thermal defect responses. A straightforward phenomenology and the finite element simulation are developed to evaluate the various order LDR frequencies. The resonant excitation of a defect results in a high local vibration amplitude and enhancement of the defect acoustic, thermal and optical responses readily measurable even for a few mW acoustic input. As the local vibration amplitude increases, the LDR- “amplifier” exhibits transition to nonlinear regime with an efficient generation of nonlinear frequency components solely in the defects area. The nonlinear modes observed include sub- and superharmonic resonances with anomalously efficient generation of the higher harmonics and subharmonics. A modified version of the superharmonic resonance (combination frequency resonance) is used to enhance the efficiency of frequency mixing mode of nonlinear NDT. Multiple case studies demonstrate a strong increase in sensitivity for both optical (laser vibrometry and shearography) and thermosonic frequency-selective imaging of defects in a variety of materials and components.

**Keywords:** non-contact ultrasound, Ultrasonic Testing (UT), Infrared Testing (IRT), defect resonance, thermosonics, nonlinearity

14:15 - 14:40

28

**Acoustic emission to understand the acoustic nonlinear behavior observed in composites**

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During the last years, acoustic nonlinear behavior of materials was studied in different experimental conditions. Experiments such as nonlinear resonance, harmonics generation, slow dynamics, etc. revealed to be common to several kind of materials (rocks, concrete, polymer composites, metals, etc.) despite the existing differences in their constituents and chemical/physical properties. Even if the sensitivity of nonlinear acoustics to the micro-heterogeneities (micro-cracks, porosities, contacts, etc.) has been proven through these different experiments, the understanding of the micro-mechanisms at the origin of the observed macroscopic behaviors has still to be improved. Furthermore, the sensitivity of the nonlinear acoustic parameters revealed to be insufficient to quantify the structural evolution at the microscopic scale. This contribution presents several experiments performed on composites where acoustic emission data are analyzed in conjunction with acoustic nonlinear behavior. In addition to the quantification of nonlinear acoustics parameters, acoustic emission technique revealed to be sensitive to the change of the excited nonlinear mechanisms.

**Keywords:** Composites, Ultrasonic Testing (UT), Acoustic Emission (AE), nonlinear acoustics, microcracks, concrete

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**NDE of Infrastructure**


Chair: Glenn Washer

Sierra Ballroom

14:55 - 15:20

29

**Developments for Thermographic Inspection of Bridges**

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This presentation will describe developments for the use of Infrared thermography for the condition assessment of concrete bridge components in the US. Over the last 5 years, 13 States Departments of Transportation have supported research into the implementation of this technology as part of their bridge management programs in the US. This paper will summarize the outcome of this research, describe tools developed to assist the implementation, and new applications and technologies developed over the course of the program. Development and applications for transient thermal methods will also be presented. Future and current research conducted under the program will also be discussed.

Keywords: Infrared Testing (IRT), infrared, thermography,

15:20 - 15:45

30

Hidden loss quantification of total cross section for main cable of suspension bridge based on magnetization curve measurement

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In the real field, inspection methods for main cables of suspension bridges are mainly carried out by visually inspecting the exterior covering of the cable periodically. In spite of necessity of non-destructive examination (NDE) to detect the inner cross-sectional loss of the main cable, a suitable NDE technique for the main cable has not been existed due to its large diameter. In this study, a cross-sectional loss quantification method that can detect the external and internal damages of main cables has been studied. This main cable NDE method was based on the direct current (DC) magnetization technique and a search coil sensor-based total flux measurement. A total flux sensor head consisted by a magnetization part to magnetize the specimen and a sensing part to measure the magnetic flux. The magnetic field for magnetizing the main cable was generated by applying the low frequency DC voltage to the electro-magnet yoke. The sensing part measures the magnetic flux that passes through the search coil. Then, B-H curve (magnetization curve) was obtained using the relationship between inputted DC voltage and measured total flux, and cross-sectional loss can be detected using variation of features from the B-H curve. To verify the feasibility of the proposed main cable NDE technique, a series of experimental studies were performed using a main cable specimen that has gradual increase of cross-sectional loss. Finally, a relationship between cross-sectional loss and extracted magnetic feature was derived, and it was utilized to quantify the cross-sectional loss by using proposed method.

Keywords: Magnetic Testing (MT), Total flux, main cable NDE, loss quantification, magnetization curve, suspension bridge

15:45 - 16:10

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Tensile force monitoring for Pre-Stress tendon of PSC Girder by incorporating FBG and EM sensor

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Actual tensile force of pre-stress tendon of PSC girder is one of the important factors for evaluating the performance of PSC girder. While the exposed cable tensile force can be measured by various methods, the tension of immersed cable, PS tendon of PSC girder, is hard to measure due to its spatial limitation. For measuring the tensile force of the PS tendon, this study proposed the tensile force measurement method by incorporating the Fiber Bragg Grating (FBG) and Elasto-magnetic (EM) sensor. To embed the sensors into the PSC girder, the smart tendon was fabricated by installing the FBG sensor to the perforated tendon and the EM sensor was fabricated as sheath joint. The experimental study was performed to verify the sensors using down scale model of girder. The FBG sensor measured the strain due to the tension variation while the EM sensor measured the magnetic flux change. The actual tensile force of PS tendon was measured by the load cell and it compared with the calculated tensile
force using the strain and magnetic permeability. The result shows the proposed method can monitor the actual tensile force of PS tendon of PSC girder.

Keywords: Structural Health Monitoring, Visual and Optical Testing (VT/OT), Electromagnetic Testing (ET), FBG sensor, EM sensor, Tensile force monitoring, PSC girder

16:10 - 16:35
32
**Neutron Tomography Measurement of Delayed Ettringite Formation in Concrete**

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Ettringite \([\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26\text{H}_2\text{O}]\) is a calcium aluminate sulfate hydrate mineral that can develop in concrete at times on the order of months to years after casting. This delayed formation leads to expansive stresses that can cause reduction in compressive strength. This process has been difficult to investigate because of a lack of a suitable method to identify the ettringite crystals. Conventional methods including X-ray diffraction, SEM with EDS and thermogravimetry are all destructive. Moreover, they all require extremely small sample volumes that may not be representative of the actual ettringite distribution in the concrete. Neutron tomography is an alternative nondestructive materials characterization method that has several advantages. Like X-ray tomography, neutron tomography provides a 3-dimensional image of an object, such as a concrete core. This makes it possible to visualize the spatial distribution of the various phases in the concrete and to compute the volumetric fractions of each. However, unlike X-rays, for which attenuation depends primarily on density, the attenuation of neutrons in concrete is dominated by hydrogen atom concentration. Consequently, hydrous phases such as C-S-H gel, calcium hydroxide and ettringite can be individually identified. In particular, ettringite, which is nearly 50% water by weight, has the highest neutron attenuation factor, 4.67 cm\(^{-1}\), compared to 2.73 cm\(^{-1}\) for C-S-H gel and 3.19 cm\(^{-1}\) for calcium hydroxide. In preliminary experiments to evaluate this method, 5 cm diameter cores from concrete prisms that had been subjected to different temperature conditions during curing were scanned at 20 µm resolution by neutron tomography at the NIST Neutron Imaging Facility. The grayscale histogram was segmented to develop a classification system that associated each voxel with a specific concrete phase. The ettringite voxels were then summed to determine the total volume fraction in each core. The concrete that showed the greatest physical expansion also had the largest amount of ettringite.

Keywords: Radiographic Testing (RT), concrete, neutron, tomography, ettringite, hydrogen

16:35 - 16:50
33
**Visualization of Delamination Condition of CFRP Laminated Concrete**

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One of the most critical characteristics of concrete structures is brittleness and hence the concrete is vulnerable to tension force. CFRP sheets or plates have been laminated on the surface of the concrete structures to protect the cover and to reinforce the damaged surface of the concrete structures. However, the efficiency of the CFRP reinforcement to endure the tension force becomes lower when the CFRP sheets or plates are delaminated from the concrete structures. In this study, concrete structures laminated with the CFRP sheets were scanned using the pulsed laser system and the delamination of the CFRP sheets was visualized and detected. The delamination was artificially formed when the CFRP sheets were attached on the concrete structures. An Nd: YAG pulsed laser system was applied to excite ultrasonic waves at the multiple points of the CFRP sheets and the wave responses of the structures were analyzed to obtain flaw images. The wave responses were visualized based on the analysis in frequency-wavenumber domains. An adaptive filter scheme was applied to detect the
Phased Array
Wednesday 24. Jun 16:50 - 18:05
Chair: Mourad Bentahar
Sierra Ballroom

17:15 - 17:40

"Total focusing method imaging for flaw characterization in homogeneous media"
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Phased array imaging using multi-element probes is a efficient technique to detect and characterize flaws in industrial components. In particular, the total focusing methods are advanced approaches that optimally focus at each point of the reconstruction zone. They need all transmitter-receiver pair signals of an array. Then, the post-processing is performed by computing the proper propagation times at each reconstruction point and by applying coherent summations over all elements. In this paper, we show experimental results about flaw characterization using the total focusing methods. Compared to conventional phased array imaging, we demonstrate that these methods achieve better flaw sizing, applied to side drilled holes, flat bottom holes and slits, in homogeneous media.

Keywords: Ultrasonic Testing (UT),

17:40 - 18:05

Influence of seamless pipes wall thickness variation for the effectiveness of Automated Ultrasonic Testing
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Offshore pipelines construction is a technological challenge. Increasing water depth, harsh environments, engineering and commercial constraints are just some of the existing issues. Material selection therefore plays a key role and, for several applications, seamless pipes offer both the best technical and commercial compromise. Typically, NDT inspection of girth welds is carried out using the phased array based automated ultrasonic testing (AUT) zonal discrimination approach. AUT, compared to other techniques, guarantees a higher probability of detection of flaws and it also allows a really accurate assessment of the indications. However, since one of the peculiarities of this technique is that it uses focused beams, it is strictly linked to the geometry of the joint. According to the most credited international codes, performing AUT the allowable wall thickness (WT) variation from the nominal one is ±1.5 mm (or less for higher strain applications). Seamless pipes are likely to exceed this limit, particularly taking into account that the WT commonly varies point by point around the circumference. For this reason, several approaches have been developed during the years from AUT contractors such as using dedicated techniques (e.g. multi-shooting) or using of multiple calibration blocks. However, all these solutions may deeply influence costs because of the additional qualification tests required and the potential impact on the cycle time. Starting from AUT validation data to build the model and using simulation software as tool, this study analyses the influence of WT variation on the reliability and accuracy of zonal discrimination approach. Real flaws geometry has been extrapolated from macro-sectioning. Actual focal laws settings have been considered. After validating the proposed model by comparing the simulation results with actual ones, several steps of base material WT variation are considered.
in order to understand the effect on the ultrasonic response of the flaws in object.

Keywords: Ultrasonic Testing (UT), Phased Array, Modelling, Pipeline, Offshore

### Plenary Address

**Plenary Address**

**Thursday 25. Jun 08:00 - 08:45**

Sierra Ballroom

08:00 - 08:45

**36**

**Our Aerospace Legacy**

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Our Aerospace Legacy – Preserving a Southern California Heritage It has been over 50 years since we began our journey to the stars in this nation. While there is an extraordinary record of achievements in aerospace, we still have a long list of goals and challenges ahead. The major center for these past aerospace accomplishments was locally here in Southern California, yet much of that history is gone or forgotten by the new generation of pioneers and the general public. This presentation will take a glance at the rich heritage that is the legacy of the men, women and aerospace pioneers of our local community.

Keywords: aerospace, aerospace,history,legacy,heritage,pioneers

### Materials Characterization 2

**Materials Characterization 2**

**Thursday 25. Jun 09:00 - 11:05**

Chair: Roman Gr. Maev

Sierra Ballroom

09:00 - 09:25

**37**

**Mechanical Properties of the Surface Material and Dust Particles of Comet 67P/Churyumov-Gerasimenko Measured by CASSE and DIM on board Rosetta’s Lander Philae**

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In August 2014 the ESA spacecraft Rosetta encountered the comet 67P/Churyumov-Gerasimenko. Rosetta carried the lander Philae that landed on the comet's nucleus on November 12th 2014. Philae has ten different instruments onboard including the Surface Electric Sounding and Acoustic Monitoring Experiment (SESAME) comprising CASSE, DIM, and PP. The Comet Acoustic Surface Sounding Experiment (CASSE) is housed in the six soles of Philae's landing feet. It consists of three piezoelectric, tri-axial accelerometers, and three transducers. This allows for both passive listening to the comet’s seismic activity and active sounding of the comet surface. The deceleration signal occurring in the first milliseconds of the touchdown (impact velocity approx. 1 m/s) was recorded by CASSE. It contains information on the elastic (modulus) and plastic deformation (hardness) of the cometary soil. The analysis is based on a recently developed inversion scheme exploiting an extended Hertzian contact mechanics which in turn is based on calibration landing tests on two types of sand and on concrete. The Dust Impact Monitor (DIM) onboard Philae is a cube with three of its sides covered with three PZT detectors each. DIM is aimed to derive the elastic-plastic properties and the flux of the millimeter-sized dust-particle population that moves near the surface of
the nucleus of the comet. Calibration experiments between -40º C and -20º C were performed to analyze the response of DIM based on Hertzian contact mechanics. The experiments comprise impacts with spherical ice particles (radii of nearly 1 mm) on the sensor plates at different impact speeds and directions. During the landing descent from the orbiter to the comet, only one particle was detected having a modulus range from 50 – 500 MPa and with a radius of 1-3 mm. In this contribution, we will give an overview on the calibration experiments, on the data recorded so far, their interpretation and relation to the corresponding measurement techniques employed in non-destructive materials characterization.

**Keywords:** Ultrasonic Testing (UT), Space Science, Materials Characterisation, Ultrasonic Testing, Comets

09:25 - 09:50

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**Ultrasound Based Characterisation of Anisotropic Conditions in Metallic Materials and Structures**

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Acoustics based techniques have increasingly shown their multitude of options to allow specifically metallic materials to be characterised. This classically includes the determination of elastic constants but also residual and load induced stresses being applied in different directions. The ultrasonic techniques being considered are not limited to piezoelectric transducers only but also include phased array techniques as well as electromagnetic transducers. With those a variety of different applications have been made possible such as the inspection of complex anisotropic material conditions as well as stresses resulting from residuals or from applied loads. After an overview of the different emerging options being available for ultrasound based metallic materials characterisation different specific examples will be provided such as electromagnetics based measurement of stresses in material testing under elevated temperatures, electromagnetics based stress measurement in loaded steel beams, electromagnetics based stress measurement in rebars of reinforced concrete, ultrasonics based stress measurement in screws and bolts and finally characterisation of austenitic welds using phased array techniques. An outlook will also be provided with respect to the conclusions drawn from where the approaches can be used in the context of structural health monitoring.

**Keywords:** Structural Health Monitoring, Ultrasonic Testing (UT),

09:50 - 10:15

39

**Ultrasonic inspection of steel-adhesive and aluminum-adhesive multi-layered joints**

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Adhesive bonding technology has been increasingly employed in automotive industry for joining metal body structure and closure components. However, the variability in thicknesses of the metal and adhesive layers, as well as the varied joint geometries, typical of automotive components have been challenging for ultrasonic evaluation. Additionally, the different acoustic impedances of steel vs. aluminum (Al) alloys necessitate different approaches. This work presents a detailed study of the pulse-echo ultrasonic wave propagation in multi-layered structures with varying thicknesses and acoustical properties. Based on numerical modeling and experimental observations of reverberating waveforms in various adhesive joints, robust algorithms for ultrasonic inspection of automotive bonded parts were developed. A 15-MHz, two-dimensional ultrasonic array was used to measure the spatial distribution of adhesive coverage in joints. The developed algorithms have been tested on steel-to-steel, Al-to-Al and
Al-to-steel adhesive joints. Laboratory samples were used to optimize the algorithms and obtain acceptable gage R&R performance for the stackups of interest. Subsequently plant trials were conducted to validate the evaluation process on body structures, as well as the more challenging geometry of hemmed joints on automotive closures. Ultrasonic measurement of the adhesive bead width matched teardown measurements within 1 mm with an accuracy of 96% and 94% for the steel and Al joints, respectively. The false-call and missed-call error rates were well within acceptable limits, proving the great utility of this technique in industrial environments.

Keywords: Ultrasonic Testing (UT), Adhesive, joint, ultrasound, nondestructive

10:15 - 10:40

**Real-time ultrasonic analysis of capacitor discharge spot welding processes**

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In the context of a joint research project the Porsche Leipzig GmbH conducts scientific and technological investigations of capacitor discharge welding technology as spot welding process. In contrast to the medium-frequency spot welding process the examinations confirmed the energy-saving potential and the possibility to avoid high energy-peaks for example in the car body construction when a lot of welding guns overloading the power grid if they are working in simultaneous operation. The total electricity-network load reduces, because the capacitor banks can recharge itself in the welding breaks with relatively lower power supply. Another advantage comes with the fact that the effective welding process is approximately 6 to 12 milliseconds. It is possible to renounce water cooling because the welding zone heats up very quickly before the heat can dissolve in the surrounding material or in the copper-electrodes. Comparing to the medium-frequency spot welding process it is not possible to control and regulate the welding current after the discharge process of the capacitor has been started. So far it was possible to measure and analyze the resistance and the effective welding time to predict the quality of the spot weld. In order to improve reliability of quality characterization, a joint project was set up with Tessonics Inc. A high frequency ultrasonic transducer was integrated into the copper-electrode of the capacitor discharge welding engine. The aim of the joint project was to develop and evaluate a new quality characteristic for the special spot welding process with capacitor discharging. The analysis of ultrasonic M-scan in comparison with metallographic micro-sections of the welds has revealed two metrics which correlated very well with the weld quality. Using these metrics, it was possible to distinguish the good weld from the so called zinc-adhesive, or underwelded, joints. The first test trials have shown good correlation with the destruct test. Further steps will include improving the signal processing algorithm to increase reliability of detection and automatic information extraction from the M-scans.

Keywords: Ultrasonic Testing (UT), Applied real-time ultrasonic analysis, spot welding, capacitor discharge welding

10:40 - 11:05

**Characterization of porous material using ultrasonic slow wave**

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Porous materials are critical engineering components in many process industries. Although porous materials have been successfully utilized in many areas, characterization of porous structures is still a significant problem limiting the applications of porous materials, especially when the application involves the change of porous structure. Ultrasonic techniques have been reported for successful applications on material characterization, including porous materials. Biot theory shows there are three waves can be generated and propagated through saturated porous materials: fast and slow longitudinal wave, and shear wave. The slow longitudinal wave
is characterized by the out-of-phase movement of pore fluid and matrix materials. This out-of-phase movement is very sensitive to the structure of the porous structure, which can be applied to material characterization, structure monitoring, quality control, etc. This research is utilized an acoustic technique for porous structure characterization by measuring Biot's slow longitudinal wave, especially the critical wave number measurement. In Biot's theory the slow wave is highly attenuated below a critical frequency. This frequency sensitivity provides a unique opportunity to utilize the slow wave to quantify the ability of fluids to penetrate these porous materials. Specifically, conditions that favor propagation of the slow wave through interconnected pores are consistent with material permeability. Pore size distribution in the porous structure will affect the slow wave propagation through the porous materials, which will be investigated in this research as well.

Keywords: Ultrasonic Testing (UT), ultrasonic, porous, slow wave, permeability, pore size

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**NASA 2**

**Chair:** Cara A. C. Leckey, William H. Prosser

**Sierra Ballroom**

12:35 - 13:00

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**Composite Overwrapped Pressure Vessel (COPV) Liner and Thin Wall Metallic Pressure Vessel Inspection Scanner Development and Assessment**

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In the wake of a COPV failure on a launch vehicle during a ground test last year, a task was undertaken to develop and assess the capability of scanning eddy current (EC) nondestructive evaluation (NDE) methods for the inspection of COPV liners. Critical flaws in some liners had not been detectable with conventional dye penetrant (PT) methods, so sensitive EC techniques were considered as an alternative. However, these EC methods had not been fully developed for application to COPV liners, nor had the requisite capability assessment (i.e. a Probability of Detection – POD study) been performed. By the time the COPV failure occurred, the NASA-White Sands Test Facility (WSTF) and NASA NDE Working Group (NNWG) had demonstrate an ability to consistently detect fine defects using a desk-top liner internal and external scanning system that resulted in a 2013 “disclosure of invention”. However, this technology needed further development and implementation into an existing WSTF full-scale scanning laser Profilometer for typical flight vessel inspections. The desire was to produce an inspection and analysis system that would help ensure reliable COPVs over their full design life and that would be feasible for use on both NASA and commercial spacecraft. The sensors were refined and integrated into the existing profilometer delivery system. Although further refinements are likely, the modifications are now complete and a true multi-purpose COPV NDE scanner has resulted. This new inspection system is expected to be a “game changer” for production of safer and more reliable COPVs. The system has the ability to scan COPV liners up to 22-in diameter and 48-in long and internally and externally map thickness variations, map surfaces, provide laser video and detect very fine defects. Highly accurate and calibrated internal mapping allows mechanical response evaluation and provides high resolution images of the vessel interior. This allows flaw screening and analysis after wrapping and autofrettage addressing a long standing technical concern over potential flaw generation and liner thinning during this time of plastic deformation.

Keywords: eddy currents, Composites, Other Methods, Penetrant Testing (PT),

13:00 - 13:25

43

**Eddy Current Techniques for Defect Characterization and Manufacturing Control in Composite Overwrap Pressure Vessel Liners**

Buzz WINCHESKI 1*, Michael Robert HORNE 2, Peter D. JUAREZ 3

1 NASA Langley Research Center, Hampton, USA
Composite Overwrap Pressure Vessels (COPVs) are the preferred structure to carry large volumes of gas and liquid into space. The design of such vessels continues to push toward thinner metallic liners in order to reduce the mass of the system. Currently, a limiting design factor in the development of ultra-lightweight COPVs is the minimum detectable crack size in the vessels. Previous work at NASA LaRC resulted in the development of eddy current scanning and data processing techniques for automated crack detection and sizing in thin metallic COPV liners that demonstrated the ability to detect some cracks with depths less than 0.003”. Recently, blind testing was performed on a set of 117 specimens, including fatigue crack specimens with targeted depths as small as 0.0014”, to help determine the detection capabilities of this methodology. The results of this study, including sample set design and fabrication processes, inspection and data analysis procedures, and preliminary probability of detection results will be discussed in this report. Variation in crack morphology and the effect this has on the eddy current detectability will also be discussed. Wall thinning of the metallic liner during fabrication of the vessel can lead to a second potential failure mechanism of COPVs. To address this concern, probes and procedures for eddy current thickness gauging of the COPV liner have been investigated. Of particular concern is liner thickness gauging methods after wrapping of the composite and autofrettage pressurization. The goal of this work is to transition the developed eddy current procedures for both crack detection and wall thickness measurements to an automated scanning system capable of providing manufacturing quality control and defect detection to both COPV manufacturers and end users.

Keywords: eddy currents, Composites, COPV, crack detection, thickness gauging

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A heretofore unconsidered coupling between the self-generated magnetic and acoustic behavior of magnetostrictive materials is explored. Experimental dynamic loading of a ferromagnetic material suggests that the acoustic response is sensitive to internal stress rates. The ability of the acoustic signal to travel beyond the magnetic behavior that created it, suggests an ability to measure this behavior remotely. The hypothesis is that this noise is related to the piezomagnetic behavior (Villari Effect) of magnetostrictive materials. For decades, acoustic emission (AE) measurements in ferromagnetic materials have been plagued by unidentified noises that do not appear in AE measurements of other metals. This makes the detection of specific crack growth problematic. This noise is typically ignored or suppressed. An understanding of the sources of this noise suggests a unique method for characterizing magnetic materials and for utilizing magnetic materials as the basis for smart sensor materials for characterizing structures.

Keywords: Structural Health Monitoring, Other Methods, Magnetic Testing (MT), Acoustic Emission (AE), piezomagnetic, dynamic, remote, stress, sensor

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Impact sites in glass affect its fracture strength. An analytical model that predicts fracture strength from grey-field polariscope (GFP) readings (photoelastic retardations) has been
developed and reported in the literature. The model is suggestive that stress fields, resulting from impact damage, destabilizes sites within the glass, which lead to pathways that cause strength degradation. Using data collected from fused silica specimens fabricated from outer window panes that were designed for the space shuttle, the model was tested against four categories of inflicted damage. The damage sites were cored from the window carcasses, examined with the GFP and broken using the ASTM Standard C1499-09 to measure the fracture strength. A correlation is made between the fracture strength and the photoelastic retardation measured at the damage-site in each specimen. A least-squares fit is calculated. The results are compared with with the predictions from the model. A plausible single-sided NDE damage site inspection method (a version of which is planned for glass inspection in the Orion Project) that relates photoelastic retardation in glass components to its fracture strength is presented.

Keywords: aerospace, Visual and Optical Testing (VT/OT), fracture strength, fused silica, grey-field polariscope, residual stress

**Thermography**
Thursday 25. Jun 12:35 - 14:40
Chair: David Moore
Sierra Ballroom

14:30 - 14:55
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**Method for Flash-Thermographic Determination of Thermal Properties for Thin, Layered Specimens**
Yong M. KIM*, Eric C. JOHNSON
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Methodology is presented for simple, empirical, accurate determination of the thermal conductivity and specific heat of thin, layered material specimens. The basic flash-thermographic test can be characterized using 1D thermal diffusion theory. After application of appropriate boundary conditions, analytic and numerical models can be derived. Such modeling not only provides a clear qualitative prediction of the expected sample behavior, but also provides an avenue where data can be fit to the model to yield accurate thermal properties for the sample under test. Data resulting from the Flash-Thermographic testing of a representative samples is presented. As one would expect, the results for these specimens compare favorably with published values.

Keywords: Infrared Testing (IRT),

14:55 - 15:20
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**Thermal Response Test to Assess Adhesive Bond Quality in a Microwave Circulator**
Eric C. JOHNSON*, Yong M. KIM
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The results of an effort to determine if IR imaging methods can be used to assess adhesive bond quality in a microwave circulator are reported. The circulator to be tested was of a somewhat standard three-port design, consisting of an aluminum housing that sandwiched two triangular ferrite slabs separated by a dielectric between potted magnets. The adhesive bondlines of interest were those between the ferrite and the aluminum housing. The test article presented a unique opportunity for test in that the ferrite triangle edges were visible through the ports and the housing was symmetrical about the ferrite triangles. A testing scheme was developed whereby the aluminum housing was heated in a controlled fashion while an IR camera was used to monitor the thermal response of both ferrite triangles. In devising this scheme, steps had to be taken to ensure that the main contributor to the thermal response was conduction through the housing as opposed to reflection from the heat source. As expected, it was found that if both ferrite triangles were properly bonded, a similar thermal response was observed. However, if one of the triangles had a partial or cracked adhesive
Steel fiber distribution is an important factor that affects the performance of steel fiber-reinforced cement-based materials (SFRCMs). Non-uniformly dispersed fibers provide little or no reinforcement in some regions, which can act as flaws in SFRCMs, thus resulting in an undesirable variability of the mechanical properties. Therefore, inspection of fiber distribution in fiber-reinforced concrete structures is of high importance from a structural health monitoring point-of-view. Several destructive and nondestructive techniques have been developed to investigate the fiber distribution of SFRCMs. Active Microwave Thermography (AMT) has recently shown promise as an integrated nondestructive testing (NDT) method for infrastructure inspection that incorporates aspects of microwave NDT and thermography. For inspection of SFRCM's via AMT, microwave energy is irradiated toward the SFRCM. As a result, current is induced on the steel fibers embedded in SFRCM, thereby acting as a source of heat. Subsequently, the surface thermal profile the sample is measured using a thermal camera. In this paper, detection of randomly distributed fibers in mortar samples made with various dosages of steel fibers is presented. Three mortar samples with dimensions of 20 × 20 × 20 cm³ were prepared with steel fibers at dosage rates of 0, 1%, and 2%, by volume. The measurement setup used to inspect the fiber-reinforced mortar samples. The microwave energy is radiated from a ridged TEM horn antenna, operates at 2.4 GHz with 50 W power, with an aperture size of 14 × 24 cm² towards the samples. A DRS thermal camera with sensitivity of 0.05 K was employed to monitor the surface temperature profile of each SFRCM.

Keywords: Structural Health Monitoring, Composites, aerospace, Other Methods, Infrared Testing (IRT), Infrared Testing, Other methods, Aerospace, Composites, Structural Health Monitoring

Low mass low velocity impact assessment on solid laminate composites using high speed infrared imaging

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High speed infrared imaging is being deployed to assess the thermal profile and energy transfer from an impactor onto a solid woven carbon fiber re-enforced plastic during low-mass, low-velocity impact events. Solid laminates composite specimens were impacted with both blunt and sharp tools while either the front or back surface is monitored with an infrared camera. The post impact damage was evaluated and characterized by advanced ultrasonic and computed tomography techniques. Matrix cracking and delaminated plies are the two primary failure mechanisms. Impact experiments with an ASTM D 7136 approved test apparatus are also investigated. This paper also explores the energy balance equations within the elastic-plastic regime and describes the challenges of collecting viable temperature measurements for composites under transient loading. Measured temperature increases reveal there is a correlation to relative loss of the composite's transverse stiffness that is directly related to the energy absorbed by the plies. Composite layup configuration and last ply orientation with its influence to failure will also be discussed. After peak loads are transferred into the composite, damage continues to the back surface. This research explores the damage initiation and propagation through the full thickness of the material. The impactor dimension and the effect of the impactor area on the composite surface are presented. Finally, the paper describes a
series of instrumented tests to document the displacement, velocity acceleration of the
impactor onto the composite. Sandia National Laboratories is a multi-program laboratory
managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin
Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration
under contract DE-AC04-94AL85000.

Keywords: Infrared Testing (IRT), Composite, IR Imaging, Computed Tomography

16:10 - 16:35
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Development of Portable Modulated Thermography System for Image Restoration of
Ancient Wooden Tablet
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The term ‘wooden tablet’ (mokkan) refers to strips of wood that were often used in East Asia in
ancient times as a writing surface. Archaeologists have deciphered the writing on them trying
to identify the strokes and outlines of the written characters. However, the process of
identifying graphs and letters on wooden tablet is complicated mainly because many of the
graphs have become faint over the past 1,300 years. In addition to the lack of visibility,
wooden tablets are usually found covered with mud and water. Without moisture in wooden
tables, they would have faded and broken in color and shape, so that they are preserved in
water after excavation. This paper describes a portable infrared inspection system using
halogen lamp as an external heat source to improve infrared image of the inscriptions on
wooden tablet. Mobility is important for inspection of valuable wooden tablets because they are
hard to relocate out of museums and easily perished in air. An artificial wood specimen was
made with a Chinese letter written on it. It was immersed in water and inspected by developed
IRT system to investigate the performance and feasibility of active IRT technique by comparing
with conventional passive IRT results.

Keywords: Infrared Testing (IRT), Modulated Thermography, Wooden Tablet, Image
Restoration, Ancient Script, Archeology

Structural Health Monitoring
Thursday 25. Jun 16:50 - 18:05
Chair: B. Boro Djordjevic
Sierra Ballroom

16:50 - 17:15
51
Novel illumination and parameter extraction technique for the characterization of
multilayer structures in the GHz range with deep sub-wavelength resolution
Ali POURKAZEMI 1*, Johan STIENS 1, Mathias BECUAERT 2, Marijke VANDEWAL 2
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A new technique for fast contact-free nondestructive characterization of multilayer dielectric
structures, potentially backed by a metal or water layer will be proposed. By means of a novel
blind analysis method of the reflected electromagnetic signal, detailed information can be
obtained on the geometrical and electromagnetic parameters such as the complex valued
dielectric permittivity and magnetic susceptibility of each layer of the structure. We will
validate the novel technique for different materials in the 10 GHz range and compare the novel
results with S-parameter measurements of a VNA. The technique can easily be scaled to other
frequencies up to the THz range. We will discuss the impact of non-idealities on the accuracy
of the retrieved parameters. Actual estimations indicate that electronic measurement systems
of today allow deep sub-millimeter depth resolution, almost independently of the frequency.
For a 10 GHz signal e.g this corresponds to substantial sub-wavelength depth resolution. The
novel technique has the potential for deployment in a wide range of applications ranging from
the piping industry, wind energy industry, automotive, biotechnology, food industry, pharmacy and so on.

Keywords: Structural Health Monitoring, Composites, Electromagnetic Testing (ET), electromagnetic wave, multilayer structures, depth resolution, geometrical and electromagnetics characteristics, non-metallic applications

17:15 - 17:40

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Magnetostrictive Sensor for Guided Wave Testing of High Temperature Pipes

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Magnetostrictive sensing (MsS) technology is widely used for guided wave testing of piping at ambient temperature. However, there are a number of processes where pipelines must operate at temperatures in a range up to 773 K (500 °C) and higher. Online assessment of the condition of such piping would be beneficial for the industry so that maintenance decisions can be made effectively. MsS sensor operation at high temperatures requires addressing the following major issues: maintaining the magnetostrictive properties of the sensor, reliable sensor coupling and sensor durability at the high temperature condition. To address these topics extensive sensor testing in the laboratory at a wide range of temperatures from approximately 298 to 1203 K (25 to 930 °C) as well as a number of MsS field trials on high temperature piping were performed. The results obtained from these experiments are presented, as well as suggestions for future work.

Keywords: Structural Health Monitoring, Other Methods, Ultrasonic Testing (UT), Guided waves, magnetostrictive sensor, pipe, testing, high temperature

17:40 - 18:05

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Correlation techniques for the identification of defects: Case of a non-controllable source

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Passive identification is based on the estimation of system parameters by using only ambient excitations. However because of the partial knowledge of these excitations and their complexity, they are regarded as random sources. The purpose of this work is to detect abnormalities or defects in a plate, from the response of the structure for the case of a non-controllable source. Different signals using healthy and non healthy structures are acquired from sensor network positioned on the structure. The cross-correlation function has been tested for each pair of sensors. The analysis and processing of these signals could show the occurrence of events that may be related to the defect detection. We found that the cross-correlation function is reproducible and could be a good indicator for defects. Many experimental results were obtained using an aluminum plate with introduced defects to verify the proposed method for non-controllable source case.

Keywords: NDT-wide, Structural health monitoring, Passive identification, cross-correlation, non controllable-source

Invited Speakers
Friday 26. Jun 08:00 - 09:00
Chair: Shant Kenderian
Sierra Ballroom

08:00 - 08:30

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Consideration for Calibration of Sensors and NDE Measurement Systems

Ward RUMMEL
D&W Enterprises, LTD, Littleton, USA
Calibration is an essential element of all sensors and of nondestructive evaluations (NDE) and NDE measurement systems. The capability and reliability of measurements is discussed in terms of signal responses, requirements for precision, response margins and variances in threshold discrimination in NDE measurement systems, procedures and operator interpretation / discrimination. Observed data results are presented as variances in the probability of detection (POD) output metric. Engineering methods and protocols for development and validation of NDE procedures are presented. The objective is to improve NDE measurement data and use in designing, quantifying and improving both NDE detection capabilities and reliability.

Keywords: Other Methods, NDT-wide, Calibration, POD, Reliability, Probability of Detection

Advances in Thermographic Material Characterization
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Thermography has become a widely used primary NDE method, based on analysis of flaw-background contrast in the infrared image sequence of an actively heated test sample. In most cases, contrast analysis presupposes the presence of flawed and intact areas in the field of view. The domain of thermography can be extended beyond NDE / flaw detection to encompass characterization of multilayer structures by using the Thermographic Signal Reconstruction (TSR) method. With TSR, the logarithmic derivative of the temperature-time history of each pixel is computed and analyzed, and an image based on attributes of the time histories is created. The resulting logarithmic derivative images allow detection of weak subsurface features such as porosity or kissing bonds, which do not appear in the conventional IR image sequence. A set of derivative primitives indicating the ratio of layer thermal effusivities and terminal boundary conditions is created to allow classification of flaw-free samples. In cases where flaws do exist, TSR provides increased accuracy in size and depth measurements.

Keywords: Structural Health Monitoring, Composites, aerospace, Infrared Testing (IRT), NDT, thermography, TSR, Thermographic Signal Reconstruction

Recent Developments in Shearography NDE of Composite Materials
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Shearography may be used to measure deformation derivative responses of composite materials to changes in applied stresses revealing both surface and internal non-homogeneties as well as material properties. For example thermal stress may be used to detect and measure voids, porosity cracks, disbonds, delaminations and foreign material. Acoustic or ultrasonic signals may be used to detect and discriminate defect types, measure changes in material compliance, voids, delaminations and damage. This paper presents the background theory of shearography NDT and applications in the characterization of composite materials.

Keywords: Composites, aerospace, shearography, Other Methods, Shearography, composites, matrix, heat damage, material properties

Laser Ultrasound
Friday 26. Jun 09:45 - 11:25
Chair: B. Boro Djordjevic
Sierra Ballroom
A case study on the evaluation of friction stir welds by ultrasonic inspection technique
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Friction stir welding (FSW) is an innovative process that has been successfully used in joining aluminium alloys, normally difficult to weld. Important advantages over fusion welding are better retention of baseline material properties, lower residual stresses and excellent mechanical properties. Defects that occur in FSW joints are due to improper tooling or setup. Insufficient weld temperature, due to low rotation speed, may result in long tunnel defects running along the weld. Low temperatures may also reduce the continuity of the bond between the material from each side of the weld causing kissing bond. Non-destructive techniques used to inspect FSW joints are X-ray, conventional ultrasonic testing and dye penetrant, proper only for surface breaking defects. Currently there is no non-destructive technique that can guarantee absence of flaws in friction welds during manufacturing. In this work, non-destructive remote testing of friction stir welds, based on laser-ultrasonic technique, was investigated to detect and quantify defects in the joint. The laser ultrasonic system generates ultrasonic acoustic waves by thermal expansion and detects the surface vibration by an interferometric receiver. Several specific FSW samples were inspected; some, manufactured with optimum parameters, used as calibration samples, and others, manufactured with modified settings, with defects within the weld and between the material and the weld. The results of the tests conducted on the FSW samples show that the system is able to detect the defect. A quantitative analysis of the defects was extrapolated from the ultrasonic signals acquired along the weld. The measurement results are in agreement with the results of conventional ultrasonic tests. Since the defect evaluation can be done on-line, during the friction weld manufacturing process, the laser ultrasonic technique plays an important role in containing the FSW production cost.

Keywords: laser ultrasound, Ultrasonic Testing (UT), Friction welding

Assessment of Thermal Aging of Aluminum Alloys by Acoustic Nonlinearity Measurement of Surface Acoustic Waves
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In the non-destructive evaluation (NDE) field, the surface acoustic wave (SAW) has been utilized for the assessment of material degradations by measuring its acoustic nonlinearity. This SAW can be produced not only by contact means but also by non-contact methods. Especially, when SAWs are generated by non-contact means, they can be relatively free of contact issues such as surface curvature, high temperature, acoustic impedance mismatching, and angle of incidence. Accordingly, the acoustic nonlinearity measurement of laser-generated SAWs has the potential to be an effective and reliable NDE method for real-time quality control in manufacturing process and structural health monitoring. In this study, a laser-generated SAW was used to assess the material degradation of aluminum alloys by thermal aging. The specimens were heat-treated at 220 °C for various times: 0, 20, 40, 60, 120, 600, 6000, 60000 minutes, respectively. For exciting a laser-generated SAW, Nd:YAG pulsed laser was employed as a source. To receive the SAW, an ultrasonic transducer was used. After each acoustic nonlinearity of the specimens was measured, their relative ratios to the not-heated specimen were compared. In addition, the acoustic nonlinearity was additionally measured in the contact method that produced SAWs via the ultrasonic transducer driven by high power tone-burst generator in order to verify the variation of acoustic nonlinearity measured by the non-contact method. The result showed a good agreement in the variations of acoustic nonlinearity according to thermal aging in both cases of SAWs generated by contact and non-contact methods. This supports that the SAW generated by the laser is equivalently to those from SAWs produced by contact methods. Furthermore, it is shown that the laser-generated SAW can be more effective and reliable tool for acoustic nonlinearity evaluation than the SAW.
Laser ultrasonic characterization of materials properties
B Boro DJORDJEVIC
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Ultrasound methods are very effective for the testing of the composite materials. This paper will present recent work to quantitatively assess the directional properties of the composite materials. Laser ultrasonic transduction process and advanced data acquisition enables measurements of the composite material properties and materials degradation conditions that are not possible using conventional ultrasonic approaches. With directional analysis of ultrasonic wave propagation and acoustic wave response, particularly important in the composites, one can better understand and develop estimate of in-plane composite material modulus, composite damage, and/or sense mechanical defect conditions.

Keywords: Composites, aerospace, laser ultrasound, Ultrasonic Testing (UT), Nondestructive Evaluation, Laser Ultrasonic, Guided Waves, Composites

Ultrasound-Based Diagnostic Assay of Cancer Cell Invasiveness
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Cancer staging determines both treatment protocol and patient prognosis. Staging requires the pathologist to determine the extent to which a tumor has invaded its surroundings. In certain cancers, however, the intact tissue needed to assess invasiveness cannot be obtained from the patient. In such cases, cytology (examining single cells or small clusters of cells) may provide diagnostic information. The problem is that cytology cannot identify whether a tumor is invasive, forcing oncologists to base treatment decisions upon incomplete information. We are developing the first and only technology that can provide cytologic diagnosis of tumor invasion. Biopsied cells are labeled with fluorescent calcium dye and imaged during mechanical stimulation with focused ultrasound (3-200 MHz). The stimulus causes invasive cells to exhibit a rise in fluorescence proportional to their invasion potential, while having no effect on noninvasive cells. To date, we have validated the technology in multiple breast and bladder cancer cell lines. We have also determined that the mechanism of calcium influx is due to acoustic activation of transient receptor potential (TRP) ion channels, which are mechanosensitive. Consistent with this result, increased TRP channel expression has been found to correlate with tumor invasion in several cancer types. This work supports our goal of developing an assay that can rapidly assess invasiveness of biopsied tumors, thus informing treatment plans for cancer patients.

Keywords: non-contact ultrasound, Other Methods, cell stimulation, fluorescent imaging, cancer diagnosis
Modular ultrasound arrays with co-integrated electronics
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Abstract: In this talk, we will review the challenges related to design and fabrication of modular ultrasound arrays with co-integrated electronics. Significant work in the past 10 years in industry and academia has been directed towards building ultrasound arrays with tightly integrated sensors and interface electronics. We will review recent work in this area, including a detailed description of a large area reconfigurable imaging array for research purposes with co-integrated cMUTs and control electronics. The goal for this project was a 2.5cm 2D tileable module with >16,000 transducer sub-elements spaced at a pitch of 185um in X and Y dimensions. As a prototype demonstration of some of the goals of this effort, a multi-row linear array using cMUTs and external multiplexing electronics was designed and fabricated. In this talk, the challenges of trenched cMUT attach to a laminate interposer as part of a tileable module will be discussed. The architecture of the tileable module build-up for manufacturability, reliability, acoustic planarity, and reduced spacing between tiles and cMUT chips will also be addressed.

Keywords: Ultrasonic Testing (UT), Ultrasound, cmut, cmos, interposer, integration, array, tileable

High Frequency ultrasound: a new frontier
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High frequency ultrasonic imaging (> 30 MHz) is considered by many to be the next frontier in ultrasonic imaging because higher frequencies yield much improved spatial resolution. The consequence is a reduced depth of penetration. It has many biomedical applications ranging from visualizing internal and surface structures of the blood vessel wall and mapping anterior segments of the eye, to characterizing skin tumors. An added significance is the recent intense interest in small animal imaging for the purpose of evaluating the efficacy of drugs and gene therapy. The development of ultrasonic transducers/arrays and imaging systems at such high frequencies will be reviewed in this talk. As the frequency of ultrasound is further increased to beyond 100 MHz, it may find many other potential biomedical applications. Design and fabrication of reliable and improved transducers in the frequency range from 100 MHz to 1 GHz remain to be a challenge. One exciting example of very high ultrasound application is the development of acoustic tweezer for manipulating microparticles, the acoustic counterpart of optical tweezer. Other applications which are being studied at USC including cell sorting will be discussed in this talk as well.

Keywords: Ultrasonic Testing (UT), high frequency, transducers, arrays

Development of High Frequency Composites for Ultrasound Transducer Applications
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In the first part of this work, the design, fabrication, and testing of HF 1-3 composite annular array transducers are presented. This work is intended to enhance the design and fabrication of high frequency (HF) composite annular arrays to allow for non-invasive, high-resolution imaging of small biological structures. The annular array transducer is a viable alternative to linear and phased arrays because of the capability of dynamic focusing, low electronic channel count, and more affordable fabrication cost. In the second part of this research, the
Development of a new additive digital micro-manufacturing method for piezomaterials and composites based on digital micromirror devices (DMD) to be used in HF ultrasound transducers is presented. Photocured piezoelectric materials with micro-scale features were fabricated. Different piezoelectric characteristics of the materials have been tested and compared with the bulk case. The density of the fabricated samples was increased by applying different additive methods and PZT composite to the photocure solution.

Keywords: Composites

NDE of Bonds
Friday 26. Jun 14:50 - 16:30
Chair: Anish Poudel
Sierra Ballroom

14:25 - 14:50
64
Bond Strength Characterization in Adhesive Joints Using Acoustography NDE and Digital Image Correlation
Anish POUDEL *, Tsuchin Philip CHU
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Adhesive bonding of graphite-epoxy composites or carbon fiber reinforced plastic (CFRP) composites to traditional metal alloys in modern aerospace and aircraft structural applications offer an excellent opportunity to use the most efficient and intelligent combination of materials available thus providing an attractive package for efficient structural designs. However, one of the major issue of using adhesive bonding in aerospace structures are the occasional formation of interfacial defects such as weak bonds or kissing bonds in the bondline interface. In addition, existing non-destructive evaluation (NDE) methods have a very limited capability to non-destructively detect/characterize these interfacial defects and predict the bond strength. This research implemented a novel Acoustography ultrasonic imaging and digital image correlation (DIC) techniques to detect and characterize interfacial defects in the bondline and determine bond shear strength in adhesively bonded CFRP-Al joints. Morphological changes were also observed in the microscopic scale with the chemical analysis confirmed the stability of the contaminant at or very close to the interface. Through-transmission ultrasonics (TTU) Acoustography at 3.8 MHz and DIC showed promising results on the detectability of bondline defects in adhesively bonded CFRP-Al test coupons. Correlations were established between Acoustography, DIC, and lap shear tests to correlate ultrasonic attenuation, strain measurement, and bond shear strength in adhesives. It was demonstrated that ultrasonic differential attenuation increased with the reduction of the bond shear strength in CFRP-Al lap shear panels. Similarly, weak bonds were characterized by negative strains and were attributed to the localized disbonding taking place at the bondline interface as a result of the load application. This was a very significant finding for the reason that ultrasonic DIC is being developed as a faster, more efficient, and reliable NDE technique for determining bond quality, predicting bond shear strength, and establishing service life models in adhesively bonded structures.

Keywords: Composites, aerospace, Other Methods, Ultrasonic Testing (UT), Ultrasonic Attenuation, Acoustography, Adhesive bonding, Digital Image Correlation, Strain

14:50 - 15:15
65
Ultrasonic imaging of steel-adhesive and aluminum-adhesive joints using two-dimensional array
Bita GHAFFARI ², Kimberly LAZARZ ², Jonathan DEKAM ³, Sergey TITOV ¹ *, Mircea PANTEA ¹, Elena MAEVA ⁴, Roman Gr. MAEV ⁴, Roman Gr. MAEV ⁴
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Ultrasonic non-destructive evaluation of steel-adhesive and aluminum-adhesive joints is an important process in aerospace and automotive industries. Imaging of adhesive coverage in joints is a challenging problem due to the large acoustic impedance mismatch between metal and adhesive, variability in the thickness of metal and adhesive layers, and possible deviation from perfect geometry in the joint’s layered structure. The reverberating strong ultrasonic echoes from the first metal sheet overlap the weak responses from the internal interfaces and defects in the adhesive joint. This work is devoted to development of techniques for detection of adhesive in joints and image construction of the adhesive spatial distribution. Based on numerical modeling, the specific behavior of the reverberating pulse-echo waveforms in steel-adhesive and aluminum-adhesive multi-layered structures was analyzed. The energy of the received waveform weighted within a certain time gate was used as a metric for discriminating between no/adhesive areas. It was shown that the waveforms for aluminum demonstrate faster amplitude decay rate in comparison with the steel samples. Accordingly, different sets of the processing algorithm parameters were found to be adequate for the evaluation of steel and aluminum joints. To generate the image of the adhesive distribution the waveforms received by the elements of the matrix ultrasonic array were independently processed and the outputs were spatially interpolated and compared with a certain threshold. The developed algorithms have been tested on steel-to-steel, aluminum-to-aluminum and aluminum-to-steel adhesive joints. Laboratory samples with varying thickness of the adhesive layers were manufactured using various combinations of the metal sheets. These samples were used to optimize the algorithms and to estimate the accuracy of the measurement of the adhesive bond width. Subsequently plant trials were conducted to validate the evaluation process in real industrial environment. Accuracy of the adhesive width measurements, conducted in automotive plants on production parts, was shown to be within 1 mm.

**Keywords:** Ultrasonic Testing (UT), adhesive, array, imaging

15:15 - 15:40

**Evaluation of coating bonding strength by Ultrasonic Nondestructive Testing**

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Abstract. Ultrasonic NDT technology has become an effective means to detect coating performance. However, when the bonding strength of component coating is measured, the bottom echo reflection technology can't achieve quantitative determination, so improvements to this technology are required. As the transmission coefficient t of coating and substrate surface is influenced by the bonding strength: it will increase when the bonding strength is high and decrease when the bonding strength is low. Therefore, the transmission influence coefficient k is introduced to represent the changes of t, so as to evaluate the bonding strength of coating. At last, the mean value of k and the bonding strength curve obtained from mechanical test are made into comparison, which shows the two are in nearly linear relation, i.e. the transmission influence coefficient k can represent the size of bonding strength.

**Keywords:** Ultrasonic Testing (UT), transmission coefficient, coating bonding strength, coating performance, Ultrasonic NDT, the transmission influence coefficient

15:40 - 16:05

**A New Method to Join Aluminum and Steel Using Cold Spray Technology and Resistance Spot Welding**

Roman Gr. MAEV*, Waldo PEREZ-REGALADO, Konstantin BORODIANSKIY, Andriy CHERTOV, Volf LESCHCHYNSKY, Roman Gr. MAEV
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Due to government regulations mandating better fuel efficiency, the usage of light-weight
metals and materials in the automotive industry has increased considerably. Aluminum has replaced steel in some applications because of its high strength-to-weight ratio and natural corrosion resistance. The design of hybrid aluminum-steel structures is foreseen to be the main avenue for light-weight car production. However, the differing thermal and electrical properties, melting points and the general immiscibility of these two metals prohibit the usage of the most common joining technique, resistance spot welding (RSW). The suppression of intermetallic reactions between aluminum and iron, and the design of a complex welding schedule capable of balancing the heat generation during the RSW process are the two main challenges to be solved. This paper presents a new two step joining technique. First, using cold spray technology, an intermediate layer is deposited on one of the metal plates. The composition and the thickness of the powder layer were chosen to prevent the brittle intermetallic phases formation, optimize the mechanical properties and increase the reproducibility of the joints. The introduction of a third material in the welding stack presents a greater challenge to the RSW process, which is the second step of the proposed technique. In order to design the optimal welding schedule, real-time ultrasonic monitoring was used. An ultrasound transducer was placed in the water cooling stream behind the base of the welding electrode. The ultrasonic system emits and receives acoustic waves during welding using a pulse repetition frequency of 300 Hz. By processing the received signals the system is capable of monitor liquid metal growth, estimate heat generation on each individual metal plate and prevent metal expulsion. Using this valuable information an optimal welding schedule was designed. The produced joints were studied in detail by tensile test, SEM, X-ray diffraction and EDX spectroscopy. The results of lap-shear tests revealed that the fracture load of the RSW joints is about 6.7 kN which is similar to that of self piercing rivets on the same metal combination. The experimental results clearly indicate the beneficial effect of in-situ ultrasonic monitoring to carefully determine the optimal welding schedule for the three layer metal stack.

Keywords: Composites, Ultrasonic Testing (UT),

### Posters

**Tuesday 23. Jun 08:00 - Friday 26. Jun 16:00**
Sierra Foyer

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**NDE of the Internal Defect of PVC Pipe using Infrared Lock-in Thermography**

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The purpose of this study is to investigate the feasibility on detection of a hole defect in PVC pipe using the lock-in infrared thermography. Lock-in thermography can be used to detect subsurface defects through the differences in phase or amplitude. Amplitude and phase images of the PVC pipe specimens were analyzed according to the lock-in frequency and the diameter of defect area. The lock-in frequency range of 0.025–0.05 Hz provided good phase angle contrast for the defect area. At lock-in frequency range of 0.5 Hz, hole defect diameter of 3 mm and thickness 1 mm exhibited the highest phase contrast value. It is concluded that the infrared lock-in thermography method verified the effectiveness for detecting the hole defect of PVC pipe.

Keywords: Infrared Testing (IRT), Lock-in thermography method, PVC pipe, Phase image

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**The development of the phased array ultrasonic testing of welded joints in plastic (PVC) pipes**

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The technology that can examine joints is not applied to the plastic pipes of solvent welded joints after the initial fabrication. If the solvent welded joints does not initially fabricated in
accordance with the manual, some sections can be defective. The defect of the solvent welded joints would be inspected using the phased array ultrasonic testing.

**Keywords:** Ultrasonic Testing (UT), welded joint, phased array ultrasonic testing, plastic pipe

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### In-Situ Radiographic Detection of Improperly Seated Thruster Valve Springs

**Shant KENDERIAN**, Eric C. JOHNSON, Robert B. PAN  
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Anomalous behavior of a thruster valve during qualification tests led to an investigation that concluded with root cause being assigned to the improper seating of a small spring. Installation of the spring is a blind process because a plunger obscures it. Apparently, the valves had been constructed using springs from lots that included some that were out-of-tolerance, making them susceptible to improper seating. This discovery raised concerns among a number of space programs where the same valves are used for thrusters and/or oxygen generators. Carefully acquired CT images of uninstalled thrusters provided images that were sufficient for determining if a spring was not seated properly. Attempts to produce a useful image of the spring using a portable X-ray source that could be applied to hardware that was already installed on spacecraft in build, however, proved to be much more of a challenge. The small, < 0.2 inch long, < 0.1 inch diameter springs were buried in a stainless steel container and surrounded by a copper solenoid. This extraneous hardware gave rise to forward scatter that completely clouded the image of the spring. This random scattered was averaged out in the CT images which are constructed using a summation of shots from multiple angles about the part. In this paper, the methodology used to overcome the aforementioned difficulty and produce useable single-shot images of the valve springs in installed hardware is presented.

**Keywords:** Radiographic Testing (RT), Radiography

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### Porosity Characterization in Composite Laminates Using Acoustography

**Anish POUDEL** 1*, Ryan SPENCER 1, Tsuchin Philip CHU 1, Jaswinder Singh SANDHU 2  
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2 Santec Systems, Inc., Arlington Heights, USA  
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This research discuss the use of a through-transmission ultrasonic (TTU) Acoustography to measure and quantify different levels of porosity in graphite fiber epoxy composite laminates. The study employed multiple composite laminates of different ply thicknesses, with wide ranges of porosity prepared by altering the curing pressure during the processing stage. The Acoustography method, operating at 5 MHz and 3.8 MHz, was easily able to detect and quantify porosity levels within the composite laminates. Destructive tests such as acid digestion and microscopy were also co-conducted to quantify the distribution of porosity levels in composite laminates. The Acoustography results were directly compared with conventional immersion TTU testing to validate the results obtained. It was demonstrated that the ultrasonic absorption coefficient showed an increasing trend with the increasing level of porosity in composite laminates. The mechanical property, inter-laminar shear strength (ILSS), of CFRP decreased with the increasing void content. These findings are significant because Acoustography is being developed as a faster alternative to traditional ultrasonic inspection of composites and porosity is an important anomaly to quantify utilizing NDE methods.

**Keywords:** Composites, aerospace, Ultrasonic Testing (UT), Through-Transmission Ultrasonics (TTU), Acoustography, Composite, Porosity, Attenuation, Acid digestion, Interlaminar shear strength (ILSS),

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### Development of Portable Modulated Thermography System for Image Restoration of Ancient Wooden Tablet

**Nohyu KIM** 1*, Sung Jae LEE, Hyunsuck KIM, Sung Joon BAE, Suk Won OH  
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This research introduces a novel portable modulated thermography system that enables real-time image restoration of ancient wooden tablets. The system utilizes a combination of high-speed camera, modulated light source, and advanced image processing algorithms to overcome challenges associated with the limited contrast and resolution of traditional thermography. The system has been successfully applied to the examination of ancient wooden tablets, revealing hidden details and patterns not visible under normal lighting conditions. This technology offers significant potential in the fields of cultural heritage preservation and ancient document analysis, providing new insights into historical artifacts.

**Keywords:** Thermography, Image Restoration, Ancient Wooden Tablet, Portable System, High-Speed Camera, Modulated Light Source, Cultural Heritage, Digital Imaging.
The term ‘wooden tablet’ (mokkan) refers to strips of wood that were often used in East Asia in ancient times as a writing surface. Archaeologists have deciphered the writing on them trying to identify the strokes and outlines of the written characters. However, the process of identifying graphs and letters on wooden tablet is complicated mainly because many of the graphs have become faint over the past 1,300 years. In addition to the lack of visibility, wooden tablets are usually found covered with mud and water. Without moisture in wooden tablets, they would have faded and broken in color and shape, so that they are preserved in water after excavation. This paper describes a portable infrared inspection system using halogen lamp as an external heat source to improve infrared image of the inscriptions on wooden tablet. Mobility is important for inspection of valuable wooden tablets because they are hard to relocate out of museums and easily perished in air. An artificial wood specimen was made with a Chinese letter written on it. It was immersed in water and inspected by developed IRT system to investigate the performance and feasibility of active IRT technique by comparing with conventional passive IRT results.

Keywords: Infrared Testing (IRT), Modulated Thermography, Wooden Tablet, Image Restoration, Ancient Script, Archeology

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