SPE
COMPOSITES

NOVEMBER 2015

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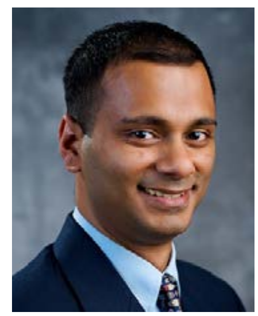

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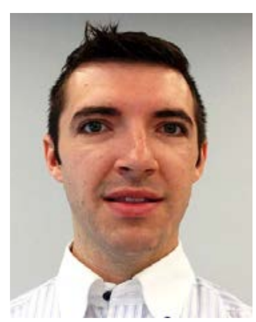

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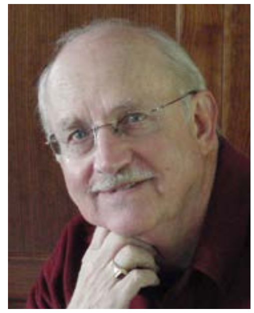

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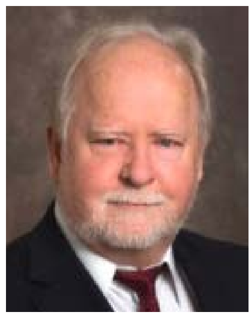

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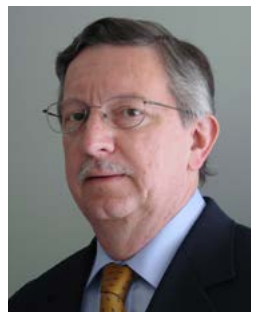

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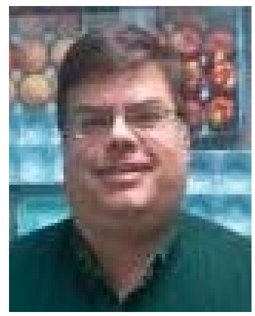

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This Issue:

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New SPE Composites BOD Member

Welcome!

Raymond G. Boeman

As director of Energy Partnerships for the Energy and Environmental Sciences Directorate at the Oak Ridge National Laboratory (ORNL), Boeman develops public private partnerships that match ORNL's capabilities with industry needs and the nation's energy challenges. He has been located in Southeast Michigan since February 2010. Prior to his current assignment, Boeman had responsibility for ORNL's transportation research efforts, including R&D programs for the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy's Vehicle Technologies Office, Bioenergy Technologies Office, and Fuel Cell Technologies Office. Research areas for which he had responsibilities included fuels, engines, emissions, advanced power electronics, energy storage and materials. Boeman also served as director of the National Transportation Research Center User Facility, a collaboration of ORNL and the University of Tennessee that houses one of America's largest concentrations of transportation researchers, laboratories and development programs.

Boeman is a founding board member of the United States Automotive Partnership for Advancing Research and Technologies (USAutoPARTs). He is currently working with stakeholders across the industrial value-chain, academia, and government on the formation of the Institute for Advanced Composites Manufacturing Innovation (IACMI). His efforts in IACMI are concentrated on establishing shared-infrastructure in southeast Michigan that provides companies, large and small, access to state-of-the-art, production scale processes for manufacturing affordable automotive composites at high volume.

Since joining ORNL, Dr. Boeman has been a contributor to technology roadmaps and multiyear program plans as well as leading the establishment of unique technical capabilities and facilities. He lead the envisioning, proposal process, and project start-up of ORNL's Carbon Fiber Technology Facility, the first open-access, pre-production scale facility of its kind. He was assigned for five years in Detroit, Michigan from 1999 to 2004 as DOE technical liaison to the Automotive Composites Consortium under the auspices of the United States Council for Automotive Research. In 2004-2005, Boeman served in the Vehicle Technologies Office in Washington, D.C, as technical coordinator to the director of the 21st Century Truck Partnership.

Boeman holds a Ph.D. in Engineering Science and Mechanics from Virginia Polytechnic Institute and State University. He has conducted research in diverse areas including: composite materials, fracture mechanics, adhesive bonding, photomechanics, mechanical properties, materials processing, damage mechanisms, and nondestructive evaluation.

This Issue:

Awards Report

By: Dr. Ian Swentek

Awards Chair

Dale Grove, the previous awards chair, is owed huge thanks for his efforts to streamline and document the awards portfolio. Through his work a standard operating procedure, updated contact lists, and annual calendar, this portfolio is not the daunting task it could have been. Dale has been an excellent resource for policy and practice and continues to volunteer his time in the oversight of the Harold-Giles award; I will endeavor to honor his legacy in this role.

Honored Service Member / SPE Fellow

During the 2015 year, there were no members nominated for the SPE Fellowship award from the Composites Division. However, Antione Rios was successfully nominated for the Honored Service Member. Antione was supported by Jim Griffing and Dan Buckley in their wholehearted recommendations. Please join me in wishing Antione the best with his application. Regardless of the outcome, Antoine continues to be a valuable member of the SPE Composites Division though his many years of service and notable accomplishments. The next honored service members will be recognized in May 2016 at ANTEC Indianapolis.

Educator of the Year Award 2015

This past year, Dr. Suresh Advani from the University of Delaware was honored with the educator of the year award, announced at ACCE. This award, sponsored by Sabic, recognizes the significant contributions of a teacher in the composites area. Dr. Advani well exceeded the requirements having nearly three decades of composites experience and numerous accounts of his educational excellence in mentorship. If you know of anyone like Dr. Suresh Advani who strive to bring composites into the classroom in innovative ways, consider nominating them for the 2016 Educator of the Year – full details can be found on our website.

Composites Division Website

The Awards sections of the SPE Composite Division website (www.compositeshelp.com) have been updated. With the help of Andrew Rich and Dawn Stephens, the recent awards recipients have been added to the respective awards and scholarship pages. A new 2016 application form has been posted for the Perkin-Elmer Scholarship, and calls for nominations will be issued in December. Though the website is aging quickly, it still represents a good singular reference for SPE Composites Division activities and contacts.

Respectfully Submitted,
Dr. Ian Swentek
Awards Chair
SPE Composites Division

This Issue:


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Board Meeting Minutes March 23, 2015

By: Antoine Rios

NPE-ANTEC, Orlando, FL
Monday, March 23, 2015
5:30 – 7:30PM Eastern US

Attendees:

Antoine Rios	Creig Bowland
Enamul Haque	Jim Griffing
Klaus Gleich	Michael Connolly
Nippani Rao	Rich Caruso
Dale Grove	John Busel
Tim Johnson	Nikhil Verghese
By phone:	
Aaron Bartel	Jack Gillespie
Andy Rich	Ian Swentek
Uday Vaidya	

Meeting started at 5:30pm
Chair: Michael Connolly

Two new board members introduced: Dr. Ian Swentek from Fraunhofer Project Center; Prof. Jack Gillespie from University of Delaware Center for Composite Materials.

Communication must improve

- Sparse communication
- Sheet sent out with roles
- Not everyone is clear on job descriptions
- ***Action: committee chairs to prepare annual plan and standard operating procedure for their committees by June meeting***

Inter-society initiative

- Seek out international board members or contributors
- ***Action: Jim Griffing to contact Jeff Helms***
- ***Action: Dale Grove to contact Dr. Hamada***

Action: update Composite Division's manual by ACCE meeting (Michael, Antoine, Dale G.)

Division Technical Program Chair: Enamul asking if this position was eliminated. It was not.

- ***Action: Enamul to define the role of the TPC***

Action: develop 2015-2016 Goals and Workplan (Michael)

Action: create Composites Division Board group within SPE's The Chain to be used for internal communication (Antoine)

Secretary: Antoine Rios

<u>Motion:</u> Dale Grove moves to approve last meeting's minutes (John seconds). <u>Motion carried.</u>

Election results: Dale Brosius, Jack Gillespie, Dale Grove, Frank Henning, Antoine Rios, Ian Swentek, Nikhil Verghese and Craig Bowland elected.

- Craig Bowland reelected as Composites Division councilor
- No write-ins
- Four voters showed interest to volunteer and help the board and two voters showed interest in publishing papers
- ***Action: Antoine to send list of volunteers to appropriate committee members***

Chair-Elect: Michael Connolly

Critical to continuity of Composites Division and leads Pinnacle Award process

Volunteer needed

Communications: Michael Connolly

Volunteer needed: Andy Rich volunteers to position

Manage and update website

continued on page 9...

This Issue:

Board Meeting Minutes continued...

Membership: A. Bartel

991 active members. Up 30 in last few months.

Composites Division represents 7% of SPE membership

Notable increase of lapse members to 267

Linkedin: continues to grow.

- ***Action: can Linkedin be used to drive membership?***

Action: Aaron to figure out plan to approach lapse members

Action: Aaron to look at data better. Is there information about 2nd or private email from members?

Councilor Report: C. Bowland

Elections: Scott Owens president elect

SPE had $103,000 profit for year.

- New initiatives highly successful and paying for themselves: new website and app

Bylaw changes:

- Students now have voting rights
- 2nd reading eliminated to change bylaws

New “e” (electronic) class created that allows access to The Chain

continued on page 10...

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Board Meeting Minutes continued...

Treasury Report: Tim Johnson

Questions:

- There seems to be confusion on how to handle the PerkinElmer and Educator of the Year items in budget.
- SPE Scholarship fund, $1,000 line item
- Waiting for decision on Jackie Rehkopf Scholarship. Should it be moved to be handled by SPE Scholarship?
- Waiting on decision from Automotive Board.

Motion: John Busel moves to have sponsored awards including Perkin Elmer and Educator of the Year (SABIC) pass through the Treasury with the division to issue the award check and invoice the sponsors. Motion carried.

Motion: John Busel moves for board to allocate $50,000 to an investment fund to be decided by executive committee (Craig seconds). Motion carried.

Awards: Dale Grove

Harald Giles Scholarship is back. Due date is May 1st.

SABIC Educator of the Year: winner is Prof Advani from University of Delaware.

PerkinElmer Award: winner is John Hincapie from the University of Oklahoma.

- ***Action: next year PerkinElmer winner should be announced earlier (45 days) so there is time for travel arrangements (Dale G.)***

Composites Person of the Year (CPOTY)

- ***Action: Dale G. to prepare plan to continue this award***

Dale to improve communication of awards via website, linkedin and updating professors list.

Education: U. Vaidya

David Jack at Baylor and Ray Boeman at Oak Ridge/DOE both volunteered to help Uday with education committee.

32 student posters at ACCE

- Need sponsor for poster's award

Composites education software

- ***Action: Uday to prepare proposal for a competition in regards to a CAE software education award***

Technical Conference Report: Jim Griffing

A panel was improvised to cover slot from Dale Brosius keynote

Action: thank moderators at next Antec (Jim)

Inter-Society: John Busel

See attached inter-society report

SPE slot at CAMX

- Dan Buckley already started working on this

Need to evaluate return to the Composites Division when considering participation in other conferences.

ACCE: Michael Connolly

ACCE was a great success in 2014. Good profits.

Sponsorship is strong for 2015.

Taking over the complete hall, which gives more space for sponsors

Open Issues:

Michael proposes four meetings per year (quarterly)

- One at Antec, one at ACCE and two via conference call

Meeting adjourned at 7:55pm

Council Report

By: Creig Bowland

Comprehensive summary of SPE's Council Meeting

October 10/11, 2015, Pittsburgh, PA, USA

This document gives a brief overview of the discussions and business of the Society discussed at the Pittsburg council meeting on October 10/11. This overview is not an official document of SPE.

Over 70 people participated at this council meeting to discuss the business of the Society. We started off with a teambuilding activity to enhance networking and getting to know each other. Historically, Councilors have come from all over the US and the rest of the world, to have very little or n contact with one another.

Below is a short recap of the most important discussions from the weekend:

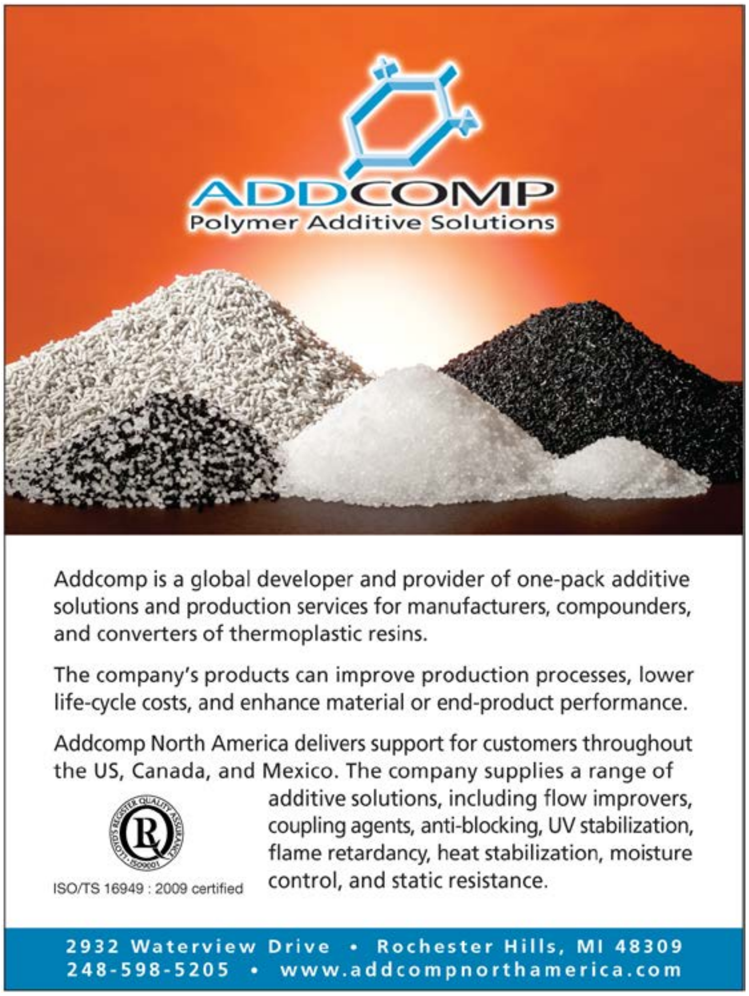
1. Financials

For the first time since 2010, SP will make loss in 2015. This is related to several very different aspects: the fact we have an NPE year and miss out 35 K in exhibit sales at ANTEC, the canceling of ANTEC Europe, the investments and expenses in new IT infrastructure, software and additional benefits for our members, as well as our affiliates, are the main reasons for it. On top of this, the financial markets have a quite bad year, adding a financial loss on top of the operational loss. Depending on the results in the last quarter, the loss could amount to – 15 K. Despite this, there is a general consensus to continue the improvement efforts and avoid a set-back in growth of non dues revenues. The budget for 2016 shows a break-even result.

2. Business Model

SP has to adapt its business model to compensate for the lower income in membership

continued on page 12...



This Issue:

dues and lower ANTEC revenues. As a reference: at the end of the nineties the sum of membership and ANTEC revenues amounted to 5.5 M and now this is merely 2.2 M.
New activities such as more Topcon's, Advertisement sales, Industry survey's for companies, Supply Chain seminars, etc… have been developed and are already starting off this year. The expectations are that these new services could bring an extra M in profit, when fully up to speed by 2017.

3. Additional and Enhanced SPE Services for Sections and Divisions

Website: the possibilities and advantages for Sections or Divisions to have its website as a micro-site, hosted o the SPE website infrastructure, was again presented. Affiliates have full control of the content and the advantage of the SEO and mobile design of the site.

Tutorial Video's: partner has been identified to produce 1 to 2 minute problem solving video tutorials. Interested Divisions or Sections can participate in the program, but will have to supply the content and cooperate in the production of the video's. On site filming will be foreseen for all of them. Estimated costs for SPE are about 2.500 video.

Personalized and customized Industry newsletter "PLASTICS INsight" was presented. It is rolled out now and will give our chapters additional advertisement income opportunities in 2016. Topcon services: New software was purchased by SPE HQ to support Topcons. The software has registration capabilities, exhibitor and sponsor management, program app, website, conference marketing module etc. All these services are included in the Topcon policy (at no additional cost)

Email marketing software: This software will help in all communications to membership and prospects (informing us about open--rate, click-through, etc.). It will be rolled out at HQ at the end of this year and later be made available to chapters.

4. Future SPE Governance

The special Governance Task force (GTF) presented a new model of governance for the Society. A comprehensive overview can be found in the posts from President--elect Scott Owens o The Chain. In the new model, much smaller, but accountable group of about 1 people (all elected by the Council) would have the responsibility and authority to govern SPE. The work will be continued as a straw-poll indicated the Council is in favor of continuing work on the project.

5. ANTEC and SIG's:

break-out / brainstorming session was held o the future of ANTEC, as well as the future of SIG's. Results will be made available o The Chain.

6. Miscellaneous

Consultants Circle is renewed and enhanced on the website
Lifetime Educational Givings of chapters showed millions of dollars have been spent o education. We intend to present this more often and hope all groups will provide input.

7. Committee Reports

Several Sections and Divisions were put into Provisional status and the Sections in Formation 'Middle East' and 'ASEAN' were approved and are now official SPE chapters.

continued on page 13...

This Issue:

Council Report continued...

A recap on the Student Activities at ANTEC 2015 was given and it highlighted again that our affiliates are massively supporting this. The call for sponsors of the students' programs at ANTEC 201 in Indianapolis was also launched.

The CCOW meeting was mostly devoted to discussing the future governance model.

8. Electronic approvals of minutes and Elections

For the future SP wants to evolve toward electing the VP's in an electronic way. Several systems are under evaluation and by-law was passed to accommodate such e-elections. The same approach will be taken for the approval of minutes and perhaps more. This will allow more time in the face-to-face meetings to discuss the important matters of the Society.

9. Membership

In 6 months time SPE has grown from zero to 3,000 e-members, of which 1,000 people joined SPE as new e-member and about 2,000 lapsed Premium members have now the e-member status. This brings the overall membership to 16,700 with stable premium membership between 13,500 and 14,000.

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- Thermoplastic Composites
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- Properties / Characterization
- Continuous Fiber Composites
- Sustainable Composites – Natural Fiber, Recyclable Composites
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Or, visit: www.antec.ws and click on "Speaker Resources"

Papers are due no later than December 8, 2015

COMPOSITES

This Issue:

Treasury Report

By: Tim Johnson, Treasurer

SPE Composites Division (D39) FINANCIAL REPORT

Financial Report for the Period: **July 1, 2015 to Sept 7, 2015**
Section/Division Name: **Composites Division D39**

Balance as of 7/01/2015	-1	$108,864.69		
Income: check the "Income"worksheet for details		**Actual**	**Budget**	**Variance**
Sponsorships for Newsletter	-2	$ 1,250.00	$ 10,000.00	$ (8,750.00)
Sponsorships ANTEC Reception	-3	$ -		$ -
SPE Rebates	-4	$ -		$ -
ACCE Earnings (after expenses, scholarships and payment to SPE)	-5	$ -	$ 22,000.00	$ (22,000.00)
Sponsorship: Educator of the Year, SABIC	-6	$ -	$ 1,000.00	$ (1,000.00)
Saving Interest	-7	$ -		$ -
Training programs	-8			
Perkin Elmer Award	-9		$ 1,000.00	
Other	-10			
	-11			
	-12			
Total Income for the period	-13	$ 1,250.00	$ 34,000.00	$ (31,750.00)
Total Funds Available (add lines 1 and 13)	-14	$ 110,114.69	$ 34,000.00	$ (31,750.00)
Expense: check the "Expense" worksheet for details		**Actual**	**Budget**	**Variance**
Website - CompHelp - 1&1.com	-15	$ 69.95	$ 500.00	$ (430.05)
Newsletter	-16	$ 650.00	$ 5,000.00	$ (4,350.00)
Perkin Elmer Award	-17	$ -	$ 2,000.00	$ (2,000.00)
BOD Meeting Expenses	-18	$ 182.00	$ 2,000.00	$ (1,818.00)
Educator of the Year Award	-19	$ -	$ 1,000.00	$ (1,000.00)
Bank Service Fees	-20	$ 44.76	$ 250.00	$ (205.24)
Antec Suite / W&C Reception	-21	$ -	$ 2,000.00	$ (2,000.00)
ANTEC Other Expenses	-22	$ -	$ 1,000.00	$ (1,000.00)
Council Travel	-23	$ -	$ 2,000.00	$ (2,000.00)
Publicity	-24	$ -	$ 100.00	$ (100.00)
SPE Scholarship Fund	-25	$ -	$ 1,000.00	$ (1,000.00)
SPE Foundation: H. Giles Scholarship	-26	$ 3,000.00	$ 3,000.00	$ -
Student Activities at ANTEC 2015 (SAC)	-27	$ -	$ -	$ -
Student Membership Program	-28	$ -	$ 4,000.00	$ (4,000.00)
UW-Madison: 2014 Summer Composites Course	-29	$ -	$ -	$ -
ACCE expenses	-30	$ -	$ 1,000.00	$ (1,000.00)
Jackie Rehkopf Scholarship	-31	$ 10,000.00	$ 10,000.00	$ -
Total Expenses (add lines 15 – 31)	-32	$ 13,946.71	$ 34,850.00	$ (20,903.29)
Ending Balance (subtract line 32 from line 14)	-34	$ 96,167.98	$ (850.00)	$ (10,846.71)
Allocation of Funds on Line 34 (enter allocations as applicable)				
Checking Account	(A)	$ 96,167.98		
Savings Account 1	(B)	$ -		
Savings Account 2	(C)	$ -		
Investment 1	(D)	$ -		
Investment 2	(E)	$ -		
Investment 3	(F)	$ -		
TOTAL	(G)	$ 96,167.98		
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This Issue:

Education Report

By: Dr. Uday Vaidya

September 08, 2015)

Involvement of Students in SPE and the ACCE meeting

There has been enthusiastic student participation at the ACCE and related SPE meetings. 20 student posters from 8 US universities and 1 Canadian university are being presented at the ACCE 2015 Novi, MI conference. The topics include recent advances in fiber characterization, natural/bio and carbon fibers, thermoplastics, nanocomposites, hybrid materials, joining and smart materials.

Please join us in welcoming the students and taking a good look at their hard work, which will be on display throughout the conference. This provides the students with an excellent opportunity to meet and talk with members of the automotive composites community and learn what it is like to work as an engineer or scientist in this field. It also provides OEMs and their suppliers with the opportunity to meet the next generation of automotive composites engineers and scientists and potentially to hire them.

We appreciate you judging these posters from 10 am to 2 pm on Wednesday Sep 9th. Judging forms will be available at the registration desk and at the poster areas. Your input and feedback will be very valuable to the students.

Poster Listings for SPE 2015

1) A new Technique to Measure the Fiber Length Distribution of Discontinuous Fiber-Reinforced Plastics
Sebastian Goris, Tim Osswald, University of Wisconsin-Madison

2) Direct Particle Simulation to Predict Fiber Motion in Polymer Processing
Camilo Perez, Daniel Ramirez, Sebastian Goris, Tim Osswald, University of Wisconsin-Madison

3) Fiber Orientation Measurements Using a Novel Image Processing Algorithm for Micro-Computed Tomography Scans, Sebastian Goris, Tim Osswald, University of Wisconsin, Madison

4) Effects of Peroxide and Thermal Treatment on the Properties of Banana Pseudostem Fibers, Patrick Chester, Baylor University

5) Novel Electrically Conductive Biobased Hybrid Adhesive from Distillers' Dried Grain with Solubles (DDGS) and Graphene, Michael Biancaniello, Tao Wang, Manjusri Misra, Amar K. Mohanty, University of Guelph, Guelph, N1G 2W1, ON, Canada

6) Emerging Materials: Torrefied Soy Biomass in the Production of Thermoplastic Composites., Ronald Koslakiewicz, Alper Kiziltas, Wonsuk Kim, Alan Argento & Deborah Mielewski, University of Michigan-Dearborn

7) Green nanocomposites from biobased poly(trimethylene terephthalate) and graphene: Process engineering and performance evaluation, Geoffrey Beamish, Petri Myllytie, Amar K. Mohanty, Manjusri Misra, University of Guelph

8) Wet laid thermoplastic carbon fiber composites, Hicham Ghossein, University of Alabama at Birmingham

continued on page 17...

This Issue:

9) Hybrid metal-composite laminates, Pritesh Yeole, University of Tennessee, Knoxville

10) Woven Fabric Composite Stiffness Property Prediction through Finite Element Modeling of Representative Volume Elements, Christopher Boise, Baylor University

11) Investigation of Woven Fiber Reinforced Laminated Composites Using a Through Transmission Ultrasonic Technique, Sarah Stair, Baylor University

12) Reversible Bonded Joints using Graphene Modified Thermoplastic Adhesives, Ewing BJ, Koricho EG, Khomenko A, Haq M and Drzal LT." Michigan State Universtiy

13) Hybrid Material, Stiffness Matching Perforated Aluminum-to-Composite Joints, Caudhill J, Koricho EG, Khomenko A, and Haq M, Michigan State Universtiy

14) Novel Hybrid Fastening of Aluminum to Composites Joints, Kalie Collins, Khomenko A, Koricho EG, Cloud GL, and Haq M ,. Michigan State Universtiy

15) Self Sensing Characteristics of Carbon Fiber Reinforced Composites using Electrical Resistivity Measurements and Guided Waves. "Saikiran NT, David DR, Karpenko O, Koricho EG, Khomenko A, Haq M, Udpa L, Udpa S, Rajagopal, P and Balasubramaniam K" Michigan State Universtiy

16) Robust, Rapid Measurements of Interlaminar crack growth in composites, David DR, Saikiran NT, Saikiran NT, Karpenko O, Koricho EG, Khomenko A, Haq M, Udpa L, Udpa S, Rajagopal, P and Balasubramaniam K . "." Michigan State Universtiy

17) Fused Deposition Modeling Nozzle Geometry Manipulation for Preferred Fiber Orientation in Printed Parts, Nate Spinnie, Blake Heller, Baylor University

18) Non-Isotropic Material Distribution Topology Optimization for Fused Deposition Modeling Products, Robbie Hagland and Douglas E. Smith, Baylor University

19) Impact resistant composites and modeling of the damage zone within a laminate, Colin Gregg ,Baylor University.

continued on page 18...

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This Issue:

Education Report continued...

20) Cure Kinetic Analysis of Different Peroxide Initiators used in Bio-based Unsaturated Polyester Envirez™ Resin, Shatori S. Meadows, Mahesh Hosur, Alfred Tcherbi-Narteh, Shaik Jeelani, Tuskegee University

Involvement of SPE Education with IACMI

With the work force development and industry outreach under IACMI, the 2015-2016 year will provide significant opportunities for SPE membership to take advantage of the webinars, modeling training, materials and processing briefings and emerging applications. The education team will align these efforts and provide information to the SPE ACCE attendees on synergistic opportunities. Example of training include:

- Lightweight materials and manufacturing for automotive and mass transit
- Design, analysis and prototyping with engineered composites for structural applications
- Manufacturing processes for automotive, truck and mass transit part
- Sustainable materials, recycling and bio-composites in mass transit

Other plans for 2015-2016

- Software support to schools that offer composites and process modeling
- Engagement of SPE student chapters
- Possible virtual poster presentations to allow more students with travel constraints to participate.

If you have any suggestions in this regard, we appreciate your advice. If you are available to contribute as a speaker to the above (or related) topics, please let us know.

Sincerely

Uday Vaidya

September 08, 2015

Lifetime Achievement Award

Fred Deans Named SPE® Automotive Division Lifetime Achievement Award Winner for 2015

Frederick (Fred) Deans, P.E., who has more than 45 years' experience at companies like Continental Structural Plastics, AZDEL, Inc., General Electric Co., and Pittsburgh Plate Glass (PPG) working in the automotive, architectural, and industrial market segments, has been named the 2015 ***Lifetime Achievement Award*** winner by the Automotive Division of the ***Society of Plastics Engineers (SPE®)***. Deans is an expert in composite materials and molding processes, product engineering, specification development, global sales and marketing, and new product introductions.

First given in the year 2000, the SPE Automotive ***Lifetime Achievement Award*** recognizes the technical achievements of individuals whose work – in research, design, and/or engineering, etc. – has led to significant integration of polymeric materials on passenger vehicles.

Deans is currently chief-marketing officer, and a co-founder and principal of Allied Composites Technologies, LLC (ACT) as well as the owner of F. Deans & Associates, a Michigan-based enterprise. Previously he has held a variety of positions including director-New Business Development at composites molder and tier 1 supplier, Continental Structural Plastics, Inc., market and industry manager at GE Plastics; program manager at the GE Plastics'-PPG Industries' joint venture, AZDEL, Inc.; application development engineer at PPG Fiberglass AZDEL Products; OEM glass sales representative at PPG; and he started his career as a production engineer at PPG Industries' Works 1-Automotive Windshield plant and moved on to the roles of technical service engineer-Architectural Glass and Solar Products, and sales representative-OEM Automotive Products.

Among his accomplishments, Deans led development of the first unidirectional glass-mat thermoplastic (GMT) composites for new-generation automotive bumper systems. The first application of this technology was a single 12-million lb/5.4-million kg application program with a Japanese automaker. Within three years, every Japanese OEM was using GMT composite for bumper beams. He managed the commercialization and use of next-generation direct-long-fiber thermoplastic (D-LFT) composites for passenger car underbody shields and underhood applications, as well as load floors for off-road vehicles and heating/ventilation/air-conditioning (HVAC) bases. He also helped develop and commercialize an automotive glass-forming process and introduced monolithic tempered privacy glass for sport-utility vehicles (SUVs).

2015 Lifetime Achievement Award

Past SPE Automotive Lifetime Achievement Award Winners include:

- J.T. Battenberg III, former chairman and chief-executive officer of Delphi Corp.;
- Bernard Robertson, then executive vice-president of DaimlerChrysler;
- Robert Schaad, chairman of Husky Injection Molding Systems, Ltd.;
- Tom Moore, retired vice-president, Liberty and Technical Affairs at then DaimlerChrysler;
- Mr. Shigeki Suzuki, general manager - Materials Division, Toyota Motor Co.;
- Barbara Sanders, retired director-Advanced Development & Engineering Processes, Delphi Corp.;
- Josh Madden, retired executive at General Motors Corp. (GM) & Volkswagen of America;
- Frank Macher, former CEO of Collins & Aikman Corp., Federal Mogul Corp., and ITT Automotive;
- Irv Poston, retired head of the Plastics (Composites) Development-Technical Center, GM.;
- Allan Murray, Ph.D., retired technology director at Ford Motor Co.;
- David (Dave) B. Reed P.E., retired staff engineer, Product Engineering, GM;
- Gary Lowndsdale, P.E., chief technology officer, Plasan Carbon Composites;
- Roy Sjöberg, P.E., retired, General Motors Corp. & Chrysler Corp.; and
- Dr. Norm Kakarala, retired, Inteva Products LLC.

Deans has a strong history of volunteering for engineering societies. He is a long-time member of the board of directors of the SPE Automotive Division (30+ years) and SPE Composites Division (13 years), as well as an intersociety volunteer on the Formula SAE® student design competition organized by SAE International®. Additionally, he is a co-founder of and three-time conference chair or co-chair for the SPE Automotive Composites Conference & Exhibition (ACCE, in years 2001, 2004, and 2015). Deans' efforts were recognized by the SPE ***Honored Service Member*** award in 2003 and the SPE Composites Division's ***Composites Person of the Year*** in 2006. He is a licensed professional engineer in the Commonwealth of Pennsylvania and holds a BSME degree from Valparaiso University and an MBA degree in Business Administration from the University of Pittsburgh.

"Fred Deans has been a pillar of the automotive-composites community for decades, and he's long been a cornerstone of the SPE Automotive Division as well," notes David Reed, General Motors Corp.-retired and also SPE ***Lifetime Achievement*** committee co-chair. "He's someone who truly has dedicated his career to developing innovative automotive composites applications, like the first GMT [glass-mat thermoplastic] composite bumper on the *Chevrolet Corvette* sports car, an application which, coincidentally, has been named our ***Hall of Fame*** award this year for its enduring industry impact. Fred's ability to combine a straight-forward, factual manner with a jovial disposition, an amazing network of contacts, and consistent dedication to engineering excellence and professionalism made him a great choice for this year's ***Lifetime Achievement Award*** winner.

"For over 35 years, Fred Deans has been a key resource for me when I had questions about a supplier, needed a contact, or when I wanted information on a material," adds Nippani Rao, RAO Associates and Chrysler LLC-retired, as well as co-chair of the SPE Automotive Division ***Lifetime Achievement*** committee. "Even if he didn't have an answer right then and there, he followed up and was always helpful. He always had a great network of contacts that he shared freely – which is definitely not something everyone will do. He's a great example for the rest of us to aspire to."

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Special Thanks to Dale Grove

Last year, it became clear to me, (as Chair) that we had accidentally underestimated the work required to maintain our growing Awards functions. For about 10 years, the Awards Chairman at the time, Phil Bates, had been gradually taking on more and more work related to the position of maintaining the Awards for the SPE Composites Division. I don't think anyone realized how much work it had become, until Phil decided to leave the Board and this function fell onto new members. Things unfortunately started to unravel, and certain functions which were needed to keep the various Awards going began to miss deadlines.

It was at that point that one of our longtime Board members, Dale Grove, stepped up and said that he would help; he took over with extreme competence and literally saved the day on more than one occasion.

Unfortunately, since he will not be able to continue in this capacity any longer, and we now have a new "official" Awards Chair, the work that Dale has done to salvage the various Awards programs from uncertainty would seem to go unnoticed.

Today, there are even more Awards Programs and scholarships available for academic achievement, and the Awards function requires even more effort than ever before. But before this heroic effort can be forgotten, I want to make a special thanks to Dale Grove for his extra effort in a time of great need. This is an all-volunteer organization, and none of us are getting paid for this work, so I want everyone to know that we all owe a debt of gratitude to him.

– Andrew Rich

This Issue:

HELPING THE AUTOMOTIVE INDUSTRY FUEL TOMORROW'S PROGRESS

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P150654

Award Winning Paper

Toughening of Aromatic Epoxy Polymers via Aliphatic Epoxy

Monomer Addition: Optimized Fiber-Reinforced Polymer Composites for Lightweighting

Markus A Downey, Lawrence T Drzal
Department of Chemical Engineering and Material Science, Composite Materials and Structures Center, Michigan State University, East Lansing MI 48824

Abstract

The use of carbon fiber reinforced epoxy composites to facilitate vehicle weight reduction (lightweighting) is gaining increasing attention in the automotive industry. Along with their positive properties, the brittle nature of the epoxy matrix used in fiber reinforced composites needs to be addressed. This research investigates the use of aliphatic epoxy monomers as a toughening agent for aromatic based carbon fiber reinforced epoxy composites. Beneficial results have been identified for applying the aliphatic epoxies to either the fiber sizing or as a copolymer in the matrix.

Investigation of the carbon fiber-epoxy matrix interface was done through the single fiber fragmentation test in order to quantify the interfacial shear strength (IFSS) in the different toughening approaches. Toughening the aromatic epoxy matrix with 1wt% aliphatic epoxy copolymer enhanced the IFSS by 11%. Applied to fiber sizing, the aliphatic epoxy fiber sizing showed a 32% increase in IFSS.

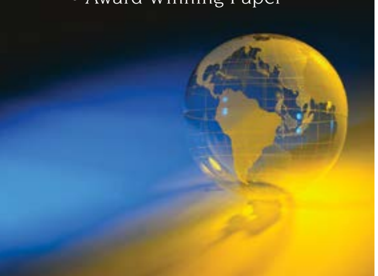
For the high fiber fraction carbon fiber reinforced composite, the addition of low concentrations (1wt%) of the aliphatic epoxy to the aromatic epoxy matrix is shown to increase the Mode I fracture toughness by about 35% over the unimproved matrix. While use of an aromatic epoxy as the fiber sizing enhances the Mode I fracture toughness of the full composite by 20% over the unsized fiber, the application of the aliphatic epoxy as fiber sizing is shown to increase both the Mode I fracture toughness and fiber/matrix adhesion dominated 90° flexural strength by 50%. Most significantly, the substantial enhancements in toughness of the aliphatically sized fiber composite are achieved without detrimentally affecting the other mechanical composite properties.

Introduction

The US EPA CAFE standard, which mandate 54.5 mile per gallon corporate average fuel economy by the year 2025, [1] is a significant challenge for the automotive industry. Large gains toward fuel consumption reductions have been made through vehicle aerodynamics and engine efficiency. To achieve the new CAFE standards however, reductions in vehicle weight will be required. Lightweighting strategies, which replace traditional materials of construction such as steel and aluminum with more advanced materials, will play an important role in vehicle weight reduction. Within these lightweighting concepts, epoxy based carbon fiber reinforced composites will be an important alternative material.

continued on page 24...

This Issue:



Carbon fiber reinforced composites usually consist of three components: first is the carbon fiber, which is the load bearing component; second is a very thin sizing (30 to 100nm) that is applied to the fiber for adhesion enhancement and handling purposes; finally, the third is the epoxy matrix that holds the carbon fibers together and transfers the applied load between the fibers.

The appeal of thermosetting epoxy resins, which are used as the matrix material in fiberreinforced composites for high-performance structural applications, is their high strength-toweight ratio, good stiffness and high corrosion resistance. One of the major drawbacks is the brittle nature of the highly cross-linked aromatic epoxy system, i.e. their lack of toughness. [2] Once formed in an epoxy material, a crack will propagate through the material uninhibited. Unlike metals, where the crack propagation will be quickly impeded by intersection of a grain boundary, no such mechanism exists in epoxies. [3]

One approach to enhancing the toughness of an aromatic epoxy is to increase the amount of energy that the epoxy network can absorb prior to fracturing. This can be achieved by the addition of an aliphatic di-functional epoxy monomer, which has the same reactive groups but a more flexible backbone. Having the same functional groups, these aliphatic epoxies will undergo the same reaction and network formation with the curing agent.

While traditionally used as viscosity reducers, the application of di- and tri-functional aliphatic epoxies to toughen aromatic epoxy has been investigated in several studies. Most investigations looked at high concentrations of aliphatic copolymers (~10 to 100 wt%). [4]-[6] While increases in toughness (70 to 120%) were detected, they were always accompanied with reductions in other mechanical properties, most notably flexural modulus (30 to 40% reduction) and glass transition temperature (up to 65% reduction). Both of these parameters are important for any epoxy system that is to be used for a structural application. The authors of this paper recently published the finding that using very low concentrations (1 wt%) of di- and tri-functional epoxy copolymers resulted in up to a 60% increase in impact toughness without detrimentally affecting other mechanical properties. [7]

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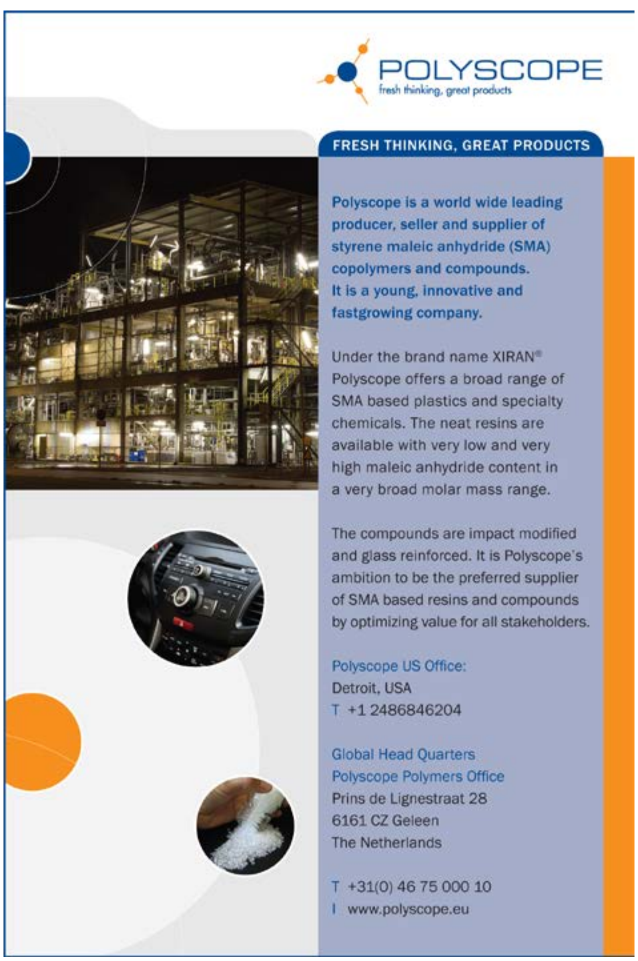

This Issue:

Materials and Methods

The aromatic epoxy, diglycidyl ether of bisphenol A (Epon 828, DGEBA), with an epoxy equivalent weight (EEW) of 185-195, was purchased from Hexion Inc. The di-functional aliphatic epoxy, polypropylene glycol diglycidyl ether (PDGE) with an EEW of 190 (Mn: 380) was purchased from Sigma-Aldrich. The curing agent meta-Phenylenediamine (m-PDA) was purchased from Acros Organics. The structures of the epoxies and curing agent are shown in figure 1. The ACS-grade 2-propanol (IPA) was purchased from J.T. Baker. All chemicals were used as received. The AS4-12k, unsized carbon fiber was purchased from Hexcel and was used either as-received or UV-ozone treated for 90s prior to use to further enhance the fiber surface (UVO-treated). Details on the UVO treatment have been published in other sources. [8]

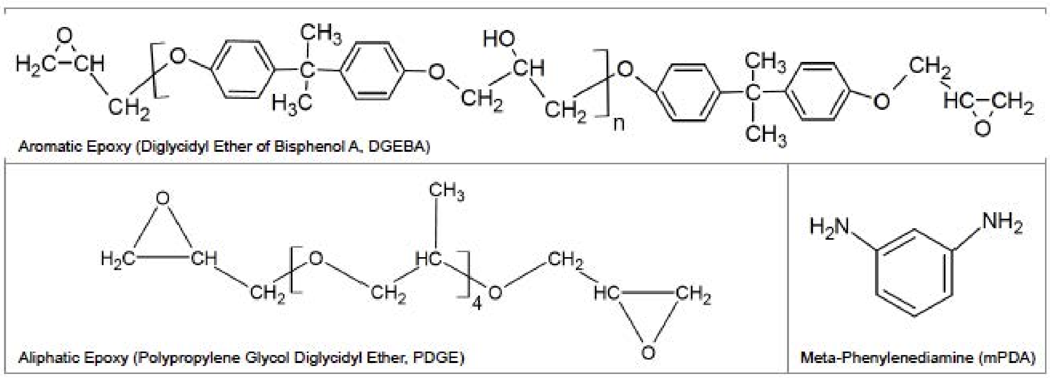

Figure 1: Chemical structure of epoxies and curing agent

A solution of 1wt% epoxy (aromatic or aliphatic) plus curing agent (mPDA) concentration was made on the basis of total solution. The appropriate amount of epoxy was dissolved in IPA. Curing agent for a concentration of 9phr (60% of full stoichiometry) was dissolved in the epoxy/IPA solution. The sizing solution was mechanically stirred for 1h prior to use.

To size the fiber for the SFFT, the fiber tow was hand-dipped into the sizing solution for 10s. The excess solution was allowed to run off the tow before suspending the tow horizontally for drying. The fiber tow was dried in a convection oven for 3h at 60°C to drive off the residual solvent. Dog-bone specimens for the SFFT were made by suspending individual carbon fibers in a silicone mold and surrounding it with the appropriate matrix material. The matrix was then cured in a convection oven at 75°C and 125°C for 2h each. A rectangular cross-section was achieved by polishing the cured samples.

The fiber diameters were determined as an average of three measurements along the fiber length using an optical microscope attached to a digital caliper. The dog-bone samples were then mounted in a tensioning device with a dial gauge extensometer. The extension was increased at prescribed in-

continued on page 26...

This Issue:

tervals and the number of fractures within a fixed length determined under polarized light. When the number of fractures no longer increased with increasing stress, the number of fractures were used to calculate the critical fracture length and interfacial shear strength using the following equations [9]:

$$\tau = \frac{\delta_f d}{2 l_c}$$

$$l_c = \frac{4}{3} l_{average}$$

where,

τ: Interfacial shear strength [MPa]

d_f: Fiber tensile strength [MPa]

d: Fiber diameter [m]

l_c: Critical fiber length [m]

$l_{average}$: Average fiber length [m]

6 to 8 samples were measured for each composition. The birefringence pattern of the fiber fracture was characterized to determine the fracture type.

For the full composite, the sizing was applied to the fiber tow using a continuous fiber sizing tower system. The fiber tow was drawn through the sizing bath containing the 1wt% epoxy/mPDA in IPA solution described above. The tow then passed through two drying towers that were at a temperature of 75°C. The fiber tow speed was regulated at about 40 m/h. After sizing, the fibers were dried at 60°C for 3h in a convection oven to drive off residual IPA solvent.

The sizing mass was determined by determining the differential mass of the fiber tow before and after an overnight soak in acetone under agitation and a drying for 3h at 60°C. This determination was done for both hand and tower sized fiber tows.

The sized fibers were processed into a prepreg tape using a Research Tool Corporation Model 30 Research hot melt pre-pregger. The appropriate matrix material was prepared by weighing out the DGEBA and adding the correct amount of aliphatic epoxy if needed. Both components were heated to about 70°C and mechanically stirred on a hot plate. The stoichiometric amount of mPDA curing

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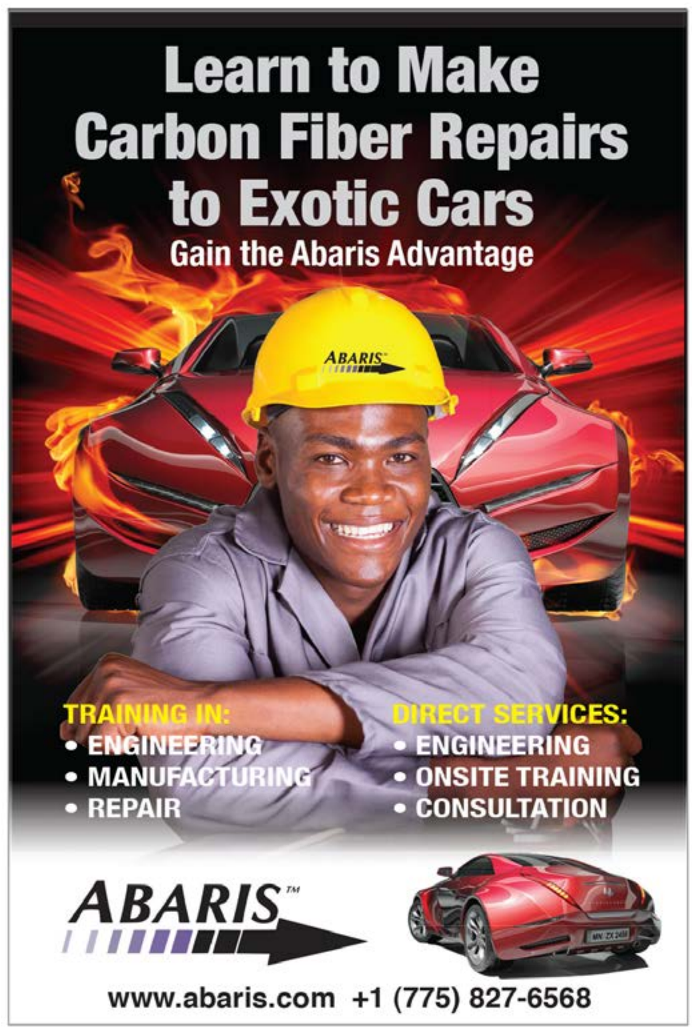

This Issue:

agent was melted in a convection oven and mechanically mixed with the epoxy. Resin bath and other pre-pregger components were held at 107°C to keep the viscosity of the matrix resin low during processing. The fiber tow was pulled through the resin bath at a speed of about 3.8 m/min and laid onto the pre-pregger drum yielding a 1930x305mm pre-preg tape.

The pre-preg tape was cut into 305 x 152mm plies and laid up as a unidirectional, 18-ply composite. On one end, a 55mm wide Teflon peel ply was inserted across the composite layup in the middle of the composite thickness between plies 9 and 10. This constitutes the starter crack for the Mode I fracture toughness samples. The layup was sealed in a vacuum bag and processed in a United McGill Minibonder autoclave. The thermal cycle was 75°C and 125°C for 2h with ramp rates of 3°C/min. The autoclave was pressurized to 5.8 atm during the thermal cycle. A vacuum of 0.82 atm was applied during the initial ramp up and 30 min into the 75°C hold to remove any trapped gases. After that the vacuum bag was vented to atmospheric pressure.After cooling to room temperature the composite was cut into the appropriate sample sizes using a 41-AR Felker water-cooled tile saw.

All mechanical properties were measured on at least 4 samples. The flexural properties of both the 0° and 90° directions were

continued on page 28...

determined according to ASTM D790 using a United Testing Systems SFM-20 load frame with a 445 N (90° samples) or 4450 N (0° samples) load cell. The flexural samples had dimensions of 114 x 12.5x3 mm. The support span width to thickness ratio was taken at 25:1 and the crosshead speed was calculated per ASTM D790-10. The Mode I fracture toughness was determined on the basis of ASTM D5528 using a United Testing Systems SFM-20 load frame with a 445 N load cell. The crosshead speed was 2 mm/min. The tests were recorded with a digital video camera and correlated to the load curve via time stamp. The crack propagation was measured using image-editing software. The composite density that was determined on the basis of ASTM D792. From the density, the fiber volume fraction was determined using the rule of mixtures and the nominal densities of matrix and carbon fiber.

The glass transition temperature was determined from the maximum of the tan δ curve from a dynamic mechanical analysis (DMA) measurement done by single cantilever beam on a TA Instruments 800 instrument.

continued on page 29...

Results and Discussion

Fiber-Matrix Interaction and Adhesion

Matrix Toughening With Low Concentrations of Aliphatic Epoxy Copolymer

The addition of low concentrations of di-functional aliphatic copolymers is expected to increase the matrix toughness. The single fiber fragmentation test (SFFT) can be used to illuminate the impact on the fiber/matrix adhesion. To isolate the influence of the matrix toughening, the composites for this set of experiments were made with unsized carbon fiber in the as-received condition.

As shown in figure 2, the toughening of the aromatic epoxy matrix with 1wt% aliphatic copolymer increases the IFSS by about 11%. Since no changes were made to the carbon fiber itself, the enhancement of the IFSS must be from the increased toughness of the matrix. According to the Cox equation [10] the two parameters that influence the fiber/matrix bond strength are the modulus and the shear strain-to-failure of the matrix. As there is no differences in the modulus, the slightly higher strain-to-failure of the aliphatically toughened matrix should be the cause for the higher IFSS.

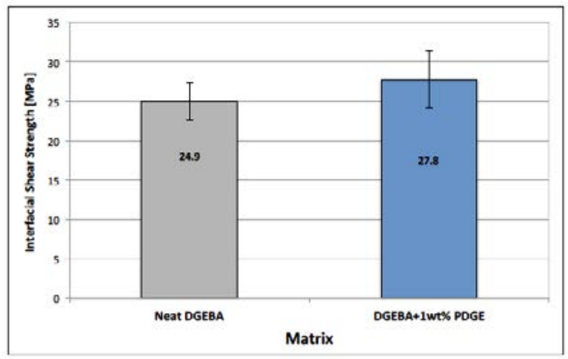

Figure 2: Interfacial shear strength of unsized, as-received AS4 carbon fiber in neat DGEBA+14.5phr mPDA and DGEBA+1wt% PDGE+14.5phr mPDA matrix

These results are mirrored in the birefringence patters and fracture morphologies seen during the SFFT as shown by representative fracture morphologies in figure 3. These morphologies are also discussed in more detail elsewhere [11]:

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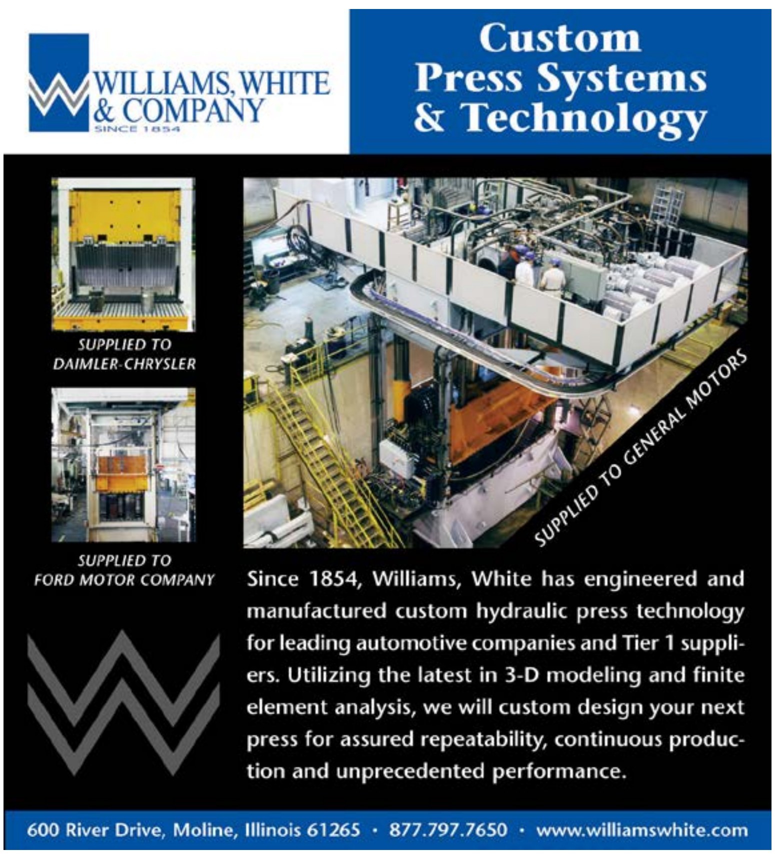

Figure 3: Fiber fractures of unsized, as-received AS4 *carbon fiber in single fiber fragmentation test in neat* DGEBA *and* DGEBA + 1 *wt%* PDGE *matrices*

Both the neat DGEBA matrix samples show interfacial debonding emanating from the fiber break. This is a typical indication of low fiber/matrix adhesion. After fracture the debonded portion of the fiber slides inside the matrix rather than further transferring the applied load into the matrix. The toughening of the matrix with 1 wt% di-functional aliphatic copolymer does not significantly change the birefringence pattern. Since the fiber interface has not been modified with the toughening of the matrix, no significant change in birefringence pattern is expected.

Fiber Sizing With Aromatic and Aliphatic Epoxy

Often used for handling proposes, the fiber sizing can also be optimized for adhesion enhancement. In this part of the work, UVO-treated carbon fiber was sized with aromatic or aliphatic epoxy polymers. The influence of the fiber sizing for both aromatic and aliphatic epoxies on the interfacial shear strength (IFSS) as determined by the single fiber fragmentation test (SFFT) is shown in figure 4:

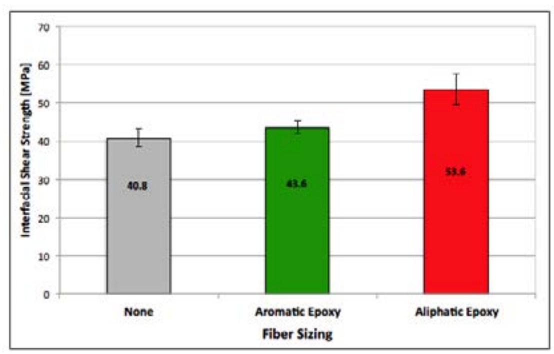

Figure 4: Influence of fiber sizing on the interfacial shear strength of UVO*-treated* AS4 *carbon fiber in* DGEBA+14.5*phr m*PDA *matrix*

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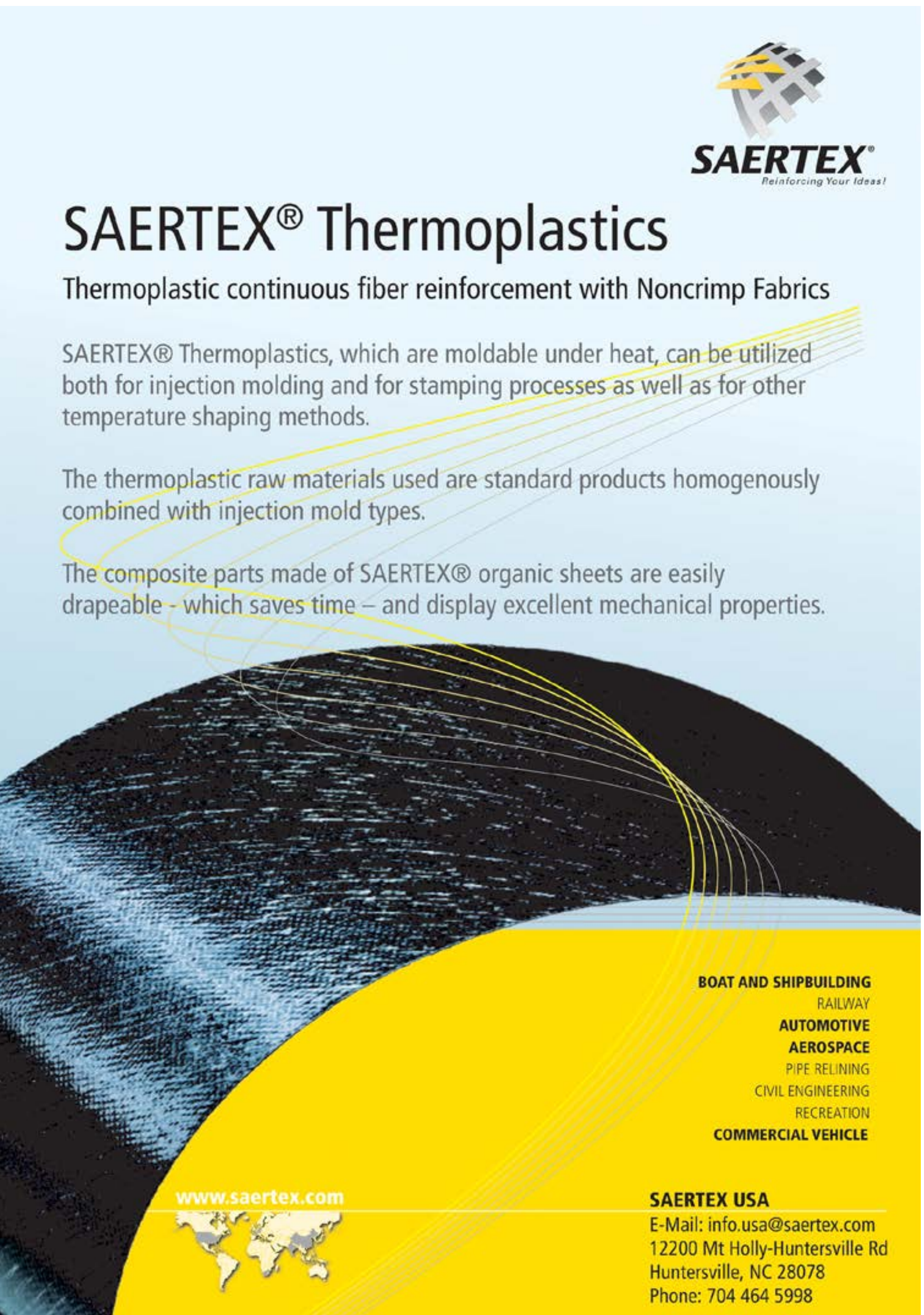

Sizing the UVO-treated fiber with aromatic epoxy improves the IFSS by about 7%. Since the composition of the sizing is very similar to that of the bulk matrix, it should be compatible with the matrix and enhance the fiber/matrix adhesion.

The aliphatic epoxy sizing shows a significantly larger increase in IFSS of about 32% compared to the unsized fiber. Compared to the aromatic epoxy sized fiber, this represents an increase of about 23%. To understand this enhanced IFSS, the factors influencing the fiber/matrix bond strength in Cox's equation are the modulus and strain-to-failure of the matrix material. There is a significant difference in modulus of aliphatic vs aromatic epoxy (8 vs 3200 MPa flexural modulus at full stoichiometry). This would imply that the IFSS with the aliphatic epoxy sizing should be significantly lower. However, the higher flexibility of the aliphatic epoxy seems to dominate the IFSS behavior. Since an under-stoichiometric amount (~60% of stoichiometry) of curing agent is used in the sizing, the sizing material will not completely vitrify and has the ability to swell and diffuse away from the fiber surface. This should lead to a stoichiometry gradient from the composition at the fiber surface to that of the bulk matrix. The true mechanical properties at the fiber/matrix interface are not known in detail at this time limiting the ability to provide an exact explanation for these improvements.

The enhancements in IFSS are mirrored in the observed birefringence patterns observed during the SFFT. Figure 5 shows representative birefringence patterns of fractures observed for the different fiber sizing:

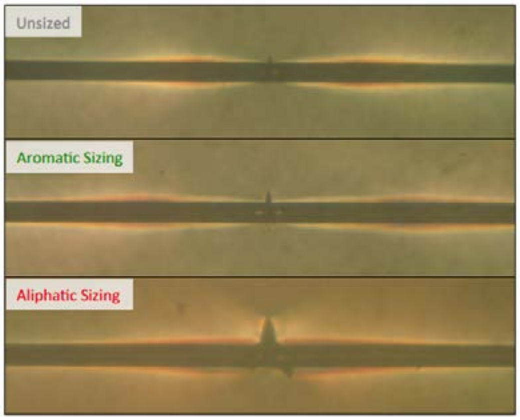

Figure 5: Fiber fractures of UVO-treated carbon fiber in single fiber fragmentation test with different fiber sizing

The birefringence pattern of the unsized carbon fiber shows typical morphology of intermediate fiber/matrix adhesion. The photoelastic stress pattern is located around the fiber fracture. Crack growth into the matrix is present, indicating a higher level of load transfer to the point where the matrix near the fiber start to fracture in a direction perpendicular to the fibermatrix interface. The application of aromatic sizing to the fiber shows similar fracture behavior to the unsized fiber. The fracture growth into the matrix is however more pronounced as is seen by the larger crack growing perpendicular to the fiber axis. The fracture pattern of the aliphatically sized fiber is significantly different and consistent with high levels of fiber/matrix adhesion. The crack growth into the matrix is now significantly larger and shear failure at the 45° in the interphase matrix now appears. The photoelastic stress pattern is more intense and emanates from the ends of the fiber fracture. The fiber/matrix adhesion is strong enough that the failure mode is shifting from the interface to the matrix. Under similar loading interfacial failure between the fiber and matrix is not detected to the same level as with the aromatic sized system.

continued on page 32...

This Issue:

Fiber Reinforced Composite Properties

Matrix Toughening With Low Concentrations of Aliphatic Epoxy Copolymer

No differences were observed during the processing and handling of the aliphatically toughened matrix composite, compared to the neat composite. As shown in figure 6, the fiber volume fraction (Vf) of both composites is similar, with the aliphatic toughened matrix having a slightly higher Vf than the composite with the neat matrix:

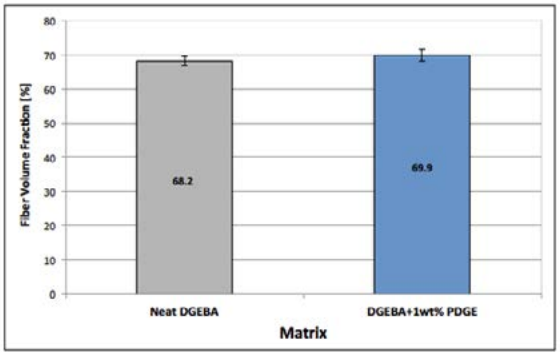

Figure 6: Fiber volume fraction of unidirectional, unsized, as-received AS4-12*k carbon fiber composite with neat* DGEBA *or* DGEBA + 1 *wt%* PDGE *matrix*

The glass transition temperature, as shown in figure 7, is unaffected by the addition of 1wt% aliphatic copolymer. This result is consistent with previously published results [7], where the addition of 1wt% aliphatic copolymer did not change the glass transition temperature of the neat aromatic matrix.

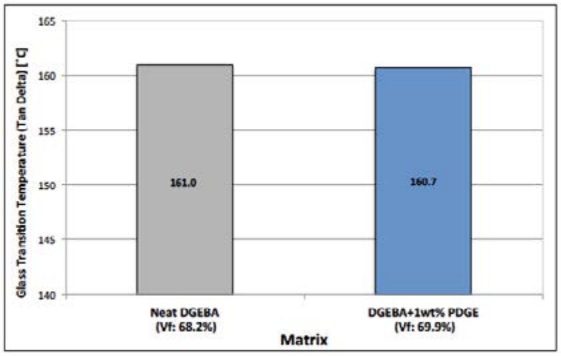

Figure 7: Glass transition temperature of unidirectional, unsized, as-received AS4-12*k carbon fiber composite with neat* DGEBA *or* DGEBA +1 *wt%* PDGE *matrix (maximum of* DMA *tan* δ *function)*

The mechanical properties of the unidirectional composite were investigated in two primary fiber orientations: 0° and 90°. The 0° direction is dominated by the fiber properties, whereas the 90° direction is dominated by fiber/matrix adhesion. As shown in figure 8, the 0° flexural modulus is constant within the scatter of the measurements. The 90° flexural modulus varies but is consistent with the differences in fiber volume fraction as predicted by the rule of mixtures for transverse properties. [12]

continued on page 33...

This Issue:

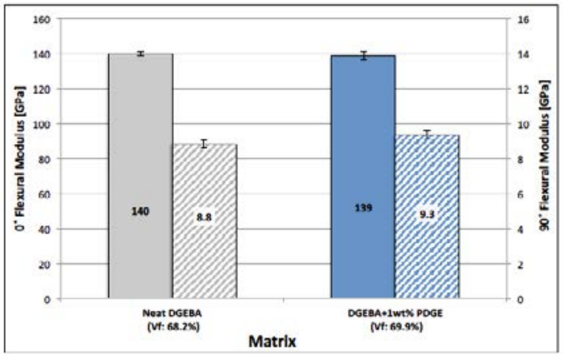

Figure 8: 0° (solid) and 90° (hatched) flexural modulus of unidirectional, unsized, as-received AS4-12k *carbon fiber composite with neat* DGEBA *or* DGEBA + 1 *wt%* PDGE *matrix*

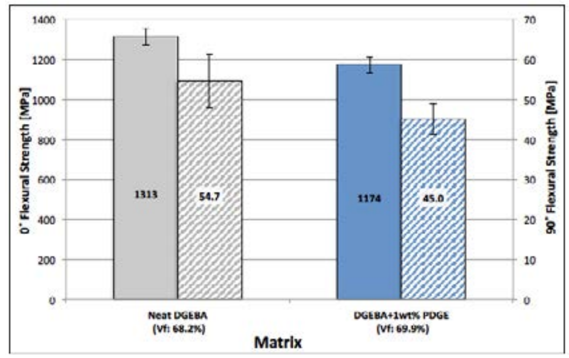

Figure 9: 0° (solid) and 90° (hatched) flexural strength of unidirectional, unsized, as-received AS4-12k *carbon fiber composite with neat* DEGBA *or* DGEBA+1*wt%* PDGE *matrix*

As shown in figure 9, both the 0° and 90° flexural strengths are slightly lower for the aliphatically toughened matrix (-11 & -18% respectively). The SFFT results shown in figure 2 indicated an enhanced IFSS. The reason of this discrepancy is currently still under investigation.

The Mode I fracture toughness is a measure of the ability of a composite that contains a pre-existing crack to resist fracture. Figure 10 shows that the toughening of the matrix with 1wt% aliphatic copolymer enhances the Mode I fracture toughness by 35% over the standard aromatic epoxy matrix. The

continued on page 34...

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addition of a low concentration of aliphatic epoxy monomer has increased the amount of energy required to fracture the matrix. This result is consistent with both the SFFT results shown in figure 2 and the previous results indicating enhanced impact toughness. [7]

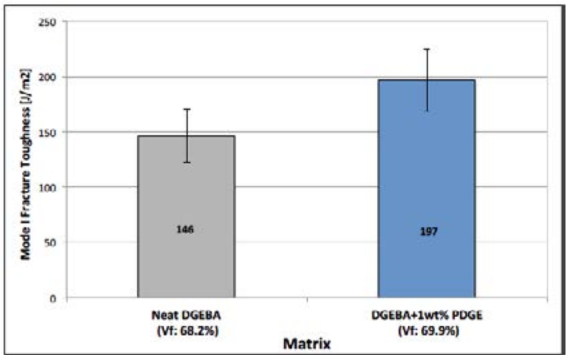

Figure 10: Mode I fracture toughness of unidirectional, unsized, as-received AS4-12*k carbon fiber composite with neat* DEGBA *or* DGEBA+1*wt*% PDGE *matrix*

Fiber Sizing With Aromatic and Aliphatic Epoxy

The composition of the fiber sizing can be used to alter fiber/matrix adhesion. As shown in figure 11, the unsized fiber composite has a high fiber volume fraction (Vf) as would be expected. The aromatic sized composite has a lower fiber volume fraction as would be expected from the addition of a fiber sizing (~23nm sizing thickness). The aliphatically sized composite has a higher Vf similar to that of the unsized composite. In this case a thinner aliphatic sizing (~18nm sizing thickness) was applied and the vitrification of the aliphatic sizing and its dissolution into the epoxy matrix is different than that or the aromatic sizing.

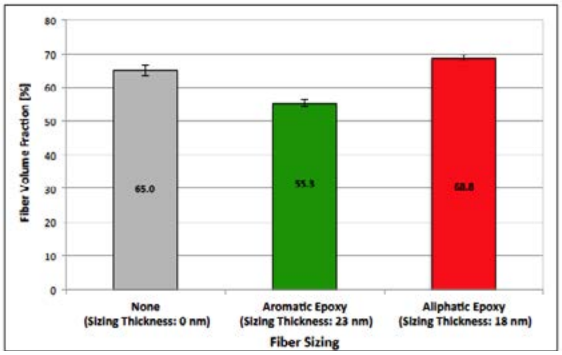

Figure 11: Fiber volume fraction of unidirectional UVO-*treated* AS4-12*k carbon fiber composite with different fiber sizing*

The glass transition temperature (T_g) of the composites, as shown in figure 12, behaves as would be expected. The aromatic sized composite shows a slightly higher T_g (+1%) compared to the unsized composite. The aliphatic sized composite shows a slightly lower (-2%) T_g. Based on the low T_g of the aliphatic sizing, a slight reduction is expected.

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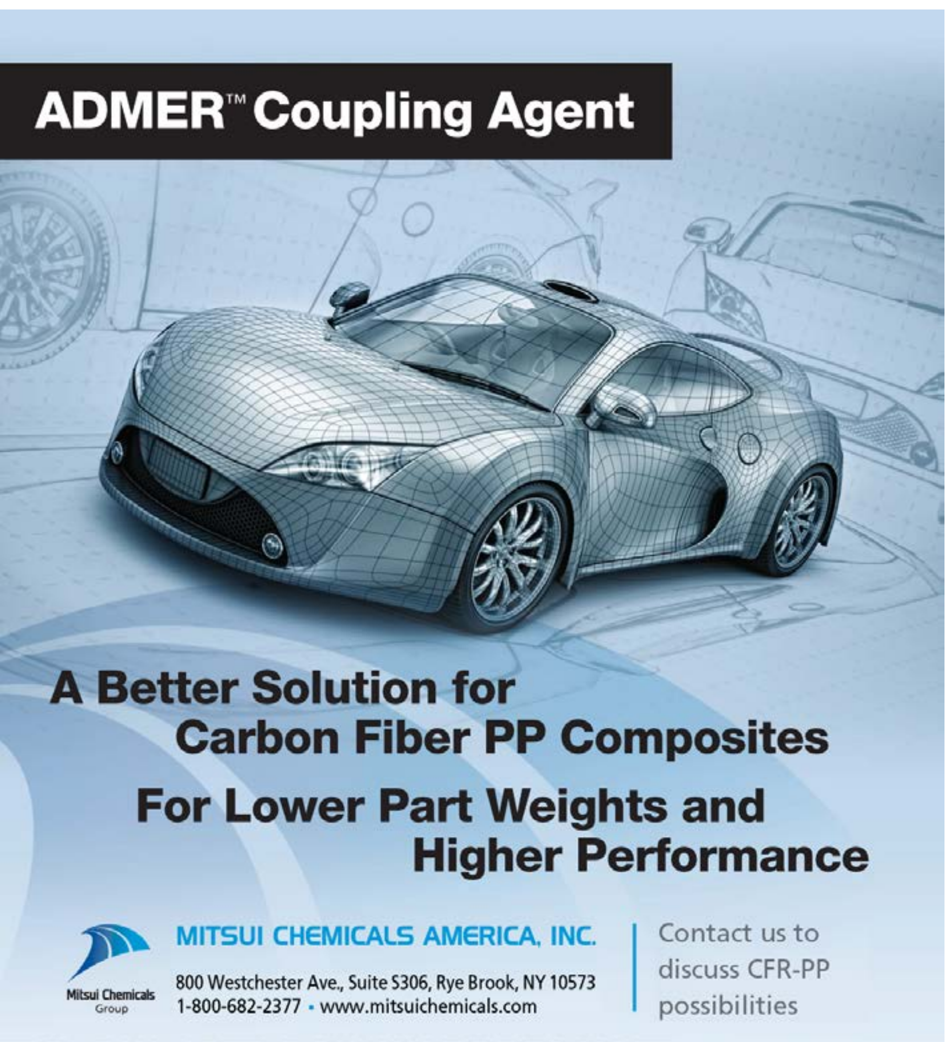

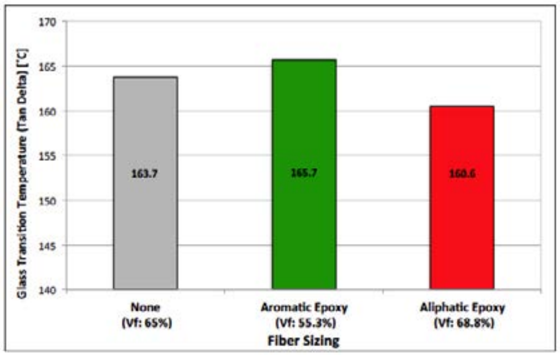

Figure 12: Glass transition temperature of unidirectional UVO-treated AS4-12k carbon fiber composite with different fiber sizing (maximum of DMA tan δ function)

Figure 13 displays the 0° flexural modulus results which appear to be unaffected by the fiber sizing (-2% for aromatic sizing and +1% for aliphatic sizing). The differences are well within the scatter of the data. The 90° flexural modulus varies but is consistent with theoretical predictions of the modulus based on rule of mixtures for the transverse properties.

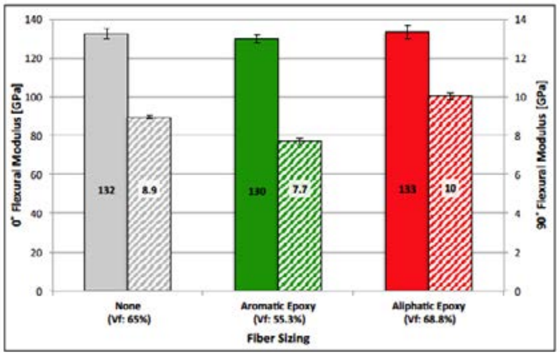

Figure 13: Influence of fiber sizing on 0° (solid) and 90° (hatched) flexural modulus of unidirectional UVO-treated AS4-12k carbon fiber composite

The flexural strength of the aromatic sized composite, as shown in figure 14, for both the 0° and the 90° directions, are lower than those of the unsized composite (-15% & -18% respectively). Based on the improved interfacial shear strength results, this reduction is unexpected. As discussed earlier, without a detailed understanding of the mechanical properties and their variation with distance perpendicular to the fiber surface at the fiber/matrix interface, an explanation is not available at this time.

The aliphatically sized composite on the other hand shows statistically similar 0° flexural strength (-1%) and significantly higher 90° flexural strength (+49%). Since the 90° direction is generally fiber/matrix adhesion dominated and in conjunction with the SFFT results, this indicates a tougher fiber/matrix interface and higher fiber/matrix adhesion.

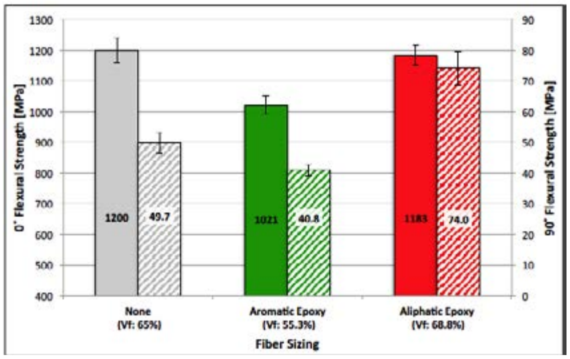

Figure 14: Influence of fiber sizing on 0° (solid) and 90° (hatched) flexural strength of unidirectional UVO-treated AS4- 12k carbon fiber composite

continued on page 36...

This Issue:

Figure 15 shows that the addition of the fiber sizing increases the Mode I fracture toughness of the composite. The aromatic sizing increases the fracture toughness by 19%. The aliphatic sizing further enhances the fracture toughness by 46% over the unsized composite and 23% over the aromatic sized composite. With the aliphatic sizing, a localized toughening of the matrix is possible, i.e. toughening of the matrix with aliphatic copolymer (figure 2) leading to further enhancement of the fracture toughness.

When considered in conjunction with the other mechanical properties, the aliphatic sizing of the fibers identifies a route to toughen the composite without detrimentally affecting other composite properties.

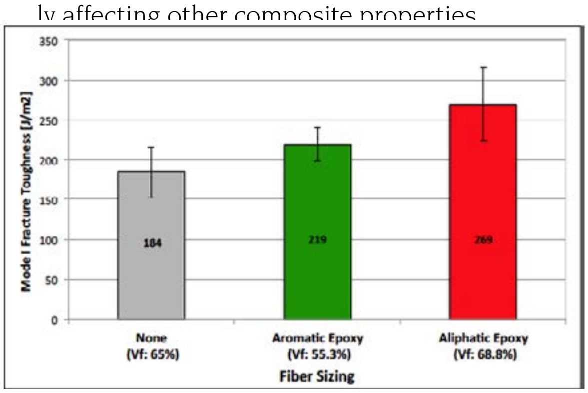

Figure 15: Influence of fiber sizing on Mode I fracture toughness of unidirectional UVO-treated AS4-12k carbon fiber composite

Conclusion

This research shows the potential for engineering the fiber-matrix interphase by incorporating a di-functional aliphatic epoxy monomer both in the matrix and as a fiber sizing.

While some questions remain about the flexural strength properties of the aliphatically toughened matrix and aromatically sized fiber composites, toughening the matrix with a low concentration of an aliphatic epoxy monomer has shown an increase in Mode I fracture toughness by 35% without reducing the glass transition temperature of the composite.

Sizing the fibers with epoxy also enhances the Mode I fracture toughness. The aromatic epoxy sizing enhances the Mode I fracture toughness by about 20% and the aliphatic epoxy increases the fracture toughness by ~50%.

Most significantly, when applied as the fiber sizing, the aliphatic di-functional epoxy monomer significantly enhances both the 90° flexural strength and the Mode I fracture toughness without detrimentally affecting other composite properties.

Acknowledgements

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continued on page 37...

This Issue:

Award Winning Paper continued...

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