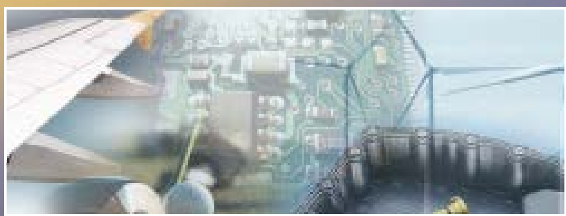
COMPOSITES

SPRING 2022



Composites Connection™

Official Newsletter of the SPE Composites Division

Reaching Over 1,000 Composites Professionals
In All Industries

Sponsored by:

BASF We create chemistry
BYK
carbon conversions closing the loop - today and tomorrow
DSC CONSUMABLES incorporated
HEXION Responsible Chemistry
MICHELMAN
MITSUBISHI CHEMICAL
Moldex3D MOLDING INNOVATION
MP Molding Products
Mitsui Chemicals Group
سابك sabic

SPE COMPOSITES
Spring 2022

Composites Connection™
Advancing Composites Technology Worldwide

Chairman's Message:

John P. Bussel, F.ACI, HoF.ACMA

On behalf of myself and the SPE Composites Division Board of Directors, welcome to the second newsletter of 2022. The past 2 years have been unusual and difficult for many of us as we deal with the COVID-19 pandemic. Many of us have not traveled, but instead, have spent countless hours in virtual meetings. Based on current trends, 2022 might be the year to return back to our business and professional lives that we used to know before the pandemic.

The SPE Composites Division Board, like most of us, carefully planned the Divisions activities and budgets to align with how the composites professional community was going to respond. Over the past few years we have supported technical programming for SPE ANTEC and Automotive Composites Conference and Exposition (ACCE). We look forward to increasing our efforts in FY23 to not only focus on ANTEC and ACCE, but to also celebrate new opportunities and most importantly our future.

One of the items the Board of Directors will be focusing on is solicitation of scholarships applications. The Dr. Jackie Rehkopf Scholarship is awarded to full-time graduate students with a focus on research activities targeted at ground transportation composite technology. Although the preference is given to female students, the best candidate will be selected. If no graduate students qualify then two $2,500 scholarships may be awarded to undergraduate students with junior or senior standing. Then there is also the Harold Giles Composites Division Scholarship which is awarded to One undergraduate and one graduate student. An essay is required documenting experience in the composites industry including courses taken, research conducted, or jobs held. Lastly, there is the Automotive and Composites Conference & Exhibition (ACCE) Scholarship where two scholarships are awarded to full-time graduate students, one graduate or undergraduate junior or senior. Students must be in good standing and pursuing a degree in Polymer Science, Composites, Plastics or a related engineering discipline. A two-page essay is required showing planned work and how it will benefit composites in an automotive or other ground transportation application. One recommendation must come from the student's advisor or mentor. Scholarship recipients are required to present their research project at the next ACCE conference. We hope this year will encourage many applications. We can use your help and get the word out to people you know and encourage them to submit.

The Composites Division Board will be working to develop strategic goals and plan to provide members with personal value to help them grow in the composites industry and in the profession. One of the ideas is to have periodic presentations of composites applications and

continued on page 4...

Chairman's Message continued...

field studies to learn about material advancements, manufacturing, and case studies of how composites are used. Be on the lookout for future updates as this idea is developed into practice.

Giving back – how can the Division members give back to the profession. One of the opportunities is to get involved on the Board. In late May we will be conducting elections for new Board members. If you are interested in steering the direction of the Composites Division or wish to champion a project that you are passionate about to help others in the composites community, we would encourage you to join the Board. If you are interested or would like to discuss your interests, please contact me at jbusel@acmanet.org.

Lastly, the Composites Division Board of Directors thanks our newsletter sponsors for their support in these difficult times. We also thank the membership, for your support and dedication to the profession. We have so much to accomplish together. I look forward to working with you and guiding initiatives in the Division to meet your needs.
Kind Regards,

John P. Busel, F.ACI, HoF.ACMA
Chairman, Composites Division

Tribute to Cedric Anthony Ball

Cedric Anthony Ball

An Automotive and Composites Industry Champion, Leading Volunteer and Dear Friend

With a most heavy heart we are announcing that Cedric Anthony Ball, age 59, of Powell, Ohio passed away unexpectedly Saturday, February 26, 2022 at The Ohio State University Medical Center. He was an associate of Hexion in Columbus. Born and raised in Chicago, he received a bachelor's degree from the University of Illinois and a master's in business administration from The University of Michigan. Cedric was known for his love for his family and his kindness to friends. He was also a lover of house music, (commonly called a "House Head") and a genealogy enthusiast. He was preceded in death by his father, Anthony Ball. He is survived by his wife of 27 years, Libby J. Spaulding Ball; his children, Lisanne, Olivia and Donovan; his mother, Jean Cates Ball; and his sisters, Arlis Ball and Lorinne Ellis.

continued on page 6...

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Tribute to Cedric Anthony Ball continued...

Cedric Ball established an outstanding global career as Innovation, Marketing and New Business development leader in composite materials with in-depth knowledge of the automotive, wind energy and building materials markets. Cedric began his career with General Motors as a chassis systems release engineer on the first-generation Saturn vehicle program. Since that time, he has served in a variety of marketing and new business development roles at Owens Corning, Ashland Performance Materials, BMC Inc. and Hexion Inc. He held a Bachelor of Science degree in General Engineering from the University of Illinois at Urbana-Champaign and co-MBA from Ecole des Hautes Etudes Commerciales (HEC Paris) and the Stephen M. Ross School of Business Administration at the University of Michigan - Ann Arbor. Cedric also was a certified 6 Sigma Black Belt.

As other achievements, we know Cedric from his role as Conference chairperson for SPE Annual Automotive Composites Conference and Exhibition 2009 and 2010. Cedric served several times as a board member in non-profit organizations, using his professional experience to set and deliver upon strategic plans, to the benefit of communities and people.

"Cedric was one of the finest gentlemen in the business and it was always my pleasure to work with him. I will miss him and so will the industry,"
– Teri Chouinard, Intuit Group, Inc.

"Cedric will be always remembered for his calm demeanor. He not only worked hard but worked with true commitment, team effort, heart in his projects. His ability to envision and communicate customer's unmet and unarticulated needs was second to none. He will be missed in the technical community by many,"
– Pritam Das, Toray Composite Materials America.

"It was my honor and pleasure to serve with Cedric on many SPE programs. His professional and personal support was well received and appreciated. I am saddened by his loss."
– Fred Deans, Honored Service Member, SPE

continued on page 7...

Tribute to Cedric Anthony Ball continued...

"I met Cedric in the late nineties when he worked for Owens Corning. We remained in touch for the following twenty-five years. Across my career in plastics, I have not met a person that exemplified the terms 'gentleman', 'businessman' and 'complete class act' more than Cedric. His work ethic was exceeded only by his integrity. His laugh was as heartfelt as it was contagious. I will deeply miss Cedric and offer my thoughts and prayers to his family."

– Len Nunnery, Plenco (Plastics Engineering Company)

"Cedric was one of those people who treated you as a friend from the first time you met him, and every time you crossed paths, he expressed genuine concern for how you were doing, before the topic changed to the business at hand. His contributions to the growth of the composites industry, and to the success of ACCE as contributor, sponsor and conference chair, are still accumulating and yet to be fully measured. I will miss his giant persona and salient insights."

– Dale Brosius, IACMI CEO & Chief Commericalization Officer

"Cedric Ball was the consummate jack-of-all-trades. His strong technical background and business-oriented mindset meant that he was able to succeed in everything to which he set his mind. Cedric was known for his positive attitude and ability to bring people together. He always knew the best spot for dinner and was full of esoteric knowledge of every spot he visited. Vocation aside, Cedric was a personal friend to everyone he met. By taking personal interest in people's lives and with his diverse experiences was able to mentor and support budding talent like myself. I will sorely miss Cedric and grieve his death."

– Ian Swentek, Westlake's Epoxy Business (formerly Hexion Inc.)

"I actually met Cedric the first time face-to-face in 2011 at ACCE in Novi where he joined our team. His involvement with the ACCE organization - as well SPE Composites division - was very clear from the start and has helped to put Hexion Westlake on the map. His commitment to growing this market was strong. More importantly, he was a trusted colleague and leader in many areas over his distinguished career. We are all better from knowing and working with Cedric."

– Francis Defoor, Westlake's Epoxy Business (formerly Hexion Inc.)

"We share the feeling of missing a much-valued person. Cedric's integrity, warmth and people-oriented personality made it a pleasure to work together. He will be sorely missed, and our condolences go out to his family and friends."

– Sigrid ter Heide, Westlake's Epoxy Business (formerly Hexion Inc.)"

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

carbon conversions
closing the loop - today and tomorrow
The Evolution of Recycled Carbon Fibers
introducing
the re-Evo® brand of products
Including our chopped carbon fiber
and non-woven advanced materials.
Find out more at CarbonConversions.com • 843-374-5600

ANTEC® 2022

ANTEC 2022 WWW.4SPE.ORG/ANTEC22

June 14-16, 2022; Charlotte, NC

ANTEC® showcases the latest advances in industrial, national laboratory, and academic work. Papers will share findings in polymer research and/or new and improved products and technologies.

SPE is hosting ANTEC® 2022 in-person, co-located with PLASTEC® South, an Informa event, in Charlotte, NC, June 14-16. PLASTEC® South is a comprehensive annual plastic design and manufacturing event for plastics professionals, suppliers, and buyers to discover innovation, engineer new technology, and expand their networks. ANTEC® 2022 will also include an online component.

The presentations at the in-person event will be selected/invited based on the applicability of their topic across a wide cross-section of the plastics value chain. Presentation/speaker selection, which will occur through a paper submission/review process and/or through invitation, will be considered based on the quality, relevance, and newness of any research done in the field as well as the speaker's position in the plastics industry. Technical Papers that are not selected for in-person ANTEC® will be recorded and delivered virtually over a schedule that will be announced soon.

The tentative schedule for in-person ANTEC® 2022 is as follows:

Day 1 (June 14)

2:00 PM – 5:00 PM	SPE Leadership Meetings
5:00 PM	General Reception with SPE Meetup Area

Day 2 (June 15)

8:00 AM – 12:00 PM	ANTEC® Sessions
12:00 PM – 1:30 PM	SPE Honors & Awards Lunch
1:30 PM – 5:00 PM	ANTEC® Sessions
5:00 PM	SPE Chapter Networking Events

Day 3 (June 16)

8:00 AM – 12:00 PM	ANTEC® Sessions
12:00 PM	Adjourn

SAVE THE DATE:

June 14-16, 2022

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Award Winning Paper

Toward Automated Foreign Object Detection Of Carbon Fiber Laminates Using Pulse Echo Ultrasound

Nathaniel J Blackman, David A Jack
Baylor University, Waco, TX

Abstract

Carbon fiber composites are becoming more desirable as a design choice in a wide range of industries due to their high strength to weight ratio. One common challenge to greater adoption of carbon fiber laminates is the reduction in performance due to the occurrence of foreign object defects introduced during the laminate manufacturing. These foreign objects lead to increased costs and waste through both the discarding of failed parts and in the need to overdesign parts to survive when foreign objects are not detected. The ability to reliably find foreign objects would lead to significant savings and would open the door to greater adoption of carbon fiber composites by making these parts cheaper, safer, and perhaps more lightweight. Nondestructive techniques are crucial to the detection of foreign objects, and ultrasound has shown to be a cost-effective and reliable technique for the identification of foreign objects. Previous work by Baylor researchers has shown the ability to determine the size and location of foreign objects made with Teflon films with high accuracy. This work focuses on the improvement of these methods and adapting them for other foreign object materials, specifically: copper, peel ply, infusion mesh, vacuum bagging, and gloving; while moving the technique towards full automated detection.

Background

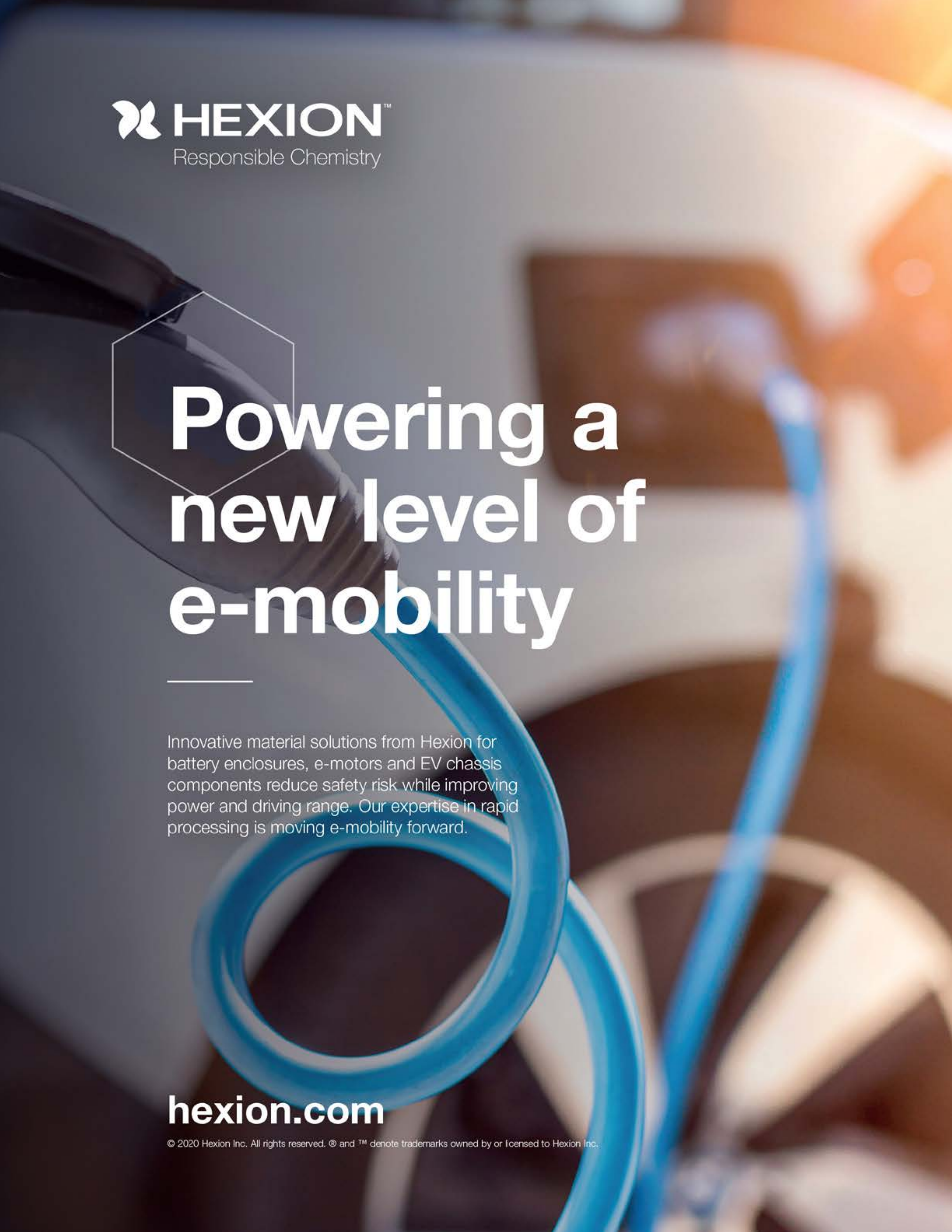
Transportation industries are feeling significant pressure to improve fuel efficiencies and reduce emissions [1]. One solution to increasing efficiency is the reduction of weight. The greater adoption of composites presents the opportunity for light-weighting. Many composites have high strength to weight ratios, and carbon fiber laminates in particular have one of the highest strength to weight ratios making them a material desirable for use in structural applications [2].

There are several different manufacturing techniques for carbon fiber laminates [2], and many of these techniques require at least some manual process. This makes carbon fiber composites susceptible to manufacturing defects. Defects such as delaminations, improper layup, inclusions etc. have been known to be caused due to faulty manufacturing techniques [3]. These defects can have a significant impact on the final part performance and increase the costs associated with using carbon fiber composites [4]. The true effects of these defects is the subject of ongoing research as researchers attempt to answer how different defects or induced damage impacts part performance through modeling [5–7] as well as experimentation [8]. This research will focus specifically on foreign objects which occur as excess material that ends up in the part during the manufacturing process.

continued on page 12...

This Issue:

• Message from the Chair
• Tribute to Cedric A. Ball
• Save the Date ANTEC 2022
• Award Winning Paper
• Councilor Report
• BOD Listings


HEXION™
Responsible Chemistry
Powering a new level of e-mobility
Innovative material solutions from Hexion for battery enclosures, e-motors and EV chassis components reduce safety risk while improving power and driving range. Our expertise in rapid processing is moving e-mobility forward.
hexion.com

Award Winning Paper cont...

Along with the need to better understand the effect of defects on composite parts, there is a growing need for adequate testing of composites. Traditional testing techniques are destructive and can add significant cost to the use of composites. This creates a need for non-destructive testing (NDT) techniques to complement traditional testing and aid in part qualification.

Several NDT methods have been examined to determine their ability to find foreign objects within carbon fiber laminates. X-ray CT [9], acoustography [10], thermography [11], terahertz [12], and eddy current [13] techniques have all shown promise in their ability to identify foreign objects in laminated composites. Ultrasound is the most popular NDT method [14], in part due to its relative low-cost and ease of use in comparison with many other methods [3]. Several researchers have explored the use of ultrasound for the detection of ply orientation [15,16], adhesive thickness [17,18], detection of wrinkles [19,20], and damage [7,21,22] among other areas of concern in carbon fiber laminates.

Multiple researchers have investigated automated or semi-automated methods for detecting foreign objects in carbon fiber laminates. Benammar et al. [23] applied signal processing techniques to ultrasonic scan data to identify simulated delaminations. They found success in determining the depth of the simulated delamination, but report no findings on the ability to determine size and shape. Poudel et al. [24] and Barry et al. [25] separately both investigated the use of artificial neural networks (ANN) to detect foreign objects within composite laminates. Both researchers were able to demonstrate success in determining the presence of foreign objects but neither work focused on the quantifying the dimensions of the defects, limiting the ability to objectively compare results against their approach.

Recent work by Mohammadkhani et al. [26] presents the use of an algorithm to detect and characterize defects using a wavelet transform on the base signal. They make use of a 10 MHz phased array transducer to scan a part with 5 different materials used as foreign objects: Teflon, paper, release tape, bag tape, and peel ply. In their work, all objects were placed between the 8th and 9th plies of a carbon fiber composite. The reported error in the size estimation of Teflon, bag tape, and peel ply foreign objects was, respectively, -41.7%, 20%,

continued on page 14...

and -66.7%. In absolute units, the errors are, respectively, 1.42 mm, 0.63mm, and 2.54 mm in capturing the effective width of the square objects. These results are highlighted as they are directly similar to the PTFE, vacuum bag, and peel ply foreign objects studied in the present work.

The recent work of Ma et al. [27] presents the use of a signal correlation algorithm to detect and size defects. They study intentional foreign objects made of graphite approximately 0.25 mm in thickness and with a diameter of 12.7 mm. They benchmark their algorithm against traditional phased array ultrasound and found they were able to size the height and width of the foreign objects accurately with an error ranging form 0.475 mm to 0.175 mm.

In a work by the current authors [28], the detection of PTFE foreign objects within a carbon fiber laminate was studied. Twelve circular foreign objects 0.05 mm thick and with diameters of 12.7 mm 6.4mm, 3.2 mm and 1.6 mm were intentionally placed within twelve different laminates at the interfaces between the 3rd and 4th plies, the 6th and 7th plies, and the 9th and 10th plies. Edge detection was applied to all samples along with a smoothing filter and the magnitude of the gradient traced (MGT) was presented for the sizing of the foreign objects. The average absolute difference in the estimation for all foreign objects studied was 0.1 mm.

This work seeks to apply the techniques described in [28] to a carbon fiber composite part containing multiple types of foreign objects while simultaneously presenting improvements towards a more automated MGT method for the sizing of foreign objects. This work will focus on a woven carbon fiber part with six different foreign objects: copper, gloving, infusion mesh, peel ply, PTFE, and vacuum bagging. While the average absolute difference in estimating size is greater than what was observed in [28], the estimation of the area of the foreign objects still compares favorably to other methods in the literature when comparing materials like for like. Future research is needed to develop the method more fully for each of the foreign objects studied and is the topic of ongoing future work.

continued on page 15...

Experimental Set-Up

Foreign Object Fabrication

Foreign objects were fabricated of six different thin materials: polytetrafluoroethylene (PTFE), vacuum bagging, copper film, infusion mesh, gloving, and peel ply. PTFE is a common material studied as a foreign object [26,28], copper film is likely to replicate the signal of an intentional foreign object such as embedded radar or lightning strike material, while the other objects are chosen as they are all common consumables used during the fabrication of the composite laminate. The PTFE foreign object is in the shape of an asterisk and was created using a Silhouette Cameo and measures 0.13 mm. The irregular shape of the asterisk is chosen to determine the ability to identify the shape of foreign objects with multiple sharp corners and a more irregular shape. The other foreign objects were not easily cut using the Cameo's preset cutting settings and were cut with scissors to be nominally 6.4 mm x 6.4 mm (1/4" x1/4").

After fabrication, and prior to placing the foreign objects in the carbon fiber composite all foreign objects were imaged with a Keyence VR3000 to determine their true size. Although the foreign objects are designed to be rectangular, there was some irregularity in their shape. The height and width are defined as the maximum distance between the nominally parallel edges. The height and width are multiplied together to create an effective area. This effective area is then compared with the true surface area measurement taken by the Keyence, based on the measured profile of each foreign object as it is imaged and profiled. The effective area for the asterisk shaped PTFE object is calculated differently than the other objects and is computed by fitting a circle to the outer points of the asterisk shape. Then, the area of the eight triangular cutaways is subtracted by measuring the interior angle of each cutaway and the distance between the center of the fitted circle and the vertex of the cutaway. Table I summarizes the measurements taken for each object. Of note is the discrepancy between the effective and surface area measurements for the Infusion Mesh object which is shown in Figure 1. This is due to the nature of the infusion mesh which has significant spatial gaps between the plastic material which are not measured as part of the surface area of the foreign object. For the infusion mesh, the effective area measurement includes the open gaps, while the surface area measurement includes only the material.

Table I: Summary of Foreign Object Measurements using Microscopy

Material	Height (mm)	Width (mm)	Effective Area (mm^2)	Surface Area (mm^2)
Copper	7.04	6.94	48.84	50.48
Glove	8.44	8.06	68.02	65.05
Infusion Mesh	7.69	6.74	51.82	16.01
Peel Ply	9.26	7.29	67.48	71.19
PTFE	12.42	12.42	96.51	93.63
Vacuum Bag	7.47	4.84	36.12	36.48

continued on page 17...

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Award Winning Paper cont...

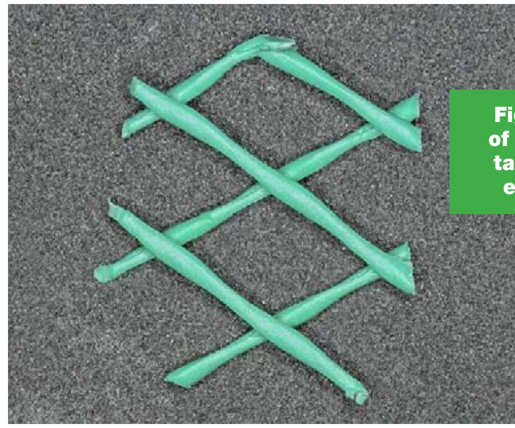


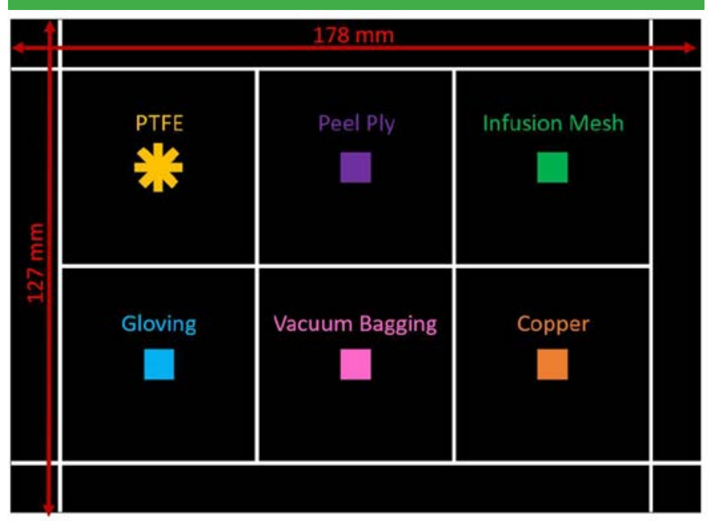
Figure 1: Image of Infusion Mesh taken with Keyence VR 3000

Composite Fabrication

A laminated composite of nominally 127 mm x 178 mm (5" x 7") was manufactured using the VARTM method. A 6 oz., 3k tow, plain weave fabric from ACP Composites was used. The composite is comprised of twelve lamina with a layup of $[0/45/0]_4$ where the foreign objects were placed between the sixth and seventh plies. Proset INF 114 resin with Proset 211 hardener was chosen as the resin-hardener combo for the infusion process, and the composite was cured according to the manufacturer's recommendations. Figure 2 shows the placement of each foreign object during the manufacturing of the part. During the layup process, all foreign objects were placed between the sixth and seventh plies at the midplane of the composite. The composite being studied did exhibit some surface porosity post-cure, but that occurs in regions other than those where the placed foreign objects are placed and as such do not impact the analysis.

continued on page 18...

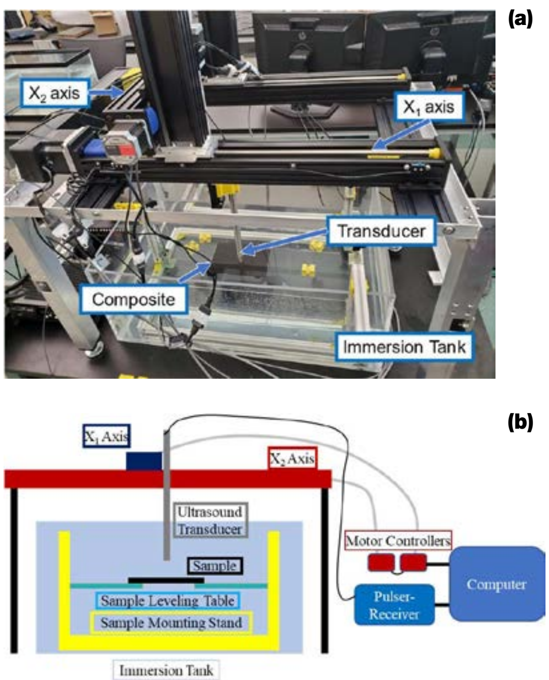
Figure 2: Diagram showing the location of foreign objects in the composite laminate when viewed from the tool side of the laminate. All foreign objects were placed at between the sixth and seventh laminate.



Ultrasonic Scanning Setup

The part was scanned using the custom immersion scanning system as shown in Figure 3. A 10 MHz spherically focused transducer from Olympus was used to scan the composite in a pulseecho mode. The ultrasonic parameters were controlled using an Olympus Focus PX. Positioning of the motors was controlled using Velmex VXM motor controllers to move two axes made up of Velmex BiSlide positioning systems. A custom MATLAB program is used to create a raster path, and send commands to the motor controller. The scan discussed in this work covers a scan region of 80 mm x 130 mm with a spacing of 0.2 mm between scans. A magnetic linear encoder reads the position of the ultrasonic transducer and the Focus PX acquires data over the scanning region. Upon completion of the scan, the data is exported to MATLAB where it is analyzed using a custom in-house code discussed below.

Figure 3: (a) Picture of the custom immersion C-Scan System used in this study. (b) Diagram of the experimental setup for scanning the composites



Analysis

Determination of Lamina Count using A-scans

During the scanning process, a-scans are collected at the designated locations by the pulserreceiver. These a-scans represent the voltage created by the displacement of the piezoelectric material in the transducer across time. The entirety of the ultrasonic dataset will be represented as $F(x_{1,\kappa}, x_{2,\iota}, t)$, which represents the received ultrasonic amplitude at a specific time t, at the k^{th} location in x_1 where k is of the set $k = 1,2, \ldots N_1$, and the l^{th} location in x_2 where l is of the set $l = 1,2, \ldots N_2$.

Prior to analyzing the data, all a-scans are fed into an algorithm that fits the signal response from the front wall of the composite to a two-dimensional 3rd order plane. This plane is then used to adjust each a-scan such that the occurrence of the front wall occurs at the same adjusted point in time $\tilde{t}$, where $\tilde{t} = t - t_0$. This algorithm is designed to identify the detection threshold which creates the optimal fit plane to the data. This optimal fit is defined as the threshold at which the value of the 3rd peak in the average of all shifted scans is highest, and the shifted dataset is defined as $F(x_{1,\kappa}, x_{2,\iota}, \tilde{t})$. Once the dataset has been shifted, a gaussian smoothing filter is applied to $F(x_{1,\kappa}, x_{2,\iota}, t)$ as is described in [28], and the shifted and smoothed dataset is then defined as $\tilde{F}(x_{1,\kappa}, x_{2,\iota}, \tilde{t})$ where the time $\tilde{t}$ represents the shifted time to align all data to the front surface of the part and $\tilde{F}$ represents the regionally smoothed data.

continued on page 19...

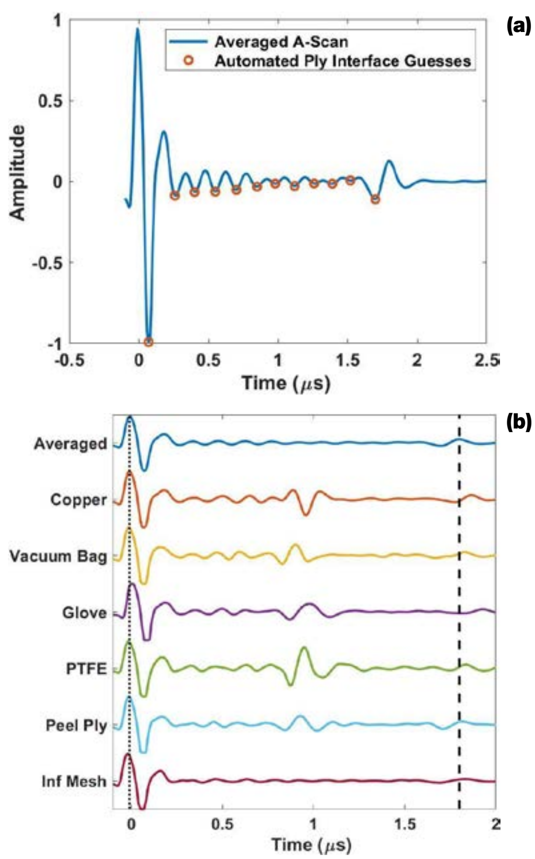
This Issue:

• Message from the Chair
• Tribute to Cedric A. Ball
• Save the Date ANTEC 2022
• Award Winning Paper
• Councilor Report
• BOD Listings

Award Winning Paper continued...

Figure 4(a) shows the averaged a-scan for the composite after shifting the data in time. This is the average a-scan over the entire region of the part scanned and includes regions without FOD and with FOD. Figure 4(b) is provided to show an example of the ultrasonic wave generated when scanning a region of the composite containing any of the six foreign objects used and comparing it with the averaged a-scan across the laminate. Five of the six foreign objects cause an appreciable change in the ultrasonic waveform with only the infusion mesh foreign object not creating a significant response. It should be noted that there is no significant indication of the presence of foreign objects in the averaged a-scan.

Figure 4: (a) Average A-scan for the composite part (b) A-Scans over the different defective regions compared with the average a-scan where the front wall echo is marked with a dotted line and the back wall echo is marked by a dashed line. Note the reflections due to the foreign objects can be observed at approximately 0.9 μs.



In order to determine the ply interface estimates, shown as the red circles in Figure 4(a), the back wall of the part is first identified, which occurs at approximately 1.8 μs. The number of plies is then determined by the distance in time between the front wall and the back divided by the nominal thickness of an individual ply. The total thickness of the part is identified using the equation:

$$d = \frac{t\,c}{2}$$

where d is the thickness of the part, t is the time between the front and back wall echoes, and c is the speed of sound of the material. The carbon fiber material used for this experiment has an measured thickness of 0.23 mm for each lamina prior to manufacturing. Equation 1 can be adapted to identify the estimated time of flight of an individual lamina as $t_{lamina} = 2\, d_{lamina}/c$ yielding the time to pass through one lamina can be determined as approximately 15.24 μs for an estimated speed of sound of 3000 m/s. Using this value in Equation 1 for the measured total time of flight, there are estimated to be 11.88 plies in the composite. This is rounded to the nearest whole number correctly identifying the composite contains 12 plies. The ply interfaces are then giving pre-seeded initial locations for the ply interfaces. The first ply interface is given an initial guess of 35 percent of the 15.24 μs for the ultrasonic wave to pass through one lamina from the front wall and each successive guess is assumed to take the full 15.24 μs. The software then determines the nearest minima to each initial guess as the location of the ply interface.

continued on page 20..

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Foreign Object Depth using B-scans

B-scans are another common way to visualize and present ultrasonic scan data. A traditional b-scan often shows the ultrasonic response as a function of time and one scan dimension. For example, a traditional b-scan would show all the a-scans stacked together taken across the x_1 dimension at a fixed point in x_2. While this is a useful tool for examining many a-scans at once, in the present context there is an extension of the standard technique for identifying foreign objects. Specifically, the b-scan is plotted with a maximum criterion for each point in time and space. Figure 5 presents such b-scans where both the x_1(left) and x_2 (right) directions are held constant as described by

$$\breve{F}\left(x_{1,k},\tilde{t}\right) = \max_{x_{2,l}\in\left\{x_{2,0},x_{2,N_2}\right\}}\left(\tilde{F}\left(x_{1,k},x_{2,l},\tilde{t}\right)\right)$$

and

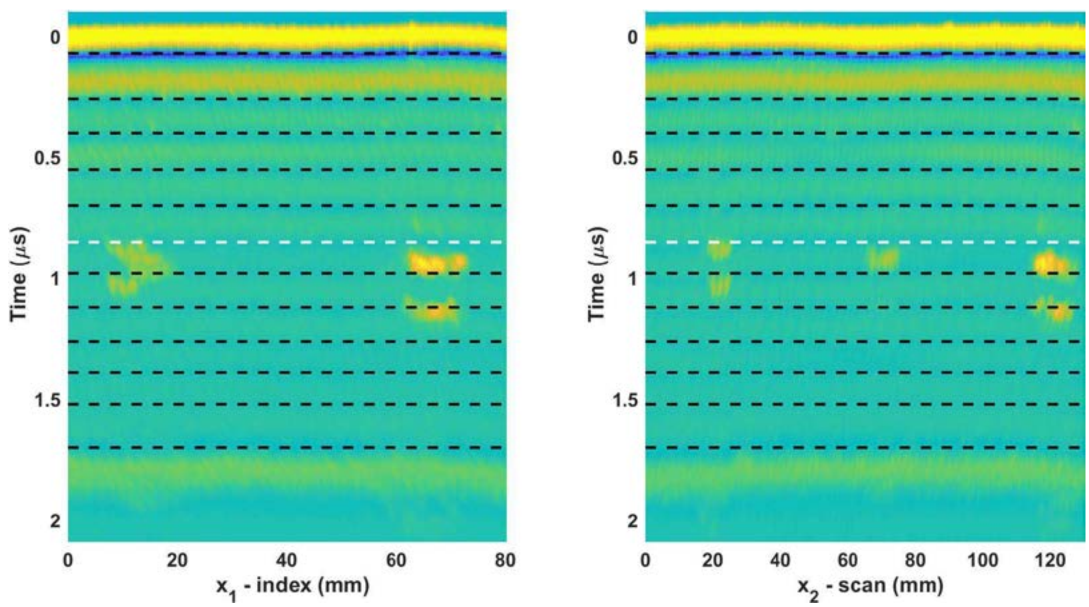
$$\breve{F}\left(x_{2,l},\tilde{t}\right) = \max_{x_{1,k}\in\left\{x_{1,0},x_{1,N_1}\right\}}\left(\tilde{F}\left(x_{1,k},x_{2,l},\tilde{t}\right)\right)$$

continued on page 21...

Award Winning Paper continued...

As can be seen in Figure 5, this is effective at quickly identifying the presence and depth of foreign objects. In these images, the locations of the calculated ply interfaces from Equation 1 are superimposed as black dotted lines except for the sixth ply interface which is highlighted and plotted as a white dotted line. The initial reflection of the ultrasonic waves from the foreign objects can be seen occurring after the sixth lamina and just before the seventh lamina as the part in agreement with the part that was manufactured. It should also be noted some of the foreign objects created additional echoes that can be seen as bright reflections between the seventh and eight ply locations, thus only the first indicator should be used in the analysis to avoid false positives.

Figure 5: B-scans along both the index (left) and scan (right) directions plotted with a maximum criterion. Dashed Lines are overlayed at the minima before each laminar reflection. The dashed line in white highlights the sixth lamina. Color represents the normalized magnitude of the ultrasonic response.



This Issue:

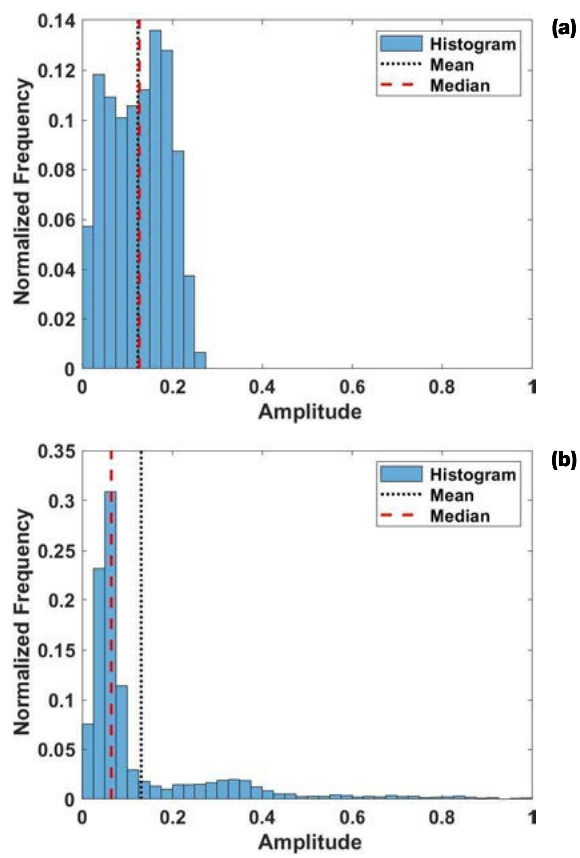
- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Further work must be done to improve the automation of determining the occurrence of foreign objects in the b-scan. One method that has been briefly investigated is to tabulate the maximum amplitude of the signal received between lamina and plot the resulting histogram of the tabulated data. Figure 6 shows the histogram of the gated maximum value of the ultrasonic signal for a gate spanning the third and fourth plies (Figure 6 a) and for a gate spanning the sixth and seventh plies (Figure 6b). It is apparent that there is a significant difference between the two gated sig-

continued on page 22...

nals. or the case of the gated signal between the third and fourth plies the resulting signal amplitudes at each spatial location are tightly grouped and the median and mean are nearly equal. Conversely, the distribution of the amplitudes of the gated signal between the sixth and seventh laminate is much different. In this region, the region encompassing the foreign objects, there is a significant difference between the mean and the median of the gated signal amplitudes. This is due to the high signal return caused by the foreign objects. This approach may be useful to helping an operator determine the presence and depth of foreign objects, but is sensitive to the overall size of the part scanned relative to the size of the foreign objects and must be used with caution.

Figure 6: Histogram of the gated signal amplitude from each spatial location (a) between the 3rd and 4th plies and (b) between the 6th and 7th plies, the latter of which is where the foreign objects occur



Use of C-Scans to Identify Area and Size

The use of a-scans and b-scans are appropriate for determining, respectively, the presence of foreign objects and the depth at which they are located. In the following section c-scans will be shown to quantify the size and shape of defects within the composite. C-scans represent the ultrasonic intensity at each point in space across x_1 and x_2 at a single instance in time or over a gated range of times. Taking the amplitudes at a single point in time is highly sensitive to determining the correct depth and is dependent on a highly homogenized material and highly trained technician. The present work focuses on the inspection of plain-weave carbon fiber laminates whose acoustic behavior is inhomogeneous and aims to simplify the art of foreign object detection to the point of semi or full automation. This makes it more practical to gate c-scans over a longer region of time, reducing the sensitivity of the methods and uses the same criterion as described in [28],

$$\check{F}\left(x_{2,l},\tilde{t}\right) = \max_{x_{1,k}\in\left\{x_{1,0},x_{1,N_1}\right\}}\left(\tilde{F}\left(x_{1,k},x_{2,l},\tilde{t}\right)\right)$$

Using the information gained from the b-scan images, $\tilde{t}_m$ is defined as the instant in time when the signal from the sixth ply interface is captured and $\tilde{t}_n$ is defined as the instant in time when the signal is captured from the seventh ply interface.

continued on page 23...

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

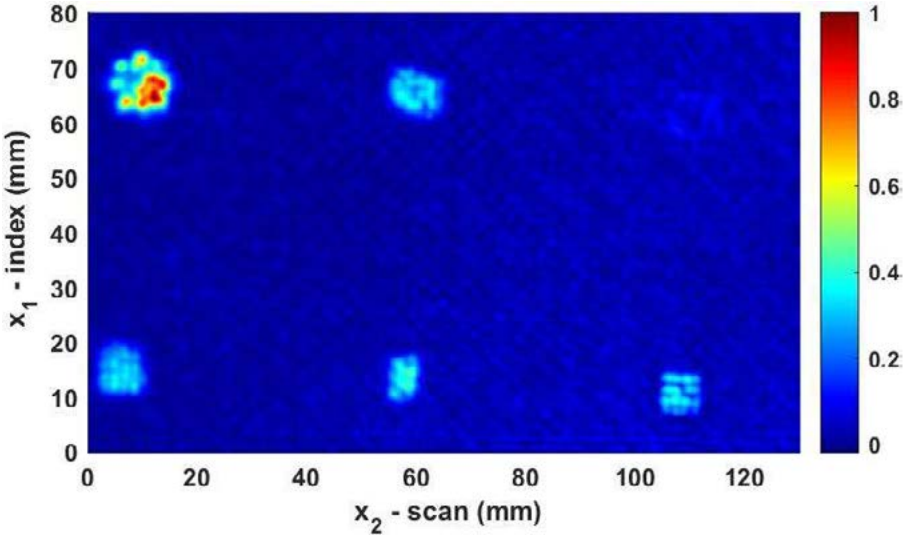


Figure 7 shows the c-scan image generated from the ultrasonic dataset. Only five of the six of the foreign objects have identifiable amplitudes, with the infusion mesh foreign object not being

Figure 7: C Scan plotting the maximum normalized amplitude between the sixth and seventh plies.

clearly identifiable. Based on the representative a-scans shown in Figure 5(b), it is not a surprise that the infusion mesh cannot be found. The infusion mesh can be observed in the top right region of the c-scan, but appears as a ghost image that could in other cases be a false positive. This feature is left for discussion in Figure 8. The shape of the remaining foreign objects presented in the c-scan roughly matches the true shape of each foreign object. The angle and projections present in the asterisk shape of the PTFE foreign object are not well defined, but the other four objects appear as roughly rectangular just as they were fabricated.

In order to quantify the shape of the identified foreign objects, the use of an edge detection technique is needed. The magnitude of the gradient is a simple method commonly used in image processing [29] that can be easily applied to the ultrasonic data. A high order central difference method (see e.g., [30]) is applied to the data to calculate the partial derivatives in both the x_1 and x_2 directions. The magnitude is then calculated as the sum of the squares of the partial derivates as shown

$$\check{F}(x_{2,l},\tilde{t}) = \max_{x_{1,k}\in\{x_{1,0},x_{1,N_1}\}} \left(\tilde{F}(x_{1,k},x_{2,l},\tilde{t})\right)$$

The MGT method, as presented by the current authors in [28], traces along the bounded maxima of the gradient to determine the size of the foreign objects. No shape is superimposed, and the trace follows the maximum surface around the boundary of the object. When no obvious maximum is available, the method takes the center value of the gradient along a single projection as the peak. Figure 9 shows the modified c-scan image created by calculating the magnitude of the spatial gradient of the c-scan.

In order to identify the size of the infusion mesh an alternative method must be employed. The reflection of the back wall is reduced in the region of the infusion mesh foreign object due to significant attenuation around the infusion mesh as can be observed in Figure 5(b). Thus, viewing the amplitudes across the back wall reveals the location and size of the infusion mesh foreign object as shown in Figure 8. Similar to the previous approach, the magnitude of the gradient is applied to the data to determine the edges of the Infusion Mesh.

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

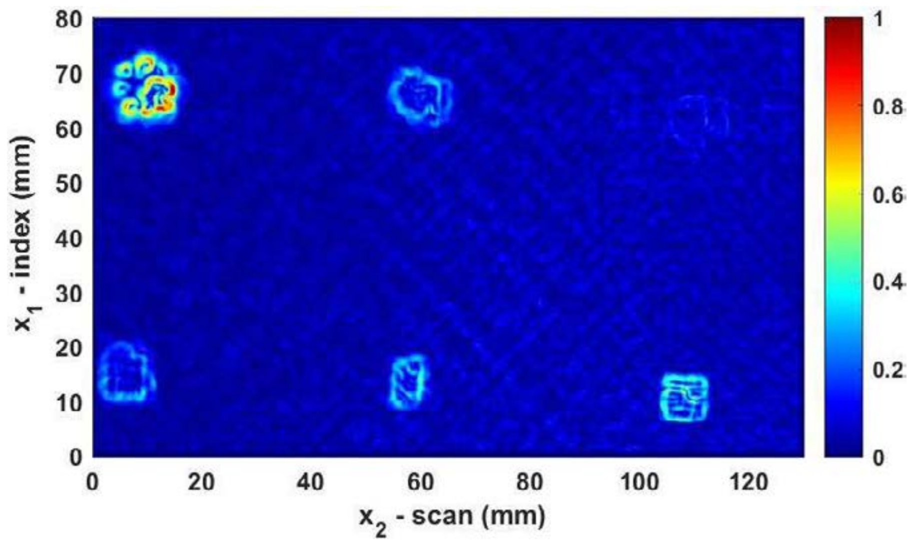


Figure 9: Normalized magnitude of the gradient applied to the c-scan between the sixth and seventh plies to determine the edges of the foreign objects.

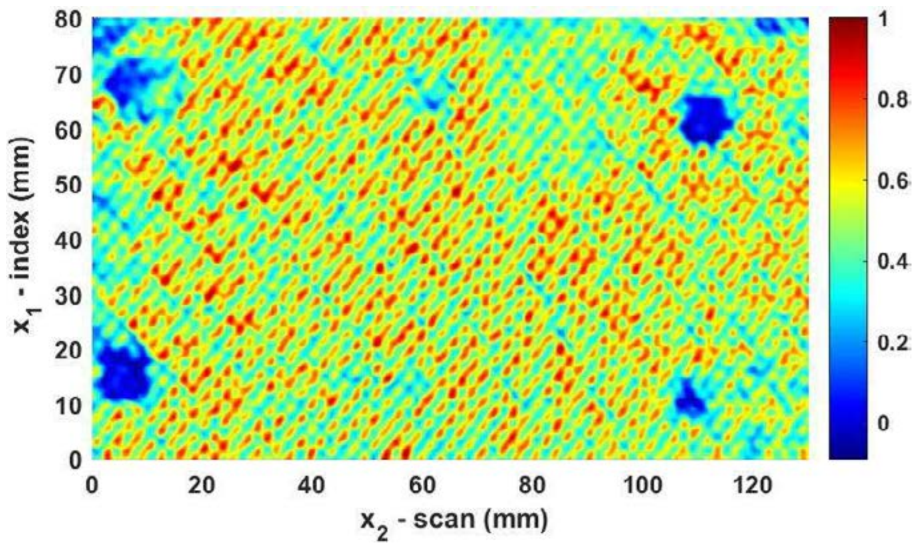


Figure 8: C Scan plotting the normalized maximum amplitude across the back wall of the composite.

Table II presents the spatial measurements obtained from the above analysis of the ultrasonic waveforms for each of the foreign objects in the composite. The height and width of the foreign objects is taken as the maximum difference in the x_1 and x_2 directions. The greater measurement is always assumed to be the height to account for any accidental rotations of the object during the manufacturing process. The absolute difference is defined as

$$\varepsilon = abs(s_{true} - s_{meas})$$

where s is the respective dimension, specifically height or width, being compared. The absolute percent error is defined as

$$\varepsilon = \frac{abs(A_{True} - A_{meas})}{A_{True}}$$

The area for each foreign object is compared with the surface area measurement from the Keyence with the exception of the infusion mesh which is compared to an estimated

continued on page 25...

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Material	Height (mm)	Absolute Difference (mm)	Width (mm)	Absolute Difference (mm)	Surface Area (mm^2)	Absolute Percent Error (%)
Copper	7.87	0.83	7.76	0.82	55.03	9%
Glove	8.10	0.34	7.50	0.56	55.43	15%
Infusion Mesh	8.97	1.28	8.37	1.63	55.68	7%
Peel Ply	8.45	0.81	7.99	0.71	51.38	28%
PTFE	10.70	1.72	9.70	2.72	68.27	27%
Vacuum Bag	8.54	1.07	5.87	1.03	40.86	12%

Table II: Ultrasonic Measurement of each foreign object using Magnitude of Gradient

area value. For comparison, in the work by Mohammadkhani et al [26], the error in estimating the size of PTFE, bag tape, and peel ply, all measuring 6 mm x 6 mm, using their automated technique are 43.8%, 20%, and -66.7%. It assumed that the bag tape discussed is similar to the vacuum bagging studied in the present work. The results in Table II are significant in that for each of the comparisons that can be made to published data, the MGT method shows a significant improvement in all but the PTFE foreign object studied here which is of a more complex geometry than other similar works. This is more significant as the sample studied in the present work has more internal reflections to add noise to the signal. These internal reflections are caused by the woven laminate studied, whereas previously published work focused on unidirectional laminates which have much cleaner acoustic signals aiding in the analysis of the captured waveform.

It should be noted that the composite being studied had noticeable amounts of surface porosity. It is reasonable to expect this surface porosity to negatively impact the ability of the ultrasonic waves to predictably propagate through the composite and is likely the cause of greater error in measurements around the foreign objects which disrupt the flow of the resin during the VARTM process and are likely to be areas with greater porosity.

In order to simplify and improve the detection of the foreign objects in the c-scan, the intensities of $\hat{F}(x_{1,\kappa}, x_{2,\iota})$ were modified to highlight signals likely to be caused by the foreign objects. This was done by determining all amplitudes in $\hat{F}$ greater than 3 standard deviations above the median signal in the dataset. All signals above this thresh-

continued on page 26...

Award Winning Paper continued...

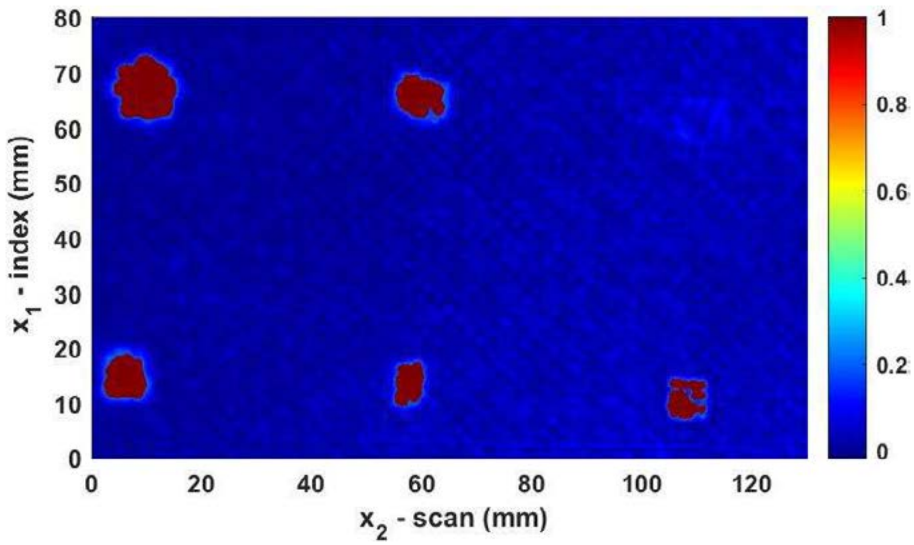


Figure 10: Modified c scan of the amplitudes between the sixth and seventh plies where signals above a threshold are forced to one.

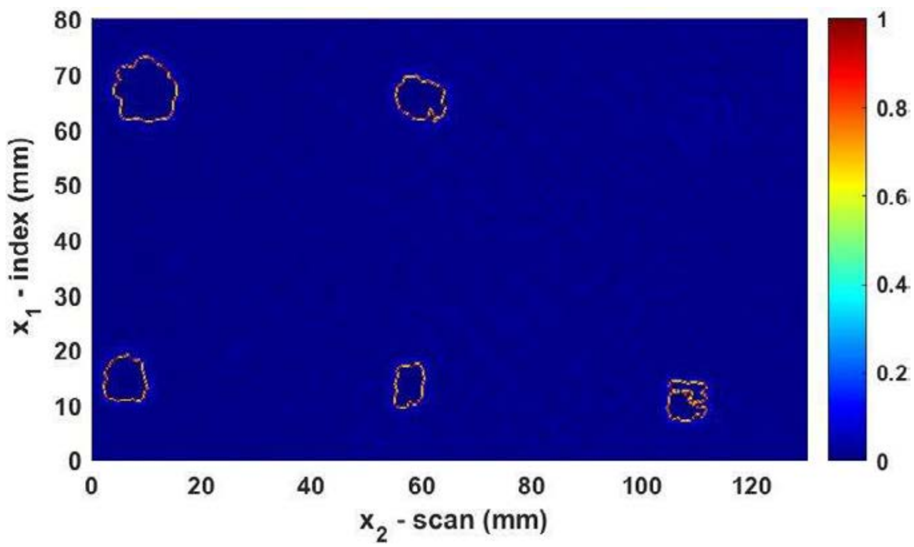


Figure 11: Magnitude of the modified c-scan highlighting the boundaries of the foreign objects.

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

old were set to 1 in the normalized dataset with the remaining amplitudes left at their current values. Figure 10 shows the results of this modification which more distinctly highlights the foreign objects. As with the original c-scan, the gradient of this dataset is calculated and used to determine the edges of each foreign object as shown in Figure 11. The forcing of the signals above the threshold to 1 creates a distinct and obvious boundary of the gradient that is easily traced to determine the size of each object.

Table III shows the results of the measurements taken of the new dataset. In general, the absolute difference in determining the height and width of the foreign objects decreased. The error in calculating the area increased for the copper and gloving foreign objects, while the error for the PTFE and vacuum bag foreign objects decreased dramatically. This new method was still unable to detect the infusion mesh object. Because of this the measurements belonging to the infusion mesh row are left blank.

continued on page 27...

Award Winning Paper continued...

Material	Height (mm)	Absolute Difference (mm)	Width (mm)	Absolute Difference (mm)	Surface Area (mm^2)	Absolute Percent Error (%)
Copper	7.21	0.17	6.81	0.13	38.41	24%
Glove	8.32	0.12	7.76	0.30	48.24	26%
Infusion Mesh	---	---	---	---	---	---
Peel Ply	9.49	0.23	7.87	0.59	52.69	26%
PTFE	11.70	0.72	11.65	0.77	97.09	4%
Vacuum Bag	7.71	0.24	5.09	0.25	33.63	8%

Table III: Ultrasonic Measurement of each foreign object using Magnitude of Gradient post modification based on histogram

Summary and Next Steps

This paper presents the use of the MGT method and other detection algorithms for the detection of foreign objects in carbon fiber laminates. A carbon fiber laminate was fabricated with six different materials intentionally placed within the part as foreign objects. A systematic approach for locating and finding the foreign objects is demonstrated using a-scan, b-scan, and c-scans analyses. Five of the six materials were successfully detected at the spatial and depth location at which they were fabricated. Conversely, the depth of the infusion mesh object can not be determined using the analysis techniques presented, but the feature can be detected and the spatial dimensions can be quantified. An improvement on the application of the c-scan and application of the gradient as compared with previously published results is also presented that provides higher contrast in defining the foreign objects as well as a more defined gradient. In addition, the MGT was found to be considerably more accurate in the sizing of foreign objects than other recent works when controlling for the material being studied.

This work directly benefits any industry that makes use of laminated carbon fiber composites as the foreign objects significantly impact the performance of these composites. The ability to reliably detect and quantify foreign objects will lead to greater safety in composites and reduce the need for overdesigning of composite parts. Future work will study each of the foreign objects in greater depth and apply the methods presented across a greater number of samples. While the method presented has components of the analysis that are at automated (e.g. the detection of layers, and preprocessing of the normalized c-scan of the magnitude of the gradient), there is still work needed to tie the different components of the analysis together in a cohesive manner and limit the need for human interpretation.

Acknowledgements

The authors would like to thank Verifi for their financial support of this research. We would also like to acknowledge the contributions of Dr. Gary Georgeson and Dr. Benjamin Blandford for the conversations and insight they provided that helped to focus this research.

continued on page 28...

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Award Winning Paper continued...

Bibliography

[1] Advances in Sustainable Polymer Composites. Elsevier; 2021. https://doi.org/10.1016/C2019-0-01748-7.

[2] Ever J. Barbero. Introduction to Composite Materials Design. Third Edition. CRC Press; 2018.

[3] Workman GL, Kishoni D, O Moore P. Nondestructive Testing Handbook: Ultrasonic Testing. Vol 7. American Society of Nondestructive Testing; n.d.

[4] Wang J, Potter K, Hazra K, Wisnom M. Experimental fabrication and characterization of out-of-plane fiber waviness in continuous fiber-reinforced composites. Journal of Composite Materials 2012;46:2041–53. https://doi.org/10.1177/0021998311429877.

[5] Carraro PA, Maragoni L, Quaresimin M. Influence of manufacturing induced defects on damage initiation and propagation in carbon/epoxy NCF laminates. Advanced Manufacturing: Polymer & Composites Science 2015;1:44–53. https://doi.org/10.1179/2055035914Y.0000000004.

[6] Wang P, Lei H, Zhu X, Chen H, Wang C, Fang D. Effect of manufacturing defect on mechanical performance of plain weave carbon/epoxy composite based on 3D geometrical reconstruction. Composite Structures 2018;199:38–52. https://doi.org/10.1016/j.compstruct.2018.05.066.

[7] Blandford BM, Jack DA. High resolution depth and area measurements of low velocity impact damage in carbon fiber laminates via an ultrasonic technique. Composites Part B: Engineering 2020;188:107843. https://doi.org/10.1016/j.compositesb.2020.107843.

[8] Ashir M, Nocke A, Bulavinov A, Pinchuk R, Cherif C. Sampling phased array technology for the detection of voids in carbon fiber-reinforced plastics. The Journal of The Textile Institute 2019;110:1703–9. https://doi.org/10.1080/00405000.2019.1616956.

[9] Amenabar I, Mendikute A, López-Arraiza A, Lizaranzu M, Aurrekoetxea J. Comparison and analysis of non-destructive testing techniques suitable for delamination inspection in wind turbine blades. Composites Part B: Engineering 2011;42:1298–305. https://doi.org/10.1016/j.compositesb.2011.01.025.

[10] Poudel A, Shrestha SS, Sandhu JS, Chu TP, Pergantis CG. Comparison and analysis of Acoustography with other NDE techniques for foreign object inclusion detection in graphite epoxy composites. Composites Part B: Engineering 2015;78:86–94. https://doi.org/10.1016/j.compositesb.2015.03.048.

[11] Marani R, Palumbo D, Renò V, Galietti U, Stella E, D'Orazio T. Modeling and classification of defects in CFRP laminates by thermal non-destructive testing. Composites Part B: Engineering 2018;135:129–41. https://doi.org/10.1016/j.compositesb.2017.10.010.

[12] Wang J, Zhang J, Chang T, Liu L, Cui H-L. Terahertz nondestructive imaging for foreign object detection in glass fibre-reinforced polymer composite panels. Infrared Physics & Technology 2019;98:36–44. https://doi.org/10.1016/j.infrared.2019.02.003.

[13] He Y, Tian G, Pan M, Chen D. Non-destructive testing of low-energy impact in CFRP laminates and interior defects in honeycomb sandwich using scanning pulsed eddy current. Composites Part B: Engineering 2014;59:196–203. https://doi.org/10.1016/j.compositesb.2013.12.005.

[14] Non-Destructive Testing and Inspection Market worth $12.6 billion by 2024 n.d. https=//www.ndt.net/search/docs.php3?id=24191 (accessed August 20, 2020).

[15] David K Hsu, Fei D, Liut Z. Ultrasonically Mapping the Ply Layup of Composite Laminates. Materials Evaluation 2002;60:1099–106.

continued on page 29...

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Award Winning Paper continued...

[16] Smith RA, Nelson LJ, Mienczakowski MJ, Challis RE. Automated analysis and advanced defect characterisation from ultrasonic scans of composites. Insight - Non-Destructive Testing and Condition Monitoring 2009;51:82–7. https://doi.org/10.1784/insi.2009.51.2.82.

[17] Benjamin Blandford, David A Jack. Ultrasonic Quantification of Spatial Variations of Adhesive Bond Thickness between Carbon Fiber Laminated Composites. Manuscript in Preperation 2021.

[18] Segreto T, Bottillo A, Caggiano A, Teti R, Ricci F. Full-volume Ultrasonic Technique for 3D Thickness Reconstruction of CFRP Aeronautical Components. Procedia CIRP 2018;67:434–9. https://doi.org/10.1016/j.procir.2017.12.238.

[19] Nelson LJ, Smith RA, Mienczakowski M. Ply-orientation measurements in composites using structure-tensor analysis of volumetric ultrasonic data. Composites Part A: Applied Science and Manufacturing 2018;104:108–19. https://doi.org/10.1016/j.compositesa.2017.10.027.

[20] Minnie W. Nondestructive Evaluation of Out-of-Plane Wrinkles Within Woven Carbon Fiber Reinforced Plastics (CFRP) Using Ultrasonic Detection. Baylor Univeristy, n.d.

[21] Wronkowicz-Katunin, Katunin, Dragan. Reconstruction of Barely Visible Impact Damage in Composite Structures Based on Non-Destructive Evaluation Results. Sensors 2019;19:4629. https://doi.org/10.3390/s19214629.

[22] Morokov E, Levin V, Chernov A, Shanygin A. High resolution ply-by-ply ultrasound imaging of impact damage in thick CFRP laminates by high-frequency acoustic microscopy. Composite Structures 2021;256:113102. https://doi.org/10.1016/j.compstruct.2020.113102.

[23] Benammar A, Drai R, Guessoum A. Detection of delamination defects in CFRP materials using ultrasonic signal processing. Ultrasonics 2008;48:731–8. https://doi.org/10.1016/j.ultras.2008.04.005.

[24] Poudel A, Li S, Chu TP, Palmer D, Engelbart RW. Neural-Fuzzy Approach in Detecting and Classifying Foreign Object Inclusions in CFRP Panel by Using Ultrasonic Testing n.d.:7.

[25] Barry T, Kesharaju M, Nagarajah C, Palanisamy S. Defect characterisation in laminar composite structures using ultrasonic techniques and artificial neural networks. Journal of Composite Materials 2016;50:861–71. https://doi.org/10.1177/0021998315584651.

[26] Mohammadkhani R, Zanotti Fragonara L, Padiyar M. J, Petrunin I, Raposo J, Tsourdos A, et al. Improving Depth Resolution of Ultrasonic Phased Array Imaging to Inspect Aerospace Composite Structures. Sensors 2020;20:559. https://doi.org/10.3390/s20020559.

[27] Ma M, Cao H, Jiang M, Sun L, Zhang L, Zhang F, et al. High Precision Detection Method for Delamination Defects in Carbon Fiber Composite Laminates Based on Ultrasonic Technique and Signal Correlation Algorithm. Materials 2020;13:3840. https://doi.org/10.3390/ma13173840.

[28] Blackman NJ, Jack DA, Blandford BM. Improvement in the Quantification of Foreign Object Defects in Carbon Fiber Laminates Using Immersion Pulse-Echo Ultrasound 2021:18.

[29] Mlsna PA, Rodríguez JJ. Gradient and Laplacian Edge Detection. . The Essential Guide to Image Processing n.d.:30.

[30] Chapra SC. Applied numerical methods with MATLAB for engineers and scientists. 3rd ed. New York: McGraw-Hill; 2012.

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Councilor Report

By: Dale Brosius

April 15, 2022

A meeting of the SPE Council was held on March 30. The main purpose was to communicate key initiatives from the executive committee and report on the financial position of SPE.

Regarding finances, the position of SPE has improved greatly over the last several years. Both revenues and expenses were down in 2020 and 2021 due to the preponderance of virtual events. The operating results, however, are showing improvement. Operating profit over the two years was $359,000 and investment income was $1,237,000. The Society is forecasting a slight loss for 2022 as the industry returns to in-person events and attendance is not expected to return fully to pre-pandemic levels in 2022.

SPE HQ staff has completed the exit of the physical space in Danbury and all employees are working remotely with occasional in-person meetings. This is saving the Society roughly $150,000 per year in operating costs

The SPE Foundation awarded $202,850 in scholarships in 2021 to 51 students at 31 universities. This includes Composites Division scholarships of $14,000 to five students.

President-Elect Bruce Mulholland presented the status update to the 2021-2022 strategic plan. Emphasis is on improving opportunities for networking and knowledge. Some highlights include:

- Honored Service Members and Fellows of the Society have been granted lifetime membership in SPE.
- Part-time students enrolled in a degree program related to plastics are now able to receive free student membership. Previously, only full time students could do so.
- SPE hosted a Diversity, Equity and Inclusion (DEI) conference in January 2022 with 103 participants and archived on-line available to SPE members.
- The Plastics in Aerospace conference held virtually in 2021 will transition to an in-person conference in November 2022 in Phoenix, AZ
- ANTEC returns as an in-person event in June 2022, including both technical and non-technical content aimed at attracting a wide base of the industry and increasing networking opportunities.
- A new parts competition to replace the Plastics for Life competition will be announced at ANTEC 2022.

SPE COMPOSITES

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

ANTEC® 2022

ANTEC 2022 WWW.4SPE.ORG/ANTEC22

SAVE THE DATE:

June 14-16, 2022; Charlotte, NC

Sponsor the Newsletter

Quarter page ad or logo ad:
3.75" x 5" $500

Half page ad:
7.5" x 5.5", 5" x 7.5", 4" x 8.5"..................$750

Full page ad:
7" x 10", 8.5" x 11" $1,250

Contact: Teri Chouinard CBC, APR
SPE Composites Division
Sponsorship Chair
C/O Intuit Group, Inc.
phone 248.701.8003
Teri@IntuitGroup.com

Please provide Logos as JPG and EPS files (send both if possible)
Please provide Ads as High Resolution PDF files
Advertising with the SPE Composites Division is inexpensive and easy. Please help us to promote the benefits of Composites in Industry.

Sponsoring the Newsletter enables the SPE to communicate the benefits of the composites in many industries, which fortifies your marketing efforts.

- **Support your SPE Composites Division**
- **Reach 1,000 Composites Professionals 3 Times a year via the E-Newsletter**
- **Also reach 1,070 SPE Composites Division Linked In Members 3 times a year and an additional 11,492 COMPOSITES Linked In Members Secondary group where the link to the newsletter is posted year-round**
- **Reach many more as a sponsorship also includes your logo on our website, www.composites.4speorg with a link to your company**
- **Maximize your exposure to the customers & the trade**
- **Stay informed on the latest composites activity**

Increase your presence on the web leading to more sales by sponsoring our Electronic Newsletter which is published on the SPE Composites Division Website and emailed to all Division Members (1,000 approx.) 3 times annually. Rates include 3 issues (not on calendar basis - published approx. Nov/Dec, Mar/April, July/August). All ads include a link to your website increasing your exposure on the worldwide web exponentially. Sponsorship also includes your logo ad with a link to your website on www.composites.4speorg further increasing your presence on the Web as a Leader in Composites Technology.

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings

Board of Directors

John P. Busel, F. ACI
SPE Composites Director, Chair & Intersociety Chair
V.P. Composites Growth Initiative
American Composites Manufacturers Association
Arlington, VA
jbusel@acmanet.org

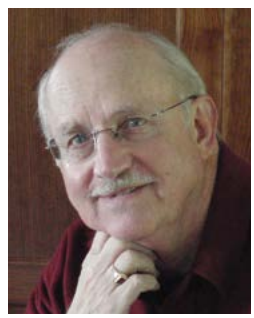
Oleksandr G. Kravchenko, Ph.D.
SPE Composites Director, Chair-elect, ACCE Technical Program Co-Chair, &
Assistant Professor, Dept. of Mechanical and Aerospace Engineering
Old Dominion University
Norfolk, VA
okravche@odu.edu

Mingfu Zhang, Ph.D.
SPE Composites Director & Treasurer
Johns Manville
Research Manager, Corporate R&D
Littleton, CO
mingfu.zhang@jm.com

Christoph Kuhn
SPE Composites Director & Secretary
Volkswagen
Group Research Materials & Manufacturing Methods
Wolfsburg, Germany
christoph.kuhn@vw.com

Dale Brosius
SPE Composites Director & Councilor
Chief Commercialization Officer, IACMI
Knoxville, TN
dbrosius@iacmi.org

Ian Swentek, Ph.D.
SPE Composites Past Chair,
Applications Development Engineer Hexion
London, ON, Canada
Ian.Swentek@hexion.com



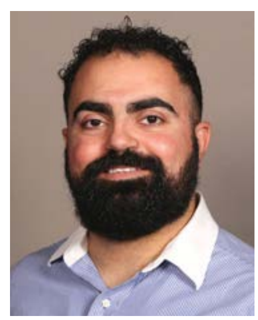
Daniel T. Buckley
SPE Composites Director (Retired)
Emeritus Director
dbuck@vermontel.net

Rich Caruso
SPE Composites Director
CEO Inter/Comp LLC
Falmouth, MA
rpcaruso@gmail.com

Michael Connolly, Ph.D.
SPE Composites Director
Huntsman (retired)
Ypsilanti, MI

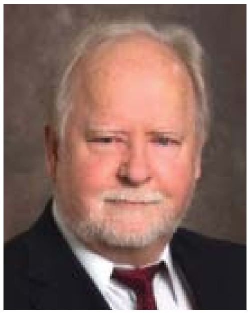
Pritam Das
SPE Composites Director & Newsletter Chair
Senior Technical Manager
Toray Composites Materials America (CMA)
Tacoma, WA
pdas@toraytca.com

Frederick S. Deans
SPE Composites Director
Principal
Allied Composite Technologies, LLC
Rochester Hills, MI
fdeans@alliedcomptech.com



Hicham Ghossein, Ph.D.
SPE Composites Director & Award Chair
President & Founder of Endeavor
Hicham.ghossein@gmail.com

Board of Directors continued...



Jack Gillespie, Ph.D.
SPE Composites Director
Director, Center for Composite Materials
Donald C. Phillips Professor of Civil and Environmental Engineering
University of Delaware
Newark, DE
gillespi@udel.edu

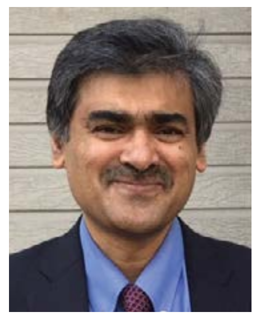
Jim Griffing
SPE Composites Director & SPE Past President
Boeing (Retired)
Seattle, WA
jsgriff1@gmail.com

Enamul Haque, Ph.D.
SPE Composites Director
A2H Consulting Group
Enamul.Haque@a2hconsultinggroup.com

Antoine Rios, Ph.D.
SPE Composites Director, Finance Chair,
The Madison Group
Madison, WI
Antoine@madisongroup.com

Khaled W. Shahwan, Ph.D.
SPE Composites Director
Sr. Technology Leader - Composites, Methods & Strategies,
Global Automotive Research & Advanced Engr., Chrysler Technology Center
Auburn Hills, MI
khaled.shahwan@stellantis.com

Shankar Srinivasan, Ph.D.
SPE Composites Director & ANTEC Program Chair
Iowa State University
Economic Development Core Facility
Ames, IA
srigshan@iastate.edu



Uday Vaidya, Ph.D.
SPE Composites Director & Education Chair
Professor in Mechanical, Aerospace & Biomedical Engineering
Chief Technology Officer (CTO), IACMI
University of Tennessee
Knoxville, TN
uvaidya@utk.edu

Pritesh Yeole, Ph.D.
SPE Composites Director
Research Associate in Advanced Composites Manufacturing
Fibers and Composites Manufacturing Facility
University of Tennessee Knoxville
pyeole@vols.utk.edu

This Issue:

- Message from the Chair
- Tribute to Cedric A. Ball
- Save the Date ANTEC 2022
- Award Winning Paper
- Councilor Report
- BOD Listings