SPE COMPOSITES

AUGUST 2016

Composites Connection™

Official Newsletter of the SPE Composites Division

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Composites Connection™
Advancing Composites Technology Worldwide
SPE COMPOSITES
August 2016

Chairman's Message:

Michael Connolly

Like the classic "Fly Like an Eagle" lyrics from the Steve Miller Band, "time keeps on slipping, slipping, slipping into the future" for me. It may be trite, but I really can't believe that more than half of 2016 has passed us by. I'm not sure about all our Composites Division (CD) members, but time is not something that I find plentiful these days. For sure, volunteer activities like participating in SPE programs take some extra time on my calendar. But, simply put, it is my "day job" that has really filled up in the past 6-8 months. And that is a good thing in my mind. Events like JEC World in Paris or our own Automotive Composites Conference and Exhibition (ACCE) are setting record attendance and sponsorship numbers. And with my own company, there is a significant uptick in customer contacts and new projects from both large and small companies in the past year. Taken as a whole, I think that indicates a strong confidence in the industrial market where companies are interested and willing to spend the time, money and personnel resources to develop new technology. And in many cases that technology could still be 3-5 years or even more to commercial fruition especially for markets like automotive or aerospace where development timelines are long.

So, I am very bullish on the future of composite material development. I am sure our SPE Composites Division can and will play a critical role in fostering that development and helping ensure it comes to pass. That's why our Board of Directors and other members put so much effort into CD technical programs such as ACCE and ANTEC as well as CAMX and Cyclitech with our partners ACMA and JEC, respectively. That's why the CD is stepping up its scholarship programs by raising the value of the Harold Giles Award and sharing the funding of the endowed Rehkopf Scholarship with our ACCE partner, the Automotive Division. That's why our CD Education Committee lead by Uday Vaidya of the University of Tennessee has been looking to support future composites scientists and engineers and soliciting university requests to the CD for funding of education programs (with university matching).

For the CD, our year started off quite busily with a large ANTEC program. And that effort hasn't let up with a record number of technical contributions and student posters, very strong (near record) sponsorship and a mountain of strong scholarship applicants for ACCE. The ACCE 2016 preliminary technical program is now available on line. I hope and expect that ACCE will set record attendance this year as well. It's only a little over a month away. So, please register to attend ACCE 2016 as soon as possible.

Soon after ACCE, the CD will be contributing to the CAMX 2016 technical program from September 26-29 in Anaheim, CA (thanks to John Busel for organizing). And, to end the year, Creig Bowland is chairing the Cyclitech

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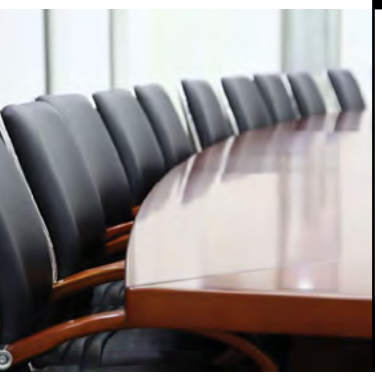
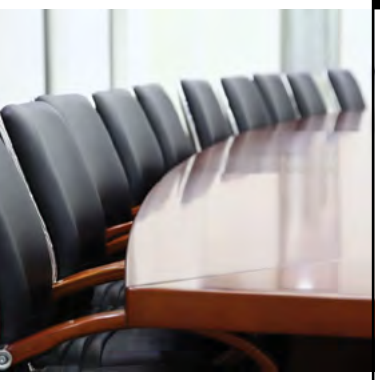
Chairman's Message continued...



2016 event in Newport Beach, CA from December 6-7 with our partner JEC Composites. Please consider attending, sponsoring or contributing a technical paper to Cyclitech 2016. Our busy calendar for the division starts up again with solicitation and review of papers for ANTEC 2017 in Anaheim, CA from May 8-10, 2017. Please submit a technical paper for the ANTEC next year.

The next face-to-face BOD meeting is scheduled to take place on Tuesday, September 6 during the ACCE from 5-7:30 PM. If any CD member is interested in participating in the meeting, please contact me so that I can send you the conference call number and, of course, you are welcome to join the BOD meeting in person. Hope to see you at ACCE in Novi, MI in September!!

Regards,
Michael Connolly
2015-2017 Chair



Board of Directors

Michael Connolly
SPE Composites
Director & Chair
Program Manager-Urethane
Composties Huntsman
Polyurethanes
Auburn Hills, MI
michael_connolly@hunts
man.com

Ray G. Boeman, Ph.D.
SPE Composites Director,
Membership Chair
& Chair-elect
Dir, Energy Partnerships
Energy and Environmental
Sciences, Oak Ridge
National Laboratory
boemanrg@ornl.gov

Andrew Rich
SPE Composites Director,
Communications Chair
& Past Chair
Element 6 Consulting
Hanover, MA
andy@element6
consulting.com

Antoine Rios
SPE Composites
Director
& Secretary
The Madison Group
Madison, WI
Antoine@madisongroup.
com

Creig Bowland
SPE Composites
Director & Councilor,
President, Colorado
Legacy Group, LLC
Charlotte, North Carolina
Cbowland@
coloradolegacy.com

Tim Johnson
SPE Composites
Director & Treasurer
Owner, President at
TJohnson LLC
Dayton, OH
TJohnsonLLC@gmail.com

John P. Busel
SPE Composites Director
& Intersociety Chair
VP, Composites
Growth Initiative
American Composites
Manufacturers
Association, Arlington, VA
busel@acmanet.org

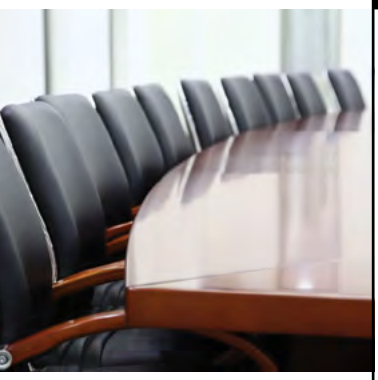
Pritam Das
SPE Composites Director
& Newsletter Chair
Technical Manager
Toray Composites
(Americans)
Tacoma, WA

Jim Griffing
SPE Composites
Director, ANTEC TPC
& Ex-President
Technical Fellow
The Boeing Company
Seattle, WA
james.s.griffing@boeing.com

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

Ian Swentek
SPE Composites Director
& Awards Chair
Applications
Development Engineer
Hexion
London, ON, Canada
Ian.Swentek@hexion.com

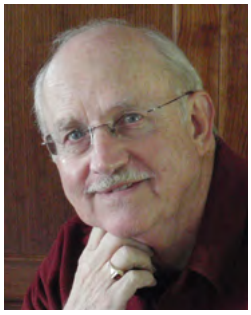
This Issue:



Board of Directors continued...

Steve Bassetti
SPE Composites Director
Group Marketing Manager
Industrial Manufacturing Group, Michelman
Cincinnati, OH
stevebassetti@michelman.com

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

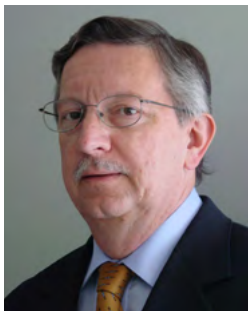


Daniel T. Buckley
SPE Composites Director (Retired)
Manager of R & D
American GFM
Shrewsbury, VT
dbuck@vermontel.net

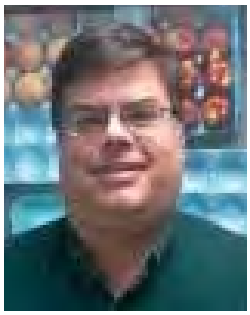
Rich Caruso
SPE Composites Director
CEO Inter/Comp LLC
Falmouth, MA
rpcaruso@gmail.com

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

Professor Jack Gillespie
SPE Composites Director
Director, Center for Composite Materials
Donald C. Phillips Professor of Civil and Environmental Engineering
University of Delaware
Newark, DE 19716
gillespi@udel.edu



Klaus Gleich
SPE Composites Director
Research Associate
Johns Manville Technical Center Littleton, CO
Klaus.gleich@jm.com



Dale Grove
SPE Composites Director
US Silica
Senior Technology Product Development
grove.dale@hotmail.com

Enamul Haque, Ph.D.
SPE Composites Director
VP & General Manager of Research and New Product Development
Cooley Group
Pawtucket, RI
haquee@cooleygroup.com

Dr. Frank Henning
SPE Composites Director
Deputy Director
Fraunhofer ICT
Institute of Vehicle Technology Fraunhofer ICT
Joseph-von-Fraunhoferstr. 7
76327 Pfinztal
frank.henning@ict.fraunhofer.de

Nippani Rao
SPE Composites Director
President,
RAO Associates
nippanirao@aol.com

Nikhil Verghese, Ph.D.
SPE Composites Director
Research Fellow, Composites
T&I
SABIC
The Netherlands
nikhil.verghese@sabic.com

This Issue:

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www.performance-materials.basf.us

BASF

We create chemistry

Welcome!

Steven Bassetti

Steven Bassetti is a Group Marketing Director at Michelman. His twenty plus years of commercial experience cover areas of engineering plastics, chemical intermediate manufacturing, fiberglass manufacturing, polymer composite component manufacturing, engineered wood release coatings and polymer science. He has worked for companies such as, LNP Engineering Plastics, General Electric Plastics, Ticona, Celanese, Johns Manville, Arizona Chemical, and others. As an innovator and commercial manager, Steve has helped to commercialize numerous new products in the fields of plastics and composites. He is a co-author of one patent in the field of polymer science. He has over 2 decades of experience in building university-industry collaborations to help in the development and commercialization of new products.

In his current role, he provides strategic marketing insight and supports Michelman's efforts to create innovative technologies and new products based on unmet market needs. He is responsible for developing and managing the Industrial Manufacturing Business Unit's strategic marketing and growth plans which include external R&D partnerships with universities and non-governmental research organizations. He maintains an active market research program in nanomaterials, composite technologies, sustainable/renewable polymers, and other markets that are aligned with Michelman's company strategy.

Steve completed his undergraduate studies at the Worcester Polytechnic Institute and his graduate Masters of Business Administration degree at Pace University's Lubin School of Business. He is a an active member of numerous industry and professional organizations such as the Society of Plastics Engineers, American Panel Association, Engineered Wood Association, American Chemical Society, Institute for the Study of Business Markets, etc.

This Issue:

Board Meeting Minutes May 23, 2016

By: Antoine Rios

ANTEC Conference
Monday, May 23, 2016

Attendees:

Ray Boeman	Creig Bowland
Dale Brosius	John Busel
Rich Caruso	Michael Connolly
Jim Griffing	Enamul Haque
Tim Johnson	Antoine Rios
Nikhil Verghese	
By phone:	
Dan Buckley	Ian Swentek
Dale Brosius	Dale Grove
Nippani Rao	Shankar Srinivasan
Jack Gillespie	

Meeting started at 5:10pm
Chair: Michael Connolly

- Introduced Shankar Srinivasan to group.
- Dates for upcoming meetings were reviewed. Dates are listed in the agenda.
- ***Actions:* Michael Connolly to follow up with Steve Bassetti and Mary Gilliam**

Secretary: Antoine Rios

- The last meetings minutes would be approved via email. There was no time to review the minutes before the meeting.
- Michael Connolly asked that the meeting minutes get distributed by 2 weeks after each meeting to allow for proper preparation.
- The board elections to be conducted after ANTEC. An email was sent to all the candidates due for reelection.
- The elections are typically conducted before ANTEC.
- ***Actions:* Antoine Rios to distribute the board roster.**
- ***Actions:* Antoine Rios to conduct the Board elections. Bio/pictures need to be collected so that the election can be done through the SPE.**
- ***Actions:* Antoine Rios to distribute the minutes and ask for a vote to approve.**

Vice-Chair: Ray Boeman

- Ray Boeman to take care of chair-elect and membership chair positions.
- ***Actions:* Ray Boeman to be in charge of data mining the membership database. Research the industry break down of our membership.**
- Rich Caruso has electronic files of past Pinnacle submissions as reference.
- ***Actions:* Michael Connolly to forward the final version of the 2016 pinnacle application to Rich Caruso.**

Councilor Report: Creig Bowland

- Governance task force proposed to change the governance of the Society.
  - Group of 11 to be in charge of day-to-day decisions. Councilors to have veto power.
  - New system to start in 2017. It needs to be voted twice. It already passed once.
  - Councilor's role would be to advice and elect group of 11.
  - Seven of the 11 are elected by council.
  - Two are elected by the membership as a whole.
  - Presentation with details of the new governance system is available in The Chain.
- During the council meeting changes to the Pinnacle Award were discussed. It has become too easy to obtain. The idea is to split it in five categories. Only one award to be given for each category.
- Michael Connolly: Craig is in his second year of three as councilor. The group should start thinking about the next person. This person needs to be identified so that they can attend a few meetings to understand the role and position duties.
- With the new changes things are moving much faster at council.

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This Issue:

Board Meeting Minutes continued...

- The Society as a whole is carrying a deficit of approximately $52k, out of a $2.5 million budget.
  - Membership up to 20,000. However, 6,500 are "e" members.
  - One person was hired to head advertisement.
  - Cash flow is doing well.

Inter/Intra Society: John Busel

- CAMX: there are three presentations for SPE's Composites session.
- Michael Connolly suggests to use SPE Composites logo at CAMX.
- It was hard to find papers for the CAMX SPE session.
- ***Actions:* John Busel to prepare an announcement of the presentations that will be given at CAMX.**
- ***Actions:* Andy Rich (Communications Chair) to send the announcement prepared by JB by the end of May, or sooner than later.**

Newsletter: Pritam Das

- Michael Connolly read the Newsletter report: Newsletter going well. Terry taking care of sponsorship. Metrics are being read from the website.
- Tim Johnson suggests that the newsletter is a necessary document.
  - Sponsors have gone down.
  - Suggests idea to promote sponsorship of newsletter to ACCE booth sponsors.
  - Suggests that a hard copy of the newsletter is distributed at ACCE.

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Board Meeting Minutes continued...

- **MOTION**: Tim Johnson proposes to add $2,500 to the budget to print hard copies of the newsletter and to distribute them at ACCE and CAMX. John Busel seconded. Motion passed.
- ***Actions:* Michael Connolly to communicate with Pritam about printing newsletter by ACCE.**
- Tim Johnson explained that $1,000 was paid for the SPE reception. It was suggested to continue next year. However, more time should be allotted for the awards presentation.
- ***Actions:* Andy Rich (Communications Chair) to e-blast before next ANTEC about the table reception.**

Communications Chair: Andy Rich

- Michael Connolly stated that there was no report.

Education: Uday Vaidya

- Michael Connolly reported that Uday could not make the meeting.
- 30+ posters presenters for ACCE.
- Request for proposals from schools to go out within next two weeks.
- It was suggested to increase the amount of the scholarship awards. Discussion tabled until the awards report is discussed.

Treasury Report: Tim Johnson

- The division is doing well.
- Income from ACCE increased.
- There is room to increase expenditure. Should increase school level grand and Giles scholarship funding.
- Jackie Rehkopf Scholarship: the Automotive Division has not yet decided a structure.
- ***Actions:* Michael Connolly to talk to Automotive Division to make sure it's understood that the scholarship is shared between Composites and Automotive.**
- Tim Johnson proposed to give travel funds for student awards.
- **MOTION**: Michael Connolly moved to match the Mettler Toledo award by $500 each year. Dale Brosius seconds. Motion passed.
- **MOTION**: Michael Connolly moved to provide $500 for travel to student award winners. Antoine Rios seconds. Motion passed.
- ***Actions:* Tim Johnson to send $500 to this year student winners.**

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This Issue:

Board Meeting Minutes continued...

- ***Actions:* Tim Johnson to send budget via email for approval.**
- Tim Johnson reported that last year expenditures were approximately $45k. This year we are in track for $40k.
- The line budget item amount for the school level grant is unknown.
- The division has $147k in the bank.
- Dale Brosius asked for when the awards are given at the SPE ceremony, there should be appropriate signage, time on the program, and display needs to be planned in advance.

Awards: Ian Swentek

- Change Perkin Elmer award to Mettler Toledo award.
- Eleven students applied for the Mettler Toledo award.
- Enamul Haque gave award at reception. Award has a spelling error.
- ***Actions:* Ian to fix and reissue plaque.**
- The Educator of the Year award received four candidates.
- Ian has the SOP for the awards submitted.
- Nikhil proposes to increase the amount of the Educator of the year award to $2,500.
- ***Actions:* Tim Johnson to adjust budget accordingly to account for increased award for the Educator of the Year to $2,500.**
- ***Actions:* Ian and Nikhil to coordinate in regards to the change in amount for the Educator of the Year.**
- Uday going for HSM this year.
- John Gillespie nominated for fellow.
- Reported that there is little progress in regards to the Jackie Rehkopf scholarship. There has been little cooperation from the Automotive Division.
- ***Actions:* Ian to send invoice for the production of awards.**

Technical Conference Report: Jim Griffing

- The call for papers for ANTEC 2017 to go out in June.
- Papers for ANTEC are due in December. Paper reviews will begin in December and must be complete by January 13.
- ***Actions:* Michael Connolly to find a co-TPC who will take over next year.**

ACCE: Michael Connolly

- $310k in sponsors.
- The exhibit room would be rearrange to facilitate flow.
- Paper submission is strong, 96 paper submissions so far.
- Expects that the attendance this year should be a record.

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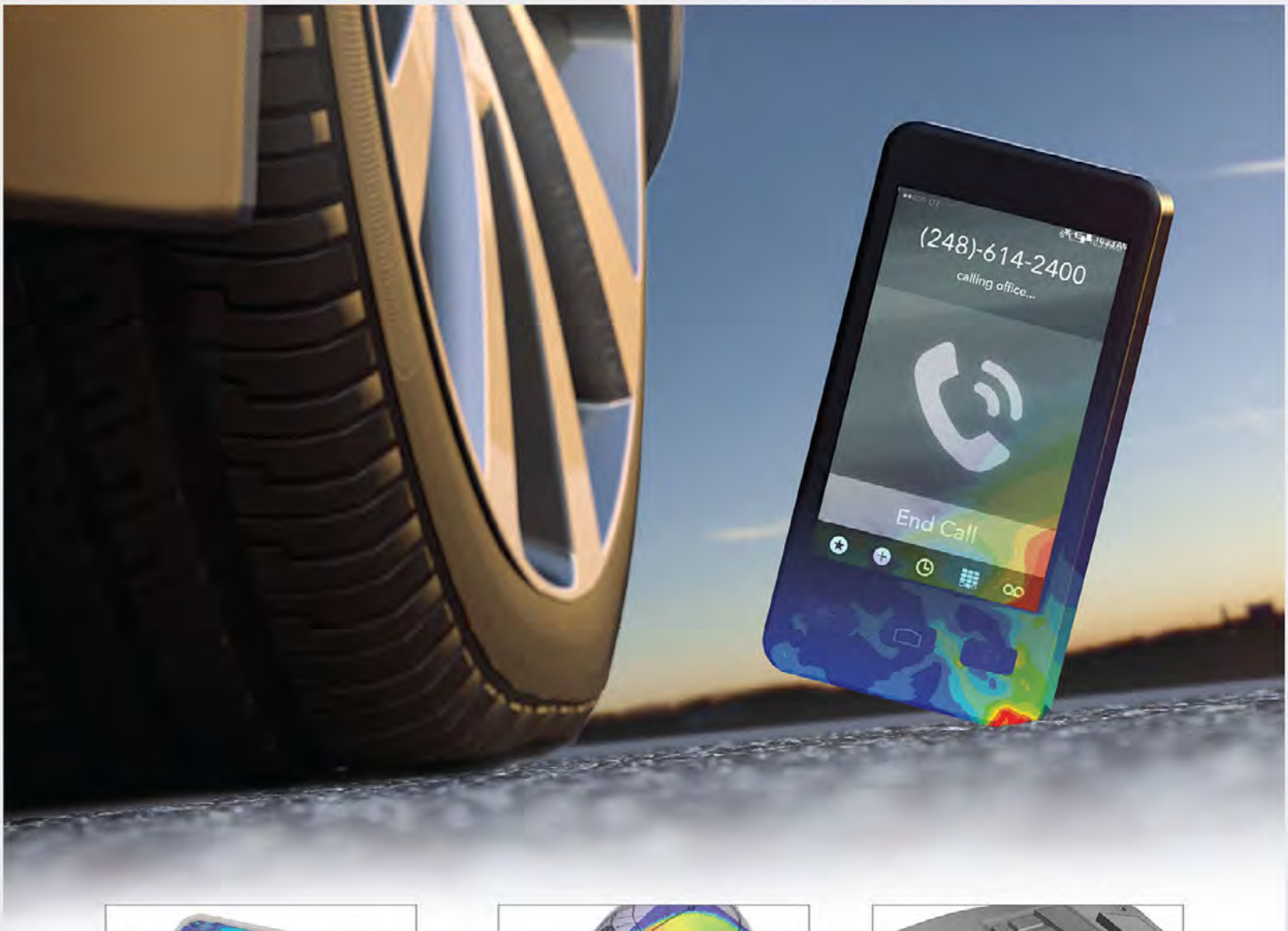
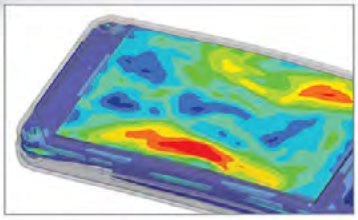
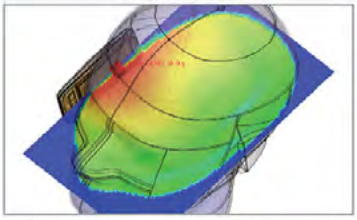
This Issue:

Been there, dropped that...

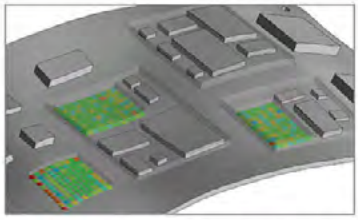




Impact Simulation: RADIOSS



Electromagnetic Analysis: FEKO



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Board Meeting Minutes continued...

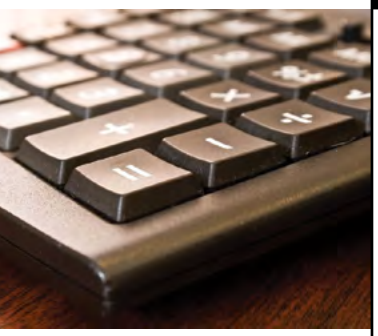
Cycletech: Craig Bowland

- Last year's profit was $40k.
- This year the COMDIV is involved.
- Michael Connolly asked to see the budget for this event. He suggests that some items may affect the COMDIV. He suggested to budget $5k.
- There should be about 250 attendees for this event. He stated that this will be a rotating conference where it would rotate between Europe and North America.
- **Actions:** ***Craig Bowland to prepare e-blast about Cycletech***
- **Actions:** ***Tim Johnson to add line item in budget for miscellaneous travel.***
- JEC offered us to participate in a Building & Construction conference scheduled for the summer of 2017. The group felt that ACMA needs to be involved in this process to make sure that there is not oversight to current activities.
- It is thought that the Cycletech conference could be expanded to a composites in sporting goods conference.
- **Actions:** ***Craig Bowland to check if SPE membership can be added to the Cycletech conference.***

Membership: Ray Boeman

- Membership showing a reduction of 80 members.
- **Actions:** ***Ray Boeman to approach members from the Automotive Division to join the COMDIV as secondary members.***
- **Actions:** ***Ray Boeman to reach out to new and expired members.***
- **Actions:** ***Ray Boeman to research demographic information from our membership.***

Meeting adjourned at 7:05pm



Treasury Report

By: Tim Johnson, Treasurer

SPE Composites Division (D39) FINANCIAL REPORT

The Composites Division had a very positive year corresponding with the success of the ACCE. This permitted the board to make significant contributions to the SPE Foundation for both the Harold Giles Scholarship and the Jackie Rehkopf Scholarship. The board has also moved to increase support of all other awards as well. With positive projections for ACCE'16 as well as the Cyclitech'16, the Composites Division anticipates another positive year.

At the close of the fiscal year, the Composite Division has over $69,000 in our account, and another $75,000 placed in an investment account.

Financial Report for the Period: **July 1, 2015 to July 1, 2016**
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**
Sponsorships for Newsletter	-2	$ 6,000.00	$ 10,000.00
Sponsorships ANTEC Reception	-3	$ -	
SPE Rebates	-4	$ -	
ACCE Earnings (after expenses, scholarships and payment to SPE)	-5	$ 67,257.41	$ 22,000.00
Sponsorship: Educator of the Year, SABIC	-6	$ -	$ 1,000.00
Saving Interest	-7	$ -	
Training programs	-8		
Sponsorship: Mettler-Toledo Award	-9	$ 1,000.00	$ 1,000.00
Cyclitech	-10		
	-11		
	-12		
Total Income for the period	-13	$ 74,257.41	$ 34,000.00
Total Funds Available (add lines 1 and 13)	-14	$ 183,122.10	$ 34,000.00
Expense: check the "Expense" worksheet for details		**Actual**	**Budget**
Website - CompHelp - 1&1.com	-15	$ 612.95	$ 500.00
Newsletter	-16	$ 4,592.50	$ 5,000.00
Mettler-Toledo Award	-17	$ 1,000.00	$ 2,000.00
BOD Meeting Expenses	-18	$ 681.65	$ 2,000.00
Educator of the Year Award	-19	$ 1,000.00	$ 1,000.00
Bank Service Fees	-20	$ 385.02	$ 250.00
Antec Suite / W&C Reception	-21	$ -	$ 2,000.00
ANTEC Other Expenses	-22	$ 1,270.33	$ 1,000.00
Council Travel	-23	$ 3,195.26	$ 2,000.00
Publicity	-24	$ 432.19	$ 100.00
Cyclitech	-25	$ -	
SPE Foundation: H. Giles Scholarship	-26	$ 10,500.00	$ 10,500.00
Student Activities at ANTEC 2015 (SAC)	-27	$ 5,000.00	$ -
Student Membership Program	-28	$ -	$ 4,000.00
Office Supplies	-29	$ 36.60	$ -
ACCE expenses	-30	$ 218.80	$ 1,000.00
SPE Foundation: Jackie Rehkopf Scholarship	-31	$ 10,000.00	$ 10,000.00
Total Expenses (add lines 15 – 31)	-32	$ 38,925.30	$ 41,350.00
Investment Transfer	-33	$ 75,000.00	
Ending Balance (subtract line 32 from line 14)	-34	$ 144,196.80	$ (7,350.00)
Allocation of Funds on Line 34 (enter allocations as applicable)			
Checking Account	(A)	$ 69,196.80	
Savings Account 1	(B)	$ -	
Investment 1	(C)	$ 75,000.00	
Investment 2	(D)	$ -	
TOTAL	(E)	$ 144,196.80	
Amount on line E should equal amount reported on line 34			
Section / Division Treasurer's Name:		Timothy Johnson	
Audit Committee Attest:			

This Issue:

Awards Report

By: Dr. Ian Swentek

2016 ANTEC Award Winners

At ANTEC 2016 in Indianapolis two awards were conferred to their worthy recipients. This year, the METTLER TOLEDO student award was presented to Yipin Duan. While the Educator of the Year award, sponsored by Sabic, was presented to Dr. Amod Ogale of Clemson University. For both awards, there was fierce competition, with high-scores across amongst all the applicants.

Yipin Duan is currently a graduate student in the accelerated master's degree program in the Department of Polymer Engineering, University of Akron since Fall 2015. Prior to moving to Akron, he had completed three years towards a bachelor's degree in the Department of Material Science and Engineering, Beijing University of Chemical Technology. Upon graduation, he will receive a bachelor's degree from Beijing University of Chemical Technology as well as a master's degree from the University of Akron. Yipin is working on the fabrication and characterization of graphene oxide composite hydrogels under the direction of Professors Nicole Zacharia and Bryan Vogt. The focus on this research is to control the mechanical and electrical properties through composition and processing towards potential application as redox active hydrogels in flexible, conformal and/or wearable devices.

Prof. Amod Ogale is the Director of Center for Advanced Engineering Fibers & Films (CAEFF) and the Dow Chemical Professor of Chemical and Biomolecular Engineering at Clemson University, and has served on Clemson faculty since 1986. He received his BS from IIT Kanpur (1982) and his PhD from University of Delaware (1986) while working at the Center for Composite Materials. He is a Fellow of the Society of Plastics Engineers and was the winner of 2013 Graffin Lecturer Award given each year by the American Carbon Society. Prof. Ogale's research expertise

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Nikhil Verghese presenting the award to Amod Ogale.

Yipin receiving the Mettler Toledo Student Award from Kevin Menard of Mettler Toledo.

This Issue:

Awards Report continued...

includes processing-microstructure-property relationships of carbon fibers, polymers, and composites. His current research involves rheo-structural studies of mesophase pitch and bio-mass as precursors for high-performance and cost-competitive carbon fibers and their composites. He has published four book chapters, one patent, and over 100 research papers. He has served as the PI or co-PI on more than 52 individual research grants worth over $8 million, and has been a co-PI in the NSF-Engineering Research Center grant worth over $29 million given to CAEFF. Prof. Ogale has taught numerous courses on polymeric materials and composites, including "Polymer Composite Engineering" and "Viscoelastic Properties of Polymers and Polymeric Composites".

The Society of Plastics Engineers – Composite Division continues to offer numerous scholarships and awards to the composites community. Our aim is recognize outstanding individuals who are contributing to building the present and future industry. We provide an organized forum to promote and disseminate information on the science, engineering fundamentals, and applications of engineered polymer composites. If you know of other worthy candidates for these or any of our awards, please encourage those individuals to apply in 2017.

Kind Regards,

Dr. Ian Swentek

Composite Division Awards Chair

Michael Connolly (left) and Enamul Haque (center) presenting Jim Griffing (right) the award.

Distinguished Member Award:

Please congratulate Jim Griffing (Ex-President of SPE and current Composites BOD) for being awarded the distinguished member of the Society at SPE. The Distinguished Member grade is the most prestigious offered by SPE. According to the SPE Bylaws, to be elected a Distinguished Member, a candidate must be a member in good standing who has served as President of the Society or who, in the opinion of two-thirds of the Past Presidents voting, provided one-half of the surviving Past Presidents participate in the ballot, is deemed worthy of this status by virtue of outstanding achievement or professional eminence.

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This Issue:

Awards Report continued...

Harold Giles Award:

2016 Harold Giles Award Winners

The 2016 year winners of the Harold Giles Scholarship awards are Emily Anne Vargas and Siddhartha Brahma. Over twenty applications were received this year, and the judging was extremely difficult, particularly on the graduate student level where the top candidates were separated by only a few point spread, but in the end, Ms. Emily Anne Vargas emerged as the clear undergraduate winner, and Mr. Siddhartha Brahma eked out the graduate student scholarship.

Ms. Emily Anne Vargas
Undergraduate Student Winner

Ms. Vargas presently attends Florida State University and is expected to graduate with a BS in Industrial and Manufacturing Engineering by May 2017. What makes Emily unique is her leadership skills in serving the Society of Hispanic Professional Engineers where she has represented Region 7 (North Carolina, South Carolina, Georgia, and Florida) as a regional student representative and where she has served as an External Vice-President for her University Chapter. She has currently stepped in to the role as the National Undergraduate Representative role, representing more than 8000 students from across the nation. This is not to mention the myriad of volunteer work including being the captain of the Relay for Life team for the American Cancer Society, finding the time to mentor young children in STEM at Amos P. Godby High School and Sail High School, and organizing the first Science Night which drew in thirty seven prospective future science students and which also tapped her corporate fund raising capabilities from ExxonMobil, Boeing, Cummins, and Shell. What also clicked with the judges was her research with Buckypaper/composite fabrication and the breadth of her intern job experiences with such companies as Boeing, Proctor and Gamble, Otis Elevator, and the High Performance Materials Institute. She lives life by the quote, "Always live at the bottom, even when you are at the top." Don't be surprised if you hear Ms. Vargas name as a young corporate leader in the future.

Mr. Siddhartha Brahma
Graduate Student Winner

Originally from India, Mr. Siddhartha Brahma is pursuing a PhD in Material Science and Engineering from the University of Alabama at Birmingham (UAB) where he expects to graduate in 2018. An avid basketball player and member of Green Peace, Brahma has maintained a perfect GPA of 4.0 while still finding the time to lead the UAB student chapter of SPE, serve as member of the Alpha Sigma Mu Society to promote engineering as a career path to high school students,

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Awards Report continued...

and mentor undergraduate and high school students. His thesis research examines the in-situ polymerization of nylon on continuous and discontinuous carbon fibers, and he has also worked on a prototype for the oil and gas industry, VARTM formed epoxy panels, stacked carbon nanotube array for emission reduction, characterizing composites from recycled carpets, and thermoplastic panels constructed from prepregs. In addition to these outstanding achievements, he has previously worked for Mahindra and Mahindra Automotive in Bangalore India and as a research scientist at the National Aerospace Laboratories where he predicted weather patterns and designed eco-friendly, hybrid composites systems used for small wind energy turbines. He displays the dedication, work ethic, and curiosity that will take him far in his future endeavors.

The Composite Division will continue to offer the Harold Giles Scholarship to worthy candidates in the future; the scholarship was developed to honor the late Dr. Harold Giles, a past Composite Division Awards Chair. As a former University Professor at the University of North Carolina, Azdel employee, and GE employee, Harold knew full well the value of scholarships to students. He was always a proponent of awarding worthy students and served the society well in this capacity. Harold would have been pleased to know that students like Emily Anne Vargas and Siddhartha Brahma received this award. So if you believe that you know of other worthy candidates, please apply in 2017.

Humbly submitted by,
Dr. Dale Grove
Composite Division
Awards Committee Member

Special Item

This Issue:

SPE Composites BOD Dale Grove releases new science fiction book “Loose Strings”

The book is available in both paperback and kindle at amazon.

Award Winning Paper

Material Characterization And Draping Simulation Of Thermoplastic Prepregs: The Influence Of Temperature

Annegret Mallach, Steffen Ropers, Frank Häusler, Marton Kardos
Volkswagen Group Research
Tim A. Osswald, Polymer Engineering Center, UW Madison
Maik Gude, Institut für Leichtbau und Kunststofftechnik, TU Dresden

Abstract

When thermoforming a thermoplastic prepreg, it is heated up above the matrix's melting temperature, to achieve drapability, and subsequently formed into a three-dimensional product. Cooling during the transfer into the mold and the contact with the mold causes a change of the mechanical properties. To improve draping simulation, which already allows virtual prototyping of textile feedstock and thus eliminates a costly trial and error development process, the temperature dependency of mechanical properties has to be accounted for. The 2015 version of ESI's PAM-FORM allows modeling this dependency. However, the determination of bending, shear and tensile properties at multiple temperatures is quite laborious. Thus, the potential of Dynamic Mechanical Analysis (DMA) for determining the temperature dependent mechanical properties of the material in addition to the viscoelastic behavior of the material was investigated.

Also, Design of Experiments (DoE) was used to identify parameters with major effects on the blank temperature in draping simulation of a hemispherical geometry. The major parameters were combined with temperature dependent mechanical properties as parameters for a subsequent DoE to identify their effect on the shear angle. Here, the results of the DMA were used to calibrate temperature dependent mechanical properties.

Introduction

Due to stringent emission requirements [1] the automotive industry is increasingly advancing lightweight design solutions and materials to continually optimize vehicle curb weights. Fiber Reinforced Polymers (FRPs) possess excellent lightweight potential due to their high specific mechanical properties. Moreover, continuous fiber reinforced thermoplastic polymers allow designing with anisotropy respecting load paths and local load distribution. At the same time they enhance short process times making them very interesting for automotive applications. However, their use in automotive series demands reliable as well as economic design and manufacturing processes.

As most FRP forming processes are complex and trial and error based development is costly and time consuming, FRP forming simulation has to be integrated in the process chain for virtual optimization. Finite Element Method (FEM) based draping simula-

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Award Winning Paper continued...

tion provides effective numerical means to model the forming steps accounting for the anisotropic, nonlinear material behavior and boundary conditions like blank holders.

The mechanical properties of thermoplastic composites greatly depend on prepreg temperature. In order to obtain reliable results, these dependencies have to be accounted for in the simulation. Accordingly, the material model used by the 2015 version of PAM-FORM provided by ESI Group allows for the addition of temperature and other dependencies to mechanical properties [4].

Wang et al. [5] demonstrated the importance of thermal conditions regarding simulation outcomes. Boisse et al. [6] studied wrinkling during composite forming and came to the conclusion that the quality of the simulation depends on the material properties taken into account. They have shown the importance of bending stiffness regarding wrinkle number and size. Liang et al. [7] investigated the bending properties of thermoplastic prepregs via cantilever tests conducted in a thermal chamber. The method is labor intensive and only able to determine the bending stiffness at distinct temperatures via quasi-static experiments. Sachs [8] studied the bending stiffness also at distinct temperatures taking curvature dependency and strain rate into account, employing a modified rheometer.

The temperature and strain rate dependency of the viscoelastic properties of unidirectional laminates were investigated by Melo and Radford [9] using dynamic mechanical analyses (DMA) and found that the results were in good correlation with the expected values. Deng et al. [10] studied the elastic moduli of epoxy resins and established good correlation between the DMA temperature sweeps and the results of the conventional mechanical tests. Margossian et al. [11] examined the potential of the DMA system for the characterization of longitudinal out-of-plane bending properties and their temperature and strain rate dependency of molten unidirectional thermoplastic composites. However, only quasistatic tests under isothermal conditions were conducted.

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In order to investigate the temperature dependency of the material's storage modulus, a series of DMA tests were conducted. A broad temperature range and multiple frequencies have been investigated. The resulting averaged storage modulus and mechanical test results were used to determine the material's bending stiffness and shear modulus with their temperature dependencies. After setting the parameters to realistic values, their influence on the simulation was investigated.

Due to the complexity of the numerical system and potential unknown interactions between the various parameters, a Design of Experiments (DoE) screening was employed to identify the important parameters regarding blank temperature. The resulting parameters were combined with temperature dependent mechanical properties as factors for a subsequent screening in order to obtain the main factor effects on the shear angle.

Material and Model

DMA tests were performed on the thermoplastic prepreg (TPP) material Tepex® 102 dynalite-RG600(x)/47% supplied by Bond-Laminates. The prepreg consist of a 2/2 twill glass fiber weave impregnated with polyamide 6 matrix system. Further properties of the investigated material are shown in Table I.

Table I: Material properties of Tepex 102, extracted from the manufacturers material data sheet [12]

Matrix material		Polyamide 6 (PA6)
Reinforcement material		E-glass
Reinforcement type		2/2 twill weave
Area weight	[g/m2]	600
Fiber volume fraction	[%]	47
Thickness	[mm]	0.5
Melting temperature	[°C]	220
Recommended processing temperature	[°C]	240 - 260

The most established processing technique for thermoplastic prepregs is matched-die forming, a specialized version of thermoforming, thus the simulation is based on this process. The model used for the DoE consists of a hemispherical punch, a matching die and a blank holder ring. The blank is positioned on the fixed die at the start of the simulation and is deformed by the moving punch into the cavity. A blank holder applies a uniform pressure onto the blank to suppress wrinkling. The tools are defined as rigid bodies.

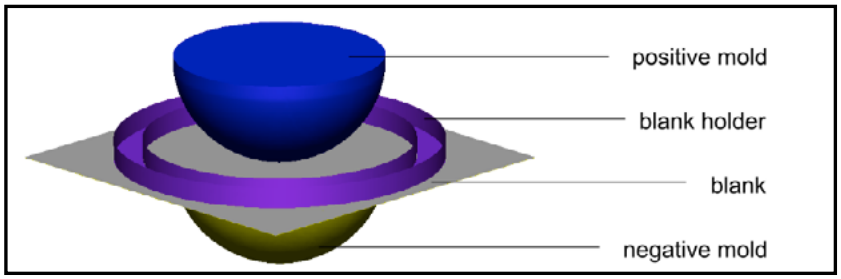

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Table II: Factors selected for the first DoE

Factors	Abbreviation	Corresponding column in design matrix
Dissipation Factor[1]	DiF	A
Conductivity	Con	B
Specific Heat Capacity	SpH	C
Initial Temperature	InT	D
Heat Transfer Coefficient	HTC	E
Imposed Mold Temperature	ImT	F
Interactions	Int act	G

Screening Of Factors Influencing Blank Temperature

The first DoE performed was a screening, conducted over a set of model and material characteristic parameters that were assumed to have influence on the blank temperature. The simulation software's interface was searched for possible parameters, and every parameter that could have a direct influence on blank temperature, including initial blank temperature, was investigated. Since radiation and convection were both disabled during the simulation, the only possible form of heat transfer between the blank and the mold was contact conductance. The factors chosen to be investigated in the temperature focused DoE are listed in Table II. Their default values were set to realistic and/or commonly used rates, and their factor settings are the product of a multiplication factor (0.5 and 2, respectively) and the default value. The multiplication factors were carefully chosen to investigate a broad range of possible (and anticipated) values for TPPs. They were applied to each applicable factor.

The Plackett-Burman screening approach was chosen, as it provides a convenient fractional factorial design for 7 factors with two levels, where only 8 experiments are required. This method is based on the assumption that the investigated factors are linearizable over the investigated range [13]. It provides a very efficient process to examine the effects of the chosen factors regarding the draping simulation and thus, to pinpoint those properties that have to be precisely characterized in the future.

The chosen factors occupy the first six column of the design matrix while the seventh column was designated for the cumulated effect of multiple-factor interactions. The Plackett-Burman design is a very effective screening design. This approach, however, yields a resolution III design, meaning that the main effects are all confounded with two- and more factor interactions. As interactions of more than two factors are usually assumed to be neglectable, a design of resolution IV, in which main effects are only aliased with interactions of three or more factors, was obtained by means of a fold-over of the original design. Folding over is a method that adds a new run to every original run with the opposite set of levels [14].

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[1] *The so-called dissipation factor describes the percentage of internal work which will be converted to heat during the deformation* [4].

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Table III: Folded-over Plackett-Burman design for 7 factors and 16 runs

n	A	B	C	D	E	F	G
1	+	-	+	-	+	-	+
2	-	+	+	-	-	+	+
3	+	+	-	-	+	+	-
4	-	-	-	+	+	+	+
5	+	-	+	+	-	+	-
6	-	+	+	+	+	-	-
7	+	+	-	+	-	-	+
8	-	-	-	-	-	-	-
9	-	+	-	+	-	+	-
10	+	-	-	+	+	-	-
11	-	-	+	+	-	-	+
12	+	+	+	-	-	-	-
13	-	+	-	-	+	-	+
14	+	-	-	-	-	+	+
15	-	-	+	-	+	+	-
16	+	+	+	+	+	+	+

Table III shows the folded-over Plackett-Burman design for 7 factors, where the lower eight experiments give the fold-over complement of the original design. The plus signs corresponds to the given factors upper setting, the minus signs to its lower setting. Every row of the design matrix constitutes an experiment with the factor settings determined by the plus and minus signs.

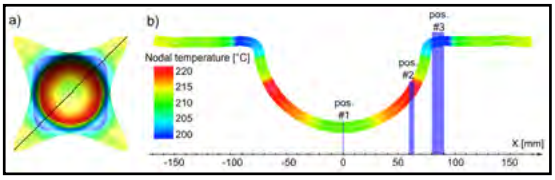
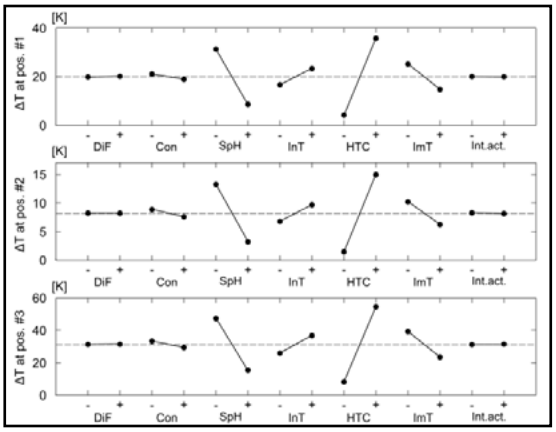


Figure 2: Cutting plane depicted with black line over the model (a) and cross sectional view with illustrated temperature and the response value ranges highlighted (b)



The considered response value in the first screening is the temperature difference between initial and end state blank temperature. The simulation model was cut to obtain a diagonal cross section, see Figure 2(a), along which the temperature was exported to calculate the response value. Since temperature values change irregularly along the cross section, three different locations have been chosen as response values. The pole of the hemisphere (position #1), the warm spot on the side of the hemisphere (position #2), and the cold spot under the blank holder ring (position #3), as seen in Figure 2(b).

The warm spot is located in the region of the blank that has the least amount of tool contact. The cold spot is underneath the blank holder, as this region experiences tool contact on both sides throughout the whole process. Instead of selecting a distinct point along the cross section, coordinate ranges were defined. The average temperatures of these ranges yield more meaningful results than the temperatures of arbitrarily chosen points on the curve, since the gradient along the cross section changes erratically. The effects of the factors investigated in the first DoE after fold-over are depicted in Figure 3.

The results delivered by the folded-over design distinctly show[2] that the heat transfer coefficient (HTC) and the specific heat capacity (SpH) are the two most influential factors. The initial, unfolded design delivered the same results with slightly greater interactions. Comparing its results with those of the folded-over design has ensured the validity of the effects.

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[2] *The gradient of the "effect line" illustrates how influential the factor is.*

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Award Winning Paper continued...

DMA Experiments

Dynamic mechanical analysis was used to qualitatively determine the temperature dependency of various material characteristic properties of the thermoplastic prepreg. The DMA 242 E Artemis device of the Netzsch Group was used to scan the materials elastic response over a wide temperature range. Five experiments have been made in both warp and weft directions, regarding the reinforcement weave. Since there was only a minor difference between directions, warp direction results are presented here exemplarily.

The elastic response of the material is described by the storage modulus, which is conceptually similar to the Young's modulus. It describes the material's ability to store and return mechanical energy in form of elastic deformation. Initial experiments ranging from room temperature to 220°C

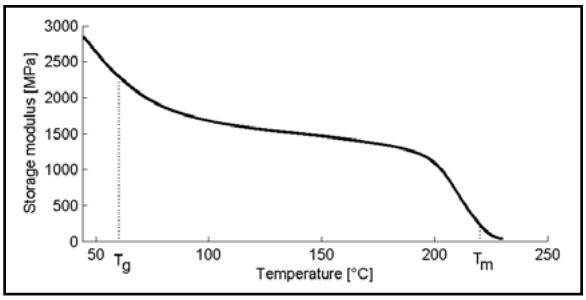

Figure 4: Storage modulus curve at 10Hz of Tepex 102 from room temperature to 230°C

have revealed that the storage modulus E' decreases linearly with increasing temperature until the glass transition temperature Tg, as shown in Figure 4.

T_g is at 60°C in case of PA6, around which temperature the curve flattens out. The storage modulus decreases linearly until approximately 20°C before the melting point, where the material begins to rapidly lose its

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elastic properties. Here, the modulus drops to a value near zero slightly above the melting point. A temperature range from 150 to 260 °C was further investigated, as this is the range of interest regarding forming processes. Storage modulus values obtained from all 5 experiments at a frequency of 10 Hz are shown in Figure 5.

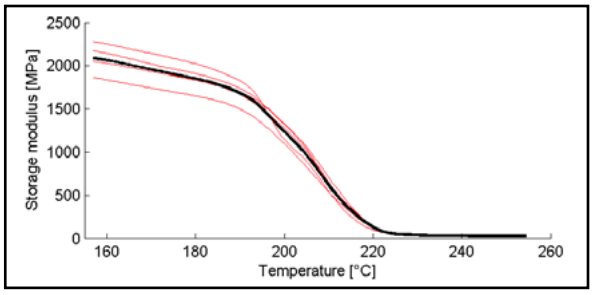

Figure 5: Storage moduli of all 5 experiments at 10 Hz and the average curve plotted as a function of temperature

The 10Hz frequency corresponds to a realistic punch velocity of 10 mm/s[3]. Therefore, the storage moduli values obtained at 10 Hz (see red lines in Figure 5) were averaged to get an average curve (black line) that was used to proportionally expand the experimentally determined values for the bending stiffness and shear modulus. These properties were characterized at 250°C in the framework of a previous study done by Volkswagen Group Research [15]. The experimentally determined values were multiplied with proportionality factors corresponding to the average curve to expand these properties to a temperature range of 150°C to 280°C. This method of property characterization is based on the assumption that the storage modulus' temperature dependency is proportionally the same as that of other moduli, and supported by the fact that the storage modulus obtained from DMA results is conceptually similar to other moduli, as it describes the material's ability to return or store energy in form of elastic deformation [16].

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[3] *The maximum amplitude of the employed DMA instrument is 240µm. It takes a quarter of the cycle time for the stamp to get from the initial position to the maximum amplitude. At a 10Hz frequency this means that the sample is flexed 0.24mm in 0.025s, which roughly corresponds to a punch velocity of 10mm/s. The actual strain rate of the blank during draping is geometry dependent and non-uniform, but this has not been accounted for in this study. This is a necessary simplification in order to tame the complexity of the model.*

Table IV: Factors selected for the second DoE

Factors	Abbreviation	Corresponding column in design matrix
Specific heat	SpH	A
Coefficient of Friction	Fri	B
Shear modulus	SMo	C
Bending stiffness	BSt	D
Young's modulus	YMo	E
Heat transfer coefficient	HTC	F
Interactions	Int.act.	G

A previous study [15] has shown that the Young's modulus of the material is inversely linearly proportional to temperature. According to these findings, Young's modulus values were calculated for the temperature range between 150°C to 280°C. Furthermore, coefficient of friction values were linearly extrapolated from experimentally determined values.

Screening Of Temperature Dependent Mechanical Properties

The second screening was focused on temperature dependent mechanical properties. The shear angle was selected as response value, as it sufficiently characterizes the (in-plane) deformation of the blank. Temperature dependent mechanical properties were chosen along with the most influential thermal properties. The chosen factors are listed in Table IV. With six selected factors the same design matrix could be used as in DoE 1, see Table III.

The default settings of these parameters were determined according to DMA results and previous studies, as discussed in the preceding chapter. Their level settings were specified as the product of a multiplication factor and their default setting.

The cutting plane introduced in the first DoE was used again to get a diagonal cross section of the model. The response value, i.e. the

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Award Winning Paper continued...

shear angle γ, was exported along this cross section as a function of x-coordinates. The response values were investigated at three different locations of the cross section, each of them located within the hemispherical part of the geometry. Instead of specifying these locations based on x-coordinates, polar coordinates θ were used. Similarly to the first DoE, regions were defined. Every region is 4° wide and is symmetrically placed around the pole, at 0°, at 20° and at 75° positions, as shown in Figure 6.

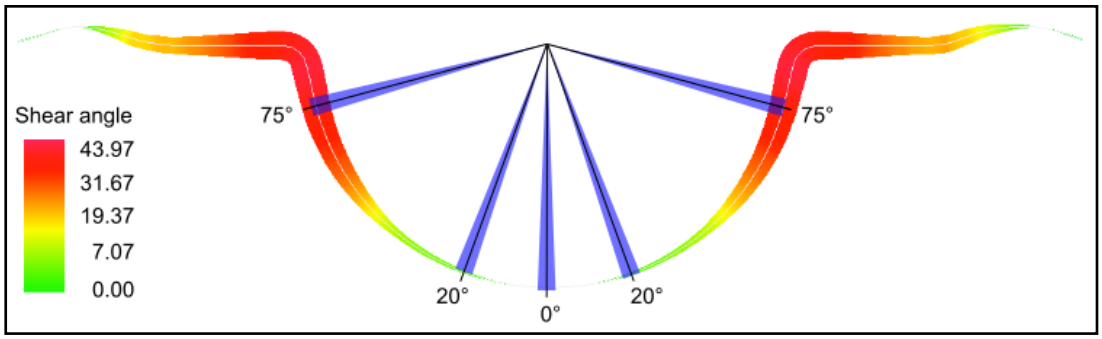

Figure 6: Cross section of the hemispherical model with the polar coordinate θ ranges of interest highlighted

Figure 6 shows a typical shear angle distribution, having a value near zero at the pole, a moderate value at θ=20° and the highest angle around θ=75°. The effect analysis of the folded-over design for these response values is shown in Figure 7.

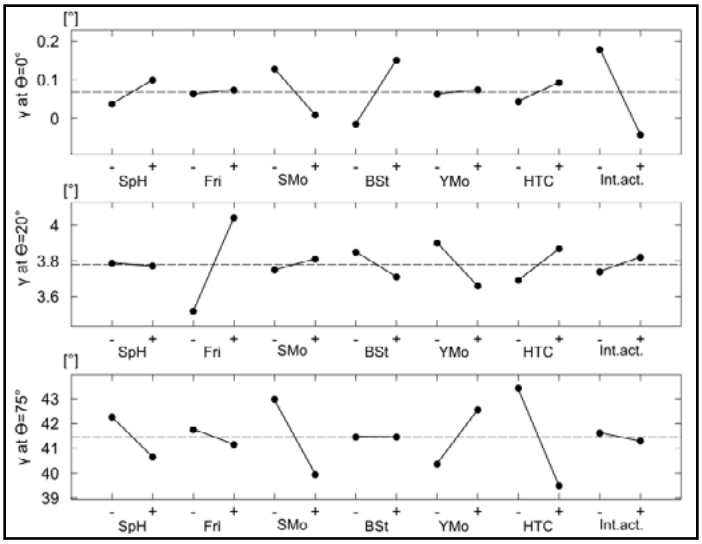

Figure 7: Effects of the factors investigated in the second DoE after the fold-over

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The variation in shear angle at position 1 is around 0.2°, which is negligible. Hence, none of the factors in this screening setup has a major effect on the shear angle at the pole. The response value at position 2 shows dependence on the coefficient of friction (Fri). The largest effects on the shear angle can be observed at polar angle 75°. According to the results, the shear modulus (SMo) and the Young's modulus (YMo) are the strongest factors here, along with the heat transfer coefficient (HTC).

Summary and Next Steps

Temperature is of significant importance regarding the forming of thermoplastic prepregs, as almost all mechanical and thermal properties show a dependency on temperature. To be able to sufficiently simulate such a process and to thoroughly understand the involved phenomena, material properties have to be investigated comprehensively.

Dynamic Mechanical Analysis was used to study the temperature dependency of various mechanical properties of a thermoplastic prepreg material with PA6 matrix and glass fiber 2/2 twill weave. Values for bending and shear moduli determined in an earlier study were used to set the corresponding simulation parameters to realistic values. DoEs were conducted to determine the influence of numerous material and model characteristic parameters regarding the simulation results. For that purpose, the current material model in PAM-FORM V2015 was investigated and the most important parameters have been identified. The relevant properties concerning temperature distribution were the specific heat capacity and the heat transfer coefficient. Regarding the factor effects on the shear angle, dependencies were particularly observed for the tool-ply friction coefficient, the shear and Young's modulus and the heat transfer coefficient. These factors will be investigated in further parameter studies and on additional, more complex geometries.

A more accurate investigation of the effects and their possible non-linearity will be the scope of future studies.

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Award Winning Paper continued...

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