Table of Contents

1. Characterizing the Effect of Transverse Strain on Carbon Nanotube Based Sensing Skins for Structural Health Monitoring

2. Multifunctional Films for Fusion Bonding and Structural Health Monitoring of Thermoplastic Composite Joints

3. A Quantitative Evaluation of AFP Steered Courses Through Inspection

4. NDE Inspection of AFP Manufactured Cylinders Using an Intelligent Segmentation Algorithm

5. Evolution of Composite Defects During Manufacturing: Wrinkles & Delamination

6. A Comparison of Surface Preparation Techniques for Wind Turbine Field Repairs

7. Remediation of Contaminated Bond Surfaces: Contaminant Mixtures


9. Structural Health Monitoring of Composites from Carbon Nanotube (CNT) Coated E-Glass Fiber
1. Characterizing the Effect of Transverse Strain on Carbon Nanotube Based Sensing Skins for Structural Health Monitoring

Abstract: Due to the advancement in the science of processing and characterization of nanostructured materials, along with the industrial-scale production and decreasing cost of carbon nanotubes, their use in technologies as sensors and sensing skins is gaining popularity. With increasing Technology Readiness Levels (TRL) and field trials implemented by researchers, it is critical to characterize the sensing response of the carbon nanotube sensing skins under complex loading scenarios in order to simulate the real-life conditions. Typically, researchers describe the sensitivity (gage factor, GF) and sensing response of a carbon nanotube sensing skin based on the electrical resistance change and the longitudinal strain (ε1), not taking into consideration the effect of transverse strain (ε2) due to the Poisson’s ratio of the material. Since the sensitivity of the sensor is dependent on the transverse strain, the sensitivity is affected by the properties of the substrate material. As a result, the calibration of the sensing skin is challenging. The principal objective of our research is to characterize the effect of transverse strain and develop a methodology to quantify the influence of transverse strain on the sensing response. The carbon nanotube-based sensing skins are manufactured using a scalable manufacturing technique and the effect of different loading scenarios on the sensing response are investigated. Carbon nanotubes are deposited on non-woven aramid fabrics with randomly oriented fibers and the resulting carbon nanotube-based sensing skin is bonded to steel and composite substrates which are subjected to flexural and axial loads to characterize the sensing response. A cruciform shaped specimen with a carbon nanotube sensor is tested using a biaxial testing machine and change in resistance under varying transverse loads is characterized. Key results indicate that the sensitivity of the carbon nanotube sensing skin is significantly affected by the transverse strain due to the Poisson effect which should be taken into consideration when calculating the gage factor or calibrating the sensors.

Author(s): Sagar M. Doshi, Michael Coatney, Madison Weiss, Amit Chaudhari, Dae Han Sung, Erik T. Thostenson and Asha Hall

2. Multifunctional Films for Fusion Bonding and Structural Health Monitoring of Thermoplastic Composite Joints

Abstract: Ultrasonic welding is a promising method to quickly bond thermoplastic composite parts. In this process, a thermoplastic film, called an “energy director”, is placed between two pieces of composite materials, and melted during the welding process to facilitate bonding. This study seeks to develop a multifunctional energy director suitable for three purposes:
1) ultrasonic welding, 2) structural health monitoring (SHM) via electrical resistance measurements, and 3) heating element for disassembly and repair of the damaged bond. Various materials and manufacturing methods were investigated to develop multifunctional films: 1) magnetic or conductive nanoparticles deposited onto polymer films, and 2) multi-walled carbon nanotubes (MWNTs) dispersed into polymers. The latter was selected as a promising candidate because of its ease of manufacturability through compression molding and its compatibility with the welding process. The thermo-electrical and electro-mechanical behavior of compression molded films containing up to 20 wt% MWNT in a polypropylene (PP) matrix was assessed via a sourcemeter and dynamic mechanical analyzer. To demonstrate multifunctionality, glass fiber/PP specimens were ultrasonically welded with the MWNT/PP films as energy directors. While the multifunctional films reduced lap shear strength by up to 10%, they did not significantly affect the welding process. Moreover, welded specimens with the MWNT/PP films were successfully tested under cyclic bending for SHM through resistance measurements.

Author(s): H. Frederick, W. Lia, W. Sands, E. Tsai and G. Palardy

3. A Quantitative Evaluation of AFP Steered Courses Through Inspection

Abstract: This article will discuss the use of a comprehensive methodology to inspect and track defects of steered Automated Fiber Placement (AFP) tows on a cylindrical surface. The high degree of automation in the AFP process makes the manufacturing method an excellent platform to produce variable stiffness composite structures. A key method in their production is the use of tow steering to create desired stiffness properties. However, with tow steering, there is an increased likelihood for the production of defects such as wrinkles and folds. A profilometry-based inspection method is utilized with a hand-crafted data processing technique to create accurate measures of tow displacement and tow deformation. This information is then used to create a quality metric which can be matched with processing parameters at the time of layup.

Author(s): Christopher Sacco, Roudy Wehbe, Anis Baz Radwan, Mazen Albazzan, Andrew Anderson and Ramy Harik

4. NDE Inspection of AFP Manufactured Cylinders Using an Intelligent Segmentation Algorithm

Abstract: This article will discuss the approach and results for the identification of defects on an Automated Fiber Placement (AFP) manufactured cylinder. While the increase in productivity in
AFP manufactured structures has allowed for the large-scale production of composite parts, imprecision in process can lead to the production of defects. A comprehensive platform for the inspection of AFP manufactured cylinders for utilizing a profilometry-based data collection approach was used. This data is then processed by a novel machine learning method. The machine learning method is based on the creation of fully convolutional neural networks and is used to fully characterize defects developed on cylindrical parts. Defect information was used to inform the repair of the cylinders and capture defects on cylinders that were intended to have hand placed defects. Cylinders were then used for validation of structural analysis tools.

**Author(s):** Christopher Sacco, Anis Baz Radwan, Andrew Anderson and Ramy Harik

### 5. Evolution of Composite Defects During Manufacturing: Wrinkles & Delamination

**Abstract:** The ubiquitous usage of polymer matrix composites in many applications demands a comprehensive understanding of composite interfaces, which critically affect both the manufacturing processes and the deformation mechanisms. Processing-induced defects in composite structures such as wrinkles and delaminations are primarily a result of inter-ply interfacial movement during manufacturing. In this paper, a new in-situ experimental approach and an ex-situ X-Ray characterization are proposed for developing a fundamental understanding of ply interfaces during composite manufacturing. A carbon fiber laminate is cured in a specially designed autoclave with viewports with plies laid-up on a mold with cylindrical tooling setup to simulate the maximum movement of plies, resulting in the formation of wrinkles and delamination. Three cylindrical tools of radius 9.5mm, 12.7mm and 15.9mm are used in preparing three different molds for the layup. Ply-movement is measured in-situ using Digital Image Correlation (DIC) during the cure cycle through the viewports of the autoclave. In addition, the resulting defects are characterized post-cure using X-Ray Micro-CT. Results show that at wrinkle the maximum out-of-plane movement of 1.32 mm is happening for a 4-ply unidirectional laminate laid up on a mold with 15.9mm tool diameter.

**Author(s):** Sandeep Chava and Sirish Namilae

### 6. A Comparison of Surface Preparation Techniques for Wind Turbine Field Repairs

**Abstract:** Wind turbine service lifetimes can exceed 20 years. This extreme operational demand necessitates reliable and consistent field repairs. However, the effects of current wind turbine field repair surface preparation techniques are not well-documented and are thus not well-

**>> Return to Table of Contents**

Society for the Advancement of Material and Process Engineering
www.nasampe.org
understood. This leads to reliance on technician experience rather than scientific data for repair procedures, which causes variability in the quality of repairs. Solvent wiping is a common procedure for contaminant removal after damaged material is removed from a wind turbine blade, but it was unknown if solvent wiping reduces the surface energy and consequently the likelihood of a durable repair. The goal of this study was to quantify the effects various surface preparation techniques have on the overall strength and reliability of wind turbine repairs. Type of reagent-grade solvent, fiber direction, matrix, and adhesive were varied for contact angle and lap shear testing. It was found that the type of solvent used affects neither the surface energy nor the maximum lap shear stress, but the fiber direction and matrix-adhesive combinations significantly affected maximum lap shear stress values.

Author(s): Ariel F. Lusty, Douglas S. Cairns, David A. Miller and Daniel D. Samborsky

7. Remediation of Contaminated Bond Surfaces: Contaminant Mixtures

Abstract: Aerospace manufacturing and repair environments include the very real possibility that bond surfaces presented to the adhesive will not always have the correct composition to ensure acceptable bond performance. There are myriad avenues for contamination of bond surfaces. Contact contamination occurs from unsanitary material handling. Common sources for these contaminants are through substandard wipers, contaminated solvents, and abrasives which contain release agents such as stearates. Aerosol contamination events from airborne substances such as cutting fluids, lubricants, and mold releases are well documented. Another less frequent but real source of contamination is from peel ply that was unintentionally coated with release agent from the manufacturer. Control of adhesive bonding operations to guarantee reliable bond performance requires careful, quantitative bond surface control along with methods for successful remediation of contaminated surfaces. This work describes the development of quantifiable, reliable, and easily deployable techniques for controlling bond surface properties in manufacturing and repair by i. ensuring that the composite surface has been prepared properly for bonding, and ii. if the surface has been identified as having been improperly prepared (e.g. contaminated), establishing quantifiable methods for remediation of the surface.

Author(s): R. Giles Dillingham, Brooke Campbell and Matthew Nichols

>> Return to Table of Contents

Abstract: In today’s world, continuous fiber reinforced composite materials are extensively used in the aerospace, automotive and other structural industries. Since the applications of such fibers demand for a high safety rating, it is of utmost importance for engineers who design such materials to analyze its safety. When cracks are developed in such materials, the mechanical, electrical, and thermal properties also get altered as a function of the cracks. Previous studies have shown that changes in electrical properties can be directly correlated with the development of cracks in the material which can then be used to predict the remaining life of such materials. In this study we propose to introduce an additional layer of Electrospun Polyvinylidene Fluoride (PVDF) nanofiber in the CFRP matrix. PVDF is a piezoelectric material, meaning it will generate electricity on encountering vibrations. Therefore, when PVDF nanofibers are introduced in the matrix, the stress on the matrix will be translated onto the nanofibers which in turn will output electrical signals. In this study, 3 types of glass fiber composites (embedded with PVDF, embedded with PVDF with Multiwalled Carbon nanotube, and no additional material) are subjected to quasi static tensile tests while the impedance across the material is continuously measured. The change in impedance was then related to the stress the material was subjected to and predict the remaining life of the material.

Author(s): Rahman J. Mazed, Muthu Ram Prabhu Elenchezhian, Vamsee Vadlamudi, Riaz Ahmed, Rassel Raihan and Kenneth Reifsnider

9. Structural Health Monitoring of Composites from Carbon Nanotube (CNT) Coated E-Glass Fiber

Abstract: This research investigated the development of a nanomaterial-based sensor for health monitoring of composite structures. To develop the sensor, carbon nanotube/epoxy mixture (2%wt CNT) was coated on a strand of E-glass fiber to be adhered onto a fiberglass composite specimen. The selection of E-glass fiber and fiberglass plate was largely due to its electrical insulating properties to demonstrate that the carbon nanotube is driving the sensing capabilities through its highly conductive nature. In addition, by adhering the coated E-glass fiber to a fiberglass coupon, the homogeneity and material properties were approximately maintained. Tensile testing of the specimen conducted through a Lloyd LD50 tensile testing machine provided data on the actual strain which was correlated with the experimental differential resistances measured by a multimeter, both at the same specified tensile loading conditions. With two sets of data, the experimental resistance data was calibrated with the...
actual strain data collected. Ultimately, the experimental sensors created a sample of gauge factors which represents 91.24% probability of replicating the observed range of gauge factors by using the same manufacturing procedures, providing a valid alternative and consistent method to detecting composite damage.

Author(s): Sidney Wong, Omar Dwidar, Sergio R. Rodriguez Herrera, Eltahry Elghandour, Ph.D. and Amro El Badawy, Ph.D.