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Basic (General Overview/Introductory)

Moderate (Working Knowledge of Technical Content)

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Additive Manufacturing

Technical Paper | Moderate

Manufacturing and Analysis Considerations of Ultem 9085 Resin in Aircraft Structures

Zeaid Hasan, Bill Skaff, and Dusty Dequine (Boom Supersonic)

The aerospace industry relies on having parts that can be built to very tight tolerances, have high strength to weight ratios, and withstand harsh environments in order to achieve a product that can withstand decades of operation with high reliability and minimal repairs. The materials used in most current civil air transport and military airplanes are metallic materials (e.g aluminum, titanium, steel) and carbon fiber reinforced polymers. It took many years and substantial funding to allow the use of composites on aircraft as primary structures given the stringent regulations imposed by the FAA and other regulatory agencies on the materials used. Over the past several years a new class of material candidates have emerged that are compatible with additive manufacturing processes, namely thermoplastic resin materials. This can be considered a revolution as the time and cost associated with building parts needed for aircraft structures can be dramatically reduced while allowing for complicated designs. For the regulatory agencies to allow its use as a mainstream alternative, it will take tremendous effort from the industry to prove its reliability across the different operating environments. This paper will discuss aspects related to the use of Ultem 9085 on flight critical aircraft structure where the primary mode of assembly is using secondary bonding. Aspects related to static, fatigue and vibro-acoustic will be discussed and guidance on how to evaluate such parts will be given.

Technical Paper | Moderate

3D Printed Dual-Cure Epoxy: Enabling High-Performance Hybrid Composite Structures

Alec J. Redmann, Paul V. Oehlmann, Rui Zhang, Sue J. Mecham, and Tim A. Osswald (University of Wisconsin-Madison)

A new process is described in this paper which provides an improved alternative to traditional joining and manufacturing methods for pre-impregnated fiber reinforced plastic (FRP). Utilizing additive manufacturing and a dual-cure epoxy resin, joining members are first 3D printed using a UV process; resulting in a semi-rigid, but only partially cured part. This part still has chemical potential and bonding availability when it is integrated with pre-impregnated fiber reinforcement. The assembly is then heated to activate the second curing reaction and co-cure the two materials, forming a permanent, void-free cohesive bond. The bonding quality of pre-impregnated fiber-epoxy composites joined with this co-curing method are compared to an industrial adhesive by single lap-shear and block shear tests, and show competitive results. A current aerospace application is also examined.

Technical Paper | Basic

Monolithic Frame Fabrication

Warren R. Ronk and Blaise F. Bergmann (Spirit AeroSystems, Inc.)

Spirit AeroSystems, Inc., (Spirit) is the largest Tier-1 supplier of composite fuselage structures. For commercial programs, Spirit fabricates and assembles co-cured composite skin stringer body panels with composite body frames. Body frames are structural members providing reinforcement to aircraft fuselages. Frames are fabricated from polymer matrix composites are typically mechanically fastened to intermediary components known as shear ties, which are then fastened to the fuselage. Monolithic frames reduce part and fastener counts, weight, and installation time by integrating the shear tie into the frame geometry such that the frame can be directly fastened to the fuselage. However, the use of monolithic composite frames is currently limited due to the need for technology advancement and development of a robust manufacturing process. This paper will present a manufacturing approach that reduces the cost and increases the quality of monolithic composite frames. This approach consists of 1) preparation of a flat prepreg charge using automated fiber placement (AFP), 2) using a hot drape forming (HDF) technique to form the flat prepreg charge into the frame geometry, and 3) autoclave curing of the frame. Experimental application of this technology to multiple frame geometries, including Z frames and C channel frames with a variety of bend radii, will be presented. Results of inspection will also be discussed, including non-destructive inspection using pulse echo ultrasonic (PE) to determine part quality.

Technical Paper | Moderate

Additive Manufacturing of a Scintillator for Radiation Detection

Peter J. Joyce, Brad Baker, and Marshall Millett (United States Naval Academy)

The objective of this work was to create an unobtrusive, discreet radiation sensor. In this paper we describe the additive manufacturing process used to fabricate an organic scintillation detector for use in detecting ionizing radiation. An off the shelf stereolithography printer was used with standard transparent resin which was doped with varying scintillant powders in varying amounts. The concentration of the dopant, the method of mixing, and the overall printing process was investigated to produce an additively manufactured scintillator which was then mated with a standard photomultiplier tube to detect and measure ionizing radiation. The overall detector was tested with gamma and neutron sources over exposure periods. The detector was able to clearly distinguish the sources from background with an expected continuum energy response relative to the strength and energy of the source. Future work will include customization of the geometry, coupling to other light sensors, and expansion to other printing methods, and evaluation of the ability to further discriminate non-ionizing radiation sources to create an effective and discreet detector.

Adaptive Manufacturing with Laser Material Deposition Using Intermittent Machine-Integrated Line Scanning

Jan Bremer, Sven Linden, Tim Fleischhauer, Andres Gasser, and Johannes Henrich Schleifenbaum (Fraunhofer ILT)

Laser Material Deposition (LMD), also known as Directed Energy Deposition (DED), has the potential to decrease production costs and lead time in repair and manufacturing applications of high-value and high-performance components. The ability to produce near-net-shape parts yields low material loss and is especially valuable when working with high-cost materials such as titanium alloys or nickel-based superalloys. LMD is commonly used for repair applications in industries such as aerospace, tooling and turbomachinery. As for most direct material deposition processes, geometrical process stability and robustness of the LMD process can be a limiting factor for applications in additive manufacturing (AM).

In this work, the principle of intermittent process control based on component geometry scans using a machine-integrated line scanner is validated and tested for tolerance to geometric deviations of the substrate. The developed prototype software is validated by hybrid-additive manufacturing of a boroscope flange geometry in 2.5 D on an industrial robotic system. To evaluate transferability into full 3D geometry applications, algorithms are presented to fit the tool center point (TCP) path to freeform surfaces, where surfaces are rasterized as a depth maps (Z-Map), clipping non-build geometry from the measurements and filtering for stability improvements of the algorithm. The layer height control strategy algorithm based on intermittent scanning and using Z-maps is tested for continuous adaption of layer height from substrate to target geometry to enable stable near-net shape processing. Based on this Z-Map algorithm as input, a free-form slicer is further developed to compute TCP paths with surface normal data, which is simulated on 3D curved components.

Development of a Test Bench for Fused Filament Fabrication

Alexander Matschinski, Alberto Juan Alburquerque, Benedikt Kriegl, and Klaus Drechsler (Technical University of Munich)

Quality of FFF parts, such as layer-layer adhesion or geometric fidelity, is mostly depending on the material flow. This flow is influenced by several parameters. Current investigations only use the known process parameters to optimize the printed products. Therefore, FFF is not reaching beyond technical readiness level (TRL) 3 for most industrial applications. In order to increase the TRL, detailed process understanding, especially the interactions of process parameters, has to be gained. This paper presents a novel test bench for the detailed analysis of the extrusion process. The setup includes three load cells. This enables the investigation of the interrelationships between process parameters and the material behavior in the melt zone. The examinations comprise a set of extrusion temperatures from 195 to 200 °C and an extrusion speed from 100 to 600 mm/min.

Thermoplastic Additive Manufacturing – Ultem 9085 for Structural Applications

Daniel R. Klenosky, Brian R. Kitt (Spirit AeroSystems, Inc.)

ULTEM 9085 is a thermoplastic Fused Deposition Modeling (FDM) material with structural potential; high thermal and chemical resistance; adherence to industry flame, smoke, and toxicity (FST) standards; and high strength-to-weight ratio (about 25% of the Ti-6-4 ratio). It not only meets the traceability and process verification requirements necessary for certification and use in the aerospace industry but there are published, statistically significant material property values. Finally, the ability to produce complex, net-shape parts via FDM with no need for post-processing opens the door for a number of design features not currently practical for other materials, especially hard-to-machine materials like Ti-6-4. With these many advantages, ULTEM 9085 has become a common material for a variety of non-structural aerospace applications. The natural next step for this material is to investigate its potential for use in secondary structural applications. In this work, a number of generic Ti-6-4 bracket-like parts were thickened based on published ULTEM 9085 and Ti-6-4 properties to have equivalent stiffness to their titanium counterparts. ULTEM 9085 parts were mechanically tested at room temperature via proof testing followed by loading to failure under service-like loads to verify strength predictions, understand failure modes, and learn about trade-offs between the FDM process and the conventional Ti-6-4 forming and machining process. Test results shed light on the relative advantages and disadvantages of the material and the FDM process for use in secondary aerospace structural applications.

Virtual Investigation of Residual Part Deformation Due to Build Plate Support Characteristics in Material Extrusion Additive Manufacturing

Eduardo Barocio, Akshay Jacob Thomas, R. Byron Pipes (Purdue University)

The Material Extrusion Additive Manufacturing (MEAM) process with fiber-reinforced thermoplastics has enabled scaling the dimensions of geometries that can be printed to the scale of multiple meters. Multiple applications including tooling for processing composites and prototype vehicle components have been successfully demonstrated with large scale MEAM systems such as BAAM and LSAM. The highly non-isothermal processing conditions developed during the printing process give rise to residual stresses and part deformations. To prevent the part from deforming excessively during the printing process multiple methods have been adopted in MEAM to adhere parts to the build plate. These include adhesives, thin sheets of polymeric material adhered with vacuum, and textured surfaces. In addition, the build plate is in some cases actively heated. Depending on the part geometry and the stresses developed during the printing process, debonding of the printed part from the build plate can occur during printing. To prevent the exhaustive process of empirically calibrating processing conditions for different configurations of part adherence, this work investigates virtually the effect of three different methods for

adhering the part to the build plate; namely an adhesive layer, a thin sheet of polymer (build sheet) held with vacuum to the build plate, and a rigid constraint at the bottom provided by some mechanisms that provide mechanical interlocking between the part and the build plate. Two geometries which include a plate and a double stringer tool are investigated under the different conditions. The investigation is carried out with ADDITIVE3D© and with a material card for which temperature and deformation predictions have been validated experimentally. It was observed that, for both geometries, the adhesive model showed maximum pull-off from the build plate whereas the model with the rigid constraint at the bottom showed the least pull-off. This preliminary study indicates that a stiff interaction between the part and the build plate reduces the part deviation from the designed geometry.

Technical Paper | Moderate

Investigating Inter-Weld Bonds Under Tension in Mechatronic AM Processing

Sean Pslkowski, Jolie Frketic, Helen Parker, Raquel Werner, Tarik Dickens (High Performance Materials Institute)

Additive manufacturing (AM) for rapid product development, has seen continued growth in adoption to facilitate complex low volume part production. However, the current process lacks true simultaneous deposition of multi-materials in a single operating space and is limited by lengthy build times and end part functionality. Attempts to correct this through unique nozzles or filament slicing still retain significant idle time between distinct material deposition. In tandem with industrial automation acquisition, a novel application of collaborative manipulators has been developed to fulfill the need for truly simultaneous AM operations in a shared space. Robotic manipulators occupy an established foothold in current industrial manufacturing settings, establishing the infrastructure for future wide scale adoption of collaborative printing. This paper aims to investigate and quantify the optimal operational scheme of a collaborative AM system sharing a workspace of non-uniform resolution. In particular, the effects of printing speed, nozzle diameter, time elapsed between layer extrusion and material overlap in dual-printed parts. The study showed larger overlap between layers and slower printing speed to have contributed significantly to higher mechanical strength in parts. Finally, this study benchmarks operational variance of multiple printing agents as it compares to modern manufacturing systems, acting as a cornerstone to facilitate a fluid workflow of collaborative AM.

Technical Paper | Moderate

Additive Manufacturing of Optical Components Using Commercial Off-the-shelf 3D Printers

Ethan Z Delannoy, Peter J. Joyce, R. Brian Jenkins, Charles Nelson, Deborah M. Mechtel, David P. Durkin (United States Naval Academy)

The goal of this research is to use 3D printing with polymers to fabricate rigid or flexible optical components (such as optical waveguides or lenses) to control light

propagation. Vat polymerization and fused deposition modeling printing techniques were used to fabricate optical components. Scanning electron microscopy, infrared spectroscopy, thermogravimetric analysis and differential scanning calorimetry were used to evaluate the structure/composition and thermal properties of the printed materials. These data identified defects in the original printed structures that were responsible for light scattering, and guided the development of novel post-processing techniques to optimize the optical properties of the additively manufactured components. Post-process annealing delivered components with significant improvements in transparency and reduced light scattering. As a result, lenses have been printed that successfully focus light, and optical refraction and reflection of laser light was observed in 3D-printed waveguide structures. Optical losses were measured to determine the extinction coefficient for the Beer-Lambert Law and a double slit experiment was used to demonstrate if the 3D printed parts maintained spatial coherence.

Technical Paper | Moderate

Additive Manufacturing of Polymer Derived Silicon Oxycarbide Ceramic Structures

Shengheng Gu, Jayanta Kapat, Jihua Gou (University of Central Florida)

This study presents the synthesis of a photo-polymeric resin towards 3D printing of polymer derived ceramic to create amorphous SiOC ceramic structures with complex geometries. The SiOC polymer derived ceramic resin was synthesized by a photosensitive methyl-silsesquioxane as preceramic polymer and 3-(trimethoxysilyl) propyl methacrylate as polymer chain graft, namely MKTMSPM. Through the hydrolysis sol-gel reaction, the MK-TMSPM system condensed into a cross-linked network with multiple photosensitive function groups, which are key to the photocuring process while free radical photo-initiator excited by the UV source. During the Digital Light Processing (DLP), the liquid resin was locally cured to the desired shape on each layer based on the input CAD model. Once the first layer cured, the building plate moves upwards to pull out resin layer by layer with a cured thickness of 0.05 mm. After DLP, the green body was sintered in a tube furnace in the nitrogen atmosphere at 1,000°C. This method allows to fabricate a component with specific 3D geometries that can be converted into ceramic structures, offering a number of potential applications, such as medical devices,

Technical Paper | Moderate

Compression Molding Tool Production Via Additive Manufactruring - Design and Part Optimization

John F. Unser, Peter Wang, Andrzej Nycz (IACMI The Composite Institute)

Advanced Composites Manufacturing Innovation (IACMI), Oak Ridge National Lab Manufacturing Demonstration Facility (ORNL MDF), Century Tool, and Lyndoll Bassell have teamed together to focus on metal printing of tooling for compression molding composites. The goal of this technical collaboration was to evaluate the use of large-scale metal additive manufacturing (AM) to print metal molds for the mainstream (>100k units/year) production of large composite components by compression molding. Today, metal tools are typically made by subtractive machining of large blanks of forged tool steel, or sometimes by metal casting in conjunction with post-cast machining. Lead time for procuring a large forged blank is often many months. This drives program schedules and generates significant metal scrap. Metal AM has the potential to reduce lead time and waste, which would increase the viability of large-scale composites. Additionally, metal AM can provide unique advantages such as increasing geometric complexity and enabling design changes mid-program. For this project, baseline metrics for additively manufactured metal tooling were established, and small-scale metal tool was additively manufactured and evaluated. The results indicate that it is feasible to produce metal tooling for composites using metal AM.

Technical Paper | Moderate

Thermal Cycling of Dahltram I-350CF

Zachary I. Skelton, Aubrey G. Jackson, Philip A. Lunn, Oliver P. Bottler (Airtech Intl.)

Using Large Format Additive Manufacturing, a layup mold was fabricated using Airtech's Dahltram I-350CF for development testing. Thermal cycle testing was then completed to validate the performance of high temperature polymers for autoclave use. All testing was completed at Airtech Huntington Beach using their in house testing capabilities. During the course of 100 thermal cycles dimensional stability and vacuum integrity were deemed critical. In addition to thermal cycle testing, a thermal survey was also performed on the mold to confirm that the printed tool could meet processing conditions for the greater aerospace industry.

Technical Paper | Moderate

Hybrid Manufacturing Technique Using Large-Scale Additive Manufacturing and Compression Molding for High Performance Composites

Vipin Kumar, Seokpum Kim, Vidya Kishore, Kaustubh V. Mungale, Avery Nowlin, Uday Vaidya, Craig Blue, Vlastimil Kunc, and Ahmed Arabi Hassen (Oak Ridge National Laboratory)

Additive Manufacturing (AM) or 3-D printing has moved from small-scale prototypes to large-scale functional structures. With the introduction of large-scale 3D printers into the market a new industry has been born. For the first time, we are pre-senting the idea of preparing large-scale 3-D printed β-stage preforms to be used in traditional compression molding (CM) manufacturing technique to prepare final functional structures. Short carbon fiber (CF) reinforced material acrylonitrile buta-diene Styrene i.e. ABS with 20% CF is used in present work. It is shown that highly aligned 3D printed short carbon fiber composite maintains its orientation after com-pression molding. A sandwich panel is prepared to show the capability to prepare complicated parts by integrating AM and CM. Interphase of the prepared dissimi-lar material is also studied using SEM. Samples prepared using AM-CM integration showed 11% and 79 % improvement in tensile strength and tensile modulus respec-

tively compared to the traditional extrusion compression molding (ECM) process.

Education Session | Basic

Large Scale Additive Manufacturing for Composite Tooling

Rick Neff (RICK NEFF, LLC)

One of the key technologies to composite manufacturing is quality tooling. Tooling often dictates the cost and schedule of a project. Additive manufacturing has the promise of reducing the cost and the lead time significantly over traditional tooling. The path has not been easy as there have been challenges along the way. Here has been an evolution in machinery, materials and methods that have resulted in a robust process for quickly making low cost tools that can hold vacuum. 3D printed tools can hold up to a production environment as well Additively Manufactured tooling has been used in the boating industry for both plugs and production molds. Boat molds and plugs can be 3D printed. There are a few examples of 3D printed watercraft as well. A variety of projects highlight the different methods that have been tried. Aerospace has been working to qualify processes, materials and methods for both production and prototype work. Years of research between leading companies, research laboratories and OEMs have continuously yielded new results. See examples of work done by Oak Ridge National Laboratory, Tru-Design, Boeing, Lockheed Martin, Airbus, IACMI, Techmer PM and Thermwood Inc.   Companies can routinely process a variety of materials from room temperature materials like ABS and Polycarbonate to high temperature materials such as PPS, PSU, PESU and Ultem. Each has its advantages and limitations. Materials with a lower glass transition temperature are easier to print, especially at large scale. Higher temperature materials cool faster so you need to print faster if you want to make large parts. The latest equipment can print quite large parts out of even high temperature materials like PSU.   AM for composite tooling has forged past the challenges and can truly be implemented today for both prototype and production tooling. Composite manufacturers really can implement 3D printed tooling to reduce the cost and lead time of their production.

Education Session | Moderate

Transforming traditional tool designs to Large Format Additive Manufacturing

Austin Schmidt (Additive Engineering Solutions)

CANCELED

As Large Format Additive Manufacturing (LFAM) gains acceptance in the marketplace, it has become increasing important to understand the key drivers that make traditional tool shapes good candidates for LFAM. Additionally, in order to reap the benefits of LFAM, it is important to redesign the tools to take advantage of the LFAM manufacturing process In the first part of this talk we will evaluate different tooling geometries and discuss what shapes, features and requirements make for good LFAM tools, while also identifying which shapes are better off produced in a traditional manner. With the good candidates identified, we will work through an example of an aerospace tool redesign for LFAM. We will start with the traditional tool design and work through the redesign process to arrive at an optimized tool geometry. During this process, we will discuss key elements such as face sheet support, back up structure design, light weighting strategies and build orientations. Additionally, we will discuss how material selection and layer time drive further design decisions. Finally, we will also discuss how the equipment employed to complete the printing drives additional design decisions. The final design will result in an optimal tool design ready to be manufactured on LFAM equipment.

Education Session | Moderate

Large scale, thermoset additive manufacturing for tooling and fixtures (PART 1)

Mike Kastura (Magnum Venus Products)

This multi-part presentation (PART 1), over two educational sessions will discuss four specific areas of 3D, additive manufactured printing; using new-to-the-world thermoset printing equipment utilizing liquid, ambient temperature cure, print media. The four speakers will focus on: advantages of the AM equipment; the processes required to pump and print with liquid materials; the mechanical and physical properties of the liquid and cured thermoset materials; while finishing with a case study of thermoset printed tooling with an inside view of advantages for printing in thermosets. Session 1-A (Kastra) 25 minutes - will discuss the details and challenges of developing a commercially viable large-scale thermoset additive machine. The speaker will elaborate on differences in thermoset printing, the associated pumping equipment and the current status of printed articles and the future state thermoset printing. Additional process advantages will be discussed such as print resolution, reframing the digital file to end product timeline, over-molding, pick and place, and more. Session 1-B (Hershey) 25 minutes – will discuss the details required in software and process development that has moved thermoset additive manufacturing from small scale desktop systems to large format prints, utilizing liquid based, reactive polymers. Chemical crosslinking between layers not only improve z direction mechanical strength, but also allow for the printing of cold joints. This allows multiple molds and fixtures to be printed, stopped then finished days later. Additional topics will include discussions on “sparse-to-solid printing” where sparse infill cores transition to solid surface layers required for machining or coating a monolithic mold or fixture surface. Session 1-B will end with a brief discussion on the significant energy savings by processing reactive polymers at ambient temperatures without melting thermoplastics or metals as is traditionally done in small or large format, 3D printing.

Education Session | Moderate

Large scale, thermoset additive manufacturing for tooling and fixtures (PART 2)

Rick Pauer (Polynt/Reichhold Composites)

This multi-part presentation, over two educational sessions will discuss four specific areas of 3D, additive manufactured printing; using new-to-the-world thermoset printing equipment utilizing liquid, ambient temperature cure, print media. The four speakers will focus on: advantages of the AM equipment; the processes required to pump and print with liquid materials; the mechanical and physical properties of the liquid and cured thermoset materials; while finishing with a case study of thermoset printed tooling with an inside view of advantages for printing in thermosets. Session 2-C (Pauer) 25 minutes – will discuss the reactive deposition material properties and associated advantages in mechanical strengths, with a major focus on Z-direction bonding strengths between applied layers, initially as well as weeks later. Discussion will include the ease of repair or modification of a 3D printed surface, without the need to go back onto the original printing unit. Session 2C will end with a brief discussion of suitable coating options (if needed) for sealing a mold surface or for developing a class A mold surface. Session 2-D (Kennedy) 25 minutes – this final session will discuss practical examples of thermoset molds and why 3D printing was chosen, along with the benefits derived from rapid build, direct-to-mold tooling. The discussion will include an in-depth analysis including time and cost by an end user that covers their previous plug building method for tools in the marine industry vs direct-to-mold using additive manufacturing.

Advances in Materials

Technical Paper | Moderate

Transport Properties of Carbon Fibers Derived from Petroleum-Based Mesophase Pitch with Modified Transverse Microstructures for Enhanced Tensile Strength

Sagar Kanhere, Dr. Victor Bermudez, and Prof. Amod Ogale (Clemson Uniersity)

Carbon fibers are extensively used in aerospace, defense, and automobile industry due to their lightweight and superior strength. Some of these applications demand high electrical and thermal conductivity, which glass fibers cannot provide because glass is an insulating material (in contrast to conducting carbon). For instance, in spacecraft electronic housing, it is important that carbon fiber reinforced composite be able to dissipate heat. Mesophase pitch-based carbon fibers possess excellent electrical/thermal conductivity due to their high graphitic crystallinity. Also, they can be produced from petroleum-based mesophase pitch, potentially a low-cost precursor. In this study, transport properties of such carbon fibers are reported. Precursor fibers possessing a wide range of micro-texture (radial to circular alignment) of discotic liquid crystalline molecules were produced using novel spinneret design. The design is well-suited for high-volume production of pitch fibers using continuous extruders. After thermo-oxidative stabilization in an air environment at 220°C and atmospheric pressure, fibers were graphitized at 2100°C. The tensile strength of carbon fibers with circular (non-radial) micro-texture was measured at 2.9 ± 0.4 GPa whereas that for radial texture was 2.4 ± 0.2 GPa. The higher strength for non-radial texture is a consequence of deflection of crack in the hoop direction along circular layers. Often, such an improvement in strength is accompanied by a reduction in other properties. However, the current results indicate that the longitudinal electrical resistivity of carbon fibers was measured to be about 5 μ·m for both types of mi-cro-textures. As estimated from the Issi-Lavin correlation, this corresponds to a ther-mal conductivity of 300 W/m·K, which is about 1500% greater than that of the best PAN-derived carbon fibers. Thus, micro-textural modification that led to enhanced tensile properties did not deteriorate transport properties. Further, X-ray diffraction revealed that the graphitic d002 layer spacing was 0.34 nm for both micro-textures, indicating about 20% graphitic crystallinity. Interestingly, the circular (non-radial) micro-texture that helped to enhance tensile strength did not result in reduced gra-phitic content, so conductivity did not deteriorate. It is hypothesized that the longi-tudinal texture of the graphitic crystallite remains unchanged even as the transverse texture changes from radial to circular, a phenomenon that will be investigated in future studies.

Technical Paper | Moderate

Synthesis of Aryl Ether Ketone-Containing Polybenzoxazines

J. Scott Murphy and Jeffrey S. Wiggins (University of Southern Mississippi)

Thermoset networks, such as epoxide-amines and polybenzoxazines, typically display brittle behavior as a result of their rigid backbones limiting sub-glass transition temperature (Tg) relaxations of the polymer network. Methods to decrease the brittleness and increase the toughness of aerospace-grade thermoset networks traditionally include the incorporation of aliphatic curatives, rubbers, or thermoplastics. However, these methods often reduce the ultimate Tg of the system and increase network heterogeneity. Alternatively, integrating thermoplastic moieties, specifically polyaryletherketone moieties, into the backbone of a polymer network is an effective approach to increase the toughness of a polymer network while simultaneously minimizing the reduction of ultimate Tg and eliminating network heterogeneity. This research incorporates aryl ether ketone (AEK) backbones into polybenzoxazine networks to increase network strain-absorbing and energy-dissipating mechanisms. Herein, an AEK containing benzoxazine monomer was synthesized, and monomer synthesis is confirmed via proton nuclear magnetic spectroscopy. Differential scanning calorimetry is used to further prove monomer purity, endothermic melting, and determine the onset and peak polymerization temperatures. Dynamic mechanical analysis is employed to quantify the Tg and glassy storage modulus of the AEK containing polybenzoxazine network. Thermogravimetric analysis is utilized to determine the thermal stability and char yield of the AEK monomer and the cured polybenzoxazine network. This work demonstrates the successful synthesis and thermomechanical characterization of an AEK containing polybenzoxazine.

Technical Paper | Moderate

Phenylphosphine Oxide Catalysis of Epoxy Polymerization

Witold K. Fuchs, Catherine, A. Sarantes, and Jeffrey S. Wiggins (University of Southern Mississippi)

Atomic oxygen (AO) attack to carbon-fiber reinforcing polymers (CFRP's) on spacecraft surfaces in low earth orbit (LEO) threatens spacecraft safe operation and service life. Incorporating phenylphosphine oxide (PPO) groups into epoxies has been shown to offer a self-regenerating method of protection from AO, but has catalytic effects on the polymerization reaction of epoxies. Herein, epoxides and diamines containing PPO groups were synthesized and the reactivity of the prepared monomers was evaluated for shelf-life and workability. The catalytic effect of PPO on the epoxy polymerization was investigated via differential scanning calorimetry (DSC), rheokinetic evaluation, real-time Fourier-transfer infrared spectroscopy (FT-IR), and real-time heated 31P nuclear magnetic spectroscopy (NMR). The catalytic mechanism was further investigated through electron rich and electron deficient PPOs to elucidate the effect of aromatic substituents on the catalytic effect. It was found that the incorporation of electron rich phosphines had significant catalytic effects on the epoxy polymerization, shifting the onset of polymerization earlier by 50 °C. Moreover, the material remains processable as evaluated by rheology and a mechanism for the catalytic reaction is proposed. This work builds upon previously reported research to fully evaluate PPO epoxies and furthermore suggests that PPO epoxies are excellent candidates for AO resistant CFRPs.

Technical Paper | Advanced

Manufacturing of Polymer Coated Glass Fibres for Increased Fibre Volume Content

Sandesh Shirke, Richard Haas, Alexander Lüking, Robert. Brüll, Thomas. Gries, and Thomas Exlager (ITA, RWTH Aachen University)

In order to overcome the shortcomings of poor resin infiltration and increasing void content in products made using Glass Fibre Reinforced Plastic (GFRP), it is important to address the issue at the micro-level. The proposed solution is to coat the glass fibres at the production stage. This is achieved by coating the individual glass fibres with the polymer matrix during the spinning process. A process chain for coating individual glass filaments during production is developed at the Institut für Textiltechnik (ITA), RWTH Aachen University, Aachen, Germany. The glass filaments are spun at 1000 m/min speed this helps in ensuring high efficiency and productivity. A coating technology with a selection of an appropriate coating resin as per the end-use application is chosen. All fibres are completely coated with the matrix which ensures uniform distribution of forces and prevents the formation of voids. Coating of glass fibres also eliminates the intermediary process thereby saving cost, time and labour efforts.

Technical Paper | Moderate

The Missing Link: How Coupling Agents Enhance Mechanical Performance

Lee R. Gunning, Brian Kleinheinz, and René Nagelsdiek (BYK USA, Inc.)

Thermoset based composites have become an essential part of our daily life. Their benefits are not limited to current technologies but also in pioneering future trends. The increasing importance of electric vehicles, wind energy, and aviation results in a higher demand of lightweight but mechanically extremely robust and reliable reinforced materials. Though it is possible to improve single components such as resins, fillers, or fibers, there is a certain limit due to the influence of each individual component. In an alternative approach, the link between the resin matrix and a dispersed phase providing reinforcement (fillers, fibers) can be optimized. An easy way to

achieve the desired coupling are additives which have the ability to cross-link with the resin and to form a bond to the filler or fiber. These additives are known as Coupling Agents. The structure of Coupling Agents needs to be adjusted according to the chemistry of the matrix and dispersed phase. The Coupling Agents of the BYK-C 8000 family solve this task by creating a strong bridge between resin and reinforcement, giving access to more durable and long-lasting materials and allowing higher freedom of design. In this article, we provide an overview about the general mode of action of coupling agents and illustrate their versatile potential by means of various application examples.

Technical Paper | Moderate

Customer Friendly Novolac Epoxy Vinyl Ester Resins

Kevin R. Lambrych, Lisa M. Adkins, and Achille Bivigou Koumba (INEOS Composites)

Novolac epoxy-based vinyl ester resins (NEVERs) were commercially introduced in the early 1970's to deliver improved thermal performance and improved chemical resistance properties as compared to bisphenol-A epoxy vinyl ester resins (EVERs). They provide high resistance to solvents, acids and oxidizing substances such as chlorine. They also offer high retention of strength and toughness at elevated temperatures. A key reason NEVERs have improved thermal and chemical resistance is due to their higher crosslinking density. Every molecule in a NEVER has more reactive sites than a molecule in an EVER. As a byproduct of this increased functionality, NEVERs are more reactive. In thicker laminate constructions or at elevated shop temperatures, this increased reactivity makes NEVERs more difficult to process due to higher heat development during the cure. Fabrication efficiency is compromised as operators are limited in the number of layers of reinforcement that can be laid up during one application. This paper will touch on the history of NEVERs and review a new novolac epoxy vinyl ester resin technology called Derakane™ Signia™ 470 resin. This new NEVER technology offers improved cure characteristics that allow fabricators to lay-up thicker parts in a single step, thus improving fabrication efficiency. This resin also has reduced styrene emissions, better surface cure characteristics, and greatly reduced grinding requirements. Together, these benefits provide a greatly improved customer experience. The new resin is built upon the same polymer backbone as previous generations of INEOS Derakane™ 470 type NEVERs so the mechanical, thermal and corrosion performance is unchanged. General mechanical properties, corrosion performance (ASTM C581 testing) and secondary bonding data will be presented to establish that this new range of resins maintain the same level of performance as previous generations of novolac epoxy vinyl ester resins. Performance data from the lab and the field demonstrating improved processing and fabrication efficiency will also be presented.

Technical Paper | Moderate

Additive Manufacturing of Strain Gauge Sensors Using Conductive Polymer by Fused Deposition Modeling and its Applications on Linerless Composite Pressure Vessels

Shamim Mondal, Ryan D. Smith, Jeremy J. Eavey, and Robert M. Villarreal (Infinite Composites Technologies)

This investigation reports on the use of additively manufactured biaxial strain gauge sensors for assessing the loads and deformations in a linerless (type V) composite pressure vessel (CPV). Fused deposition modeling (FDM) is a widely used rapid prototyping/additive manufacturing technique due to its relatively fast processing time and low cost. However, additive manufacturing of strain gauge sensors using FDM is uncommon because there are very few suitable conductive filaments commercially available. The filament selected for the strain gauge sensors in this study is a conductive polymer with low resistivity and high melting point which are crucial for the strain gauge to maintain its shape and integrity to obtain accurate, low power readings after being subjected to high temperatures during the post-curing process of CPVs. A small footprint and the lack of a permanently attached substrate allows the placement of strain gauges integrated into the composite layer to have minimal impact on the structural integrity of the pressure vessel. The applications for this study include but are not limited to pressurant and propellant tanks for launchers and spacecraft, self-contained breathing apparatus, space habitats and alternative fuel tanks.

Technical Paper | Advanced

Mechanically Improved and Multifunctional CFRP Enabled by Resins with High Concentrations Epoxy-Functionalized Fluorographene Fillers

Junhua Wei, Eugene Beh, Rahul Pandey, Gabriel Iftime, Jessy Rivest, and Sean Garner (PARC)

To meet the maximum potential of the mechanical properties of carbon fiber reinforced plastics (CFRP), stress transfer between the carbon fibers through the polymer matrix must be improved. A recent promising approach reportedly used reinforcing particles as fillers dispersed in the resin. Carbon based fillers are an excellent candidate for such reinforcing particles due to their intrinsically high mechanical properties, structure and chemical nature similar to carbon fiber and high aspect ratio. They have shown great potential in increasing the strength, elastic modulus and other mechanical properties of interest of CFRPs. However, a percolation threshold of ~1 % of the carbon-based particle concentration in the base resin has generally been reported, beyond which the mechanical properties deteriorate due to particle agglomeration. As a result, the potential for further increase of the mechanical properties of CFRPs with carbon-based fillers is limited. We report a significant increase in the strength and elastic modulus of CFRPs, achieved with a novel reinforced thermoset resin that contains high loadings of epoxy-reacted fluorographene (ERFG) fillers. We found that the improvement in mechanical performance of CFRPs was correlated with increase in ERFG loading in the resin. Using a novel thermoset resin containing 10wt% ERFG filler, CFRPs fabricated by wet layup technique with twill weaves showed a 19.6% and 17.7% increase in the elastic modulus and tensile strength respectively. In addition, because of graphene's high thermal conductivity and high aspect ratio, the novel resin enhanced CFRPs possessed 59.3% higher through-plane thermal conductivity and an 81-fold reduction in the hydrogen permeability. The results of this study demonstrate that high loadings of functionalized

particles dispersed in the resin is a viable path towards fabrication of improved, high-performance CFRP parts and systems.

Technical Paper | Advanced

Cure Path Dependence of Reaction-Induced Phase Separation in Glassy Amorphous Polymer Networks

Matthew C. Hartline, Jared Bates, Nathaniel L. Prine, David C. Walker, David E. Garcia, Xiaodan Gu, Jeffrey S. Wiggins (University of Southern Mississippi)

Reaction induced phase separation of high Tg thermoplastics from epoxide/amine networks during cure is one common method for the toughening of networks. However, the toughness realized in the final network entirely depends on the morphology, which can range from droplet dispersed, co-continuous, to phase inverted. An additional complication the dependence of mechanism of phase separation on the cure path on the. Spinodal decomposition is the preferred phase separation mechanism, but the competing process is nucleation growth phase separation. To realize maximum toughening effect, co-continuous morphology is desired, and the most consistent morphologies are developed through the spinodal decomposition phase separation mechanism. For this work, tetraglycidyl -4,4'-diaminodiphenylmethane (TGDDM), 4, 4'-diaminodiphenylsulphone (44DDS), and non-reactive polyetherimide (PEI) are dissolved in solvent until homogenous, then the solvent is removed and the 44DDS is clarified at 125 °C until only the b-staged, transparent yellow film remains. Rheology from clarified sample through gelation resolves the phase separation mechanism. Samples are cured from 80 °C to 180 °C at ramp rates of 1 and 5 °C/min and remain at the 180 °C isotherm for two hours. Samples are further post cured at 220 °C for an additional hour to ensure full cure. Morphology of cured networks is examined with atomic force microscopy-based infrared spectroscopy (AFM-IR), which additionally establishes the chemical identity of each phase. Morphology is confirmed with optical microscopy, and dynamic mechanical analysis (DMA), where thermomechanical response correlates with morphology type. Final morphology depends heavily on the thermoplastic loading level, while the mechanism of phase separation can depend upon the cure rate. At all cure rates, co-continuous networks are realized when PEI loading ≥ 15 wt.%.

Technical Paper | Moderate

New high-temperature polyimides to push high-performance polymer boundaries

Christian Maurer, Günter Gasparin, Dieter Danzer, Ankur Kant and Nathan Schindler (Evonik Fibres GmbH)

In this paper the authors review the main properties of polyimides and explain the influence of certain chemical structures on the obtained mechanical and thermal properties. Based on two examples new developments are presented, with which limitation of existing products have been overcome and the operating temperature could be expanded. A new type of polyimide molding powder shows extraordinarily high thermo-oxidative stability with constant strength over more than 1000 hours,

when storing at 340°C in air. A new polyimide fiber with higher Tg demonstrates less shrinkage, enabling use in filtration processes with surge temperatures up to 280°C.

Technical Paper | Moderate

Close the Gap – A Durability Study of Epoxy-Basalt Fiber Composite Rebar for Concrete Reinforcement

Yi-Ling (Ivan) Liang, Huifeng Qian, Francisco De Caso, Prof. Antonio Nanni (Olin Corporation)

Nonconventional rebar made by fiber-reinforced polymer (FRP) composite has been available to the industry for many years, mainly due to its unique value propositions, including: (a) high mechanical performance to weight ratio, and (b) corrosion free nature in those constructions exposed to harsh environments. Unfortunately, even nowadays, engineers have to adopt relative excessive safety factors when using FRP reinforcement because of the lack of durability-performance information. To address this need, this study presents laboratory results conducted at a Florida Department of Transportation approved testing facility. The tested bars were pultruded using epoxy-anhydride thermoset and basalt fibers. The durability performance was evaluated after an accelerated environmental treatment that involves a 90-day immersion in alkaline solution at 60 oC. Details, including testing method, specification, and promising outcomes are discussed in this paper.

Technical Paper | Moderate

A Break-Through Technology Reducing Residual Formaldehyde in Phenol-Formaldehyde Resins

Carlos Maldonado, Frank Ludvik, Ramji Srinivasan (Georgia-Pacific Chemicals LLC)

Reducing residual formaldehyde content in phenol-formaldehyde resins (phenolic resins) is a frequent request in composites and other industries. Phenolic resins used for industrial applications, such as abrasives, filtration, honeycomb, foaming, etc., historically contain free formaldehyde levels ranging from 0.3 % to greater than 1.5 %. A new break-through technology reduces the free formaldehyde in phenolic resins to below 1000ppm (or less than 0.1 %). This new ultra-low free formaldehyde resin was compared to a commercial phenolic resin used for industrial applications. The resin characterization (gel permeation chromatography and high-performance liquid chromatography) and thermal analysis (differential scanning calorimetry, dynamic mechanical analysis) as compared to the standard commercial phenolic resins will be discussed.

Technical Paper | Moderate

Multi-Walled Carbon Nanotube Dispersion for Aerospace Adhesives Via Continuous High Shear Reactor

Matthew C. Hartline, Christopher D. Croshaw, Hayden A. Hanna, David E. Garcia, Kyzysztof K.K. Koziol, Sameer S. Rahatekar, Jeffrey S. Wiggins (University of Southern Mississippi)

Often, carbon nanotubes are utilized to increase the conductivity and/or mechanical performance of a polymer matrix. The improvements in mechanical performance are directly related to the high modulus and high aspect ratio of the carbon nanotubes. The conductivity of the nanocomposite is related to the purity, quality of the dispersion, and dispersion state of the nanotubes. The high aspect ratio multi-walled carbon nanotubes (MWCNTs) used in this work are grown in aligned "carpets", which is in contrast to the more common "tangled balls" of MWCNTs. This reduces the required shear to untangle and disperse the nanotubes, which are bound together through strong Van der Waals interactions. Once a dispersion is created, it can be disrupted during the cure of the material, as viscosity drops and diffusion increases. This work prepares MWCNT dispersions in the continuous high shear reactor, which greatly reduces the time required to adequately disperse the nanotubes, while simultaneously b-staging the epoxide-amine network. The dispersion states of the uncured and cured nanocomposites are examined using optical microscopy and transmission electron microscopy. Dispersion throughout cure is monitored using real-time optical microscopy digital imaging and oscillatory shear rheological experiments to determine the critical viscosity, above which reagglomeration is minimized. Mechanical, thermomechanical, and electrical characterization of nanocomposite networks is presented.

Technical Paper | Moderate

Role of Surface Functionality and Polyamic Acid in Carbon Fiber/PEI Interface

Munetaka Kubota, Joseph M. Deitzel, John W. Gillespie Jr. (University of Delaware)

The promise of chemical resistance, high toughness, recyclability, and fast cycle times have reignited the interest in fiber-reinforced thermoplastics. To fully realize the synergistic effects of fiber-reinforced composites, the fiber/matrix interface becomes critical. Fiber manufacturers apply a sizing package to protect the fibers from damage during handling and weaving, but also include adhesion-promoting coupling agents onto fibers designed for thermosetting resins such as epoxy. Analogous coupling agent options become scarce since many of the organic oligomers used for adhesion promotion degrade at the high processing temperatures of the engineering thermoplastics such as polyetherimide (PEI) or polyether ether ketone (PEEK). Furthermore, unlike thermosetting resins, which have an opportunity to covalently bond to the coupling agent, the mechanism to improve the fiber/thermoplastic interface is unclear. This work investigates the role of the surface functionality and polyamic acid in improving carbon fiber/PEI interface employing the single fiber fragmentation test (SFFT). Surface functionalization was done using a thermal oxidation technique, and polyamic acid was selected for its ability to imidizes at the process temperature of PEI. The interfacial shear strength was increased by about 20% with a combination of surface functionalization and a coating of polyamic acid.

Technical Paper | Advanced

Thermal Decomposition and Fire Retardancy of Polyimide a0nd Graphene/Polyimide Composites

Jude O. Iroh, Caroline Akinyi (University of Cincinnati)

CANCELED

The effect of graphene on the decomposition and flammability behavior of polyimide-graphene nanocomposites was investigated using thermogravimetric analysis, TGA performed both in nitrogen and air atmosphere. The composites were tested at heating rates of 10 °C/min and 30 °C/min over a temperature range of 25 °C – 1000 °C. The decomposition of the composites was observed to follow similar pattern in both air and nitrogen atmosphere. The rate of degradation of the polyimide was found to decrease by 45% at 50 wt.% graphene. This decrease in the rate of polyimide degradation can be correlated with a decrease in fuel generation rate and by extension, a decrease in heat release rate. Degradation of polyimide and graphene/polyimide nanocomposites in air was observed to occur in multiple stages; polyimide matrix degradation, polyimide char degradation and graphene degradation. The rate of degradation of the polyimide char in air was found to decrease by up to 67% in the composites.

Education Session | Moderate

Overmolding with Continuous Fiber Reinforced Thermoplastic Composites for Selective Reinforcement

Brent DeSilva (Avient, formerly known as PolyOne Advanced Composites)

Continuous fiber reinforced thermoplastic (CFRTP) composites are emerging as the next generation of composite materials for highly engineered applications and as metal replacement. Overmolding with CFRTP integrates composite tapes or laminates into traditional thermoplastic molding processes, such as injection and compression molding, to create locally-reinforced, molded components. Incorporating CFRTP reinforcement into molded thermoplastic components combines the design flexibility and fast cycle times of traditional molding with the strength, stiffness, and light-weighting benefits that composites offer. Key topics include an overview of thermoplastic composite tape and laminate properties; an explanation and demonstration of the overmolding process; and examples of applications for overmolded components. Data presented will include strength and impact performance comparisons of reinforced and unreinforced materials, and stiffness and weight comparisons of varying ratios of polymer and reinforcement to achieve specific performance targets. Data on theoretical versus empirical test data for stiffness will be discussed. Case studies demonstrating the value of overmolded components in various applications will be presented. Material studies include the use of filled and unfilled thermoplastic injection-molding grade materials, namely polypropylene and nylon 6 with long fiber glass and carbon fiber. These materials were testing in 3 and 4 point bending at room temperature and elevated temperatures, in impact, and in flat-wise tensile.

Design and Manufacturing with high-end Thermoplastic Composites

Christian Braun (Ensinger Composites Schweiz GmbH)

Many advantages of thermoplastic polymers are well known. Among them are high toughness, temperature resistance and chemical resistance. When considering continuous fiber reinforced composites made from these matrix materials, a much wider field of requirements can be met thanks to the wide selection of available polymer types and grades. However, since the variety is so vast, selecting the right material requires a thorough knowledge. In addition, since the processing of thermoplastic composites has high technological demands on equipment, heating and mold technology, this is often seen as an obstacle for engineers new to the field. Material selection criteria, amongst them mechanical, chemical and thermal criteria, are discussed and guidelines for the right selection are given. Materials range from engineering plastics like PA and PC up to high-end thermoplastics like PPS, PEEK and PEKK, while reinforcing fibers can be carbon, glass or other more exotic fibers. All usual kinds of fiber architecture are generally suitable for thermoplastic composites, be it unidirectional, weave, spread-tow or staple fiber. Even though the mechanical properties of widespread thermoset composites and thermoplastic composites are very similar, the processes and molds are very different. The molds have to be matched molds; high pressures in the area of 10 to 50 bar and high temperatures between 200°C and 400°C are used, depending on the matrix material. The weldability of thermoplastic composites can be used both in preforming and on finished parts. Examples are shown where multi-part components are joined through welding. Design guidelines are given with a focus on design and manufacturing of complex parts with highly variable thicknesses. As an example, a full-CRFP car wheel made from carbon fiber reinforced Polyetherimide (PEI) is discussed. Its rim has a highly variable wall thickness and has 4 distinct fiber orientations (0°/60°/90°/-60°). To manufacture this rim as a one-piece part, not only a new press process had to be developed, but also a completely new approach to preform manufacturing. The preform was built fully automated by a combined winding and pick-and-place robot. The manufacturing of such a demanding part could only be achieved using the synergy of accuracy delivered by the automated preform assembly process and dedicated press molds and machinery. Using the right processes, thermoplastic composites can be much more than the ubiquitous organosheets and simple thermoformed blanks; they can be manufactured into highly intricate and thick-walled parts that achieve the same complexity as parts made from thermoset composites, all while maintaining their own inherent advantages.

Education Session | Basic

Testing and Selection of Thermoset Resins for Optimal FRP Equipment Service Life

Kevin LAmbrych (INEOS Composites)

The goal of this session is to educate the audience on best practices in corrosion barrier and cure package design for industrial fiber reinforced plastic (FRP) equipment. Examples of FRP equipment are reactor vessels, storage tanks, pipes, and protective linings. Critical services where FRP is used are chlor-alkali, hydrometallurgical mineral processing, fuel and solvent storage, wastewater treatment and other aggressive industrial chemical process applications. Assurance that the proper resin is used for equipment fabrication is of great importance to the fabricator, engineer and asset owner. There are many considerations taken into account by material scientists when recommending the appropriate resin for a given chemical and thermal environment. This session will cover corrosion performance differences between FRP made with epoxy resins (EP), unsaturated polyester resins (UPR), epoxy vinyl ester resins (EVER), brominated epoxy vinyl ester resins (BrEVER) and novolac epoxy vinyl ester resins (NEVER). The corrosion performance of FRP compared to metal alloys will also be discussed. The basics of veil selection and how to design a proper corrosion barrier as well as considerations for structural performance will be covered. ASTM C-581 corrosion data combined with case studies will be used to demonstrate how anti-corrosion resins, veils and reinforcements are selected for appropriate corrosion barrier design. The final portion of this education session will touch on the history and effects of these improvements and compare them to a new line of epoxy vinyl ester resins built on the well know Derakane technology but with unique features such as improved fabrication efficiency, lower styrene emissions, and longer resin shelf-life.

Education Session | Basic

Powder Coating Carbon Fiber and Plastics using UV Curing, Conductive Primers, and Plasma Treating

Evan Knoblauch (Project Manager)

The increasing use of lightweight materials has significant implications for the paints and coatings industry. As manufacturers have incorporated lightweight materials into their production systems and products, they have made substantial process and manufacturing changes. Lightweight materials are fundamentally different from the materials they replace. Besides lower weight, they have different surface characteristics, and physical and thermal properties. They have unique handling, processing, and finishing requirements and, unlike metals, many of them are heat sensitive. As excessive curing times and temperatures can deform a material, compromising its integrity, new coating materials and processes are needed for the finishing of lightweight materials: powder coatings instead of liquid coatings, water-borne liquid coatings instead of solvent-borne liquid coatings, and UV curing instead of thermal curing. Inherent in these material and process changes is the need for new types of coatings, application processes and curing technologies. This presentation will explain how the combination of a conductive primer, plasma treatment, and UV-curable powder coatings is an appropriate way to finish lightweight materials without causing thermal damage or deformation to the substrate. It will describe in detail plasma treating, operating conditions, and surface condition measurements before and after plasma treatment. The second half of the presentation will describe adhesion results of UV-cured powder coatings with and without plasma treating on various plastics and composites. It will conclude with an evaluation of suitable substrates for plasma treating, UV-cured powder coating, and UV-cured powder coating performance results.

Education Session | Moderate

Improving Engineering Plastics Performance by Fluoropolymer Modification

David Lavanga (AGC Chemicals Americas, Inc.)

Due to the evolving needs of various industries, AGC has developed fluoropolymer (FP) technology to enhance the performance of Carbon Fiber Reinforced Thermoplastic Composites (CFRTP). Fluoropolymers, themselves, are intrinsically high performance materials used in harsh chemical and high-temperature environments. They also, typically, are inert and do not interact or combine easily with other hydrocarbon semi-crystalline polymers. By incorporating specially designed functionalized fluoropolymers into CFRTP matrix resins, AGC's new technology greatly expands the performance window by improving the material's impact resistance, flexibility, wear resistance, electrical properties and reduces water absorption in susceptible polymers. Improved flow properties of these unique materials can reduce product defects, such as micro-cracks, that occur during high temperature processing and improve yields. The subsequently enhanced CFRTP allows for a wider range of applications in automobiles, aircraft, energy, and sports products that require lighter-weight materials. In addition to CFRTP, this technology can also be applied to improving engineering plastics with superior tolerance against high loads and a wide temperature range (-200°C up to 260°C). Examples of the semi-crystalline polymer development case studies that will be highlighted include: FP modified Polyamides (mPA), FP modified PolyEtherEtherKetone (mPEEK) and FP modified Polyphenylene Sulfide (mPPS). New or improved applications and market potential will be addressed.

Bonding and Joining

Technical Paper | Moderate

Cohesive Zone Modeling Simulation of Thermal Stresses in Dissimilar Material Joints

Grant Percy and Seyed Soltani (Florida Polytechnic University)

This paper describes the finite element simulation of an adhesively bonded composite/metal single lap joint undergoing cyclic thermal loading with cohesive zone modeling (CZM) in Ansys Workbench. Single-lap joints are widely used in structural applications to join two parts via an overlapping bond. The Ansys model was comprised of a carbon fiber composite laminate bonded with an epoxy adhesive to an aluminum plate. The model was used to study the aggregate structural effects of cyclic thermal loadings applied through periodic temperature boundary conditions simulating the service temperatures typical for the aircraft. The simulation results revealed that the heat flux was highest around the adhesive. This was attributed to the extremely low thermal conductivity of the adhesive. Additionally, since there was such a large difference in the thermal conductivity of the aluminum and the carbon fiber composite, there ended up being almost no heat transfer at the carbon fiber composite and adhesive interface. The modeling approach described in this paper is a promising technique not only for modeling dissimilar material joints, but also for modeling the composites individually. This is mainly because the model can be easily modified to incorporate similar and dissimilar materials per application requirements.

Technical Paper | Moderate

Surface Activation Methods for Bonding to Thermoplastics: Plasma and a New Tailored UV Based Method

Sina Chaeichian, Kaspar Schaerer, Ruairi O'Kane, and Michael D. Halbasch (Henkel Corporation)

The constant trend to optimize the costs of raw materials and related processing costs has accelerated the use of thermoplastic composites as alternatives to traditional thermoset composites in the Aerospace Industry. While thermoplastics can be easily fused together above their melting temperatures, it is difficult to bond them to dissimilar substrates, including thermosets and aluminum. The high melting temperatures of engineered thermoplastics like Polyarylether Ketone family (350 – 430 °C) limit their process. Therefore, lower temperature bonding systems would be desirable. This paper discusses the development of a new and rapid UV pretreatment method for thermoplastic composites allowing improved bonding to dissimilar substrates. In addition, plasma pretreatment is also investigated as a common method since it can have good proficiency in some cases depending upon the chemistry of adhesives. Contact angle measurement was done for surface analysis of treated substrates where regarding to the new tailored UV method, complementary analysis such as XPS and TOF-SIMS was conducted. To evaluate the bond strength, mechanical tests including fracture toughness (G1C) and tensile lap shear tests were conducted. Contact angle measurements, XPS, and TOF-SIMS analysis revealed an increase in polarity and wettability of the thermoplastic surface after pretreatments due to the formation of new oxygen-containing functional groups. This rapid UV surface treatment method led to a significant improvement in bonding of PAEK thermoplastic composites with both low and elevated temperature-cure adhesives verified by mechanical test results. This method offers new opportunities for fast and safe bonding to the thermoplastic materials resulting in excellent bond strength comparable with plasma pretreatment.

Technical Paper (no recording available) | Moderate

Nanomechanical Property Characterization of Composite Adhesive Bonding Systems

Rita J. Olander, Brian D. Flinn, Ashley C. Tracey (U. of Washington)

This research is directed toward further understanding how manufacturing methods affect initial bondline formation between matrix resins and adhesives. Nanoindentation techniques were used to characterize various regions of adhesively bonded carbon fiber epoxy samples including the matrix resin, adhesive, and bondline mixing zone (interface/interphase). Bondlines from two co-bonded systems (Toray 3900/3MAF 555 and Toray 3900/Solvay FM309-1) and one secondarily bonded

(Toray 3900/Cytec Metlbond® 1515-4) were characterized to understand the differences in interface and/or interphase development. Co-bonds produce a mixing of the matrix resin and the adhesive, resulting in a mixed interface, or interphase region, as compared to a sharper interface produced by secondarily bonded samples. For this preliminary study, three specific bonding systems were characterized using nanoindentation extreme property mapping (XPM™). By measuring mechanical responses on the micron scale, the data identifies various structures and regions, such as where the adhesive/adherend interphase begins, and if it is heterogeneous or homogeneous in nature. This work is unique in that other mechanical property characterization methods have not been able to isolate the adhesive/adherend interphase due to the micron scale of this region. These methods not only measure the adhesive/adherend interphase thickness but also allow for the evaluation of properties that may be related to bond quality and performance.

Technical Paper | Moderate

Improved Adhesion in Pultruded Composite Materials and Test Methods for Evaluation

Leigh Nolen, Yves Cordeau, Christiaan Mauldin, Dr. Mac Puckett (Avient, formerly known as PolyOne Advanced Composites)

Many composite materials are subcomponents of a larger assembled structure. Adhesives are an excellent way to attach these smaller components into a larger structure, distributing load across a large surface area without damaging the composite, as compared to mechanical fasteners which can concentrate the load at what is often a site of damage in the composite. Typically pultruded composites are completely cured coming from the die and will have a mold release on the surface. Both of these factors can reduce the ability to achieve maximum adhesion to a pultruded surface. Depending on part geometry, a peel ply material may be pultruded onto the part, which can be removed to prepare the surface before adhesive is applied. Alter-natively, sanding or abrading the part followed by thoroughly cleaning the surface is a typical – and labor-intensive – method for preparing a part to maximize adhe-sion. This paper will discuss the addition of a modifier to the resin formulation that acts as a "primer" on the pultruded surface of the part. This eliminates the need to prepare the surface beyond the removal of dust and other particulates that accumulate on most surfaces. Cleanliness of the surface to be bonded is still essential to creating a bond of maximum strength. This unique process of surface preparation eliminates the time consuming and expensive methods typically required to prepare an adhesively bonded structure. This novel "priming" process does not significantly affect the thermal or mechanical properties of the underlying composite. Comparison of composite properties and adhesive bond strength of parts made and bonded in various ways will be discussed.

Technical Paper | Advanced

Plasma Treatment of Composites and Carbon Fibers to Increase Bond Strength

Daphne Pappas, Nathaniel Eternal, Raul Gonzalez, Tim Smith (Plasmatreat USA, Inc.)

Atmospheric pressure plasma (APP) is a surface engineering method that has been widely used in the manufacturing of lightweight composite materials. APPs have proven effective in overcoming the poor interfacial strength between the fibers and matrix through the plasma-induced surface functionalization. Due to the propensity of composite structures to delaminate under loading, it is necessary to develop composite structures with inherent resistance to such damage. Traditional methods aiming to improve performance include thickness reinforcements and toughened matrices. However, these methods do not enhance the fiber and matrix interface strength. Non-thermal atmospheric–pressure plasmas have gained popularity due to their ability to easily produce non-hazardous waste processes, low operating costs, fast materials processing speed and industrial scalability. APPs have the ability to modify polymeric fibers via mild plasma etching and cross-linking and the grafting of surface functional groups that can be tailored to enhance adhesive strength in polymer-based composites without affecting the bulk mechanical properties of the material. In this paper, results from the air plasma modification of carbon fiber materials and carbon fiber reinforced polymer (CFRP) composites will be presented. Lap shear specimens made with carbon fiber reinforced polymers were bonded with an epoxy-based adhesive were tested before and after short exposure to air plasmas. A 40 % increase of lap shear strength was observed for the specimen that were plasma treated prior to the application of the adhesive. Characterization of treated CFRPs and carbon fiber fabric was also performed by Water Contact Angle (WCA) goniometry measurements and X-ray Photoelectron Spectroscopy (XPS) analysis. While the as-received materials were hydrophobic and had low surface energy, few seconds of air plasma exposure led to complete surface wetting. This can be attributed to the mild oxidation of the surface and the attachment of polar groups as confirmed by XPS analysis. While the study involved the bonding of identical composites, bonding to other composites or dissimilar materials can benefit from plasma treatment as well. The mechanical properties of composites such as tensile strength is increased when the reinforcing material is treated with plasma before being molded to the matrix material. Analyzing the strength by performing other fracture tests like a four point flexular test can be performed to further demonstrate the plasma effect. Inspection of the fracture surface will also determine the mode of failure and the contribution of plasma treatment to increasing strength.

Technical Paper | Moderate

Static and Fatigue Evaluation of Flat and Tee Joints of Pultruded Sandwich Panels

Ruifeng R. Liang, Hota VS GangaRao (West Virginia University)

CANCELED

The paper was based on the work that was sponsored by the National Shipbuilding Research Program with a focus on the development of a manufacturing and assembly methodology for low cost pultruded composites. At the time the work was conducted, this project was considered as the Export Administration Regulations (EAR) – governed technology.

Joints are integral part of many structural systems and play a critical role in determining the actual loading capacity of a structural system. Three types of joints including flat, Taper Tee, and Box Tee of glass fiber reinforced polymer (GFRP) composite panels sandwiched with balsa core were designed, pultruded, fabricated and tested under static and fatigue loads using special testing fixtures. The sandwich panels were manufactured with a two- inch balsa core, one-eighth of inch E-glass face sheets (skins), and an epoxy modified vinyl ester resin. Majority of jointed test samples comprised of 18-inch wide joint configuration with 50.25 inch length except for 2 test samples comprising of 120 inch longitudinal joints. More specifically, flat joints were tested under static tension, three-point bending and four point bending as well as corresponding fatigue load testing of the same configurations, while Tee joints were tested under axial-tension pull, off-axis pull and lateral pull, resulting in a total of 66 tests. Each specimen was heavily instrumented with a large number of strain gages and linear variable differential transformers (LVDT) for automatic data acquisition. This paper presents data from testing and evaluation of the above three types of joints under a variety of loads. The static and fatigue responses of the pultruded panel joints were discussed in comparison with data of "no-joint" VARTM control joints.

Education Session | Moderate

Advanced Heating Solutions for Accelerated Cure of Adhesives and Sealants

Larry Christy (Veelo Technologies)

The cure time of adhesives in the aerospace market today are a limiting factor in composite manufacturing throughput. The cycle time for room temperature curing adhesives and sealants can takes upwards of 24 hours or more. These adhesives are often used to bond parts, such as fasteners and nut plates, to composite surfaces. They are often applied on the backside of the part, and then either temporarily clamped, or molded while the adhesive cures. Using VeeloHEAT Blankets, these adhesives can be cured in under 2 hours, or as low as an hour, when cured at an elevated temperature of 180°F or higher depending on the adhesive chemistry. Additionally, certain adhesives or sealants used for bonding gaskets to composite or metallic parts can be reduced from a 24 to 48-hour room temperature cure to only a couple hours by applying heat (120°F) locally at the bond line. Typically for every 20 degrees Fahrenheit (10°C), the rate of cure for the adhesives is enhanced 20-25%. Several technologies have been investigated in the composite processing community to accelerate the adhesive cure using elevated temperature. These include induction heating, ovens and forced air, heated tooling and using strip heaters. Traditional heating blankets available today utilize a metallic filament for electrothermal heating. These filaments are either single conductor or multi-conductor braided together, these filaments are further required to be precision placed on typically a silicone sheet to form a heating circuit or grid which is then further integrated into a heating blanket. These grids do not provide uniform heating and are prone to failure and breakage due to work hardening and don't typically allow for it to be indexed properly around the part that needs the heat. Additionally, if a single strand breaks the specific zone or entire blanket is rendered unusable. Blankets made with VeeloHEAT do not exhibit these downfalls. This heating element is a carbon-based thin film that can be customized for specific applications. The heating element is a thin film planar sheet that doesn't produce excessive variations in temperature due to the presence or proximity of a metal heating element. The entire sheet is conductive producing an unmatched heat uniformity. Further benefits of the technology include elimination of work hardening (the heating element is non-metallic), and complex curves, tight radii, or excessive flexural cycling do not affect performance. This continuous electrothermal film allows heating elements to contain holes, which can be designed to index around fasteners.

Design, Analysis, and Simulation

Technical Paper | Moderate

Virtual Testing of CFRP Coupon Using Digimat VA

P. MARTINY AND A. CHERUET (e-Xstream engineering, part of Hexagon Manufacturing Intelligence Division)

In the research of light weighting solutions, the use of CFRP has dramatically increased during the last two decades both in aerospace and automotive industries. However, designers are still facing the challenge to accelerate the insertion of new materials for applications. Traditionally, screening, characterization and even design of new materials is done by physical testing. However, composites materials offer an extraordinary choice of material combinations so that such traditional approaches become inefficient at best. Simulation accelerates these test campaigns, providing insights and answers well before physical coupons can be ordered, created, tested and reported. It will help to address some of the inefficiencies in the process and reduce the total time from initial screening to final, fully characterized materials. Tools, like DigimatTM propose a complete framework to conduct simulations. This framework includes a continuum damage model to accurately capture the damage initiation and propagation that take place during the loading. Additional features are added to this model, such cohesive element to model the interface, in-situ strengths, mesh sensitivity control and effect of manufacturing stresses. The framework is applied on several coupon configurations with several aerospace composite grades.

Technical Paper | Moderate

A Tool Analysing the Drapeability of Unidirectional Carbon Fiber Textiles on Any Given Geometry

Santino Wist (Institut für Textiltechnik Aachen)

The combination of lightweight design and high mechanical properties of fiber composite materials plays a crucial role in meeting the current demands for higher energy and resource efficiency. Unidirectional carbon fiber textiles can be produced based on preforms. During the forming of the preform the textile undergoes drape-mechanics to alter its initial flat shape to three-dimensional geometry. Undulations and folds are adverse effects of these necessary drape mechanics. It is of great importance to design the final part's geometrical shape according to the draping abilities of the carbon fiber textile to achieve the desired physical properties. This research project designed a software tool for geometrical analysis of any given surface geometry. It analyses the geometry for problematic zones for unidirectional draping processes and visually highlights them. Local vector lengths are representing the unidirectional fibers. By comparing local lengths, the effect of relative fiber motion can be modeled. Through experiments, critical relative fiber motion has been quantified and implemented into the calculation. Resulting is a tool that requires geometry and basic information about the textile as input. The output, however, is the geometry with local scaled colors representing the drapeability in that area

Technical Paper | Moderate

Validation of the ITRAC Material Response Code for Glass/Phenolic Composite

Colin Yee, Jon Langston, Hao Wu, William Fahy, and Joseph H. Koo (University of Texas at Austin)

A simulation of the glass/phenolic ablative MXB-360, produced by Sioux Manufacturing, is validated in an oxidative hyperthermal environment using the Northrop Grumman Insulation Thermal Response and Ablation Code (ITRAC). Temperature profile and surface behavior data are generated by testing MXB-360 samples at heat fluxes of 500, 1,000, and 1,500 W/cm2 using an Oxyacetylene Test Bed (OTB). K-type thermocouples embedded at staggered depths within the test models (30 mm diameter and 15 mm thick) provide in-depth temperature profiles. These data are used to demonstrate the accuracy of the 1D material response model using ITRAC. Complete Kinetic Modeling Parameter (KMP) factors for MXB-360 are developed through the use of Thermogravimetric Analysis (TGA), while both pyrolysis gas enthalpy tables and B-prime tables are developed through the use of Electron Dispersion X-ray (EDX) mass spectrometry and the ACE surface thermochemistry code, respectively.

Technical Paper | Advanced

Characterization of GFRP Bars and Couplers for Prestressed Concrete

Nafiseh Kiani, Marco Rossini, Antonio Nanni (University of Miami)

Glass fiber-reinforced polymer (GFRP) bars have significant potential in prestressed concrete (PC) applications. Recent technical literature indicates that the creep rupture threshold for state-of-the-practice GFRP bars can be higher than 40% of their guaranteed tensile strength, thus allowing a sufficient level of tensioning at the time of construction. To develop field-deployable systems for PC elements with particular focus on partially-prestressed applications (i.e., combination of tensioned and non-tensioned reinforcement), an experimental investigation was conducted. This paper reports on the mechanical properties and behavior of two different GFRP bar diameters, an anchorage system that uses polymeric wedges, and a bar splicing solution that may be necessary to meet the length of conventional prestressing beds. Experimental results obtained in this study support the use of GFRP bars in PC elements. The composites investigated in this study were deployed in the construction of two partially-prestressed piles serving as a real-case demonstrator for the viability of GFRP prestressing in substructure applications.

Technical Paper | Moderate

Modeling Spring-In Variability Due to Residual Stress in Contoured Autoclave Composite Parts

Matthew L. Kirby, Geoffrey J. Frank, David S. Riha, Andy Ko, Robert W. Koon, Michelle U. Serna (Southwest Research Institute)

Spring-in variability due to variations in the residual stress field of contoured autoclave composite parts is a primary source of nonconformances that result in costly part-rework. The main driver of spring-in and warpage is the difference between through-thickness and in-plane cure shrinkage and thermal expansion. State-of-the-art finite element process modeling frameworks are capable of capturing this phenomenon, and thus could be used to predict variability in spring-in for contoured parts. However, simulations of full three-dimensional representations of these parts remain computationally expensive and are generally not tractable for manufacturing environments. The objective of this work was to develop a tractable process model for predicting spring-in variability in a representative contoured part. A formal model verification and validation framework was used to develop models to predict the final part state due to variations in the materials, lay-up, and processing. The models developed in this effort included a reduced-order finite element process model using the COMPRO® plug-in for ABAQUS and a general analytical model was implemented in ModelCenter® for use in a manufacturing environment. Although there remain variations in the materials and processes that the models were not able to capture, both the reduced-order model and analytical model were relatively successful at capturing trends in spring-in variability.

Technical Paper | Advanced

Understanding Size Effects on Flexural Properties in Discontinuous Fiber Reinforced Nylon Composites

Siavash Sattar, Benjamin Beltran Laredo, Diego Pedrazzoli, Mingfu Zhang, Oleksandr G. Kravchenko (Old Dominion University)

Discontinuous fiber reinforced composites are increasingly becoming more common among the aerospace and automotive industry. Their manufacturing cost and material characteristics make them quite versatile in their uses, especially for secondary structures. Due to discontinuous fiber morphology of the reinforcement these materials typically exhibit a size effect in the mechanical behavior, including both strength and stiffness. The flexural properties of long discontinuous fiber composites are subject to the span effect typical for high-performance continuous fiber composites. However, the meso-structure of long fiber- discontinuous composite is significantly different from continuous fiber laminates. Therefore, it becomes important to understand how the meso-structure in composite is affecting the mechanical response under flexural loading, especially taking into consideration the size effects due to proximity in scales between the fiber reinforcement and macroscopic composite. The present work considered organosheets produced using 1" (25.4mm) long glass fiber, which is embedded within a in situ polymerized polyamide 6 (nylon) matrix. The meso-scale morphology of the glass fiber bundles is preserved during the impregnation process, resulting in the collimated fibers. The flexural properties of the material were tested with different span ratios in 3-point. The size of the tested coupon had thickness of about 2.5mm, while the loading span was varied. Digital image correlation was used to understand the strain field deformation under different loading configurations. The material system revealed strong dependence of the flexural response with the loading span size. The initial increase of the flexural modulus with span below 1" is explained by the large contribution of shear deformation in case of short beam, while further increase in span lead to more gradual increase of the flexural modulus reaching the plateau behavior at spans exceeding 2" (50.8mm). The flexural strength on the other hand showed gradual decrease and plateau-like behavior with span increase from 1" to 2". Increasing the spans beyond that point was not considered due to large deformation and hard to reach complete failure. The behavior was explained by the reduced fiber damage mechanism as the span increases beyond the nominal fiber length, causing more substantial matrix plasticity and local disbanding between the collimated fiber bundles. To support the understanding of the present results, a computational modeling was established to describe the observed mechanical variability for this material system, including the dependence of the flexural properties.

Education Session | Basic

Challenges and Benefits of Implementing a Digital Twin in Composites Manufacturing

Charles Anderton (CGTech)

For most companies, the idea of a digital twin is purely theoretical. The path towards implementing, and more importantly, benefitting from a digital twin is not clear. This presentation will highlight several practical challenges in implementing this tool as well as discuss multiple real-world benefits of the digital twin. Through the power of simulation and large data sets, companies can truly begin to maximize their profitability by optimizing part programs and minimizing machine downtime. However, the mere act of purchasing a virtual simulation of a physical machine does not automatically guarantee an upsurge in productivity. Several vital steps must take place to see real benefits, including determining what data is essential to collect, deciding how to obtain that critical data, encouraging a culture of decision-making through data, and creation and maintenance of vital supplier relationships necessary to realize a digital twin. Though the implementation is not trivial, a digital twin offers newfound opportunities to leverage gathered data to both optimize programs and allow for continuous improvement. Examples of potential optimization include part analysis resulting from manufacturing conditions,

closed-loop feed rate optimization factoring in feature-based controls and their effect on layup quality, and upstream traceability of root causes to downstream issues.

Green & Sustainability

Technical Paper | Moderate

Improvements in the Sustainability of SMC and BMC Composites

Mike Gruskiewicz and Tim Pfister (Lyondellbasell)

Continued environmental and market pressures underscore the need to improve the sustainability aspects of all materials, including composites. Products which effectively achieve the most favorable life cycle performance will tend to gain market share in the long run. The requirement for cost and performance parity relative to traditional materials is a given; in fact, those factors largely play into the overall sustainability equation. Uses of composites in many current applications are driven by the performance benefits during the life phase of the product. Composites are used in many cases because they improve sustainability in the application. For example, composites offer weight savings that save fuel in vehicles ranging from cars, to trucks, trains, and aircraft. In other examples, design flexibility allowing complex shapes achieves greater energy output in wind turbines, and lower energy consumption in HVAC blower housings. The durability and corrosion resistance of composites drives sustainability as well—a material that resists corrosion through multiple replacement cycles of alternative material inherently has a more favorable environmental footprint than shorter-life alternatives. The challenge for composites is to build upon the great sustainability achieved in the life phase of the product by improving sustainability in the build phase of the product, and at the end-of -life phase. This paper examines some of the options to improve sustainability during the initial build phase. Specifically, SMC's (Sheet Molding Compounds) and BMC's (Bulk Molding Compound) have been compounded using raw materials that include renewable and recycled sources. These sustainably-sourced raw materials comprise components of the resin matrix, and can include functional fillers and reinforcing fibers as well. Through well-designed formulation approaches, molding characteristics and end-use performance attributes are maintained with little or no compromise in performance relative to traditional composites. Key examples of sustainable composites in high performance applications will be presented.

Technical Paper | Moderate

Mode I Interlaminar Fracture Toughness of Biolaminates Composites Charged with Reinforced Particles

Edgar A. Franco-Urquiza, Victoria Renteria, Ruben Perez-Mora, Pedro González-García, Mauricio Torres-Arellano (CIDESI-CENTA)

Composite biolaminates are a renewable resource, low-cost, with good mechanical properties and are totally biodegradable. Recently, the use of nanoparticles as reinforcement, has allowed the increment of the mechanical and thermal properties these materials. In this work the mechanical properties of biolaminates based on Agave fibers (Henequen) embedded in a bioepoxy resin with 45% natural component and with ZnO nanoparticles at different percentages by weight are evaluated. The mechanical properties show an increase in stiffness and strength with the presence of ZnO nanoparticles. The fracture behavior in mode I registered moderate changes in toughness, related to the type of fibers and the ZnO fraction. The results show the potential application of these biolaminates on commodities, building and automotive industries.

Technical Paper | Moderate

Thin-Ply: Exploration and Manufacturing with Automated Fiber Placement

Ramy Harik, Andrew Lovejoy, Catherine Yokan, and Dawn Jegley (University of South Carolina)

Highly repeatable and nearly defect-free fabrication of composite parts is critical to the success and widespread acceptance of composite materials. Through optimization using thin-ply materials, composite parts can be manufactured to be lighter and tailored more specifically to anticipated design loads than with standard prepreg materials alone. However, defects arising from the thin-ply manufacturing process are not always similar to defects found with standard tows. These new defects warrant evaluation. At NASA Langley Research Center, the manufacturing process parameters associated with automated fiber placement (AFP), a slit tape-based composite manufacturing process, were optimized for the use of a thin-ply prepreg carbon-epoxy material. Carbon-epoxy tows with areal weights of 30 g/m2 and 70 g/m2 were used in these manufacturing trials. The AFP process parameters of heater output, compaction force, tow feed rate, and tow tension were adjusted and optimized for successful manufacturing. This article documents an exploration of thin-ply fabrication on both flat and complex-shaped surfaces. Ultimately, aerospace-quality laminates were made from the 70-g/m2 material, but imperfections in the 30-g/m2 material itself and the fact that the AFP machine was not designed for such a thin material meant that more research and trials are required to obtain flight-quality 30-g/m2 laminates.

Technical Paper | Moderate

3D Modeling and Printing of Automated Fiber Placement Defects

Alex Brasington, Trevor Schachner, and Ramy Harik (University of South Carolina)

Automated Fiber Placement (AFP) is a composite manufacturing technique used to fabricate lightweight air and space vehicles. AFP uses tows, or strips of composites, laid side by side to build plies and laminates. A major consequence of this technique is the defects induced via the AFP process. Knowledge and detection of defects requires some expertise on the size, shape, and significance of the considerable number of possible defects. Detection then becomes increasingly difficult due to the substrate and incoming material both being a dark black color. The inability to detect defects leads to a part with poor quality. This report aims to provide some education on these defects using 3D modeling and 3D printing to visualize each defect. To ease visualization, the model can be printed in three different colors as follows: First, the tool surface is printed in one color, then the tows are printed in a second color. The contrast of these two colors can then be used to visualize defects such as

boundary coverage or tow drops. Defects associated with single tows such as gaps, overlaps, and twist can be modeled and printed using a third color. This method creates 3D models with easily identifiable defects that can be used to educate or train AFP personnel.

Technical Paper | Basic

Stitched Composites with Three-Dimensional Stitch Paths

Andrew E. Lovejoy and Dawn C. Jegley (NASA Langley Research Center)

Stitched composites have been shown to exhibit damage tolerance and to reduce weight compared to traditional layered composites through unitization of the structure by elimination of fasteners. Stitching capabilities have been incorporated into the Integrated Structural Assembly of Advanced Composites (ISAAC) system at NASA Langley Research Center with the introduction of two stitching heads. Stitching path control was initially implemented as straight lines in space, as was done for previous stitching development. However, more complex stitched structures such as a wind tunnel blade or around cutouts within a fuselage or wing skin, require that the stitching paths be implemented as three-dimensional (3D) stitching paths in space. Unfortunately, control programming output by an existing preprocessor program cannot stitch these curved paths due to problems that arise in stitch formation and the introduction of side forces on the needles using the conventional programming approach whereby the head is simultaneously controlled through translations and rotations. This lack of capability is most significant for the single-sided stitching head, where two needles are in the preform at the same time for the majority of the stitching process. A means to program 3D stitching paths in space was developed whereby the translation and rotation of each stitch were decoupled, thereby eliminating the problems associated with current control programming approach. Using this newly developed stitching path definition and control programming, complex stitching paths have successfully been stitched at the ISAAC facility. The ability to stitch general 3D stitching paths in space enables the use of stitching on more complex parts.

Technical Paper | Moderate

Nondestructive Evaluation (NDE) Data Correlation For Manufacturing Improvement

Roger W. Engelbart (The Boeing Company)

Nondestructive evaluation (NDE) is often considered to be strictly a quality assurance tool, used exclusively as a mechanism for acceptance or rejection of parts. NDE processes may be viewed as having a negative cost impact to any program, due to rejections that may result in repairs, scrap, and additional labor and documentation. However, NDE can also be a valuable engineering tool for process improvement if the data are utilized for correlation to manufacturing parameters and events. This can result in a positive cost advantage to the program by avoiding future rejections. Under the RApid High-Performance Molding (RAPM) for Small Parts program, a variety of different composite part configurations were manufactured utilizing fabrication processes that were geared toward automotive applications. Ultrasonic and radiographic NDE were performed on these parts to understand the general output of the chosen manufacturing processes. This paper will show how correlation of the NDE data to destructive analysis led to refinement of manufacturing parameters and, for the resin infusion challenge part, showed the path to implementation for an existing aerospace program.

Technical Paper | Moderate

Development of a Thermoplastic Continuous Fiber Reinforced Access Panel

Peter Levesque, Justin Schell, Jonathan Sourkes, Claire Steggall-Murphy, Nicholas Turcotte, and Gail Hahn (TxV Aero Composites)

TxV Aerospace Composites, LLC (TxV) developed and manufactured a continuous fiber reinforced access panel, with joggle features and injection overmolded plastic, in collaboration with Boeing Research & Technology (BR&T) in support of the RApid high-Performance Molding (RAPM) for Small Parts, a program under the Defense Advanced Research Projects Agency (DARPA) Tailorable Feedstock and Forming (TFF) initiative. Overmolding composites integrates the mechanical performance of continuously reinforced thermoplastic composites with the design flexibility of injection-molding to create complex geometries and features. The hybrid molding process offers continuous manufacturing with the potential for short cycle times and mechanical performance equivalent to or better than traditional aerospace metals. TxV's hybrid overmolding process is made possible by VICTREX AE™ 250, a low-melt temperature polyaryletherketone (LM-PAEK). The polymer matrix offers substantially similar fatigue performance, chemical and corrosion resistance as polymers in the polyaryletherketone family but with a melt temperature of about 40°C less than VICTREX™ PEEK. This temperature delta is responsible for a strong bond during the overmolding process. These materials combined with TxV's highly automated manufacturing facility, designed for high-rate production, enables the manufacture of composites parts at potentially lower cost than typical aerospace metals. This paper outlines the development and manufacturing of an overmolded thermoplastic composite access panel demonstrator part following a design-for-manufacture approach covering: automated tape laying, consolidation, forming, over-molding, finishing and inspection.

Technical Paper | Moderate

Pultrudable Bio-Based Epoxy Resins

Terry S. McQuarrie, Martin Sutton, and Yaroslav Germanov (EcoPoxy, Inc.)

Numerous studies have reported on the properties of replacing a portion of a Bis A epoxy resin with bio-based components. An extensive review of these studies included epoxidized soybean oil resins (ESO), blends with alternatives to ESO such as epoxidized glycidyl soyate (EGS), and allyl soyate (EAS) blended with standard petroleum-based epoxies along with alternative bio-based hardeners and accelerators. These studies supply excellent data with regards to the casting and some laminate

properties of these alternative composite materials. The experimental work done in this product development program consisted of preparing ESO and epoxidized linseed oil (ELO) resins, selecting the best curing agent to maximize properties, running dynamic mechanical analysis (DMA), liquid resin and neat casting properties, ASTM D6866 Biobased Carbon Content and scanning electron microscopy (SEM) to evaluate resin/glass interface bonding. Most importantly, pultrusion processing data was developed for these ESO and ELO bio-based epoxy resin systems. This development of both ESO and ELO based epoxy resin systems supplies the pultrusion industry with all the necessary technical data that includes the full package of resin gel and cure data, casting properties, pultrusion line design as well as in-line curing parameters before and after the heated die and includes cured composite properties. The result is pultrudable ESO and ELO bio-based epoxy resin systems with zero styrene emissions, bio-based contents of 33% and full pultrusion processing parameters.

Technical Paper | Moderate

Creation of a Digital Twin for Automated Fiber Placement

Max Kirkpatrick, Alex Brasington, Andrew D. Anderson, and Ramy Harik (Siemens Digital Industries Software)

Automated Fiber Placement (AFP) is a manufacturing process used to produce large, lightweight composite structures at high rates and increasing reliability. Currently, the process is black box where paths and process parameters are sent to the machine, and it is trusted to maintain the correct values. There are limited methods of monitoring real time process parameter values for current and future analyzing. Even when the exact same parameters are used on the same part multiple times, the resulting manufacturing quality can differ largely. This report will discuss the creation of a digital twin with the capability to simulate and monitor the entire AFP process. A digital twin will provide the ability to examine the process in real time, in addition to after the process is completed. The data collected will then be compared to expected data to examine any differences. Analysis of each point during manufacturing will lead to a deeper understanding of AFP.

Technical Paper | Basic

Low-Cost Manufacturing for Carbon Fiber Bulk Molding Compound

Connor W. Lowry, Dean C. Chan, and Raymond Choi (The Cooper Union for the Advancement of Science and Art)

Our research explores the development of a low-cost alternative to carbon fiber bulk molding compound (CFBMC). The motivation is to replace aluminum components used in a vehicle for Formula SAE® a collegiate automotive design competition. Our goal is to reduce the overall weight of the competition vehicle with the constraint of retaining comparable strength and stiffness to existing aluminum components. We adapted existing manufacturing processes to utilize cheaper, commercially available products such as low-cost carbon fiber tow and high-strength epoxy instead of expensive prepreg systems. Stiffness, strength, and weight targets were set based upon commercially available CFBMC products. Test specimens were produced and tested according to ASTM standards D3039, D6641, D5379, D7264, D256, and D671. These properties were used to inform the design of components and the expected part-to-part deviation due to manufacturing differences.

A suspension upright was designed as a proof of concept for future development. This component was selected because of its weight-savings potential, complexity, and its wide breadth of loading cases. From a monetary perspective, per-part costs are expected to be only 20-40% of commercial CFBMC using this alternative method. The CFBMC upright is 20% lighter and ten times stiffer than a comparable aluminum upright.

Technical Paper | Moderate

Development of Novel Tooling Materials for Next Generation Air Mobility Components with Intricate Structure

Hiromichi T. Fujii, Naoki Sakaguchi, Haruyasu Ohno, and Kotaro Ona (Shinhokoku Steel Corporation)

Thermal expansion characteristics between room and molding temperatures were analyzed in low thermal expansion alloys developed as novel tooling materials for small CFRP components with intricate structure. Low thermal expansion characteristics of the developed alloys could be maintained up to 400 ºC. The developed alloys prepared by casting were processed by cryogenic treatment and annealing to improve the mechanical properties. The mechanical properties were examined by tensile tests of round-bar specimens. Yield stress of the processed alloys showed more than twice of as-cast alloys. The drastic improvement of the mechanical properties was found to be attributed to the grain refinement and the high density dislocations through microstructural characterization. Cryogenic treatment and annealing process was also found to possibly reduce variation of mechanical properties. These discoveries suggested that the developed alloys could improve the tooling lifetime and reduce the manufacturing cost in CFRP molding for next generation air mobility.

Technical Paper | Moderate

High Conductive Multi Filament Fiber Material Made of Inorganic Fibers Coated with Aluminium

Alexander Lüking, Richard Haas, Robert Brüll, Francesco Biscaglia, Danilo Marini, Francesco Marra, Marco Valente, and Thomas Gries (Institut für Textiltechnik of RWTH Aachen University)

Conductive textiles are used in applications such as battery shielding in electric vehicles, EM-shielding from 5G emission or the mounting of a solar panel. Electrical textiles can be used to build a Faraday cage to protect high sensitive electronic devices or behave as a wire or sensor. However, conductive textiles are a bottle neck in achieving the goals of the electricmobility. [9] Electric vehicles are to be produced in large quantities and offered at affordable prices. However, the current state of research does not allow such a low-cost production. Currently used metal fibers have a diameter of 2 – 40 µm. The fibers are usually produced by the drawing process, the Taylor process, by melt spinning or extraction. Due to the slow and manual production processes, metal fibers with a diameter of 50 µm cost about 100 €/kg. To realize frequency shielding from 3 – 300 GHz new shielding materials are required. The decisive factor here is that simple EMI shielding by reflection is not sufficient, but for a shielding effect (SE) above 50 dB, the absorption of EM radiation supported by multiple internal reflections is of primary importance. [3, 9] The aim of the presented work is to develop a low-cost conductive fiber material for electromagnetic shielding. The approach of this technology is the metallic coating of inorganic fibers in the spinning process. The conductivity is achieved by a thin aluminum sheath of only 2 - 4 µm. A flexible inorganic fiber is used as the core, which enables the formation of fabrics like wovens or nonwovens. These fabrics can be draped into complex geometries. The multifilament yarn production is running at a speed of up to 1000 m/min to achieve high productivity. The aluminum coating is happening in the spinning process and covers each single filament. The resulting yarns electrical resistance is 100 Ωm and its temperature resistants is up to 500 °C. Fiber and fabric design can be adapted to the requirement of different applications. [5]

Technical Paper | Moderate

Cure Characterization of a Fast Curing Epoxy System For Resin Transfer Molding

Prashanth Badrinarayanan (Olin Corporation)

Resin Transfer Molding (RTM) is a high throughput method to produce composite structures. In the high pressure RTM process, resins are mixed, rapidly injected, and cured in a mold cavity at a high pressure (>100 bar) in typically less than 10 minutes. The ability to achieve high fiber volume fractions, combined with the short cycle times through RTM, has resulted in extensive applications ranging from automotive to high-volume industrial composites. Epoxy resins offer an excellent balance of processing ease for composite applications along with good thermal and mechanical properties following cure; however, fundamental to the effectiveness of epoxy resins for RTM applications is the development of chemistries that enable the fabricators to achieve fast curing of the parts in a desired processing window. Epoxy resins for RTM should exhibit an ideal thermorheological profile for effective infusion during the injection step along with fast reactivity during the molding step. Hence, it is crucial to gain an understanding of the cure kinetics for such fast reacting resins to predict and optimize curing conditions for improved RTM process speed. In this work, we explored the ability of a model-free, isoconversion approach to predict the cure progress for a fast-curing epoxy resin system developed for RTM. The isoconversion approach was found to provide an excellent description of the dynamic DSC measurements. The predictions of cure progress from the isoconversion calculations were found to be in excellent agreement with isothermal DSC measurements for a wide range of cure progress from 66% to full cure. Since fabricators and formulators for processes such as RTM have a significant interest in achieving the highest levels of cure at the shortest cure schedule, this approach could offer a quick and effective screening method to identify the process conditions that would lead to high levels of cure in an accurate manner.

Using Digital Technology in Composites Fabrication to Create a Comprehensive As-built Digital Twin

Scott Blake (Aligned Vision)

As composites manufacturers advance the state of the art by applying automation, laser templating, sensors and other data-dependent and data-generating systems to their fabrication processes, an important opportunity is developing to create a comprehensive as-built digital twin. A digital twin is a virtual representation of all critical aspects and attributes of a component or process. The digital twin of product is already a mature technology, consisting of CAD and other digital design data. Likewise, the digital twin of process is well-developed, consisting of manufacturing engineering data, electronic work instructions, digital process control settings, and more. Of course, for any digital twin to be more than a label applied to raw data, the data must be aggregated and contextualized to produce a unified, searchable digital representation. To a significant extent, the digital twins of product and process are achieving this status. Still emerging is the as-built digital twin, which consists of all available information about each individual finished component – materials used, processing details, personnel involved in its production, in-situ and post-processing inspection data, non-conformances and corrective actions, and more. In the composites industry, the as-built digital twin requires two advancements, each of which is currently being developed. First, inspection technology must be applied not only to commonly inspected attributes (e.g., edge location, fiber orientation, absence of FOD) across full plies, but also to quality-critical attributes that were economically and/or technological infeasible to inspect in the past (e.g. anomalies in raw material). Second, the data generated by these inspections, along with process data, must be used to populate a digital twin for each component as it is built. The as-built digital twin will also include quality events and corrective actions taken during manufacture. This paper will present the current status of developments leading to comprehensive as-built digital twin technology and will discuss the implications of the as-built digital twin for closed-loop manufacturing and continuous improvement of product design and manufacturing processes.

Technical Paper | Moderate

Performance Evaluation ff 2.5D Needle-Punched CFRP/Phenolics Composites

Esmerehildo Trevino, Jitendra Tate and Camila Belduque (Texas State University)

With the increase of composite components being introduced into the aerospace industry, the adoption of new manufacturing processes that improve the performance of the created parts when compared to traditional methods can be highly advantageous for a company. In the case of 2D composites, where reinforcement fibers are oriented along two axes, the result is a composite with anisotropic properties, which are typically weaker in the out-of-plane direction. Under high stress conditions, composite parts can delaminate resulting in a drastic loss of the load bearing capabilities of the part. One of the solutions to improve the thru-thickness mechanical properties is to add non-woven fiber layers to a dry composite preform stack and process it through a needle-punching operation. Needle-punching consists of rows of evenly spaced, barbed needles which repeatedly penetrate through the preform. The needles re-orient the loose web fibers through the thickness of the composite laminates, providing the z-axis or out-of-plane fiber reinforcement. In this project, Carbon felt and plain-woven carbon fabric preform is needle-punched and infused with a Phenolics resin, suitable for the Vacuum Assisted Resin Transfer Molding (VARTM) technique. The design and manufacturing parameters of the needle-punching process such as the number of non-woven web layers added to the preform, alternate layup configurations, and varying levels of needle-punch density are analyzed. To evaluate the in-plane and out-of-plane mechanical properties of the 2D and 2.5D needle-punched composites, the following mechanical testing will be performed per ASTM standards: tensile test, flexure, interlaminar shear and impact testing. Additionally, scanning electron microscope (SEM) analysis is conducted on the specimens.

Technical Paper | Moderate

Effects of Thermal Cure Protocols on Gelation Behavior and Cure-Induced Shrinkage of Benzoxazine Networks

Bernardo Barea López and Dr. Jeffrey S. Wiggins (The University of Southern Mississippi)

Volumetric shrinkage of glassy amorphous polymer matrix networks during cure leads to internal strain in carbon fiber composite parts which resultantly translate to warpage in the final parts. Polybenzoxazine thermomechanical properties such as high glass transition temperatures, superior UV resistance, low coefficient of thermal expansion (CTE), and low shrinkage upon cure compared to more traditional aerospace thermosetting polymers. Recent advancements in continuous prepolymer reactor science provide new opportunities to prepare benzoxazine monomers with high degree of purity without the necessity of performing tedious work-up protocols. However, the polymerization conditions of this promising class of thermosets are still poorly understood with regard to cure-induced shrinkage. This research seeks to establish the relationship between cure shrinkage and cure protocol of polybenzoxazine networks. Herein, three different isothermal curing procedures were selected to achieve different degrees of conversion for the same network. The impact of the curing protocols on the frequency-independent gelation times of polybenzoxazines is determined. Futhermore, the effect of the three different cure protocols have on the chemical shrinkage is investigated through a novel technique which allows to track in real time the volumetric change of the polymer network. This research will ultimately contribute towards the understanding of the relationship between network formation of thermoset materials and the creation of internal strain in the manufacturing process of composite materials.

Technical Paper | Moderate

The Use of Post Consolidation to Improve the Mechanical Properties of Light Weight Reinforced Thermoplastic Composites

Hongyu Chen, Ruomiao Wang, Mark O. Mason (Hanwha Azdel)

Light weight reinforced thermoplastic (LWRT) composites are widely used in the automotive industry because of the advantage of light weight resulting in high fuel efficiency. This paper discusses the use of post consolidation to improve the mechanical performances of the fiber composite material developed at Hanwha Azdel. This high performance composite material is comprised of a porous core with chopped glass fiber and thermoplastic resin, and surface finish layers on each side. A post process was developed to improve the mechanical properties by further consolidation of the porous core. Mechanical performance was investigated by both flexural and tensile tests, and the surface morphology was examined by scanning electronic microscope. Both mechanical and morphology investigations indicate that, especially for the lighter materials, this post process significantly improved the consolidation level of the porous core. Therefore, this promising post consolidation method is expected to further reduce weight without sacrificing the mechanical strength of the material.

Technical Paper | Basic

Resin Infusion of a Hollow Airfoil Using an In-situ Polymerizing Low Viscosity Thermoplastic Matrix

Samuel D. Strassler, Patrick A. Rodriguez, Mark E. Bourgeois, Donald W. Radford (Colorado State University)

Thermoplastic polymer resins that can be in-situ polymerized have been demonstrated, on a number of occasions, as low viscosity alternatives for composite matrices, enabling the manufacture of composites using resin infusion molding (RIM). Elium from Arkema has been commercialized which, when processed, results in a methacrylate thermoplastic. This in-situ polymerized thermoplastic promises the advantages of a thermoplastic matrix in terms of toughness and recyclability with the ability to be used in production of relatively large composite articles in reduced amounts of time and with no requirement for added heat during the initial phase of processing the composite. The Elium resin has a viscosity of 100 cP which has the potential to reduce processing time and consumable expenditure; however, this low viscosity can introduce challenges when following common practices developed for thermoset infusion resins which are typically in the 250 – 300 cP range. This effort, focusing on process optimization for a low viscosity, resin infused in-situ polymerized thermoplastic resin, considers various styles of expendables and process parameters. The demonstration article is a small hollow airfoil geometry of high length to chord aspect ratio that is representative of a small vertical axis wind turbine blade. The manufacturing process under evaluation uses a RIM technique to produce hollow blades, with molded exterior surfaces. Processed composite blade sections, infused with variations in process parameters and consumable arrangement, were evaluated. The results describe how flow rate and flow path manipulation can be used to reduce the number and size of defects observed on the wind turbine blade. More specifically, this study shows that variations in process parameters and consumable arrangement can be used to limit the defects in a resin infused carbon fiber reinforced thermoplastic wind turbine blade section using a resin with a low viscosity.

Technical Paper | Moderate

Filament Winding and Compression Molding Process for High Performance Composite Structures

Dan B. Hannula (Advanced Composites, Inc.)

A mandrel-less filament winding and compression molding method was developed to manufacture high performance composite structures. Goals of the process were to create high fiber volume and low void content solid composite structures with control of fiber orientation from 0 to 90 degrees to the winding axis utilizing a highly automated and repeatable process. To generate the material, a filament winding machine was modified to allow the material to be wound between a driven headstock and a driven tailstock. During filament winding, material that was part of the manufactured end use component would also serve as the support material and tooling for fabrication. After filament winding, the produced material was compression molded to enhance material properties. For demonstration of this technology a high-performance ball (also known as a frac ball) used as a seal/valve for oilfield applications was manufactured and tested with this material. The use of this material to construct the ball would overcome several of the issues with current composite frac balls in the market related to fiber orientation or short strand fiber reinforcement. The frac ball was developed to withstand a service temperature of 177 °C (350 °F) and pressure of 69 MPa (10 ksi) in any orientation. Testing of the ball demonstrated excellent performance at the required temperature and pressure, independent of the specific tested orientation of the ball. This mandrel-less filament winding and compression molding technique successfully produced high performance composite material in a scalable and efficient production process.

Technical Paper | Moderate

Comparison of Hand-Layup and Automated Tape Placement Processing of Thin Ply IM7/8552 Composites

Uday Kiran Balaga, Verena Gargitter, Dirk Heider, John Tierney, Suresh Advani, Shridhar Yarlagadda (Center for Composite Materials)

Composite structures offer higher lightweight performance when compared to traditional metals yet lack sufficient tolerance for damage onset. The focus of this effort is on thin-ply thermoset prepreg materials manufactured by Hexcel, which have shown higher resistance to damage initiation under applied load when compared to standard ply-thickness materials. To manufacture large structures currently Automated Tape placement (ATP) process is used. However, composites manufactured using thin-ply materials require placement of many more layers to achieve the same net volume of coverage. Gaps and overlaps between adjacent prepreg layers are unavoidable with tape placement and can result in degradation of mechanical properties due to these changes in the microstructure. Placement of thin-ply tape will also cause microstructural variability due to the low handling stiffness of this material. Modifications to existing automated tape placement equipment were made to address the steering of the thin-ply tapes which resulted in improved placement accuracy. Unidirectional and quasi-isotropic panels were fabricated from 12´´ wide unidirectional prepreg sheet with traditional hand layup method and compared with

panels fabricated with ATP process using a 1/4´´ unidirectional prepreg tape from the same 12´´ prepreg stock under varying processing conditions. All panels were cured in the autoclave with the recommended cycle. This paper compares the effects of processing parameters on the mechanical properties and the microstructure of the processed panels. This was achieved by characterizing the microstructure using
C-scans, confocal microscopy and conducting mechanical tests.

Technical Paper (no recording available) | Moderate

Development of a Low-Cost Silicone Mold Tool for Injection Molding Plastic Parts

Irfan Tahir, John Rapinac, Abdulaziz Abutunis, Venkatagireesh Menta (University of Minnesota Duluth)

The design and development of injection molding (IM) tools is a very expensive and time-consuming process which makes it uneconomic to incorporate traditional IM into the prototyping stage of a product. Currently, the most widely researched method used for rapid prototyping of IM tools is 3D printing with engineered plastics. This project investigates an alternative to 3D printed IM tools by investigating a cost-effective mold tool made of silicone. Design of Experiment (DOE) is used to measure the main and interaction effects of design parameters (e.g., durometer hardness, geometry, and design complexity) on the performance of the silicone mold. It was found that a durometer of Shore A Hardness 40 is the most optimal value for a silicone mold tool. Using 3D printed inserts and a short runner improved the mold performance. Comparison of mechanical properties of the silicone mold test coupons with those produced using a metallic mold tool revealed that there was a 7.3% decrease in Ultimate Tensile Strength, bettr than those previously reported for some 3D printed mold tools. Results show that the silicone mold tool is a promising alternative to 3D printed mold tools for low-volume injection molding.

Technical Paper | Moderate

The Convergence of Composites and Topology Optimization, Ushering in the Next Era of Aircraft Lightweight Structures

Riley Reese, Sana Elyas, Yang Shen, Luis G. Bahamonde Jácome (Arris Composites)

Although advanced composite material outperforms metal on material data sheets, actual composite structures often fail to provide a significant improvement. In part, this is due to the application of design approaches that were originally meant for metallic constructions. As a result, advanced composite structures end up having a redundant layup, with a quasi-isotropic stacking sequence that eliminates anisotropy, instead of leveraging it, so called black aluminum. Today's approach to take better advantage of continuous carbon fiber's mechanical properties, fibers are aligned based on the anticipated loading conditions. This can be achieved using hand layup or automated tape layup (ATL) / automated fiber placement (AFP) techniques. Though this provides a significant improvement over the "black aluminum" approach, it still falls short of realizing the full potential of continuous fiber anisotropy. Since carbon fibers perform best in tension, the part itself should be redesigned to

take advantage of this effect. Though this exercise may seem intuitive for simple parts, in the aerospace industry these coupled design activities easily become non-intuitive due to the complex loading conditions the aircraft structures are subjected to. Arris Composites has developed a new process, additive moldingTM, capable of manufacturing complex geometries, using continuous fiber. This paper presents optimizing topology and fiber orientation for an aerospace bracket, having complex 3D load cases. These optimized structures are shown to outperform current composite structures as well as structures machined and 3D printed from metal, making them ideal for next generation aerospace brackets and joining structures.

Education Session | Moderate

Robotic Sanding, Grinding & Finishing tasks on your industrial or collaborative robot

Michael Haas (FerRobotics)

Robotized processing is important for sanding, grinding, polishing, deburring, etc. since a consistent contact force is crucial for the final product quality. However, human workers are not able to perform such a consistent contact force over longer time. Furthermore, experts for these 3D jobs (dirty, dangerous and demining full) are increasingly hard to find. Consequently, all industries (aerospace, automotive and general industry) tend to automate their surface finishing sequences. Key criteria for a reproducible, uniform surface finish is to control the process and therefore the process force. Previous approaches have been either force control or physical compliance. The state of the art approach combines the benefits of both principles and results in an active compliant force control. An autonomous sensitive compliant force control not only allows to controlling the forces but also compensate a certain range of positioning tolerance. Through this physical compliance the contact force can be controlled very fast. It has a further impact on the usability. Within a self-adapting stroke, the robot paths may be programmed rather inaccurately. Robotics applications based on active compliant force control deliver a consistent high-quality production, high process security and a faster return on investment. In form of best practice cases we will demonstrate those challenging robotics applications by using different robotics technologies and compare the suitability on different industry tasks. The focus will be on the applications in raw composite, carbon parts sanding – paint preparation – paint/primer sanding, local spot repair even on clear coated parts, as well as deburring and turbine blade operations.

Education Session | Moderate

The Implementation-Use-and ROI of IIoT and AI Technologies in Composites Part Manufacturing

Clay Bolick (Plataine) and Vincent Tran (Virtek Vision)

Facing increasing market demands, advanced manufacturers must examine methods to support high-rate programs at lower costs. Industrial IoT and AI (Artificial Intelligence) technologies open a new horizon of possibilities for these advanced manufacturers and increasingly allow them the eminent ability to address this complexity: support shop floor staff and managers in daily decisions, increase throughput, reduce costs, meet strict quality and time-to-market requirements - all to remain profitable and competitive.. Real-time, context-aware recommendations and actionable insights driven by AI and real-data collection, allow factories to become smart and to optimize their operations, increase production, reduce costs and stay ahead of the competition, by digitizing and optimizing their complex production environments. As with any case of new technology adoption, challenges must be overcome, and best practices used. Learn through real-life challenges, implementation examples and best practices: What are the major trends in this space; How AI-based technologies and methods create new opportunities for advanced manufacturers, fitting a range of business models, needs and constraints; How automation and end-to-end digitization of advanced manufacturing, including additive manufacturing, enable enhanced productivity and efficiency levels across industrial and business processes, creating a sustainable competitive advantage with a tangible, fast ROI; All to capture the disruptive value AI can bring to today's manufacturing world.

Education Session | Moderate

Fundamentals of Tool Design for Composite Manufacturing

Tom Margraf (Smart Tooling)

Have you ever got to the end of a first-article part and realized something is wrong. You look back and find a little mistake during the design/processing phase. You realize your team got wrapped up in the big picture and forgot about the details. Think about a football game. When you boil it down to its most basic level, the team that is better at blocking and tackling is going to win the game. While developing plays and making correct strategic decisions are important, if the team can't run the ball or make a tackle, they are not going to win. These basic but essential factors are vital to creating the foundation of success. In tool design for composite manufacturing, fundamentals such as attributing for bulk/scale factor, or vacuum bagging techniques are often overlooked but are vital factors. Likewise, in processing composites, the various factors that all lead to quality parts like cure cycle, breathing strategy, etc. all need to be considered during the design stage. All of these small factors that should be taken into account during the design phase of the project can add up to mean the pass or fail of the final composite part. Using a case study of a composite co-cured integrated control surface, we'll dive deep into the core fundamentals that make such an intricate part possible. Our learning objectives are to understand and apply bulk scale factors, advanced vacuum-bagging techniques, cure cycle optimization & design, sequencing & structural design, and apply these concepts for complex real-world problems.

Education Session | Moderate

When Do My Raw Materials Expire and What Does It Mean

SCOTT LEWIT (Structural Composites, inc)

There is much misconception about the expiration date for materials. For example the 90 day standard expiration time for polyester resin is not really an expiration, it is the end of the manufacturers warranty date. Resin is not good on day 90 and bad on day 91. These dates are driving manufacturers to costly disposal and replacement. A significant source of waste for the industry. So for this session I want to have resin, fiber, core and adhesive suppliers explain the difference between warranty date and when the product should no longer be used. For each of the materials we will discuss in-house and out-of-house tests that can be done to ensure the material is still suitable for use even though the "best buy" date has passed. Also importantly we need to know when not to use a material that is past its warranty date. For many manufacturers using a resin past the warranty date presents a potential problem with the customer they are supplying. Customers currently view the resin warranty date as the expiration date. Explaining this can be quite a challenge. I would like the panel to address how to approach customers and give examples of how to re-certify or otherwise show that the materiel is suitable for use.

Education Session | Basic

No F.O.D.

Steven Wilson (Cold Jet LLC)

Whether you're making composite parts or preparing them to be painted or bonded, there can be no F.O.D. Traditional cleaning methods can be slow, inconsistent, and abrasive. Cleaning with dry ice is fast, efficient, safer and most important, removes all F.O.D. Dry ice cleaning allows manufacturers to clean while tooling at operating temperatures and on-line, significantly reducing downtime. Dry ice cleaning solutions can be manual or automated. Tooling is the heart of making a good composite part and maintaining mold surface finishes and tolerances is mission critical. Dry ice cleaning is non-abrasive and does not leave any secondary waste behind. Whether you are compression molding, resin transfer molding,m injection molding, prepregging, bagging or we-layup, all processes can see an improvement in O.E.E. Scores. Cleaning composite parts prior to painting or bonding often involves the use of aqueous methods requiring part drying. Dry ice eliminates the need for part drying and water containment/treatment systems. This presentation discusses how the dry ice cleaning process works, research studies, customer testimonials, and case studies. Also included are the top 5 reasons for considering this solution: improve quality, lower cost, increase productivity, extend the asset life of the tool, and improve worker safety and the environment by eliminating cleaning chemicals.   The attendee will have a working knowledge of not only how the dry ice cleaning process works and how to adapt it to various applications.

Market Applications

Technical Paper | Advanced

Effect of Nanocalcite-Modified Epoxy Resins on Burst Pressure and Design of Composite Overwrapped Pressure Vessels for Hydrogen Storage

James Nelson, Douglas Goetz, Jay Lomeda, Nicholas Larson, Wendy Thompson, Paul Sedgwick, Dave Sewell, Daryl Thompson, Jake Walker, and William King (3M Company)

A study was undertaken to investigate the effect of nanocalcite matrix modification on Composite Overwrapped Pressure Vessels (COPVs) for hydrogen gas storage. Thick-walled type III COPVs were prepared via filament winding using a conventional unfilled epoxy matrix as a control material and an epoxy matrix resin modified with surface-treated nanocalcite particles at 35% by weight (3M Developmental Resin AMD 931). The COPVs were evaluated for burst pressure. The results show that the modification of the filament winding matrix resin with nanocalcite significantly improved burst pressure relative to the unmodified control resin. Additionally, impregnated strand tensile strength testing was performed on Toray T700S carbon fiber to investigate the effect of matrix resin on realized fiber strength. Data from impregnated tow specimens made using 0 and 35 weight% nanocalcite in the epoxy show that nanocalcite modification shifts the delivered fiber strength (DFS) distribution. The higher performance demonstrated for a given design suggests that use of nanocalcite-modified matrix resin could enable improved margins of safety, qualification at increased burst pressure, or redesign to reduce COPV weight and cost. To examine the implications of the measured increase in hydroburst pressure on article design, a design optimization study based on finite element analysis (FEA) was performed for a nylon-liner 52L COPV design using the increased DFS values. The optimized tank having the same external envelope had overall weight reduction of 12% and increased gas-carrying volume of 12 % due to reduction in composite wall-thickness enabling increasing the internal volume. The impact of increased hydrogen tank capacity on fuel cell electric vehicle range will be discussed as well as additional design options that are enabled.

Technical Paper | Moderate

Carbon Fiber- Fiberglass SMC Hybrids in Relationship to Resin Chemistry Systems

James Bono (Polynt Composites LLC)

With the onset of light weighting opportunities across multiple markets, the demand for advanced composites is growing. Reduction in component weights have forced material engineers to evaluate high modulus materials- reducing the thickness of parts thus reducing their weights. Carbon fibers are widely used for the exception al high strength and stiffness to weight ratios. This has resulted in carbon fiber composites being used in aerospace and wind energy markets where the material cost is not as critical. The problem with carbon fiber in higher volume applications has been its unit cost does not break through the cost to performance barrier. One of these higher volume markets is the automotive sector where light weighting opportunities are in high demand for electric and hybrid car designs. Fiberglass composites, while having similar component costs to metal and aluminum substrates, does not have the same weight reduction opportunities. Usually, standard density fiberglass components must be designed with higher wall thicknesses based on their modulus in comparison to carbon fiber materials. Carbon fiber composites- specifically sheet molding compounds (SMC)- can reduce the laminate wall thickness based on their higher stiffness. Hybrid combinations of fiberglass and carbon fibers used in SMC applications would result in minimal increase in the cost of the components and increased modulus to aid in the weight reduction. This paper will evaluate carbon fiber: fiberglass SMC hybrids and compare their mechanical properties relationships to both density and generic cost structures. In addition, three alternate resin systems- including vinylester and urethane modified resin chemistries- will be compared to determine their effect on the mechanical properties for the carbon fiber: fiberglass SMC hybrids.

Education Session | Moderate

Mitigation of Skin Wrinkling in Sandwich Structures with Thin High Density Core

Eric Anyanwu (Diab Americas LP.)

CANCELED

This paper summarizes the results of potential mitigation of facesheet wrinkling in sandwich structures, through the use of functionally graded core. Facing wrinkling is a failure mode commonly observed in sandwich panels with thin facesheets and lightweight cores. Traditionally, wrinkling is treated as a local, short wavelength buckling phenomenon in one or both facesheets due to the shear and compressive modulus of the core, and the skin stiffness of the laminate. The extremely small buckling wavelength in the wrinkling mode is independent of structural boundary conditions and curvature in most cases. Wrinkling stress has been shown to increase as a result of an increase in the density of the core. However, with this comes the added weight penalty from increasing the density of the core. Varying the core density through the thickness and having a high-density thin core adjacent to the facesheet, can significantly increase the wrinkling stress of the facesheet without a noticeable penalty of added weight and panel thickness. The types of core that will be tested are polyvinyl chloride (PVC) cores, polyethersulfone (PES) cores, and aramid fiber honeycomb cores. The type of facesheet that will be tested is an epoxy/carbon fiber prepreg. Two types of test methods will be conducted. The first will consist of a 4-point bending test to induce wrinkling due to compression in on the top facesheet. The second test will consist of a T-shaped load application device that will load the sandwich structure in a vertical, in-place direction.

Education Session | Basic

Continuous Fiber Reinforced Thermoplastic Application Development and Implementation: Case Study Review

Darcy Hornberger (Avient, formerly known as PolyOne Advanced Composites)

Continuous fiber reinforced thermoplastic (CFRTP) composites are used in a wide variety of applications to reduce weight, improve performance or to replace other materials. This presentation will focus on three (3) case studies to illustrate the versatility of CFRTP materials and the advantages they bring to specific applications and manufacturing processes. Case study topics will include an injection overmolded snowboard binding, a compression molded ATV skid plate and an injection overmolded stiffening member. The injection overmolded snowboard binding highback component is a CFRTP 8-ply laminate overmolded in nylon. It adds flexibility in target areas without reducing strength and performance, and enables fast injection molding cycle times and improved design flexibility over thermoset composites. The ATV skid plate, produced by compression molding multi-axial CFRTP laminates, replaces metal by reducing weight and improving impact resistance for underbody protection. The injection overmolded stiffening member is a demonstrator part. This component illustrates the ability of injection overmolding to enable the reduction of weight, wall thickness and overall material use through the addition of CFRTP reinforcement. The case study will compare traditional injection molded vs. composite overmolded parts to illustrate design and manufacturing optimization and part consolidation possibilities. The presentation will review the application development process from material selection, design and analysis, to testing and manufacturing. Data will be presented to compare the performance advantages of CFRTP composites to traditional materials.

Education Session | Basic

The Future of Advanced Materials in Consumer Products

Andrew Dent (EVP Material Research)

This session aims to educate attendees on the current needs and challenges regarding performance materials faced by consumer product companies. Using a format of case studies, evolving consumer trends and current materials demands from successful brands, the presentation will deliver a wide range of insights into the way brands approach new materials development, how best to deliver on their needs and how to address cost and sustainability questions. These insights come from a company that has spent the last two decades working closely with all the major household names in consumer electronics, home appliances, furniture, automotive, fashion, sportswear and equipment as well as packaging, giving them unparalleled access to the opportunities these companies face in the materials realm. Attendees will leave with a better understanding of what motivates brands to choose advanced materials, the types of marketing and sales efforts that best suits the storytelling aspect of modern design needs and what consumer benefits they are looking for their products to provide.

Material ConneXion is a leading innovative and sustainable materials resource and consultancy that connects materials manufactures with leading brands through its 10,000 sample strong library in New York and global locations, as well as its network of materials specialists

Education Session | Basic

New Transportation Applications for Composites using Technology StairStepping

Scot Lewit (Structural Composites, inc)

This CAMX session shows how DOD, commercial and supply chain investment can be used together to generate and advance composite technology along with taking the technology to commercial deployment. A case study will show how a Navy Small Business Innovative Research (SBIR) award for an advanced combatant craft, generated new technology that gained the interest of disruptive commercial innovators in the transportation market. The large market potential of the commercial partner allowed for significant supply chain investment to make the technology commercially ready. Once commercially in use; the DOD now can leverage the commercial and supply chain investment allowing for DOD deployment. The session will show how the SBIR program works. We will discuss the requirements to participate in the SBIR program and teaming approaches that allow large businesses to participate. Technology and data rights for SBIR's will be explained along with the direct contract rights that come with an SBIR award. For Government, the session will discuss the power of including commercial pull and the influence it has on the supply chain. Many DOD applications are low volume production rates, which inhibits supply chain investment. Attracting commercial interest early in the program increases advances in the technology which in-turn speeds commercial readiness for DOD use.

Education Session | Basic

Advancements In Composite Infrastructure Deployment In Florida

Steven Nolan (Florida Department of Transportation)

Previous FDOT presentations at CAMX focused on isolated pilot demonstration projects for new construction of highway infrastructure using Fiber-reinforced Polymer (FRP) composites. This presentation will highlight the ever-expanding range of applications and materials thru mid-2020, and the maturing of FDOT specifications for design and construction. Highlights include the adoption of new specifications for Basalt-FRP reinforced concrete as part of a federally sponsored innovation grant, and development of Composite Bridge Beam competitive design and bidding strategies. The latest advancements.in full-scale testing and research support for FRP in prestressed precast bridge beams and piles continues to expand the range of product applications and owner design solutions for improved durability and lowering life cycle costs. Refinements to the design specifications continue to be explored to provide economically competitive solutions for low-bid government procurement systems, while developing education tools for designers, contractors, and owners. Case studies will be selected from a wide range of recently completed projects

Non-Destructive Evaluation & Materials Testing

Technical Paper | Moderate

Effects of Materials Characteristics and Equipment Configuration on Profilometry Scanning Results for Error Mitigation

Jacob O. Ondeck, Wout De Backer, and Michel J. L. van Tooren (McNair Center University of South Carolina)

The Automated Fiber Placement (AFP) process is a composite manufacturing process for constructing layered parts by placing tapes of material on a tool using a compaction roller and heat to make the material tacky. Manufacturing artefacts, such as unintentional tow twists, gaps, overlaps and even missing tows during the layup process may occur during layup. These defects deviate the manufactured structure from the as-designed structure, and have been proven to introduce stress concentration sources, which can ultimately undermine the performance of a structure. To detect and avert these defects during manufacturing, a profilometry driven topology analysis system can be used to scan the placed tows, check for layup defects, and record a history of the part. However, for certain materials and environmental conditions certain profilometers do not currently return reliable readings of the material topology, resulting in noisy or missing topology data. An experimental investigation into the feasibility of improving scan results of specific thermoset composite materials is summarized by investigating settings on commercially available profilometry scanners. Additionally, the impacts of material characteristics including surface quality are explored. Presented are the challenges, analysis, and potential solutions discovered to improve scanning results.

Technical Paper | Advanced

A Minimally Intrusive Impact Detection System for Aircraft Moveable using Random Forest

Li Ai, Vafa Soltangharaei, Wout de Backer, Paul Ziehl, and Michel van Tooren (University of South Carolina)

Impact events are of interest during the service life of commercial and military aircraft and reliably assessing the location of impact damage is important for aircraft maintenance. Traditional impact detection for aircraft is generally confined to visual inspections between the flights intermittently followed by more comprehensive and detailed inspections. The purpose of the study described herein is to investigate a path forward for the automated detection and localization of impact events. Machine learning is investigated as a means to improve upon traditional inspection methods. A flight amenable impact monitoring system was developed and utilized to detect and localize impact events on a thermoplastic aircraft elevator in a laboratory setting at the McNAIR Aerospace Center. Steel spheres were dropped from a controlled height on the elevator skin to simulate damaging events that may occur during flight. To keep weight, power, and cabling to a minimum a single sensor was attached to the spar of the elevator. A source localization approach based on random forest is proposed. Several features were extracted, and feature importance was ranked using random forest. The selected features were gathered as a dataset to train and test the performance of the proposed source localization approach. Results demonstrate the efficacy and potential of the random forest-based approach for localization of impact event monitoring for the application of a thermoplastic aircraft elevator.

Technical Paper | Advanced

Characterization of Anisotropic Thermal Conductivity for Big Area Additive Manufacturing with Polymers

Artem A. Trofimov, Hsin Wang, Ahmed Arabi Hassen, Halil Tekinalp, Vlastimil Kunc, Seokpum Kim, and Soydan Ozcan (Oak Ridge National Laboratory)

Additive manufacturing with polymers has been used mainly for prototyping. A recent development of Big Area Additive Manufacturing (BAAM) at Oak Ridge National Laboratory has opened its applications in the mold and die industry. A numerical simulation and prediction for a mold heating performance requires accurate anisotropic thermal properties of the printed material, which are challenging to obtain and often requires the use of multiple techniques. The transient plane source (TPS) technique has been widely used due to its ability to measure the thermal properties of an extensive range of materials (solids, liquids, powder). Despite the capability to characterize thermal conductivity (k) of isotropic and anisotropic materials, the measurements of latter materials are limited to the cases, where the samples have the same thermal conductivity (k) along x- and y-axis that form the radial plane. In this work, the method for a characterization of k in all three dimensions is developed, and the application of TPS is extended to the determination of thermal properties along the x-, y-, and z-axis individually. The materials are represented by additively manufactured polymers including polylactic acid (PLA) and styrene maleic anhydride (SMA). The developed method consists of (1) a determination of the heat capacity of the polymers by means of TPS in combination with the model developed in this work for the data analysis procedure, (2) a machining three types of cylindrical samples from the same material, with the height corresponding either to x-, y-, or z-direction of printing, and (3) a determination of axial thermal conductivity employing anisotropic model and using previously determined heat capacity

Technical Paper | Moderate

Thermoplastic Uni-Tape Quality Inspection

Joseph P. Heil, Andi C. Meyer, Waruna P. Senevirante, and Brandon L. Saathoff (Spirit AeroSystems)

Recently, high performance thermoplastic resins from the Poly Ether Ketone family have been integrated into carbon fiber unidirectional prepreg (uni-tape) formats for use in aerospace manufacturing. However, the quality level of thermoplastic uni-tape is much more influential on processing and final part quality compared to thermoset uni-tape. The primary goal of this research is to document thermoplastic uni-tape quality from different suppliers and determine the impact these characteristics have on the ability to fabricate high-quality high-performance structural parts per a defined process. Six material systems derived from five suppliers and three polymer systems are characterized. Parts will be fabricated using oven consolidation, autoclave consolidation, and stamp forming. Differences in void content and crystallinity are expected as a result of the varying pressure and thermal history. Results from this work will support future processing methods such as automated fiber placement (AFP) in-situ consolidation.

Technical Paper | Moderate

Comparison of Accelerated UV Lab Tests for UV Effects on Fiberglass Crossarms

Jiayi Jenny Zhu and Michael S. Schoenoff (GEOTEK LLC)

Fiberglass crossarms are built with fiber-reinforced polymer (FRP) composite materials that are mounted on utility poles or transmission towers to support overhead power lines. The service life of a fiberglass crossarm is influenced by outdoor weath-

ering, which includes ultraviolet (UV) radiation, temperature, and water from rain and condensing humidity (dew), etc. In this paper, we compared two standard accelerated UV lab tests based on the commonly used Cycle 1 specified in both ASTM G154 and ASTM G155 to evaluate the effects of UV radiation on samples of fiberglass crossarms. Upon completion of 10,000 hr of accelerated UV lab test and along with inspections of the test specimens at intervals of every 1,000 hr, we were able to monitor the onset of fiber blooming and the progressions of both loss in gloss and fade in color. We also evaluated changes in sample weight and surface roughness of each test specimen at the end of the accelerated UV lab tests. We found that the data collected from the 10,000 hr of accelerated UV lab tests were comparable to the results we published previously from a different study of FRP crossarm samples which was based on 12 months of accelerated outdoor weathering test per ASTM G90. These results demonstrated that the progression of UV effects on FRP composite materials can be monitored using standardized accelerated UV lab tests and that they are comparable to the UV effects under sunlight on fiberglass crossarms.

Technical Paper | Moderate

Test Sample Preparation of Pultruded Unidirectional Carbon Parts – Issues in Machining Practice and Alternatives

Leigh Nolen, James Orr, Christiaan Mauldin, Dr. Mac Puckett, and Dr. Lei Zhao (Avient, formerly known as PolyOne Advanced Composites)

The advantages of carbon fiber composites are well known – lightweight, corrosion resistant, high strength and high modulus. The economic advantages of producing composites by a continuous pultrusion process are also well understood. But testing these unidirectional carbon composite parts can be problematic. Most composite testing methods call out the use of thin flat rectangular strips or in some cases cylindrical sections. Unfortunately, shapes produced by pultrusion are not limited to cross-sectional areas or geometries that are easily or directly tested. Unlike isotropic metals or quasi-isotropic prepreg lay-ups, the unidirectional parts typically made in pultrusion are very anisotropic, not perfectly symmetrical in the Z-axis, and have a propensity to fail in shear during a variety of testing. It is often the case that full scale sample testing is required to meet consumer or regulatory compliance. Some end market specifications require testing that can be challenging or nearly impossible to perform based on composite structural shape or testing limitations. In order to complete testing, samples are manipulated through traditional machin-ing methods to create a sample that can be tested. One such test is tensile strength as measured by ISO 527-5 (ASTM D3039). For carbon composites made of a standard modulus carbon, this test is particularly difficult to perform if the part tensile strength exceeds the shear strength of the tabbing adhesive and shear area combination. Traditional practice would dictate that the part thickness be ground down to achieve a breakable cross-sectional area for this carbon composite. However, grinding unidirectional pultruded composites can terminate fibers producing a false material failure point. This paper will highlight the challenges of using the tensile test to qualify carbon unidirectional composites and discuss the merits of producing and testing a thinner representative sample in place of a ground sample for qualifica-tions.

Technical Paper | Moderate

Fatigue Life Assessment Of GFRP for Longitudinal Leaf Springs

Fabian Becker, Christian Hopmann, Francesco Italiano, Alberto Girelli (Institute for Plastics Processing)

Due to the high specific properties, fiber reinforced plastics are ideal candidates for the substitution of steel parts in the automotive sector enabling high weight savings and increasing the efficiency of automobiles. One application are composite leaf springs made of glass fiber reinforced plastic (GFRP). Because of the simple bending load case, the fiber direction can be aligned with the loading direction. For longitudinal leaf springs, the axle is clamped in the center to the leaf spring component leading to a different stress state compared to pure bending. The aim of the research presented (in a cooperation between Institute for Plastics Processing and Ford Research and Innovation Center) is to develop a testing method on specimen level that is able to determine the fatigue life including the complex stress state in the clamping section. For this purpose, three point bending experiments on unidirectional specimens made of GFRP epoxy pre-preg material are performed including a miniaturized clamping system. This results in a more realistic representation of the leaf spring stress state in the fatigue experiments. The applied force in the clamping section is measured during experiments and reveals the creeping behavior of the composite material. Fatigue testing also shows a significant change in damage evolution compared with the pure bending stress state resulting in shorter fatigue lives. With the results of this research, higher safety in the design of this component and less testing time is achieved.

Technical Paper | Moderate

In-Situ Composite Rotor Damage Detection

Dan Kominsky, Brian Rife, Elias D. Bearinger, Nur Aida Abdul Rahim (Luna Innovations)

A Rapid In-Place Composite Rotor Damage Detection (RIPCoRDD) System was developed for determining and tracking the structural health of composite rotorcraft blades. This fulfills the need for accurate and reliable assessment of the condition of composite parts which may have been damaged through impacts or fatigue, especially for cases where damage is not visible from the surface. The approach utilizes high-definition fiber optic strain sensors (HD-FOS). Sensor lengths up to 50 m can be embedded during fabrication and provides spatially dense strain measurements (sub-millimeter) from within the composite structure. In this work, HD-FOS is used to build a system of spatially distributed strain rosettes over flat and curved surfaces. The software and algorithmic work developed for interpreting the RIPCoRDD system output is described. Finally, the system is characterized through a series of impact tests performed on panels and beams. This data is used as a training data set to distinguish impact based on distance to the fiber sensor as well as energy content. Blind testing of the impact damage detection algorithms is then shown to achieve a success rate of at least 51 out of 54 trials. This approach can be applied to a variety of composite structures as a means of assessing if they have sustained any damage during service.

Using Dielectric Analysis for Monitoring Composite Curing

Peter Ralbovsky (NETZSCH Instruments)

Dielectric Analysis (DEA), also known as Dielectric Thermal Analysis (DETA), is a technique for monitoring changes in the viscosity and cure state of a thermosetting composite, resin, adhesive, and/or paint. DEA can be used to test the effectiveness of accelerators, inhibitors, anti-oxidants and measure the impact of fillers. The method allows for sensors to be placed into molds to monitor the curing process of the sealed system or can be imbedded into materials as the cure. From the data you can investigate the degree of cure, gel-point, glass transition temperature, aging, diffusion properties as well as other effects. The basic principle of DEA is similar to an impedance measurement. A single dielectric sensor is made up of two electrodes. A sinusoidal voltage is applied across the two electrodes which creates an electric field. Any charge carriers in the field will migrate to it's opposite pole and any dipoles within the sample will align to the electric field. The movement results in a sinusoidal current which is phased shifted from the applied electric field. This response signal, both in phase shift and amplitude, is a function of the dipole and ion mobility. During curing, the mobility decreases as a function of the cure and this is easily measured in both the shift and attenuation of the signal. Dielectric Analysis can easily be applied in the composites field. For example, in-process characterizations of Sheet Molding Compounds (SMC) where the ability to monitor the cure in the mold is possible. Tests can be performed at various temperatures and pressures to optimize the process reducing time, cost, and waste. Other closed mold process such as Resin Transfer Molding (RTM) can also benefit from real-time cure monitoring. In this education session the DEA method will be described in detail including the strengths and weakness of the approach. Furthermore we will compare and contrast this method with other thermal methods commonly used for composite characterization to show synergistic opportunities to develop a deeper understanding of the materials and processes. Several case studies will be used to highlight these topical areas.

Education Session | Basic

Tensile Testing of Advanced Composites

CANCELED

Donald Klosterman (University of Dayton)

This presentation describes the various details involved in tensile testing of advanced composites, including equipment, sample preparation, test execution, and data analysis. In short, it explains how to collect a valid data set. The tensile properties of a composite material are among the most fundamental and commonly published pieces of information because they can be used for material comparisons as well as structural design. However, the test method is more complicated than many people expect due to the anisotropic nature and high stiffness of advanced composites made from carbon, glass, and aramid fibers. This talk will be relevant for those setting up a new lab, upgrading an existing capability, or contracting test-ing services to an independent lab. It will also help those reviewing the literature to evaluate whether a given data set is valid based on the stated test conditions. The scope will focus on continuous fiber composites (including unitape and woven fiber composites) tested at ambient temperature. However, issues involved in testing chopped or short/long fiber composites will also be mentioned. The key topics to be discussed include equipment (frames, load cells, grips, alignment systems), sam-ple preparation (cutting, tabbing, bonded strain gages), test methods (strain rates, sample monitoring, differences in ASTM vs. ISO standards), data analysis (strength, modulus, failure strain, identifying failure mechanisms), and fractography. If time per-mits, some advanced topics will be briefly discussed, including hot/wet testing, high strain rate testing, and digital image correlation (DIC).

Education Session | Advanced

Damage sensing using a mechanophore crosslinked epoxy resin in composites

Jeffrey Gilman (NIST)

Here, we report a novel method to directly visualize the local damage from fiber fracture in mechanically deformed composite materials. This new method reveals polymer matrix yielding, which occurs during the fiber fracture event, and agrees with a dynamic model that predicts yielding behavior in the matrix during fracture. This is demonstrated in a model composite, comprised of a spirolactam-based mechanophore-functionalized epoxy resin with a single embedded glass fiber. The ductile epoxy matrix is loaded under tension, which transfers load through interfacial shearing to the embedded brittle fiber, causing the fiber to break into segments. Fluorescence lifetime imaging microscopy (FLIM) of these single fiber fragmentation test (SFFT) samples reveals localized damage zones in the epoxy matrix, not only at the point of fiber fragmentation, but also at distances remote from the fracture site that extend radially into the matrix up to two fiber diameters. Evidence of this damage comes from both the fluorescence intensity and fluorescence lifetime of the activated mechanophores in the yielded regions of the epoxy. The SFFT is a widely used method for determining the interfacial shear strength (IFSS) between a fiber and matrix polymer. These results suggest that this test may be better viewed as a measure of a damaged interface instead of a pristine interface. The use of this new approach and the derived insights into the damage mechanisms of reinforced composites promise to dramatically accelerate the development of tough, durable, and damage tolerant composites in a broad range of applications from infrastructure and transportation to aerospace. If this new mechanophore were embedded in FRP composite structures, this would offer a new approach to structural health monitoring of structures like wind turbine blades.

Education Session | Moderate

What Matters Most? Surface Treatment Optimization for Thermoplastic Composites

Giles Dillingham (BTG Labs)

A wide range of variables affect the reliability of adhesive bonds when using advanced materials such as thermoplastic composites. In order to have the most effective bonding process that produces joints of adequate strength, the variables relating to creating a bondable surface need to be understood and controlled. This presentation puts forth the findings of surface treatment evaluations using adhesive joints constructed from PEEK laminates. The effects of solvent wiping, abrasion, and different levels of plasma treatment on surface chemistry and adhesive bond performance were studied to quantitatively assess the most effective surface treatment techniques for thermoplastic composite bonding. The results of these studies revealed significant differences in the effects on adhesion reliability between the surface preparation methods examined. Furthermore, the results indicate factors, such as surface roughness and variations in surface chemistry, which were proven to be critical or inconsequential to interfacial strength. Studying the impact on surface energy, which correlated strongly with adhesive joint performance, the experimentation was able to narrow surface treatment options to the most useful for positively altering the factors most related to adhesion strength. Determined through X-ray Photoelectron Spectroscopy and simple water contact angle measurements, treatments shown to be particularly robust and quantifiably controllable techniques for thermoplastic composite bonding were identified.

Miscellaneous

Education Session | Moderate

Formulating with Flame Retardants, Fire Safety and Changing Requirements

Margaret Baumann (PInfa NA/FRX Polymers)

Pinfa North America is a not for profit trade group of Non Halogenated FR producers and users. Our main focus is to educate about alternative chemistries and applications for flame retardant additives as well as identifying challenges and opportunities. We have 33 member companies and have chapters in the EU, Asia and NA. We would like to present trends in Fire Safety, Changing requirements, formulating and testing of FR materials. We can offer a 55 minute overview or organize a panel discussion with experts in the field of fire safety. Our website is: www.pinfa-na.org. We will discuss fire mechanisms, market trends and their influence on the development and formulation of materials to meet current and changing fire safety requirements. Included in that discussion will be challenges facing formulators and compounders regarding their choice of effective and more sustainable fire safety solutions. There are both current and future technologies in development that are improving the options and foot print for specifiers of applications requiring fire safety considerations. We will discuss both thermoplastic and thermoset material solutions in primarily transportation, Aerospace and building and construction markets. Finally we will discuss the major drivers influencing the performance requirements for fire retardants/safety. If you prefer the panel discussion we will select producers, formulators, converters and end users to discuss challenges and opportunities in the field of fire safety.