SPE COMPOSITES

SPRING/SUMMER 2023

Composites Connection™

Official Newsletter of the SPE Composites Division

Reaching Over 1,000 Composites Professionals
In All Industries


BASF
We create chemistry
IDEA L
Engineering plastics and polyurethanes by BASF for the automotive industry
We turn your ideas into ideal solutions: BASF plastics for the automotive industry.
Shorter development times, enhanced performance, greater freedom in design. You do not want to settle for anything less than the perfect car. Neither do we. That is why we will stay by your side at every stage of your project - with our comprehensive expertise in plastics and application development, individual parts testing, consultancy in design, simulation and much more - available to you around the world. When your idea turns into the ideal car, it's because at BASF, we create chemistry.
www.performance-materials.basf.com

SPE Foundation

By: Eve Vitale

The SPE Foundation Releases 2022 Impact Report

Please take a moment to review the SPE Foundation's 2022 Impact Report. You will find details about the PlastiVan® program, our new Girl Scout polymer science patch, our SPE Junior Researcher program, SPE scholarships and more. There's also a timeline of the SPE Foundation from 1996-2022. I hope you have a reaction similar to mine.

Joy. The excitement I see on the faces of children during a PlastiVan experience, the gratitude of the teachers whose classrooms we serve, the "aha" moment of a Girl Scout when she realizes that a science or engineering career is a real possibility – these things bring me great joy.

continued on page 4...

SPE Foundation continued...

Belief. Introducing students to positive plastics education, awarding scholarships to deserving students who feel the weight of a high-price education, asking for the necessary resources from plastics-industry stakeholders to change lives – these are the things that require my belief that our work matters.

Gratitude. The way I feel about the mentors who have stepped up to guide students in Detroit, the amazement when our top scholar shares his award with other first-generation college students, the true desire of our funding partners to use their own riches to support the hopes and dreams of children – these are things for which I am grateful.

When reflecting on 2022, I was heartened by our continued and collective work as members of SPE, supporting and caring for our next generation of plastics and polymer professionals.

I know as you read this year's report you will feel these things, too. The SPE Foundation's positive plastics education supports workforce development, creates opportunities for children everywhere, and addresses the challenges and the innovation required to create a sustainable future for plastics. Our partnership matters to so many who will follow in our footsteps and to our industry and together we're making a difference – for children, for communities, and for our world.

For more information on how you or your company can support the work of the SPE Foundation or if you'd like to receive a hard copy of the 2022 Impact Report, contact me at foundation@4spe.org.

With gratitude,
Eve Vitale

Link to report:
https://www.4spe.org/files/foundation/ImpactReport22.pdf

SPE FOUNDATION

This Issue:

SPE Fellow Recognition

BOD member Dr. Uday Vaidya receives prestigious SPE Fellow Recognition

Dr. Uday Vaidya, one of the BOD members at the SPE Composites Division and also The University of Tennessee (Knoxville) Governer's Chair in Advanced Composites Manufacturing was recently awarded the prestigious Fellow status by the Society of Plastics Engineers (SPE) at the 81st Annual Technical Conference (ANTEC 2023) in Denver, Colorado . This recognition is given to individuals who have made significant contributions to the plastics and composite materials industry and have demonstrated a high level of expertise, innovation, leadership, and dedication in their field.

Picture on the left shows Dr. Vaidya receiving the award from Bruce Mulholland, current President of SPE. He comments "This awards ceremony is SPE's version of the Oscars, and I'mvery pleased to receive this honor.

With over 25 years of experience in the field of composite materials, Dr. Vaidya has made significant contributions to research, education, and industrial applications. He has also been a strong advocate for education and outreach in the field of composite materials. He has mentored numerous students and young professionals and has established several partnerships with industry and government organizations to promote research and innovation in the field of composites materials. In his own words, ""I've been fortunate to establish four student sections of SPE, starting with Tuskegee University, then North Dakota State, followed by University of Alabama Birmingham, and most recently the University of Tennessee."

Dr. Vaidya's research focuses on the development of lightweight, high-performance composite materials for various industries, including automotive, aerospace, and defense. He has authored numerous research papers, book chapters, and technical reports and has received numerous awards and honors for his research contributions.

As shown in the picture above, Dr. Vaidya was joined by his wife and sons at this special occasion.

A long term member of the SPE community, Dr. Vaidya mentioned that "Back in the 1980's you waited patiently for each month's magazine to arrive to learn when ANTEC will occur, and you worked to attend. That's when I learned the real value of networking."

This Issue:

Award Opportunities

By: Dr. Pritesh Yeole

Part of the mandate of the Society of Plastics Engineers – Composites Division is to recognize excellence in composite materials development and proliferation. Several awards have been organized for this purpose to honor and recognize such individuals, both on academic and industrial levels. Every year the Composites Division issues these awards based on rigorous competitions through the solicitation of nominees and applicants. The awards are a) the Harold Giles Award, b) the Jackie Rehkpof Scholarship, c) the Travel Award, and d) the Educator of the Year Award. Other non-financial awards are a) Honored Service Member / SPE Fellow and b) Composite Division Person of the Year Award. These two awards aim to recognize distinguished contributions from dedicated members of society.

Harold Giles Scholarships

This award was created in honor of the late Harold Giles who was taken from this world too soon. Harold was among the best Composite Division Awards Chairs that many of us worked with during his days at Azdel and UNC. He would have been thrilled to know that we are honoring his name in awarding worthy students. This award is run through SPE International in their Foundation Program series. The Composites Division will select the winners from the pool of applicants in two categories, Graduate and Undergraduate students. This year, we received 34 applications (10 undergraduates and 24 graduates). The award is dispensed through SPE International to the winners.

The scoring criterion is based on twenty points for the category of scholastic achievements, community service, and other honors, up to ten points based on the strength of the recommendation letters, ten points for previous employment history particularly if this involved composite activity, up to five points for filling out the application form correctly and using good English, five points for providing their transcript and for getting good grades, and a final five points for the reason they applied for the scholarship.

Award Requirements:

- Two awards presented to one undergraduate and one graduate student, who will maintain the academic status for at least two semesters after award announcement.
- An essay documenting experience in the composites industry is required (courses taken, research conducted, or jobs held)
- Have not received the award in previous years.
- Winners are typically students who not only maintained a good grade point average but also served their community, had some experience in the composite area, and are backed by solid reference letters from former professors and employers

The award can be up to $3500 per student depending on funding availability.

Key Dates:

Issue call for nominations ..... February 1st
Close call for nominations .... April 1st
Complete award adjudication ....June 30th
Notify recipients by ....July 30th
Present awards ....SPE ACCE

continued on page 9...

This Issue:

Award Opportunities continued...

Dr. Jackie Rehkopf Memorial Scholarships

This award is in honor of the late Jackie Rehkopf, a recognized engineer who published books and was actively involved in the composites industry. The Automotive and Composites Divisions co-sponsor these awards and therefore co-coordinate. This award is presented annually at the SPE ACCE conference each fall and is a premiere award for exemplary performance. This year, we received 6 graduate student applications.

Award Requirements

- A single full-time grad student or two undergrad students if no grad students qualify
- Preference will be given to female students, but the best candidates will be selected
- Focus should be on research activities targeted to ground transportation composite technology
- Students must be in good academic standing and pursuing a degree in Polymer Science, Composites, Plastics, or a related Engineering discipline
- A 2-page essay is required showing planned work and how it will benefit composites in an automotive or other ground transportation application
- A letter of recommendation from the student's advisor or mentor is also required
- Scholarship recipients are required to present work at an SPE technical conference and/or have it published in an SPE technical journal

The award can be up to $5000 if one student is selected or up to $2500 per student if two are selected, depending on funding availability.

Key Dates

Issue call for nominations ....January 1st
Close call for nominations .... April 1st
Complete award adjudication .... June 30th
Notify recipients by ....July 30th
Present awards ....SPE ACCE

continued on page 10...

Award Opportunities continued...

Travel Award:

This is a two-year award where the applicant fills out an abstract form the first year and returns the second year to present a paper/poster to discuss how the topic has progressed. This reward is presented at ANTEC during the business meeting. Typically, scoring has been based on English, the concept's novelty, and the research plan's strength. This is a $2000 award, dispensed in two installment payments over 2 years. This award is sponsored by industry partners every year. If any company like to sponsor this award, please reach out to the Awards Chair Dr. Pritesh Yeole (priteshyeole.mse@gmail.com).

Award Requirements

- A two-part award presented annually to an undergraduate or graduate student.
- At the time of application, master's students must be in the first year of their program and doctoral students must be in the first two years of their program
- The winner is selected based on a 250-word abstract describing their composites research
- In the first year, the recipient receives a $1000 (USD) scholarship award and a plaque, presented at ANTEC
- To be eligible for the second $1000 installment, the research described in the winning abstract must be presented in a paper at ANTEC the following year

Educator of the Year Award:

The Educator of the Year Award is an industry-sponsored award. A certificate/plaque combination will be presented at ANTEC during the business meeting. The present score sheet provides scoring of up to ten points for English at 1X, ten points for recommendation letters at 2X strength, and student support examples at 3X strength. This prestigious recognition is aimed to honor an Educator who has influenced his students to excel in the composite field and grow their composites careers.

Award Requirements

- Someone in the educational field (high school, university, or college level)
- Has made a significant contribution to the training of students in the composites area. E.G.:
  - o the creation of new educational programs
  - o the development of new pedagogical tools
  - o motivating students to enter the composites sector
- Selection will be based on contributions made during the previous year.
- Must submit a nomination form and two letters of support

The award is $2500, covered by an industry sponsor. If any company like to sponsor this award, please reach out to the Awards Chair Dr. Pritesh Yeole (priteshyeole.mse@gmail.com).

ACCE Keynote Speakers Announced

First Keynote Announced For SPE® ACCE 2023 Event

What Does Disruptive Electrification of Transport Mean for Industrialization of Composites?

Joe Summers,
Commercial Director Airborne and Managing Director Airborne UK

TROY (DETROIT), MICH.

The executive planning committee for the SPE® Automotive Composites Conference & Expo (ACCE) is announcing the first keynote speaker for their ACCE 2023 event September 6 – 8, 2023 at the Suburban Collection Showplace in Novi, Michigan (Detroit suburb).

Joe Summers, Commercial Director Airborne and Managing Director Airborne UK, will present "What Does Disruptive Electrification of Transport Mean for Industrialization of Composites?" The presentation will show how electrification is disrupting most transport segments and creating new ones. In all cases, the additional mass of batteries creates a need for some degree of weight-offsetting and composites are the obvious solution. However, the very specific demands of carrying batteries are a challenge for composites to meet.

Many issues are typical to any new application for composites, trying to balance fixed vs recurring costs, functional performance, sustainability, qualification and repeatability, but scalability is bringing another dimension of challenge. This keynote will summarize the key functional challenges for composites in a variety of new and emerging segments and focus on how EVTOL brings functional challenges of aerospace, with production volumes more akin to automotive, and how technology developments are trying to solve them.

"I think the conference subject is a perfect description actually - 'Composites the Key to EV' encapsulates our thinking too and the approach of Airborne," said Summers. "Everyone recognizes that design-for-X is vital but more than ever, with the need for composites, and the drive to achieve rapid

continued on page 13...

This Issue:

scaling of rate manufacture, design-for-automation is critical," continued Summers. "We support that through "Industrialization Partnership" which are all the steps before readiness for automation," added Summers.

The keynote will include how UAM/EV-TOL (Urban Air Mobility/Electric Vertical Take Off and Landing) combines the challenges of aerospace and automotive, how the demands of both sectors magnify the challenges to the composites industry, and how we might collectively rise to that challenge with solutions.

The keynote will refer to a specific example of the crossover between Automotive and Aerospace approaches. Airborne is working within the ASCEND consortium (Aerospace and Automotive Supply Chain Enabled Development) to accelerate the development of composite material and process technologies for the next generation of energy efficient aircraft and future mobility. Other industry partners include Assyst Bullmer, Cobham Mission Systems Wimborne, Cygnet Texkimp, Des Composites, Far-UK Ltd, GKN Aerospace, Hexcel Composites, Hive Composites, LMAT, Loop Technology, McLaren Automotive, the National Composites Centre, Rafinex, Sigmatex (UK) and Solvay Composite Materials with collaboration and investment support from Axillium Research. Through a 3-year commitment established in March 2021, the £40 million consortium, funded by a £20 million commitment from industry and a £19.6 million commitment from the UK government via ATI, is focusing on greater adoption of composite technologies today, the industrialization of new technologies, as well as accelerating aerospace production rates to meet future high-volume requirements. ASCEND is helping to develop technologies from across the UK supply chain to develop the advanced materials and automation equipment required to manufacture lightweight structures for the sustainable air mobility, aerospace and automotive industry.

About the SPE ACCE

Held annually in suburban Detroit, the ACCE draws over 800 speakers, exhibitors, sponsors and attendees and provides an environment dedicated solely to discussion, education and networking about advances in transportation composites. Its global appeal is evident in the diversity of exhibitors, speakers, and attendees who come to the conference from Europe, the Middle East, Africa, Asia/Pacific and South America as well as North America. About 20% of attendees work for automotive and light truck, agriculture, truck & bus or aviation OEMs and another 25% represent tier suppliers. Attendees also work for composite materials processing equipment, additives, or reinforcement suppliers; trade associations, consultancies, university and government labs; media; and investment banks. ACCE has been jointly produced by the SPE Automotive and Composites Divisions since 2001. For more info go to: https://speautomotive.com/acce-conference/.

The mission of SPE is to promote scientific and engineering knowledge relating to plastics worldwide and to educate industry, academia, and the public about these advances. SPE's Automotive Division is active in educating, promoting, recognizing, and communicating technical accomplishments in all phases of plastics and plastic-based composite developments in

continued on page 14...

This Issue:

Speakers Announced continued...

the global transportation industry. SPE's Composites Division does the same with a focus on plastic-based composites in multiple industries. Topic areas include applications, materials, processing, equipment, tooling, design, and development. For more info go to: https://speautomotive.com/ and https://composites.4spe.org/. For more information on the Society of Plastics Engineers, see www.4spe.org.

Joe Summers, Commercial Director Airborne and Managing Director Airborne UK will present "What Does Disruptive Electrification of Transport Mean for Industrialization of Composites" at the SPE ACCE 2023 Event, September 6 – 8, 2023

Bio: Joe Summers has been in the composites industry for nearly 25 years, starting his career at Gurit where he held various roles including Head of Engineering and Program Management, and Director of Business Development. He joined Airborne in 2017 and is Commercial Director for the automation business, along with being Managing Director of the UK subsidiary. Joe is also a director of Composites UK, the UK composites trade association.

For more information and the SPE ACCE see https://speautomotive.com/acce-conference/ .

For more information on the Society of Plastics Engineers, see https://4spe.org/

This Issue:

spe

AUTOMOTIVE COMPOSITES CONFERENCE & EXHIBITION

Novi, MI • September 6-8, 2023

Presented by SPE Automotive and Composites Divisions

WORLD'S LEADING AUTOMOTIVE COMPOSITES FORUM

COMPOSITES THE KEY TO EV

AUTO & AIR MOBILITY

CALL FOR PAPERS

SPONSORSHIP OPPORTUNITIES

The automotive and transportation industries are advancing with composites playing a key role in the development of electric vehicles, air mobility, and sustainability initiatives worldwide. Lightweight composites are ideal materials for improving vehicle performance, reducing mass, extending range and compensating for battery weight. Polymer composites are enabling lower emission vehicles, reducing the carbon footprint and saving energy to benefit the environment now and in the future. Thermoset and thermoplastic composites are THE KEY TO EV AUTO & AIR MOBILITY

For more information and to register, go to: https://speautomotive.com/acce-conference/

The presentations are organized into the following categories: Composites in Electric Vehicles, Thermoplastic Composites; Thermoset Composites; Modeling; Additive Manufacturing & 3D Printing; Enabling Technologies; Sustainable Composites; Bonding, Joining & Finishing; Carbon Composites; and Business Trends/Technology Solutions. Paper abstracts are due **ASAP.** Final scientific papers or non-commercial presentations are due by **May 31, 2023.** Authors who submit papers (not presentations) in the proper format will be considered for the conference's Best Paper Awards, which are presented during the event's opening ceremony. A template for papers can be downloaded from the SPE ACCE website online via http://speautomotive.com/acce-forms. Abstracts and papers or presentations must be submitted online via the **SUBMIT 2023 ABSTRACTS/PAPERS OR PRESENTATIONS HERE** button on https://speautomotive.com/acce-conference/.

SPONSORSHIP AND EXHIBIT OPTIONS offer companies the opportunity to support the event and promote their products and services to a very targeted and interested audience. All sponsorships include passes to the event including access to all keynotes, panel discussions, technical sessions and daily networking opportunities. Sponsorship also includes corporate exposure on SPE ACCE websites, advertising, publicity, social media, signage throughout the event venue and more. Companies interested in sponsorship should contact Teri Chouinard at **teri@intuitgroup.com**.

THANK YOU TO OUR 2022 SPONSORS

FEATURED SPONSOR & EXHIBITOR: MP Molding Products

PREMIER PLUS SPONSORS & EXHIBITORS: INEOS Composites; LANXESS; Westlake Epoxy (+ RECEPTION SPONSOR)

STUDENT POSTER COMPETITION SPONSOR: Dassault Systèmes

LUNCH SPONSORS: Lotte Chemical; Mitsubishi Chemical Group

COFFEE BREAK SPONSOR: 3M Science. Applied to Life.

PREMIER SPONSORS & EXHIBITORS: AOC Trusted Solutions; BASF; Bostik; BYK Additives & Instruments; Forward Engineering; IDI Composites International; Hexagon

ASSOCIATE SPONSORS & EXHIBITORS: A.P Technology; ATF; Baylor Protolab; Baylor MTACC; Composites One; Applus DatapointLabs; Dieffenbacher; Fagor Arrasate; Fraunhofer; HRC; ACTC; Huber Engineered Materials; Johns Manville; Schmidt & Heinzmann; plenco; trilion; UL Solutions; Zoltek

TABLE TOP SPONSORS & EXHIBITORS: 3A Core Materials; Aero; CAR Center for Automotive Research; iacmi The Composites Institute; plasmatreat; Rassini

ADVERTISING SPONSOR: DSC Consumables

MEDIA / ASSOCIATION SPONSORS: ACMA; Additive Manufacturing; Autonomous; CW CompositesWorld; Gardner; Plastics Business; Plastics Decorating; Plastics Engineering; Plastics News; Plastics Technology; SAE; sampe; Urethanes Technology; WardsAuto

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:

ACCE Best Paper Finalists

Reconstruction of Full Fiber Orientation Distribution in Molded Composites Using Deep Learning

Mohammad Nazmus Saquib[1], Siavash Sattar[1], Richard Larson[1], Jiang Li[1], Sergii G. Kravchenko[2], Oleksandr G. Kravchenko[1]
[1]Old Dominion University, Department of Mechanical Aerospace Engineering, Norfolk, Virginia
[2]Department of Materials Engineering, University of British Columbia, Vancouver, BC, Canada

Abstract

Molded composite materials are key to the functionality, mobility, and sustainability of electric vehicles (EVs), on-demand air mobility, and aerospace structures. Fiber orientation distribution (FOD) characterization of composite materials is necessary to understand the mechanical variability in prepreg platelet molded compounds (PPMC). A novel U-Net deep learning model was developed to predict the local through-thickness fiber orientation (FOD) field in PPMC composites using the thermal strain field as an input. The deep learning model was trained with synthetically generated PPMC morphologies and tested on a molded plaque. Thousands of virtual PPMC plates were subjected to uniform temperature change and used to collect the thermal strain components $(\epsilon_{xx}, \epsilon_{yy}, \epsilon_{xy})$ on the surface of PPMC plates. The strain components were used to train the U-Net model to predict average through-thickness FOD in the entirety of the molded plate. A heating stage with a digital image correlation (DIC) setup was developed to analyze the thermal expansion behavior of PPMC samples. The trained deep learning U-Net model was used to predict FOD in a physical part by providing surface strain fields collected through thermal DIC. The obtained U-Net model prediction of FOD was compared to FOD obtained through microscopy and image analysis. The predicted non-uniform behavior of FOD was compared with the experimentally measured FOD along several polished cross-sections and revealed close agreement. The present results indicate the opportunity for rapid inspection to detect manufacturing-induced FOD in molded composites using the proposed deep learning model.

continued on page 18...

ACCE Best Paper Finalists continued...

Introduction

Prepreg-Platelet Molded Composites (PPMC) are an important section of the molded composites, as it has better processability into complex geometric shapes to be used in the automotive and aerospace industry [1], [2]. PPMCs are discontinuous fiber reinforced polymer composites made from slitting prepreg tapes heat pressed within a mold to give desired form [3]. PPMCs offer high structural grade properties although made with discontinuous fibers [4]–[10]. FOD in a PPMC depends on several factors including material deposition, compaction, flow direction, heat supplied, pressure applied, etc. [11]. Due to high material anisotropy, PPMC exhibits complex mechanical behaviors as platelets during production could not be deposited in a controlled way [12]. Hence, PPMC's FOD is locally varying from production due to stochastic deposition during manufacturing. Variations of FODs locally in PPMC morphology are known as manufacturing-induced signatures. Spatial variability of FOD leads to the local variation of thermo-mechanical properties of the PPMC throughout the plate. Although many industrial-scale productions have the same global orientation, variations of FOD locally make each part unique [8]. After the application of uniform temperature differential, varying deformation configuration on the surface of the PPMC was found due to local FOD variation on the PPMC plaque [13].

To know the physical-mechanical properties of composite material, it is important to find its fiber orientation [14]. Conventional Non-destructive evaluation (NDE) methods like flashtomography and pulse echo C-scan ultrasound can detect voids, and defects but these are currently unable to analyze local FOD in PPMC [15]. Some traditional FOD inspection methods like optical microscopy and micro-computed tomography (μCT) are proven to deliver accurate analysis, but they are time-consuming [16], [17]. Some other limitations include the destructive nature of the optical microscopy process and μCT having a restriction on analyzing larger specimens [18]. A reliable rapid inspection method for characterizing the FOD of PPMC mesostructures is a necessity for predicting structural mechanical properties to ensure composite reliability.

Data-driven modeling is becoming popular day by day. The application of Artificial Intelligence (AI) and Machine Learning (ML) was found useful to solve many composite manufacturing and performance-related problems [19]. Application of deep learning extracts and analyses information from images using machine learning techniques [18]. Image classification and

continued on page 19...

semantic segmentation in deep learning enable to store fine detailed information about an object. For quality inspection at different stages of manufacturing and to predict FOD within, computer vision should be considered [21], [22]. In this study, a new method was proposed to combine thermal DIC response and artificial neural network rapid FOD analysis.

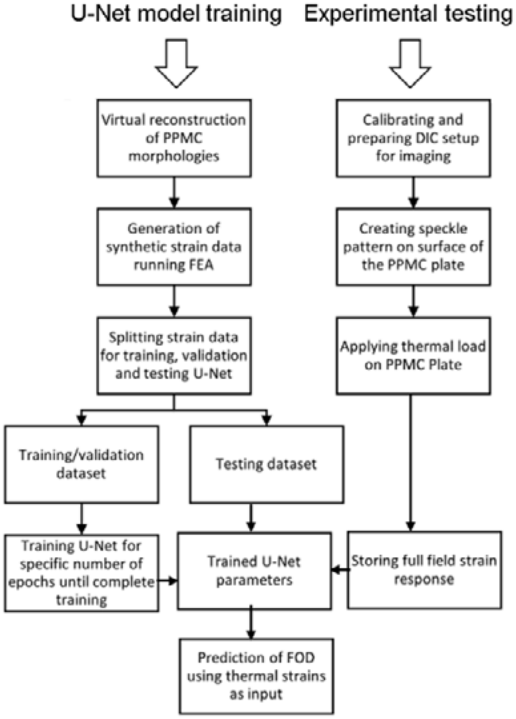
A fully convolutional network (FCN) U-Net, which is a pixel-based image segmentation model, was used throughout our work to predict the manufacturing-induced FOD in PPMC plates. Fiber orientations on the PPMC averaged through the thickness were predicted based on the images of the full field strain distribution on the PPMC plates. Experimental images of strain distributions were captured via the thermal DIC technique on the top and bottom surface of the PPMC plate and applied to the trained U-Net model to predict FOD. This paper describes the proposed method, accuracy, and validity of the developed U-Net model for predicting local FOD. Thermal DIC strain data was used to provide the input of the algorithm to predict FODs in a PPMC plate, whereas optical microscopy image analysis was used to measure and validate the predicted FOD on the surface of the PPMC plates [17], [23], [24].

Method

The proposed framework uses virtual PPMC morphology for extracting the calculated data obtained via linear finite element analysis. Next, U-Net model training is conducted along with model performance evaluation using experimental validation. U-Net is a type of FCN, which is different from the regular contracting convolutional neural network (CNN). U-Net allows for up-sampling expansion that provides the same resolution of the predicted output data (FOD field), as the input resolution (strain fields). Specifically, average through-thickness FOD was predicted by U-Net from a given strain field. U-Net was also used because it can work with fewer training images to provide better segmentation in a comparatively lesser amount of time [25].

The structure of the reconstruction of FOD and its prediction in PPMC plate is shown in Figure 1. A finite element model was developed to simulate PPMC response under uniform thermal loading. Ten thousand of virtual morphologies and corresponding strain data were used to train the U-Net model. The advantage of using the high-fidelity synthetic morphology is apparent when considering the amount of time that would be required to generate the equivalent number of experimentally molded samples, followed by the FOD evaluation for ML

Figure 1: Framework of FOD reconstruction in PPMC using U-Net.



continued on page 20...

This Issue:

training and thermal expansion experiments. The use of the synthetic data is also free from the associated experimental errors during all of the specified steps. Upon completion of training, U-Net can rapidly predict local through-thickness FOD in PPMC. To experimentally validate U-Net performance, experimental strain data obtained from thermal DIC was used as input for the trained U-Net model to predict the through-thickness FOD of the respective sample. The FOD prediction was compared with the measurement of FOD via microscopic analysis using image segmentation.

The reconstruction of the FOD study is mainly comprised of two parts: a) A forward linear finite element model to extract strain data on the part surface due to the uniform temperature change of PPMC plates, b)To solve the inverse problem utilizing strain data from finite element analysis output to predict FOD in a PPMC plate. The second part is solved using FCN. The FCN was trained to form a relation between strain fields and FOD identifying parameters.

Generation of synthetic datasets

Virtual PPMC morphologies were modeled in Digimat FE e-Xtream Engineering defining specimen dimensions, platelet dimensions, and global fiber orientations as input. A representation of virtual PPMC morphology produced by Digimat is shown in Figure 2. The morphologies were then imported into ABAQUS/Standard to perform FE analysis. The platelet dimensions for PPMC were set as 6.35 x 12.7 x 0.13 mm and the PPMC plate dimensions as 126.4 x 126.4 x 1.95 mm. The prepreg tapes used for the analysis are IM7/8552. A Uniform temperature difference was applied to the PPMC plate to perform the thermo-elastic analysis. The full PPMC plate was then meshed into 160 x 160 x 15 eight brick node C3D8 finite element voxels, each having dimensions 0.79 x 0.79 x 0.13 mm for performing the FE analysis.

PPMC structures with the same global FOD typically had different locally variable FOD due to the Monte Carlo method of generating the synthetic PPMC morphologies. Application of uniform thermal load on PPMC plates results in non-uniform strain responses throughout the surface. These strain fields $(\epsilon_{xx}, \epsilon_{yy}, \epsilon_{xy})$ were provided as input to U-Net later to predict locally varying FOD in PPMC morphologies.

continued on page 21...

ACCE Best Paper Finalists continued...

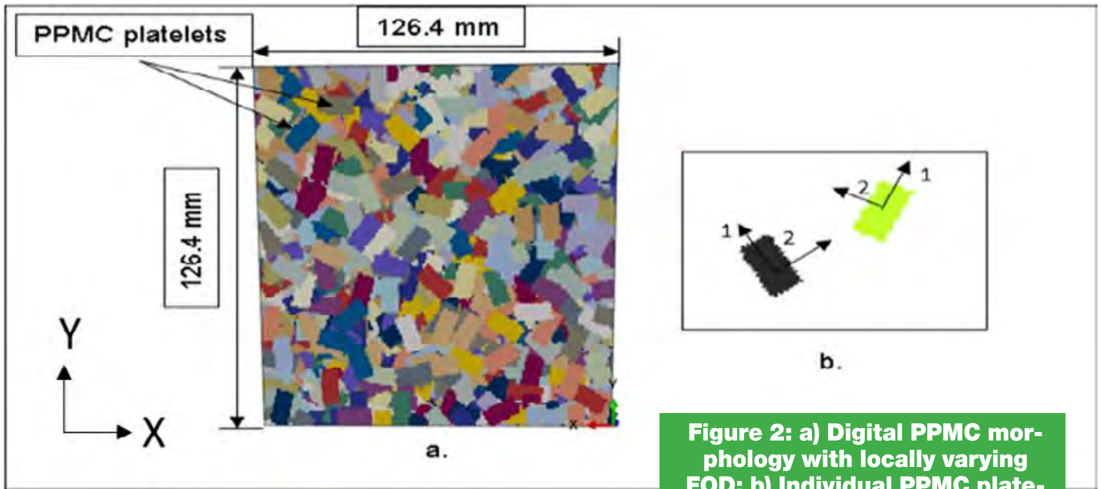


Figure 2: a) Digital PPMC morphology with locally varying FOD; b) Individual PPMC platelets in space.

A python script was generated to produce multiple PPMC morphologies with different global orientations (A_{xx}= 0.1, 0.3, 0.5, 0.7, 0.9), and FOD varying locally within the plates. A_{xx} is the probability of finding fiber alignment in an X-direction. Another script was used to import these morphologies in ABAQUS and perform FE analysis to extract surface strain fields on the top and bottom surfaces of the PPMC plates. The results were stored as arrays of structured data and used in U-Net training later.

The PPMC plate was constructed with 160 elements on both the X and Y-axis. It was treated as a 160 x 160-pixel image to be used for Fully Convolutional Network (FCN). From the FE analysis, local FOD characteristics (A11, A12) and surface strains $(\epsilon_{xx}, \epsilon_{yy}, \epsilon_{xy})$ of top and bottom surfaces were stored.

Deep Learning Model for FOD reconstruction

The input for U-Net training was the structured data array of surface strains, which were obtained from FE analysis. The surface strain data of the PPMC plate was stored as a 160 x 160 x 6 data array. The 160 x 160 data points were strain data of each element voxels and the 6 depth channels were surface strains $(\epsilon_{xx}, \epsilon_{yy}, \epsilon_{xy})$ of top and bottom surfaces. The U-Net training was done using 25 patches with 32 x 32 x 6 voxel dimensions. Thus, the extracted patches covered the whole in-plane 160 x 160 voxels of the synthetic PPMC plate. The total number of patches used for training, testing, and validation was 2,50,000 with 70,15,15% split, respectively. The neurons (weights and biases) of the neural network were arranged as layers to give an output, whereas filters help to extract unique features in the sample. 4 such U-Net layers and 128 filters were used for its training purpose. The U-Net trained with data extracted from total 10,000 morphologies having global FOD, A_{xx} = 0.1, 0.3, 0.5, 0.7, 0.9. For each global FOD state, equal 2000 morphologies were generated for training purposes. An epoch is the complete travel of the training dataset through the algorithm. 4000 such epochs were performed to complete the training process.

continued on page 22...

This Issue:

ACCE Best Paper Finalists continued...

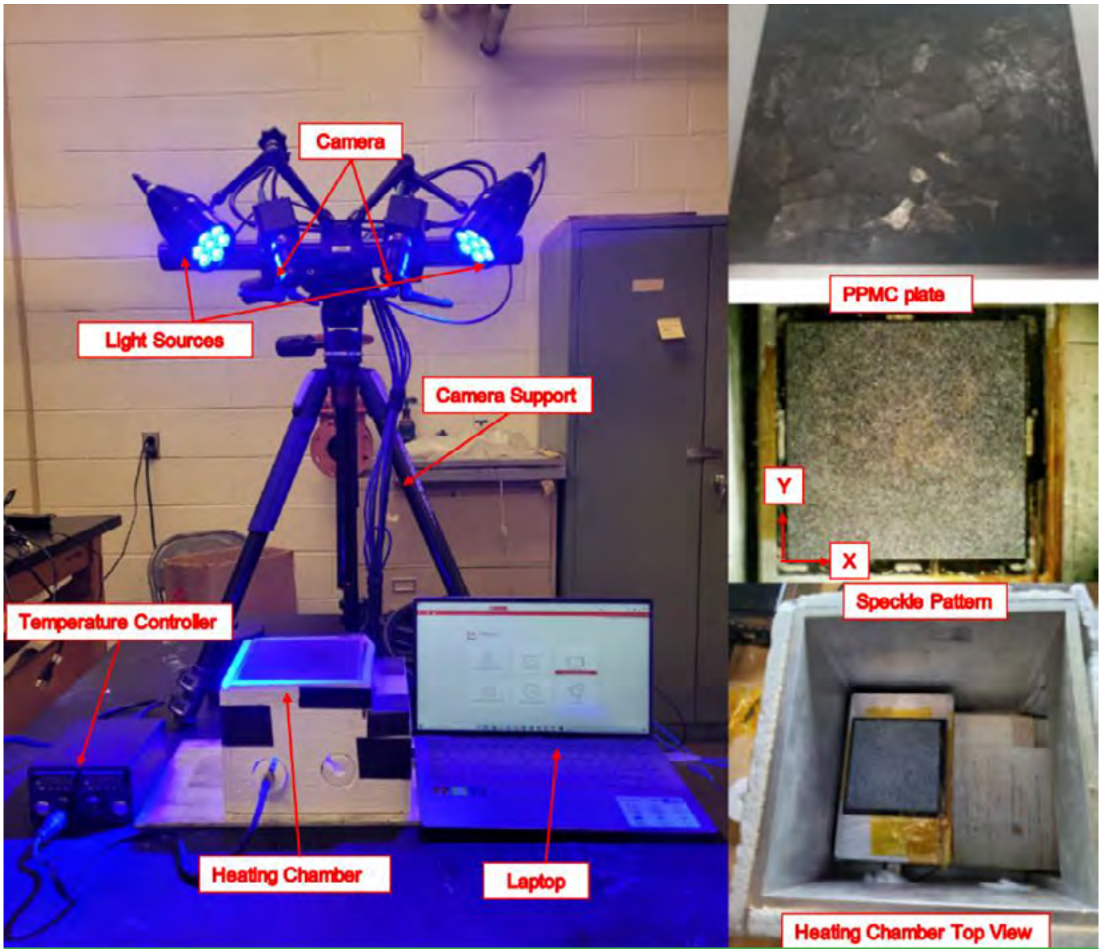


Figure 3: Schematic of Digital Image Correlation Experimental Setup.

Digital Image Correlation and extraction of thermal strain fields

Digital Image Correlation (DIC) is a non-contact process that compares different images of a specimen at different deformation stages due to applied load, taken at a time interval. The system tracks pixel displacement with respect to the reference undeformed configuration of the image to calculate the strain field components. The experimental setup for this study consisted of two cameras, a heating chamber, a temperature controller, external light sources, and a computer with GOM Snap software. The schematic of the overall experimental setup is shown in Figure 3. The two cameras capture timed pictures during the heating cycle.

The heating chamber used thermal insulation to ensure the application of uniform thermal load on the PPMC surface. Quartz glass was used to cover the heating chamber, as it helps to keep the heating stage insulated. The PPMC specimen was also placed upon a hollow square to ensure a uniform heat load was applied to it. Before starting the process, the PPMC plate was painted to create speckle patterns on both, top and bottom surfaces, to analyze deformation during a thermal expansion (Figure 3). The temperature inside the heating chamber was elevated from room temperature with the help of a temperature controller to create a temperature difference. The painted specimen was placed inside the

continued on page 23...

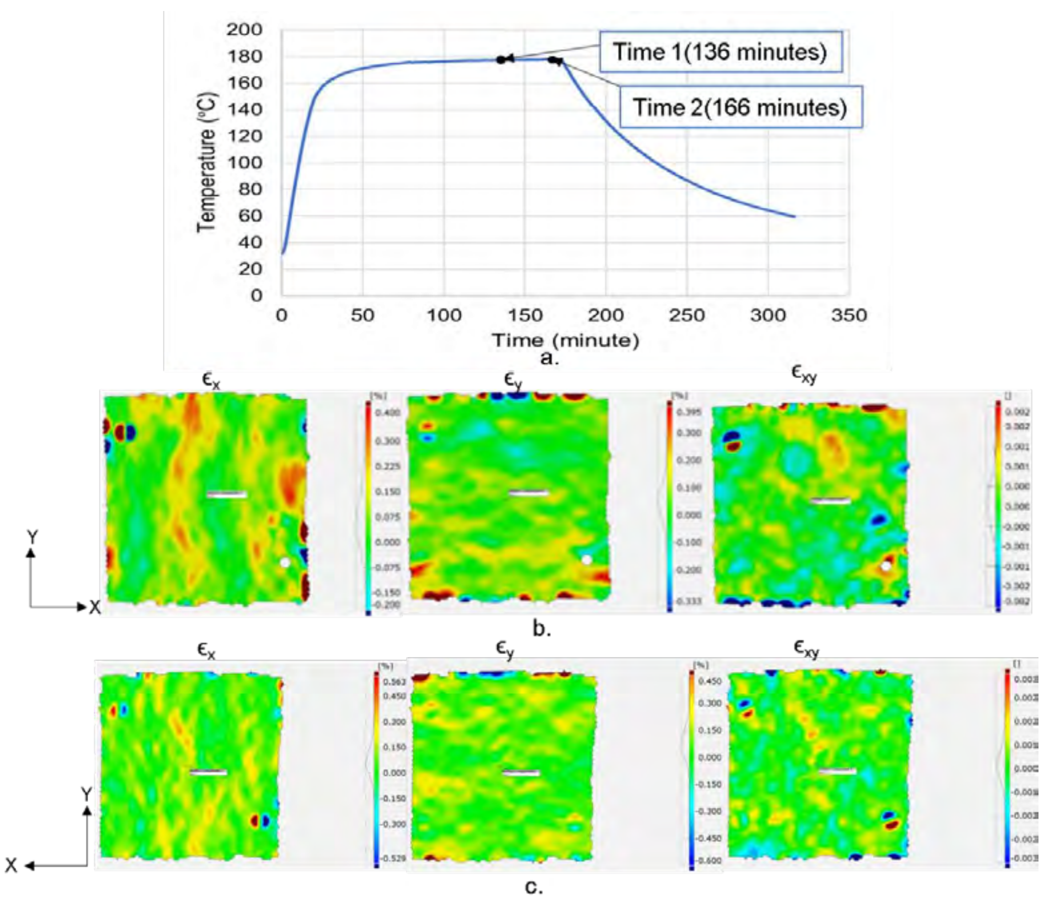
This Issue:

ACCE Best Paper Finalists continued...

insulated heating chamber to minimize any kind of heat loss as much as possible. The sample was then heated following a ramp of 1.3°C/min. To apply thermal load uniformly, isothermal heat was applied for 45 minutes, followed by the cooldown stage. During the application of load, an image was taken each minute and stored. The heating cycle was recorded by the thermo-couple inside the heating chamber and is shown in Figure 4. Two sets of images were captured for calculating the deformation of the specimen once the thermal equilibrium was reached during the iso-thermal stage: strain data was recorded at Time-1 (136 minutes), and Time-2 (166 minutes). Time 1 was selected after reaching the isotherm and Time 2 was 30 minutes into the isothermal stage. The same steps were repeated for the other surface (top/bottom) to capture specimen deformation images.

All the images captured were imported into GOM Correlate to extract deformation data. Firstly, surface strain components were created on the PPMC specimen (63.5 x 63.5 x 1.95 mm) reference image using the squared facets metric. Squared facets were set at 19 pixels and a point distance of 16 pixels. These squared facets identify painted stochastic patterns within its space and later track the change of its position gradually with the application of load to find de-

Figure 4: a) Full-field application of thermal load inside the heating chamber; b) Thermal strains (E_x, E_y, E_{xy}) heatmap on the front surface of PPMC plate; c) Thermal strains (E_x, E_y, E_{xy}) heatmap on back surface of the PPMC plate



continued on page 24...

This Issue:

formation. 81 x 81 such data points were created on the surface of the PPMC specimen to extract full-field strain distribution $(\epsilon_x, \epsilon_y, \epsilon_{xy})$. MATLAB griddata function for 2-D data interpolation using nearest method for discontinuous data interpolation was used to sort the extracted strain fields to specific grid locations, determined by the pixel size in U-Net training to get full field FOD as output. 0.79 x 0.79 mm grid sizes were maintained to match the finite element mesh sizes, which were used to generate the synthetic datasets to be used for U-Net training. Strain data were extracted, sorted and stored this way using image sets captured at Time 1 and Time 2. Strain field at two different times during isothermal heating stage were averaged before using as U-Net input. Strain distributions of both front and back of the specimen were provided as an input and passed through the trained U-Net 4 layers and 128 filters of weights and biases to predict the average through-thickness FOD of the specimen.

Optical microscopy and image analysis to characterize FOD

Optical microscopy and image analysis combination were used to characterize FOD locally through the thickness. A 63.5 x 63.5 mm sample PPMC plate was used for inspection. The plate was cut open along 14.5-mm and 31.75-mm lines from the top for inspecting and measuring local FOD. The cut-through samples were mounted for microscopy using epoxy resin and then went through seven stage polishing process: 300, 400, 600, 800, and 1200 grit sandpaper grinding, followed by 3 μm and 1 μm deagglomerated diamond polishing. The prepared sample was then taken to a Leica DM6 M microscope for microscopic analysis. The micrographs

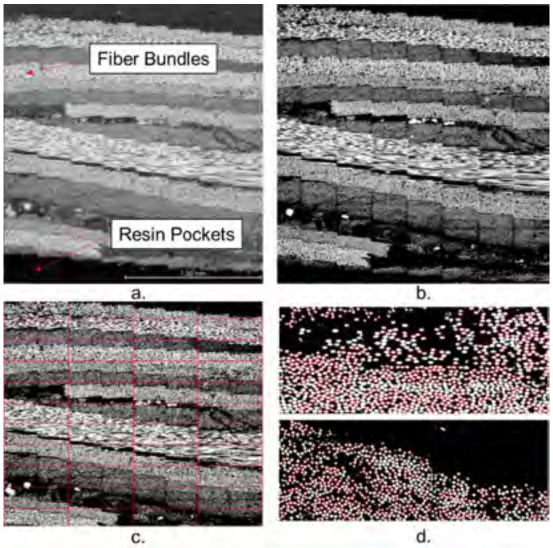


Figure 5: a) 8-bit greyscale micrograph of 1/38th part of the PPMC plate along the length; b) binarized, filtered and segmented 2-bit micrograph; c) 4 x 12 grid line segmentation of the micrograph for accurate measurements; d) Ellipse measurement within a grid using MATLAB image processing toolbox to characterize FOD.

were captured in 38 different segments, 1.67 x 1.95 mm each, and stitched together using Leica software. Microscope-captured greyscale images are shown in Figure 5a.

The 8-bit grayscale micrographs captured were taken into ImageJ software to binarize, filter, and segment them (Figure 5b). After complete binarization, the black and white colors in the micrograph referred to the matrix and fibers in the PPMC plate. The threshold of the binarization was adjusted in such a way that, the micrograph can represent the fiber boundaries accurately. The binarized image was then taken into MATLAB for FOD measurement with the help of the image processing toolbox. First, the micrographs were segmented into 4 x 12 grids, and then the image was split into 48 parts according to the grids (Figure 5c). It was split in such a way to find similar

continued on page 25...

This Issue:

ACCE Best Paper Finalists continued...

fibers within the image, which helps the MATLAB script to identify and fit ellipses perfectly for FOD measurements. The grid segmentation representation of the micrograph is shown in Figure 5d. Some of the fiber bundles contain almost parallel to the plane long fibers, which are very difficult to capture by MATLAB image processing. Those segmented micrographs were taken into Ellipse fit software to measure and calculate the fiber orientation manually. Some of the images were also analyzed using EllipseFit to cross-check and validate MATLAB image processing.

Results

Virtual testing of U-Net Response

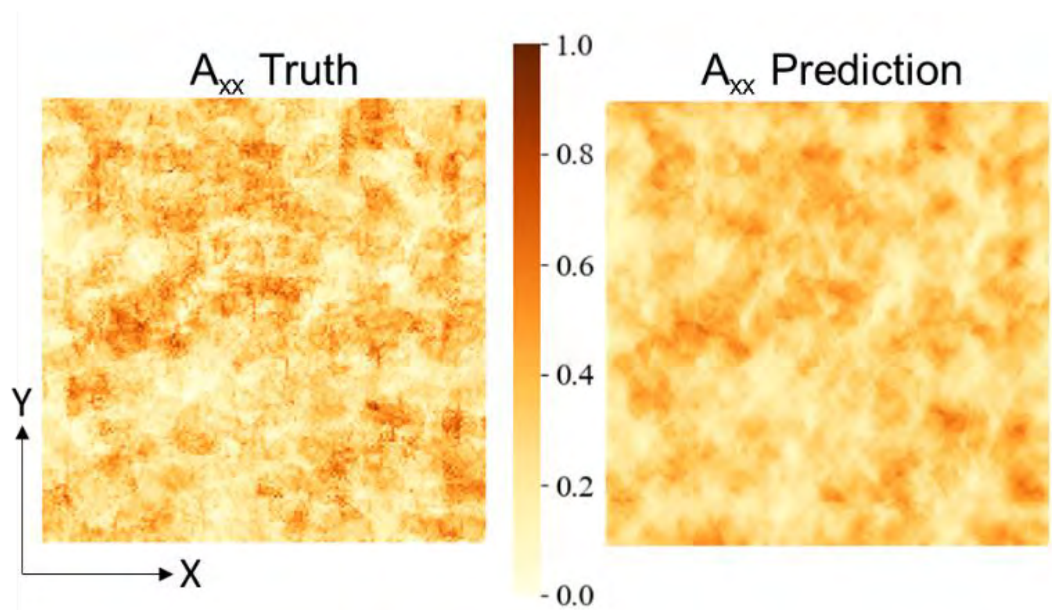
15% of synthetic datasets produced were stored for testing purposes. A method of testing U-Net response virtually is to pass a randomly selected PPMC plate through U-Net for FOD prediction and compare it with the ground truth value. Figure 6 shows the heatmap comparison of the U-Net prediction of spatial FOD of a PPMC plate with its actual FOD. The region with a darker shade exhibits a higher degree of fiber alignment region in the X-direction. One difference is the prediction seems to show less sharpness in some places of higher alignment. Other than that, it can be conferred that model is correctly predicting local FOD for the virtual responses.

Comparison of FOD measurement with U-Net prediction

The FOD measurement of each grid was averaged column-wise to get a local average degree of alignment along the X-axis through the thickness. Image representation of voxelized FOD calculation is shown in Figure 7. All fibers aligned almost parallel to the X-axis were found to have Axx close to 1 and fibers perpendicular to X-axis were measured close to 0. Again, fibers with a smaller elliptical cross-section having close minor and major diameter values were measured to have significantly higher Axx compared to fibers with a bigger elliptical cross-section having a minor diameter significantly smaller than its major diameter.

continued on page 26...

Figure 6: Truth vs Prediction heatmap of a random plate tested on U-Net.



This Issue:

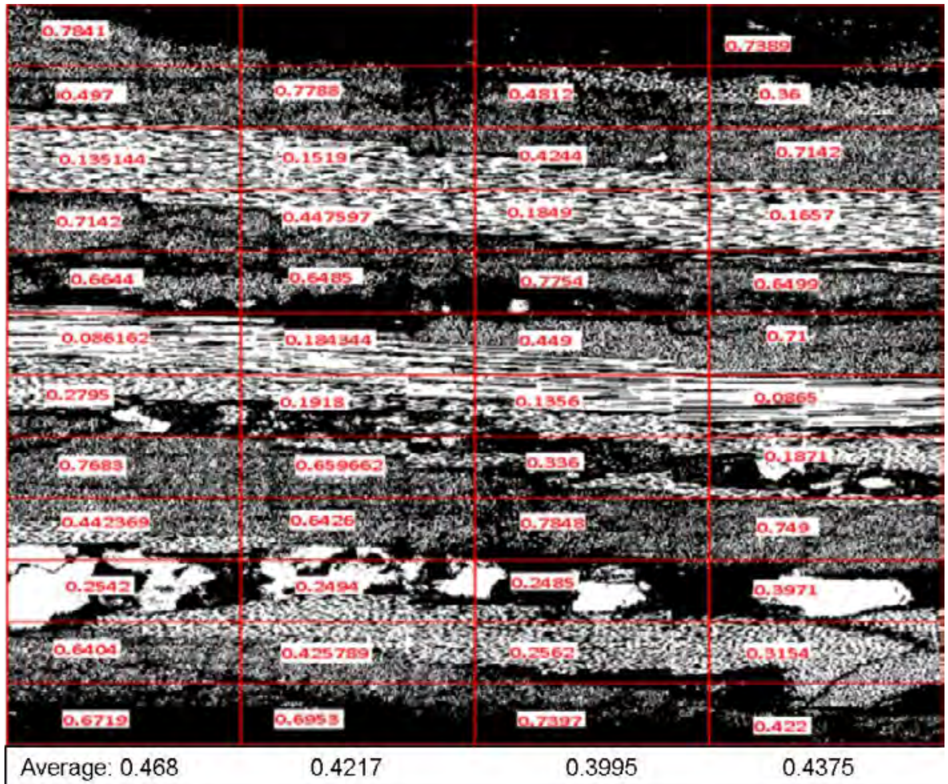


Figure 7: Measurement of Axx in individual platelets to get average FOD through thickness locally.

PPMC plate FOD distribution was measured along 14.5mm and 31.75mm lines from the top edge of the surface. 14.5 mm line was symbolized as line 1 and 31.75mm line as line 2. Line 1 showed a lower degree of alignment in FOD along X-axis compared to line 2. The presence of long and larger elliptical fibers along the X-axis resulted in lower Axx values. Resin-rich pocket regions are also responsible for variability in FOD. FOD measurement along line 1 and line 2 is shown in Figure 8 below.

continued on page 27...

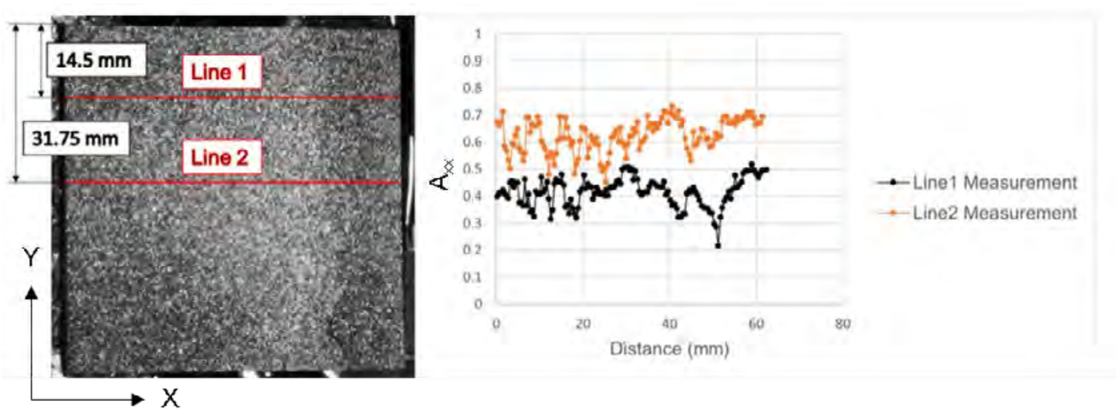


Figure 8: Measurement of FOD along line 1 and line 2 to check fiber orientation variation locally.

This Issue:

ACCE Best Paper Finalists continued...

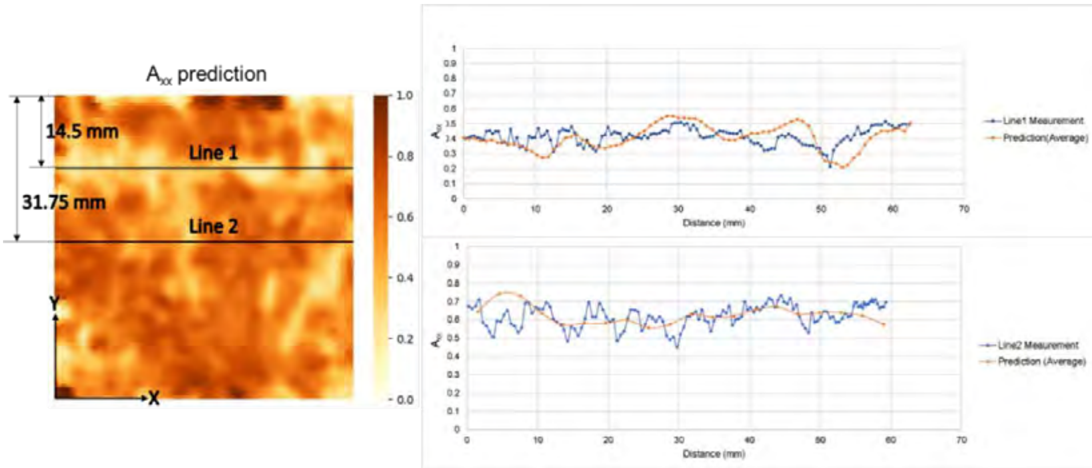


Figure 9: Measurement vs Prediction comparisons along inspection lines in a PPMC plate.

Measurement along different lines and U-Net predictions in the same place are compared in Figure 9. Line 2 was selected for comparison along the middle of specimen, whereas line 1 was selected based on the U-Net prediction, where heatmap was showing higher variability and lower value in fiber alignment along X-direction.

U-Net predictions were made based on the thermal DIC strain data. Strain fields were extracted on two different times during isothermal heating and were averaged to predict full field FOD via U-Net. Later, U-Net prediction was compared with measurement for validation. For Line 1, some variation in FOD was found between U-Net prediction and measurement data in the latter half of the specimen. There was a difference also in the strain data extracted during two times during isothermal heating stage. This happened due to unexpected heat loss during experiment performance. To minimize this effect, strain extracted at two different times were averaged before using as U-Net input. Other than this, the rest of the line FOD measurement revealed a close comparison with test prediction along line 1 giving 13.99% error on an average.

For Line 2, FOD measurements and prediction average showed a similar trend along the line. The U-Net prediction along line 2 gave 7.02% error in comparison with FOD measurement along same line. Measurement of FOD leads to some high peak and low peak points. Optical microscopy micrographs with even smaller dimensions to extract more data points along the line would minimize this discrepancy. It can be conferred from the line Inspection that, the U-Net model can accurately predict local FOD in a PPMC plate.

Conclusion

The developed U-Net model established a relation between supplied deformation data and spatially non-uniform through-thickness average component of fiber orientation tensor in PPMC. The partially defined inverse problem was solved by deep learning, wherein the thermal strain fields on the top and bottom surfaces of the part were used to predict local FOD in the PPMC plate. The deep learning model was trained and validated using 10000 virtual PPMC morphologies with varying degrees of fiber alignment. Based on the machine

continued on page 28...

This Issue:

ACCE Best Paper Finalists continued...

learning training and validation the model was found to predict fiber orientation with average error of 6.3%. To validate the model, a physical PPMC strain response was generated via thermal DIC setup and was used for the U-Net model. The PPMC plate was cut for polishing along the specific locations to measure FOD. Image analysis of the fiber ellipses was conducted to measure FOD through the thickness and compared with U-Net prediction. In comparison with U-Net prediction, FOD measurement revealed similarity in trend after inspections and image analysis. The functioning U-Net model allows for microstructure reconstruction and opens possibilities to rapidly inspect local variability of FOD in PPMC components allowing to capture the manufacturing-induced signature of the part.

Bibliography

[1] Tim Osswald, Discontinuous Fiber Composites. 2019.

[2] S. Alam and M. N. Saquib, "Impact Analysis of a Composite Armor System," Nov. 2019. doi: 10.1115/IMECE2019-11748.

[3] S. Sattar, B. B. Laredo, D. Pedrazzoli, M. Zhang, and O. G. Kravchenko, "Understanding Size Effects on Flexural Properties in Discontinuous Fiber Reinforced Nylon Composites," in CAMX, 2020, p. 15.

[4] I. Taketa, T. Okabe, H. Matsutani, and A. Kitano, "Flowability of unidirectionally arrayed chopped strands in compression molding," Composites Part B: Engineering, vol. 42, no. 6, pp. 1764–1769, Sep. 2011, doi: 10.1016/j.compositesb.2011.01.021.

[5] B. Landry, A. Levy, P. Hubert, D. Leblanc, S. Roy, and A. Yousefpour, "Compression moulding of complex parts using randomly-oriented strands thermoplastic composites Thermoplastic Composites Adhesion View project Multiphysical simulation in composites forming processes View project COMPRESSION MOULDING OF COMPLEX PARTS USING RANDOMLY-ORIENTED STRANDS THERMOPLASTIC COMPOSITES," 2014. [Online]. Available: https://www.researchgate.net/publication/263231423

[6] D. E. Sommer, S. G. Kravchenko, B. R. Denos, A. J. Favaloro, and R. B. Pipes, "Integrative analysis for prediction of process-induced, orientation-dependent tensile properties in a stochastic prepreg platelet molded composite," Composites Part A: Applied Science and Manufacturing, vol. 130, Mar. 2020, doi: 10.1016/j.compositesa.2019.105759.

[7] S. G. Kravchenko et al., "Tensile properties of a stochastic prepreg platelet molded composite," Composites Part A: Applied Science and Manufacturing, vol. 124, Sep. 2019, doi: 10.1016/j.compositesa.2019.105507.

[8] S. G. Kravchenko, D. E. Sommer, B. R. Denos, W. B. Avery, and R. B. Pipes, "Structure-property relationship for a prepreg platelet molded composite with engineered meso-morphology," Composite Structures, vol. 210, pp. 430–445, Feb. 2019, doi: 10.1016/j.compstruct.2018.11.058.

[9] S. Sattar, B. B. Laredo, D. Pedrazzoli, M. Zhang, and O. G. Kravchenko, "Understanding Size Effects on Flexural Properties - SAMPE," in SAMPE North America, Sep. 2020, p. 15. Accessed: Aug. 14, 2022. [Online]. Available: https://www.nasampe.org/store/viewproduct.aspx?id=17720565

[10] S. Sattar, B. Beltran Laredo, R. Larson, S. Kravchenko, and O. G. Kravchenko, "Effect of Platelet Length and Stochastic Morphology on Flexural Behavior of Prepreg Platelet Molded Composites."

[11] J. Teuwsen, S. K. Hohn, and T. A. Osswald, "Direct fiber simulation of a compression molded ribbed structure made of a sheet molding compound with randomly oriented carbon/epoxy prepreg strands—a comparison of predicted fiber orientations with computed tomography analyses," Journal of Composites Science, vol. 4, no. 4, 2020, doi: 10.3390/jcs4040164.

[12] D. E. Sommer, S. G. Kravchenko, and R. B. Pipes, "A numerical study of the meso-structure variability in the compaction process of prepreg platelet molded composites," Composites Part A: Applied Science and Manufacturing, vol. 138, Nov. 2020, doi: 10.1016/j.compositesa.2020.106010.

continued on page 29...

This Issue:

ACCE Best Paper Finalists continued...

[13] R. Larson, R. Hoque, V. Jamora, J. Li, S. G. Kravchenko, and O. G. Kravchenko, "Prediction of Local Fiber Orientation State in Prepreg Platelet Molded Composites via Deep Convolutional Neural Network."

[14] S. B. Visweswaraiah, M. Selezneva, L. Lessard, and P. Hubert, "Mechanical characterisation and modelling of randomly oriented strand architecture and their hybrids – A general review," Journal of Reinforced Plastics and Composites, vol. 37, no. 8, pp. 548–580, Apr. 2018, doi: 10.1177/0731684418754360.

[15] P. Feraboli, T. Cleveland, M. Ciccu, P. Stickler, and L. DeOto, "Defect and damage analysis of advanced discontinuous carbon/epoxy composite materials," Composites Part A: Applied Science and Manufacturing, vol. 41, no. 7, pp. 888–901, Jul. 2010, doi: 10.1016/j.compositesa.2010.03.002.

[16] P. Bing, X. Hui-min, H. Tao, and A. Asundi, "Measurement of coefficient of thermal expansion of films using digital image correlation method," Polymer Testing, vol. 28, no. 1, pp. 75–83, Feb. 2009, doi: 10.1016/j.polymertesting.2008.11.004.

[17] O. G. Kravchenko, S. G. Kravchenko, A. Casares, and R. B. Pipes, "Digital image correlation measurement of resin chemical and thermal shrinkage after gelation," Journal of Materials Science, vol. 50, no. 15, pp. 5244–5252, Aug. 2015, doi: 10.1007/s10853-015-9072-3.

[18] B. R. Denos, D. E. Sommer, A. J. Favaloro, R. B. Pipes, and W. B. Avery, "Fiber orientation measurement from mesoscale CT scans of prepreg platelet molded composites," Composites Part A: Applied Science and Manufacturing, vol. 114, pp. 241–249, Nov. 2018, doi: 10.1016/j.compositesa.2018.08.024.

[19] H. Fernandes et al., "Machine learning and infrared thermography for fiber orientation assessment on randomly-oriented strands parts," Sensors (Switzerland), vol. 18, no. 1, Jan. 2018, doi: 10.3390/s18010288.

[20] A. Garcia-Garcia, S. Orts-Escolano, S. Oprea, V. Villena-Martinez, P. Martinez-Gonzalez, and J. Garcia-Rodriguez, "A survey on deep learning techniques for image and video semantic segmentation," Applied Soft Computing Journal, vol. 70. Elsevier Ltd, pp. 41–65, Sep. 01, 2018. doi: 10.1016/j.asoc.2018.05.018.

[21] T. Sabiston, K. Inal, and P. Lee-Sullivan, "Application of Artificial Neural Networks to predict fibre orientation in long fibre compression moulded composite materials," Composites Science and Technology, vol. 190, Apr. 2020, doi: 10.1016/j.compscitech.2020.108034.

[22] D. M. Dimiduk, E. A. Holm, and S. R. Niezgoda, "Perspectives on the Impact of Machine Learning, Deep Learning, and Artificial Intelligence on Materials, Processes, and Structures Engineering," Integrating Materials and Manufacturing Innovation, vol. 7, no. 3. Springer Science and Business Media Deutschland GmbH, pp. 157–172, Sep. 01, 2018. doi: 10.1007/s40192-018-0117-8.

[23] B. Landry and P. Hubert, "Experimental study of defect formation during processing of randomly-oriented strand carbon/PEEK composites," Composites Part A: Applied Science and Manufacturing, vol. 77, pp. 301–309, Oct. 2015, doi: 10.1016/j.compositesa.2015.05.020.

[24] S. Sattar, B. Beltran Laredo, D. Pedrazzoli, M. Zhang, S. G. Kravchenko, and O. G. Kravchenko, "Mechanical behavior of long discontinuous glass fiber nylon composite produced by in-situ polymerization," Composites Part A: Applied Science and Manufacturing, vol. 154, Mar. 2022, doi: 10.1016/j.compositesa.2021.106779.

[25] W. Weng and X. Zhu, "U-Net: Convolutional Networks for Biomedical Image Segmentation," IEEE Access, vol. 9, pp. 16591–16603, May 2015, doi: 10.48550/arxiv.1505.04597.

This Issue:

Board of Directors

SPONSOR LINKS

Applus+ DatapointLabs

BASF We create chemistry

BYK

carbon conversions — closing the loop · today and tomorrow

DSCCONSUMABLES incorporated

MICHELMAN

MITSUBISHI CHEMICAL

MP Molding Products

Mitsui Chemicals Group

سابك sabic

Westlake Epoxy

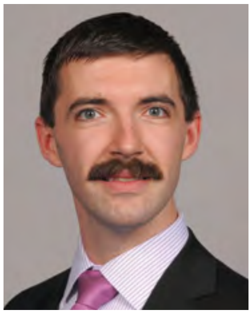
John P. Busel, F. ACI
SPE Composites Director,
Chair & Intersociety Chair
V.P. Composites
Growth Initiative
American Composites
Manufacturers Association
Arlington, VA
jbusel@acmanet.org

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

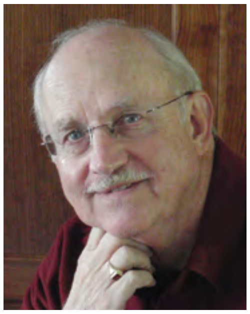
Mingfu Zhang, Ph.D.
SPE Composites Director,
and Treasurer
Johns Manville
Sr. Research Manager,
Corporate R&D
Littleton, CO
mingfu.zhang@jm.com

Christoph Kuhn, Ph.D.
SPE Composites Director,
and Secretary
Volkswagen Group of
America, Inc.
North American Engineering
& Planning Center
Chattanooga, TN
christoph.kuhn@vw.com

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



Ian Swentek, Ph.D.
SPE Composites Director,
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,
(Retired)
Ypsilanti, MI
Consultant,
MC Material Design
michael@
mcmaterialdesign.com

Pritam Das
SPE Composites Director,
Newsletter and Director
of Technical Engineering,
Toray Composites
Materials America (CMA)
Tacoma, WA
Pritam.das@toraytcma.com

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

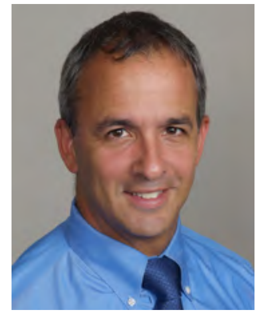
Hicham Ghossein, Ph.D.
SPE Composites Director,
President & Founder
of Endeavor Composites, Inc.
Knoxville, TN
Hicham.ghossein@
gmail.com

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 and Membership Chair
(Retired)
Seattle, WA
jsgriffl@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. Advisor – Technologies & Strategies, Applied Materials & Manufacturing
Pacific Northwest National Lab
khaled.shahwan@pnnl.gov

Shankar Srinivasan, Ph.D.
SPE Composites Director and Industry 4.0 Leader at Lesaffre (Location and email to come)

Uday Vaidya, Ph.D.
SPE Composites Director, and 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, and Award Chair
Research Associate in Advanced Composites Manufacturing
Fibers and Composites Manufacturing Facility
University of Tennessee
Knoxville, TN
pyeole@vols.utk.edu

This Issue:

See page 16 for more details