SPE COMPOSITES

APRIL 2017

Composites Connection™

Official Newsletter of the SPE Composites Division

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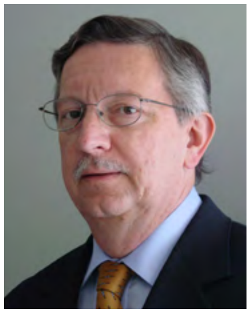
This Issue:

Board of Directors continued...



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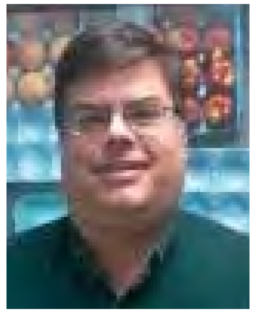

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This Issue:

Scholarship Annoucement

By: Dr. Dale Grove

Harold Giles Scholarship

The Composite Division has been offering a scholastic scholarship for numerous years in honor of 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 Giles 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.

Two $3500 scholarships will be offered—one for an undergraduate student and the second for a graduate student. These scholarship awards are open to outstanding students who not only maintained a good grade point average but also served their community, had some experience in the composite area, and are backed by solid reference letters from former professors and employers. If you are or know of worthy candidates for this scholarship, please consult the SPE foundation at the following website: http://www.4spe.org/Foundation/?navItemNumber=639

If you have any questions, please contact me. The due date is April 1st 2017.

Dr. Dale Grove
Member of the Composite Division
Awards Committee
grove.dale@hotmail.com

SOCIETY OF PLASTICS ENGINEERS

ANTEC Award Winners 2017

By: Ian Swentek

Congratulations to our 2017 award winners!

Part of the mandate of the Society of Plastics Engineers – Composites Division is to recognize excellence in composite materials development and proliferation. Two new award recipients are being recognized at ANTEC 2017 in Anaheim, California. This year, the METTLER TOLEDO student award recipient is Munetaka Kubota from the University of Delaware. While the Sabic Educator of the Year award is presented to Dr. Tim Osswald from the University of Wisconsin-Madison. Please join me in congratulating these gentlemen on their accomplishments and best wishes as they continue their efforts in advancing composite materials research.

Munetaka Kubota started at the University of Delaware with a chemical engineering major. During his internship at University of Delaware Center for Composite Materials he found his passion in mechanical engineering, material science, and composite materials. Mr. Kubota soon thereafter switched into the mechanical engineering major. During his internship, he participated in a wide range of composite research, including advanced composite material characterization, investigation of environmental aging on aerospace grade prepreg, validation of advanced accelerated out of autoclave manufacturing techniques, and development of accelerated curing techniques for aerospace qualified structural adhesives. After successfully completing his Bachelor of Mechanical Engineering with a minor in material science and engineering from the University of Delaware in 2011, Munetaka started working under Professor Suresh G. Advani as a Research Associate. He worked on polymer morphology manipulation for optical applications and published his findings in Polymer Science and Engineering. He also worked as a member of the FIBERS (Facilitating Industry by Engineering, Roadmapping and Science) Composites Manufacturing Industry Consortium, sponsored by NIST, to propose the development of an education module for composite materials to be integrated into existing undergraduate engineering curriculums. He started working with Professor John W. Gillespie and Dr. Joseph Deitzel on investigating fiber/matrix interface improvement techniques as well as methods to characterize the interfacial shear strength. He was accepted into the Master's program in Mechanical Engineering at the University of Delaware in 2016 and then successfully switched into the Doctoral program in January 2017. Munetaka hopes to use his skills and knowledge acquired to advance composite materials and accelerate their adaptation into consumer markets.

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This Issue:

ANTEC Award Winners 2017 continued...

Dr. Tim Osswald is a Professor of Mechanical Engineering and Director of the Polymer Engineering Center at the University of Wisconsin-Madison. Originally from Cúcuta, Colombia, he received his B.S. and M.S. in Mechanical Engineering from the South Dakota School of Mines and Technology and his Ph.D. in Mechanical Engineering at the University of Illinois at Urbana-Champaign in the field of Polymer Processing. He spent two and one half years at the Institute for Plastics Processing (IKV) in Aachen, Germany, as an Alexander von Humboldt Fellow. He received the National Science Foundation's Presidential Young Investigator Award, as well as the 2001 VDI-K Dr--Richard-Escales-Preis. In 2006 he was named an Honorary Professor at the University of Erlangen-Nuremberg in Germany and in 2011 he was named Honorary Professor at the National University of Colombia. Professor Osswald teaches polymer and polymer composites processing and designing with polymers and polymer composites and researches in the same areas, in particular in the area of fiber orientation, fiber density and fiber length distributions. Professor Osswald has published over 300 papers, the books Materials Science of Polymers for Engineers (Hanser, 1996, 2003, 2012), Polymer Processing Fundamentals (Hanser 1998), Injection Molding Handbook (Hanser, 2001, 2007) Compression Molding (Hanser, 2003), Polymer Processing Modeling and Simulation (Hanser 2006), International Plastics Handbook (Hanser 2006), Plastics Testing and Characterization (Hanser, 2008), Understanding Polymer Processing (2010, 2017) and Polymer Rheology (Hanser 2015). His books have been translated into Italian, German, Spanish, Japanese, Chinese, Korean and Russian. Professor Osswald is also the series editor of Plastics Pocket Power (Hanser, 2001), which currently includes 6 books, is the Editor for the Americas of the Journal of Polymer Engineering and the English language Editor for the Journal of Plastics Technology. Professor Osswald has been consulted by several industries, is one of the co-founders of The Madison Group, and is in the Technical Advisory Board of several companies.

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This Issue:

ANTEC Award Winners 2017 continued...

The SPE Composites Division welcomes these worthy recipients and again congratulates them on their success. The Society of Plastics Engineers – Composite Division continues to offer numerous scholarships and awards to the composites community. 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. Please also reach out if you would like more information on the many benefits of membership in our growing society.

Kind Regards,
Dr. Ian Swentek
SPE Composite Division Awards Chair

See page 38 for more details

Treasury Report

By: Tim Johnson, Treasurer

SPE Composites Division (D39) FINANCIAL REPORT

Financial Report for the Period: **July 1, 2015 to March 27, 2017**
Section/Division Name: **Composites Division D39**

Balance as of 7/01/2016	-1	**$146,177.73**		
Income: check the "Income"worksheet for details		**Actual**	**Budget**	**Variance**
Sponsorships for Newsletter	-2	$ 8,500.00	$ 7,500.00	$ 1,000.00
Sponsorships ANTEC Reception	-3	$ -		$ -
SPE Rebates	-4	$ -		$ -
ACCE Earnings (after expenses, scholarships and payment to SPE)	-5	$ 42,084.21	$ 50,000.00	$ (7,915.79)
Sponsorship: Educator of the Year, SABIC	-6	$ -	$ 2,500.00	$ (2,500.00)
Saving Interest	-7	$ -		$ -
Training programs	-8			
Sponsorship: Mettler-Toledo Award	-9	$ -	$ 1,000.00	
Cyclitech	-10		$ 5,000.00	
	-11			
	-12			
Total Income for the period	-13	**$ 50,584.21**	**$ 66,000.00**	**$ (9,415.79)**
Total Funds Available (add lines 1 and 13)	-14	**$ 196,761.94**	**$ 66,000.00**	**$ (9,415.79)**
Expense: check the "Expense" worksheet for details		**Actual**	**Budget**	**Variance**
Website - CompHelp - 1&1.com	-15	$ 377.19	$ 1,000.00	$ (622.81)
Newsletter	-16	$ 6,236.75	$ 7,500.00	$ (1,263.25)
Mettler-Toledo Award	-17	$ -	$ 4,500.00	$ (4,500.00)
BOD Meeting Expenses	-18	$ 504.66	$ 2,000.00	$ (1,495.34)
Educator of the Year Award	-19	$ -	$ 2,500.00	$ (2,500.00)
Bank Service Fees	-20	$ 453.88	$ 500.00	$ (46.12)
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	$ 1,602.50	$ 3,000.00	$ (1,397.50)
Publicity	-24	$ -	$ 500.00	$ (500.00)
Cyclitech	-25	$ 3,839.21	$ 5,000.00	
SPE Foundation: H. Giles Scholarship	-26	$ 8,000.00	$ 6,000.00	$ 2,000.00
Student Activities at ANTEC	-27	$ 5,000.00	$ 5,000.00	$ -
Student Academics Program	-28	$ 7,500.00		$ 7,500.00
Office Supplies	-29	$ -	$ 75.00	$ (75.00)
ACCE expenses	-30	$ 384.69	$ 1,000.00	$ (615.31)
SPE Foundation: Jackie Rehkopf Scholarship	-31	$ 6,000.00	$ 6,000.00	$ -
Total Expenses (add lines 15 – 31)	-32	**$ 40,898.88**	**$ 47,575.00**	**$ (5,515.33)**
Investment Transfer	-33	$ -		
Ending Balance (subtract line 32 from line 14)	-34	**$ 155,863.06**	**$ 18,425.00**	**$ (3,900.46)**
Allocation of Funds on Line 34 (enter allocations as applicable)				
Checking Account	(A)	$ 80,863.06		
Savings Account 1	(B)	$ -		
Savings Account 2	(C)	$ -		
Investment 1	(D)	$ 75,000.00		
Investment 2	(E)	$ -		
Investment 3	(F)	$ -		
TOTAL	(G)	$ 155,863.06		
Amount on line G should equal amount reported on line 34				
Section / Division Treasurer's Name:		Timothy Johnson		
Audit Committee Attest:				
Distribution:	Copy to Section / Division Board of Directors			

This Issue:

Session Details ANTEC 2017

Time	Control #	Title	Presenters
Monday Morning		**Composites Modeling / Analysis**	
Moderator		**Antione Rios**	
8:00	6	Material Characterization Of Cf-Nonwovens With Thermosetting Matrices	Jasmin Mankiewicz
8:30	107 Keynote	A New Strength Tensor Based Failure Criterion For Anisotropic Materials	Tim Osswald
9:00	348	Study Of Fiber Length And Modeling Of Partially Compacted, Commingled Polypropylene Glass Fiber Fleece Composites	Blanca Maria Lekube
9:30	230	Lateral Torsional Buckling Of Anisotropic Laminated Thin-Walled Rectangular Simply Supported Composite Beams Subjected To Pure Bending	Habiburrahman Ahmadi
10:00	150	Optimizing Process Condition Of Resin Transfer Molding: Determining Material Properties For Numerical Simulation	Jessica Lin
10:30	245	Analytical And Finite Element Buckling Solutions Of Fixed-Fixed Anisotropic Laminated Composite Wide Plates Under Axial Compression	Rund Al-Masri

Monday Morning		**Nanocomposites I**	
Moderator		**Steve Bassetti**	
8:00			
8:30	104	A Model For Permeability Reduction In Polymer Nanocomposites	Sushant Agarwal
9:00	105	Nanocomposites Of Sebs/Cnt For Electromagnetic Shielding: Effect Of Processing Method And Maleic Anhydride	Scheyla Kuester
9:30	182	Fabrication And Characterization Of Electrospun Polyvinyl Alcohol Fibrous Nanocomposite Reinforced With Wood Flour	Sheikh Rasel
10:00	253	Stabilized & Optically Tailored Plasmonic Nanocomposite Preparatoin Using Laboratory Scale Extrusion	Joshua Orlicki
10:30	323	Comparison Of Selective Localizaton Of Swnts In Blends Of Powdered Pa6/ Polypropylene And Granule Pa6/Polypropylene	Dongho Kang

Monday Afternoon		**Composites / Thermosets Joint Session**	
Moderator		**Marc Imbrogno**	
2:00	305	Investigation Of Chemical Foaming Agents Application For Thermoset Injection Molding	Stefan Haase
2:30	377	New Metrics For Evaluation Of Network Defects In Glassy Thermosets	Madhura Pawar
3:00	221	Enhancement Of Flame Retardancy Of Unsaturated Polyester Resin Based On Dopo Derivatives And Aluminum Hypophosphite	Shi Xing Xing
3:30	249	On The Filler Orientation Of Functionalized Thermoset Molding Compounds During Injection Molding	Torsten Maenz
4:00	85	Influences On The Flow Behavior Of Phenolic Molding Compounds Measured In Continuous Kneaders	Thomas Scheffler
4:30	258	Three-Dimensional Numerical Flow Simulation Of Resin Transfer Molding Process With Draping Analysis	Sejin Han

Session Details ANTEC 2017

Time	Control #	Title	Presenters
Monday Afternoon		**Nano Composites Ii**	
Moderator		**Enamul Haque**	
2:00	134	Aligned Nanocomposites From Cellulose Nanocrystals By Electrospinning With A Soluble Polymer Followed By Thermoset Impregnation	Craig Clemons
2:30	222	Enhanced Hydrophobicity Of Electrospun Polyvinylidene Fluoride-Co-Hexafluoropropylene Membranes By Introducing Modified Nanosilica	Lingli Zhang
3:00	390	Ultrasonic Processing Of Epoxy/Cnt Nanopaper Composites	Yanan Zhao
3:30	138	Multifunctional Ply Interphases In Hierarchical Composite Laminates	Oleksandr Kravchenko
4:00	115	Nanocomposites From Lignin-Containing Cellulose Nanocrystals And Poly (Lactic Acid)	Liqing Wei
4:30	68	Synthesis And Characterization Of Microcellular Injection And Injection-Compression Molded Ppgma/Graphene Nanocomposites	Shyh-Shin Hwang
5:00	195	Non-Isolthermal Crystallization Kinetics Of Tin Nanoparticles Filled Poly(Ethylene Terephthalate)	Ting Wu

Session Details ANTEC 2017

Time	Control #	Title	Presenters
Tuesday Morning		**Composites Processing And Materials I**	
Moderator		**Feraboli Colleague 1**	
8:00	Keynote	Carbon Fiber Sheet Molding Compounds As Materials For The Future	Paolo Feraboli
8:30			
9:00	98	Viscosity And Screw Assembly Effects On Mechanical Properteis Of Glass Fiber Reinforced Nylon Compounds	Ying Shi
9:30	326	Novel Liquid-Dispersion Technology For Making Industry Leading Highly Filled, Well-Dispersed Masterbatches	Philip Brunner
10:00	206	Tensile Behaviors Of Polypropylene Single-Polymer Composites Prepared By Extrusion-Calandering Method	Shi Xing Xing
10:30	259	Interlaminar Reinforcement Of Composite Laminates With Heat Activated Shrinking Microfibers	Sundong Kim

Tuesday Afternoon		**Long Fiber Composites**	
Moderator		**Creig Bowland**	
2:00	153	Study On The Micro-Structures Of Long Fiber Through Runner And Cavity In Injection Molding For Reinforced Thermoplastics (Frt)	Chao-Tsai Huang
2:30	38	Experimental Study On Fiber Attrition Of Long Glass Fiber-Reinforced Thermoplastics Under Controlled Conditions In A Couette Flow	Sebastian Goris
3:00	56	A Direct Particle Level Simulation Coupled With The Folgar-Tucker Rsc Model To Predict Fiber Orientation In Injection Molding Of Long Glass Fiber Reinforced Thermoplastics	Ian Walter
3:30	171	Lightweight Design With Long Fiber Reinforced Thermoplastics - Mechanistic Direct Fiber Simulation For Prediction Of Long Fiber Effects During Compression Molding	Christoph Kuhn
4:00	366	Impact Of The Process-Induced Microstrucutre On The Mechanical Performance Of Injection-Molded Long Glass Fiber Reinforced Polypropylene	Jan Teuwsen
4:30	369	Effects Of Extruder Temperature And Screw Speed On Thermal Properties Of Glass Fiber Reinforced Polyamide 6 Composites Throughout The Direct Long-Fiber Reinforced Thermoplastics Precess	Takashi Kuboki

Tuesday Afternoon		**Composites Processing And Materials Ii**	
Moderator		**Ray Boeman**	
2:00	572 Keynote	Multifunctional Energy Storage Composites For Lightweight Transportation Applications	Fu-Kuo Chang
2:30			
3:00	371	Injection Molding Of Glass Fiber Reinforced Polypropylene Composite Foams With Laminate Skins	Takashi Kuboki
3:30	445	A Comparative Study Of The Tensile Properties And Failure Behavior Of Glass/ Polyethylene Terephthalate (Pet) Mat Composites	Zhao Defang
4:00	448	Multi-Material Joining For Carbon Fiber Thermoplastic B-Pillar	Shridhar Yarlagadda

Session Details ANTEC 2017

Time	Control #	Title	Presenters
Wednesday Morning		**Natural And Bio Composites**	
Moderator		**Feraboli Colleague 2**	
8:00	122	Man-Made Cellulose Fiber Reinforced Polypropylene – Characterization Offracture Toughness And Crack Path Simulation	Jan-Christoph Zarges
8:30	189	Polypropylene Bio-Composites Utilizing Camelina Press Cake	Brent Tisserat
9:00	191	Improving The Flame Retardancy Of Polypropylene /Rice Husk Composites Using Graphene Nanoplatelets And Metal Hydroxide Flame Retardants	Shu-Kai Yeh
9:30	446	Flexural Behavior Of Needle Punch Glass/Jute Hybrid Mat Composites	Zhao Defang
10:00	432	Evaluation Of The Mechanical And Morphological Characteristics Of Pla-Lignin, Pla-Tannin And Pla-Cnf Composites	Muhammad Anwer
10:30	67	Flax Fiber-Polyamide 6 Composites Via Solid-State Shear Pulverization: Expanding The Portfolio Of Natural Fiber-Reinforced Thermoplastics	Katsuyuki Wakabayashi

Wednesday Morning		**Composites Innovation**	
Moderator		**Dale Brosius**	
8:00	Keynote	A Path For Composites	Tom Tsotsis
8:30			
9:00	Panel (120 Min)	Future Of Composites - Challenges And Opportunities	Panel (Dale Brosius, Tom Tsotsis, Matt Carroll, Ed Pilpel, Lisa Mueller, Max Thouin, Jeff Sloan)

Wednesday Afternoon		**Composites Potpourri**	
Moderator		**Shankar Srinivasan**	
2:00	411	Surface Texturing Of Composite Materials By Induced Damage: Surface Morphology And Friction	Reza Rizvi
2:30	117	Surface Treatment Of Carbon Fiber By Anodic Oxidation And Improvement Of Ilss In Cfrp	Hirofumi Kyutoku
3:00	477	Ultrasonic Method For Determining Ply Orientation In Unidirectional Carbon Fiber Composites	Benjamin Blandford
3:30	48	Characterization Of Developed Hybrid Moldings By Textile And Short Fiber Reinforced Composites	Taiga Saito

Board Meeting Minutes Nov 21, 2016

By: Antoine Rios

Conference Call
Monday, November 21, 2016

Attendees:

Michael Connolly	Andy Rich
Dale Brosius	Ray Boeman
John Busel	Rich Caruso
Tim Johnson	Antoine Rios
Nippani Rao	Dale Grove
Klaus Gleich	Ian Swentek
Jim Griffing	Jack Gillespie
Pritam Das	Mingfu Zhang
Shankar Srinivasan	

Meeting started at 12:05pm EST

Chair: Michael Connolly

Wants to implement more frequent shorter meetings. Will try to arrange one meeting every two months. Invitations were sent via email for meetings up to September 2017.

Currently reviewing the Composites Division policy manual. Have heard feedback from some board members, but still needs more feedback.
Action (M. Connolly): ***to send latest revised policy manual to group.***

Introduction of new volunteers: Hicham Ghossein (U. Tennessee), Christoph Kuhn (VW-DE), Mingfu Zhang (Johns Manville)

Standard operating procedures (SOP): received SOP from some members, but waiting for others.
Action (All): ***all committee chairs should prepare a SOP document for their respective area***

Secretary: Antoine Rios

Last meetings minutes approved via email.
Action (A. Rios): ***add volunteers to contact list and distribute.***

Chair-Elect: Ray Boeman

Working on Pinnacle award. Similar to last year's. Will approach specific individuals for information. The submission deadline is January 27, 2017

Searching for next chair-elect.
Action (R. Boeman): ***continue search for next chair-elect***

Technical Conference Report:

JEC Automotive Forum 2016 (Oct 15-16, 2016, Knoxville, TN) – Dale B.

- Approximately 200 attendees. The exhibit consisted of table tops for exhibitors

Cyclitech 2016 with JEC (Dec 6-7, 2016, Newport Beach, CA) – Rich C.

- Attendance to date: approx. 120 (70 discounted). There are about 7-8 sponsors

Thermosets 2017 (March 21-22, 2017, Phoenix, AZ) – Dale Brosius

- Conversations with Larry Nunnery. COMDIV could help with contents for 2018

ANTEC 2017 (May 8-11, 2017, Anaheim, CA) – Jim G./Shankar S./Rich C.

- Papers are due on January 13, 2017. Reviews to occur by January 27, 2017. Final paper revision deadline is February 24, 2017.
- Expectations are that if you are in the board that you will review papers.

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This Issue:

Board Meeting Minutes continued...

JEC Building & Construction Forum 2017 – Summer 2017 – Rich C.

- Conference focused on building and construction located in Chicago.
- J. Busel: if the focus is the end user it may be difficult to pull attendees. At this time COMDIV may need to focus on other venues

ACCE 2017 (September 5-8, 2017, Novi, MI) – Dale Brosius

- Peggy won't be providing support anymore. Trying to sort out with SPE to understand what can they provide in regards to organization services. CAMX is the week after so this may affect ACCE's sponsorship.

Composites MiniTec with Philadelphia Section (Fall 2017) – Jack Gillespie

- One-day event, industry from the region. At this time the level of support needed is unknown

Education: Michael Connolly in lieu of Uday Vaidya

Uday is not in the conference call.

Discussed funding proposal from Winona.

Action (D. Brosious): email Uday to find out if machine pricing is a "general" price or a university price. Voting to be postponed after we get the answer

Newsletter: P. Das

New meeting format confusing in regards to contents for the newsletter. It was clarified that there will be minutes for every meeting, but reporting only from those committees that are providing updates. Each committee chair should be preparing a report when their topic is in the agenda.

It was decided to continue printing one newsletter a year at ACCE

continued on page 17...

Board Meeting Minutes continued...

Membership: Ray Boeman

- New SPE membership software allows improved data mining.
- Membership has held steady since August.
- Need new volunteer for membership committee.

Treasury Report: Tim Johnson

Account balance showing an approximate $50k cash + $75k in investments (Vanguard Mutual Fund – Investment grade corporate bonds)

Awards: Ian Swantek

- We were not in time for fellow or HSM award submission.
- May need one volunteer to help with communications of the awards.

Communications: A. Rich

Peggy designed current website a long time ago. It has not been updated in a while and needs revamping

Looked for proposals from different web designers. There may be an advantage to host website with SPE. Monthly maintenance would be considered part of the plan. The plan would include seeking information from BOD in a monthly basis to feed the website. ***Action (A. Rich): seek approval to authorize expenses to redevelop website.***

Meeting adjourned at 1:58 pm EST

Award Winning Paper

Effects of Processing Parameters on the Thermal and Mechanical Properties of LFD-D-ECM Glass Fiber/ Polyamide 6 Composites

Y. Fan, Y.C Liu, T. Whitfield, T. Kuboki and J. T. Wood1
Department of Mechanical and Materials Engineering, University of Western, London, Ontario, Canada
V. Ugresic
Fraunhofer Project Centre for Composites Research University of Western Ontario

Abstract

In this work, the influences of the process parameters (i.e. melt temperature, extruder fill level, glass fibre (GF) temperature and screw speed of the mixing extruder) on the thermal and mechanical properties of the dry, as-molded materials were investigated. The material system of focus is 30wt% GF reinforced polyamide (PA6) manufactured via the Direct Long Fibre Thermoplastic Extruder Compression Molding (LFT-D-ECM) process. Characterization by tensile, flexure and impact tests on both the in-flow and cross-flow directions was carried out. Glass transition temperature, which plays an important role in the properties and failure mechanism of PA6 composites, was examined using dynamic mechanical analysis (DMA) and the degree of crystallinity was measured by differential scanning calorimetry (DSC). Fill level and melt temperature were observed to play the greatest role in determining the properties of the composite. The effects of processing parameters on glass transition temperature, melting temperature and the relative degree of crystallinity values of composites are presented.

Key Words: LFT-D-ECM; polymer composites; extruder fill level, mechanical properties; glass transition temperature; DMA; degree of crystallinity

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Introduction

Due to the high impact resistance and recyclability, long fiber reinforced thermoplastic (LFT) has gained a rapid growth recently, especially in the automotive industry as a replacement for traditional metal parts [1-4]. In terms of processing, LFT can be divided into three types: glass mat thermoplastics (GMT), long fiber thermoplastic granules (LFT-G) and direct long fiber thermoplastic (D-LFT). Having combined the advantages of relative high performance (GMT) and low cost (LFT-G), D-LFT has been developed into injection molding compounding process (LFT-D-IMC) [5] and extruder compression molding process (LFT-D-ECM) [6]. The latter process employs two extruders for the polymer-additives plasticizing and fiber-polymer compounding respectively as well as a hydraulic press for compression molding [7].

In general, the core of LFT-D-ECM process is a single screw or two co-rotating screws. The screw is always designed to provide desired mixing quality with separate modules, such as kneading, conveying and restricting modules. In order to increase the mixing quality, some parameters, such as the screw speed, can be adjusted. But on the other side, the

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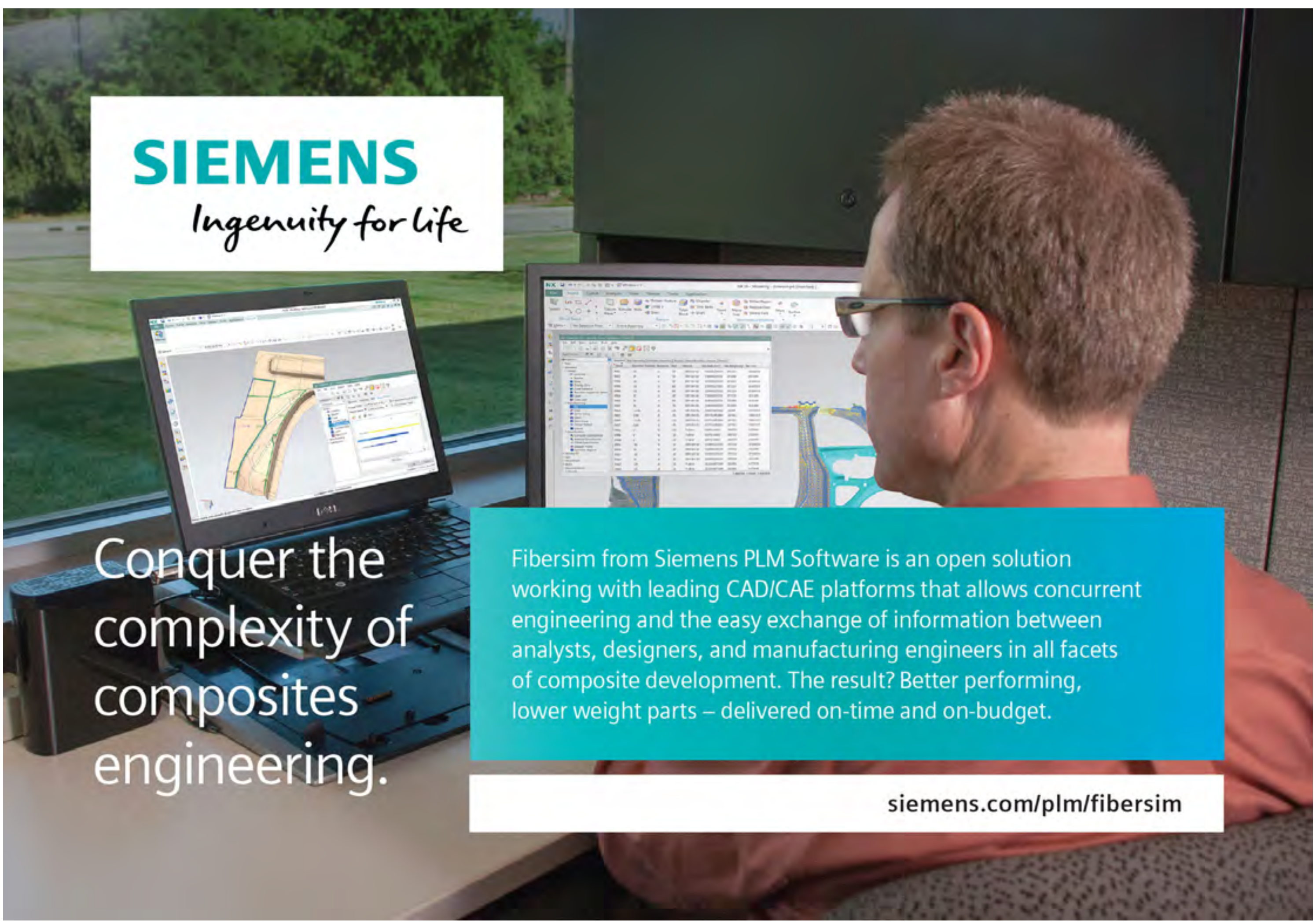
$$k_2 = \frac{(L_2)(\rho)(f)(N)(A_f)}{F} \quad [1]$$



high shear flow, which is required for good mixing quality, might bring damage to the fiber. Shimizu [8] concluded that the total number of rotations and shear stress are the major factors which influence the fiber breakage. According to the empirical formulation listed below, the relationship between different processing parameters and fiber length can be predicted [9]

where k2 is the key factor for the average glass fiber length in a composite, L2 is the length of the mixing section of extruder, ρ is the average density of the material, f is the fill ratio, N is the screw speed, Af is the free cross section of the extruder, and F is the feed rate of the composite. Therefore, in order to optimize the mechanical properties, the processing parameters need to be controlled to find a balance between mixing quality and fiber length distribution. Czarnecki and White [10] proposed a mechanism for fiber breakage during rotation in shear flow for polystyrene composites. Fisa [11] reported that more fiber breakage was found when screw speed, mixing time and fiber content increased in polypropylene (PP) based composites. Wall [12] also found that average fiber length decreased with increasing screw speed. Yilmazer and Cansever [13] concluded that when the shear rate increased via a high screw speed or low feed rate, the average fiber length decreased. However, impact strength, Young's modulus, and tensile strength increased, whereas elongation at break decreased. Priebe [14] found that higher screw speeds generated shorter fi-

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bers, but had little effect on mechanical properties and lower viscosity polymer led to short fiber in PP/GF composites. G. Ozkoc [15] reported that the increased screw speed reduced the fiber length and also had some negative effect on mechanical properties. The increased extrusion temperature helped increasing the final fiber length and therefore improved the mechanical properties. Jonas [16] and Rodgers [17] studied the effect of screw speed and filling level on mechanical properties of PA66/CF and reported that the screw speed had very little influence on the measured material properties and increased filling level had negative effect on mechanical properties. Mechanical properties are typically the main area of focus when characterizing the effect of processing conditions [18-20] because ultimately they are the most desirable attribute of composite materials. However, the factors that affect these properties are also of high importance for further process optimization. Knowledge of causal factors comes from understanding molecular structure and material behaviour during high temperature processing. Thermal properties have previously been used with an effort to characterize the effect of modifications to the processing conditions during fabrication of a PA6/GF composite [21, 22].

In this paper, the specimens are manufactured using a LFT-D-ECM line. The influence of processing parameters, including screw speed, filling level, melt temperature and fiber preheating, on the thermal properties of the compression molded composite are studied by means of thermogravimetric and DSC analyses in an attempt to better describe some of the causal influences of material property changes. Mechanical performance including tensile, flexure and impact are also characterized, with stiffness compared to theoretical predictions.

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Experimental

Materials and processing

The materials used are the polyamide 6 (PA6) from BASF (Ultramid® 8202 HS) and glass fibres with an average diameter of ~16µm from Johns Manville (JM 886). The fraction of glass fiber is set to be 30wt%. Before processing, the PA6 pellets were dried at 80°C for about 16h using a forced air dryer.

Dieffenbacher's LFT-D-ECM process line was used to compound and compress the flat plaques as shown in Figure 1. Polymer pellets and additives are plasticised and mixed in twin screw extruder I. The polymer melt exits the compounding extruder through a film die into twin screw extruder II. Rovings are continuously fed through a hose system and pulled into the mixing extruder together with the melt by the screws. Preheating of the rovings, if employed, is accomplished by guiding them around heated steel rollers. The cutting of the rovings inside the cylinder is defined by its geometry and the screw configuration. The compound is continuously extruded on a conveyer belt through a servo die which makes the strand shape adjustable. The plastificate charges are then placed into a press for compression molding. Four different parameters, screw speed, filling level, melt temperature and fiber preheating, are adjusted in 8 independent trials as shown in the Table 1. The glass fiber weight fraction was set to be 30% for all 8 trials.

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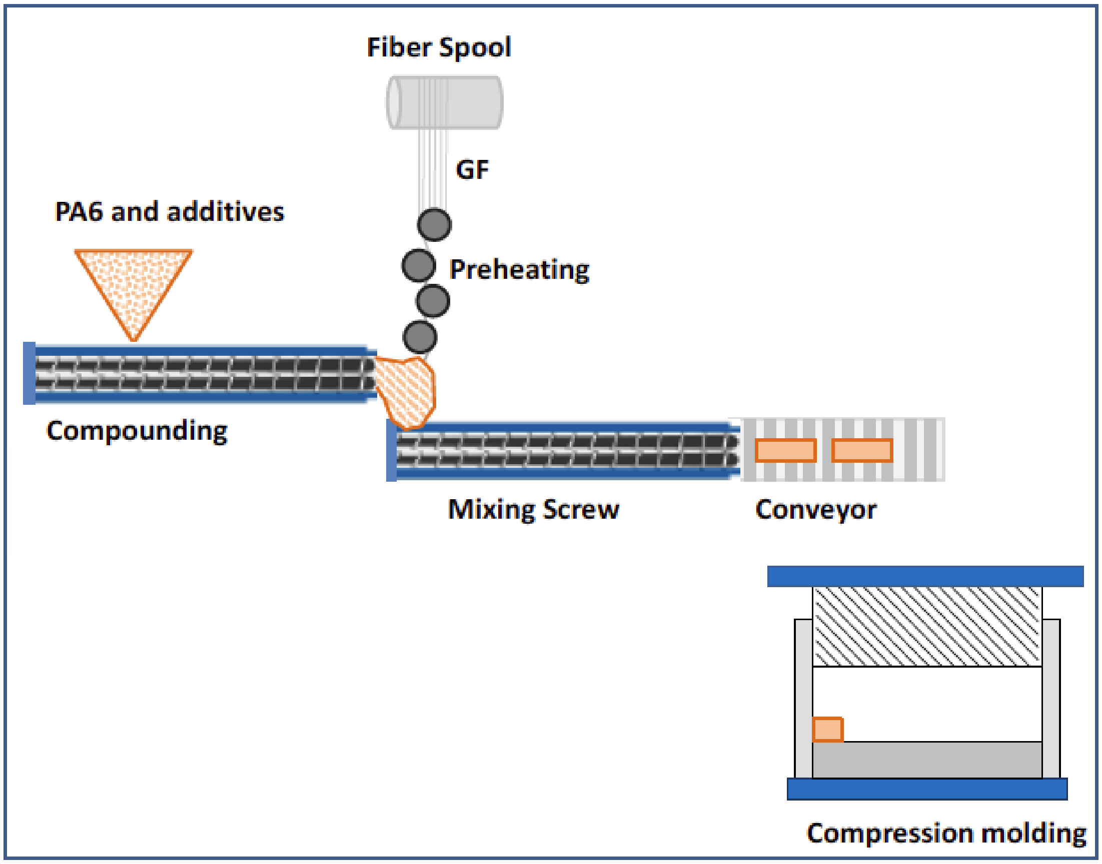

Figure 1. Diagram showing the LFT-D-ECM line used for producing plaques

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Table 1. Processing Parameters

	Melt Temperature (°C)	Screw Speed (rpm)	Volume Fill (cm^3/rev)	Fiber Temperature (°C)
T1	280	50	30	R.T.
T2	280	100	30	R.T.
T3	280	25	30	R.T.
T4	280	50	65	R.T.
T5	280	50	10	R.T.
T6	270	50	30	R.T.
T7	290	50	30	R.T.
T8	270	50	30	120

Characterization Procedure

All the specimens were collected from the compression molded plaques produced using the LFT-D-ECM line at Fraunhofer Project Center (FPC). Before testing, all specimens were dried in a conventional oven with desiccant at 100°C for 48 h to maintain the dry, as-molded condition. Tensile, flexure, Izod impact and DMA specimens were cut in both the in-flow and cross-flow directions.

Fiber Content Measurement by Burn-off Test

Burn-off tests were performed at 500-525°C in a tube furnace. The samples with an average size of 20x20mm were collected from 4 different locations on each of the compression molded plaques. The fiber weight fraction can be calculated by measuring the specimen mass before and after the matrix material has been burned away.

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Thermogravimetric Analysis

Thermogravimetric analyses (TGA) were performed using a TA Instruments SDT Q600. 8mg samples (±0.5mg) were cut from the resulting compressed plaque in each trial. The samples were cut from the same location on each of the plaques to maintain consistency. To avoid any external reactions with oxygen, nitrogen was used as a purge gas with a flow rate of 100ml/min into the cell. The thermal cycle began at room temperature and was ramped to 600°C at a rate of 10°C/min. The instrument measured mass loss as a function of temperature throughout the heating cycle.

Differential Scanning Calorimetry

Differential Scanning Calorimetry analyses (DSC) were performed using a TA Instruments DSC Q200. 8mg samples (±0.5mg) were cut from the resulting compressed plaque in each trial. Samples in each trial were cut directly adjacent to the samples used in the TGA analysis to maintain consistency and have accurate measurement of the fiber weight. Similar to the TGA analysis, nitrogen was used as a purge gas to avoid external reactions (with a flow rate of 50ml/min into the cell). The scan began at room temperature and was ramped to 300°C at a rate of 10°C/min as the instrument measured heat flow (W/g) into the sample as a function of temperature.

Determination of Dynamic Mechanical Properties

The dynamic mechanical properties of specimens were analyzed with a Thermal Analysis Instrument, TA Q800 dynamic mechanical analyzer (DMA). The samples (60x12.7x3mm) were cut from the same location on each of the molded plaques in 0° and 90° directions to maintain consistency, and were subjected to a three-point bending mode with a support span of 35 mm. Measurements were conducted over a temperature range of room temperature to 150 °C with a heating rate of 3 °C/min and a constant frequency of 1.0 Hz.

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Mechanical Testing

Tensile tests were conducted following ASTM638 using an Instron 8800 universal frame equipped with hydraulic grips using a load cell of 250kN and crosshead speed of 2mm/min. A 50mm extensometer was used to measure the strain. Flexural tests were performed in accordance with ASTM D790 using an MTS universal tester with a load cell of 100kN. Un-notched Izod impact tests was conducted following ASTM D256 using an Instron impact tester with built-in software for data acquisition. Dart test was conducted using an Instron Dynatup 9250HV drop tower impact tester and Impulse Data Acquisition software according to ISO 6603-2, using a test speed of 2.2 m/s and a potential maximum energy input of 48.6 J. The striker with a hemispherical tip is mounted on a drop weight. The test specimens were 60 x 60 mm plaques cut from molded flat panels. The resulting force versus time curves were analyzed to determine the peak load and the total energy absorbed during the impact.

Results

Mass Loss Analysis using TGA method

Figure 2 shows the resulting decomposition profile from the thermogravimetric analysis. The curves shown in the figure have been normalized to show a percent of the total mass loss to compare Tonset between samples. The total mass loss is measured from 150°C until the end of the heating cycle to remove the effect of moisture. All the curves follow a single-stage decomposition. The figure also shows a change in decomposition onset temperature, T_{onset}, which is defined as the point where 5% of the total mass loss has occurred. Past studies have attributed a shift in the decomposition curve to a higher temperature under the same conditions to an increase in thermal stability [23]. Table 2 shows average T_{onset} and $\mathbf{W}_f$ of each sample. The mean weight fraction of fiber present in all samples was 31.22% (st.dev. = 3.30%). The deviation in the fiber weight is a typical result from the inhomogeneity of fiber distribution from plaque to plaque. The decomposition onset temperature showed some small variation between trials but remained fairly consistent in each trial. Namely, the onset decomposition temperature was not affected by the changes in screw speed, volume fill or melt temperature, and fiber preheating had almost no effect on the onset decomposition temperature.

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Table 2. TGA results showing the difference of on-set temperature and fiber weight percentage of the composites due to varied processing parameters

	Initial Mass (mg)	Total Moisture Mass Lost @150 (mg)	Mass at the start of the heating (mg)	Mass at the end of the heating (mg)	%mass of Fibres	T. onset (°C)
T1	8.58	0.01	8.57	2.72	31.71	377.1
T2	8.92	0.02	8.90	3.19	35.82	378.5
T3	8.94	0.00	8.93	2.63	29.44	378.3
T4	8.41	0.02	8.39	2.31	27.59	382.5
T5	8.68	0.03	8.66	3.06	35.32	378.2
T6	8.10	0.02	8.09	2.60	32.15	383.3
T7	8.46	0.06	8.40	2.24	26.67	377.4
T8	8.43	0.04	8.39	2.60	31.03	376.6

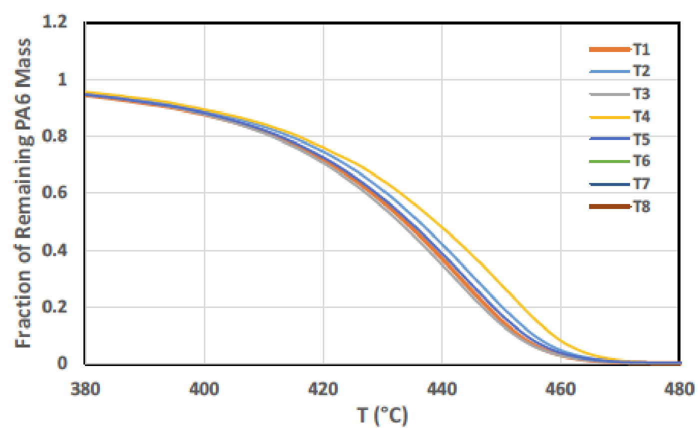

Figure 2 Comparison of weight loss with different processing parameters

Heat Flow Analysis

Results from DSC analyses are presented in Figure 3. These thermograms provide quantitative insight into the temperature of composite melting (T_m), enthalpy of melting (ΔH_m), as well as the degree of crystallinity (X_c) of the composite material being tested [24]. The degree of crystallization was calculated using Equation 2):

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$$X_c = \frac{\Delta H_m}{\Delta H_f(1 - W_f)} \times 100\% \qquad [2]$$

where ΔH_m is enthalpy of fusion of fully crystalline Polyamide 6, which is taken to be 230.1 J/g [25]. The resulting values of the tested samples are shown in Table 3. The results showed that the change in the processing conditions had only a small effect on the degree of crystallinity.

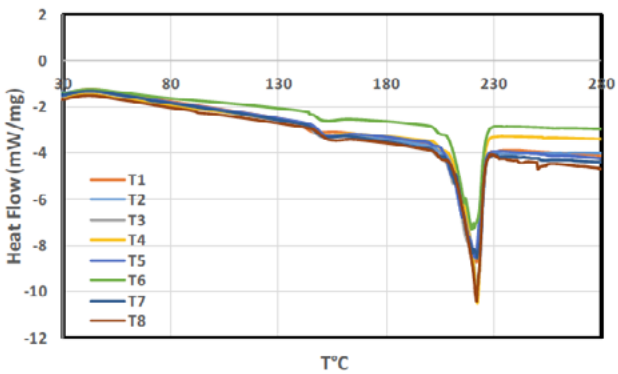

Figure 3 Comparison of thermograms with the change of processing parameters

	T_{melt}	H_m	%mass of Fibers	Xc
1	222.1	37.5	31.7	23.9
2	222.1	35.3	35.8	23.9
3	222.3	33.7	29.4	20.8
4	222.4	40.7	27.6	24.4
5	221.2	35.2	35.3	23.7
6	219.8	35.4	32.1	22.7
7	221.7	34.9	26.7	20.7
8	222.1	36.5	31.0	23.0

Table 3. DSC results showing the difference of melting temperature and crystallinity of the composites due to varied processing parameters

Dynamic Mechanical Analysis (DMA)

Results from dynamic mechanical analysis of the compression molded composites are summarized in Table 4 and Figure 4 which depicts E´ and tan δ as a function of temperature at a frequency of 1 Hz. It was observed that, over a temperature range of 30 °C to 150 °C, only one transition region as indicated by the damping maxima is recorded, corresponding to a relaxation arising from the chain segmental motion of the molecules. The peak, which is at the maximum value of tan δ in α-transition [26], Tα is generally known as the glass transition temperature, Tg. It was noticed that Tg for all specimens is about 78°C as shown in Table 4, which is similar as revealed by An et al [27] while higher than Kroll et al [28] who reported Tg of 55°C for 40wt% GF/PA6 with DMA test run in the range of -85°C-150°C. This means that the change of processing parameters didn't generate significant trend in deviation of Tg of GF/PA6 composites. Polyamide plastics are normally used below their Tg as their mechanical strength and stiffness is optimal in this field. This can be related to the improved stiffness of the composite of the PA 6 reinforced with glass fiber.

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	Glass Transition Temperature (Tg)		R.T. Storage Modulus (GPa)	
	In-flow	Cross-flow	In-flow	Cross-flow
T1	77.95°	77.84°	7.09	4.37
T2	77.59°	77.23°	7.02	4.42
T3	77.30°	76.71°	6.61	4.13
T4	77.58°	76.88°	6.49	4.13
T5	77.24°	75.93°	7.76	3.61
T6	77.77°	77.32°	6.79	4.14
T7	77.73°	76.57°	6.17	3.50
T8	76.78°	76.07°	6.19	4.01

Table 4. DMA results showing the difference of glass transition temperature and room temperature storage modulus of the composites due to varied processing parameters

The effects of each processing parameter on the room temperature storage modulus are compared. It can be noted that no visible difference has been observed with T1 and T2 which use different screw speeds of 50rpm and 100rpm, respectively, while a lower modulus was obtained when the screw speed was chosen as 25rpm for T3, at both cross-flow and in-flow directions. With the increase of fill level, the in-flow storage modulus decreases. This storage modulus changing trend is similar as in the cross-flow direction for fill levels of 30 and 60 at room temperature while showing the lowest magnitude when the fill level is 10. In both the in-flow and cross-flow directions, the low temperature storage modulus increased when the melt temperature was raised from 270°C to 280°C and dropped to the lowest when the melt temperature was further increased to 290°C. For both the in-flow and cross-flow directions the storage modulus decreased when the fiber was preheated to 100°C before processing.

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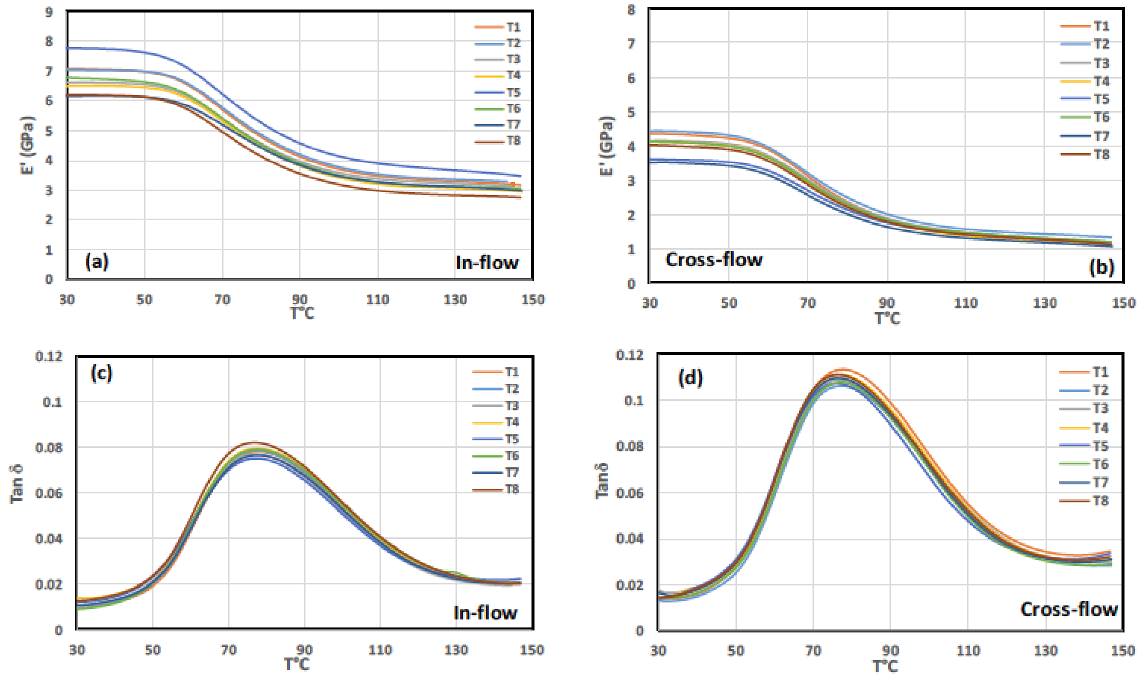

Figure 4 Storage modulus as a function of temperature with the change of processing parameters

Mechanical properties

The mechanical testing results are summarized in Table 5 which shows superior properties in the in-flow direction compared with that at cross-flow direction, similar to the DMA results. To some extent, the tensile and flexure moduli of the composites are influenced by the processing parameters as demonstrated in Figure 5 & 6 (a). It can be seen that there isn't big difference found with the variation of screw speed. It is noted that the T5 specimens with the lowest fill level gain the highest Young's modulus and flexural modulus. On the other hand, with the increase of melt temperaure, the Young's modulus shows a trend of increase while a relatively notable variation is observed from specimen to specimen. It is also noted that preheating of the glass fibre before mixing with PA6 matrix results in lower tensile and flexural moduli in both directions and lower tensile strength in flow direction. No significant difference is found for either the tensile or flexural strengths due to varied processing parameters as shown in Figure 5 & 6 (b).

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	Young's Modulus (GPa)		Tensile strength (MPa)		Flexure Modulus (GPa)		Flexure Strength (MPa)		Impact Strength (J/mm²)	
	In-flow	Cross-flow	In-flow	Cross-flow	In-flow	Cross-flow	In-flow	Cross-flow	In-flow	Cross-flow
T1	10.75	6.64	201.67	90.46	9.77	5.66	311.29	160.84	50.08	17.78
T2	10.59	5.77	208.81	95.36	10.06	5.64	308.15	159.70	47.27	13.41
T3	11.05	6.22	202.20	97.05	10.32	5.63	307.80	162.89	62.21	12.17
T4	9.71	5.34	190.87	87.88	9.41	5.37	302.26	164.11	52.79	19.63
T5	12.28	7.03	193.14	94.18	10.94	6.19	311.99	153.89	47.28	22.35
T6	10.01	5.87	188.52	87.86	9.92	5.36	310.05	161.40	53.18	16.81
T7	11.49	5.53	190.57	95.71	10.19	5.56	303.02	161.86	49.51	20.05
T8	9.77	5.88	179.17	97.50	9.48	5.52	298.51	167.72	55.54	15.16

Table 5. Tensile and flexure testing results showing the difference of mechanical properties for compression molded composites with varied processing parameters

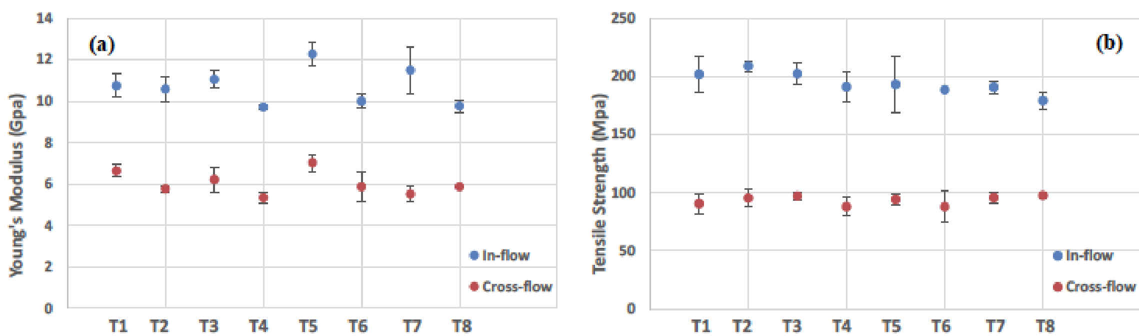

Figure 5 Comparison of the effects of processing parameters on tensile properties: (a) Young's modulus; (b) Tensile strength

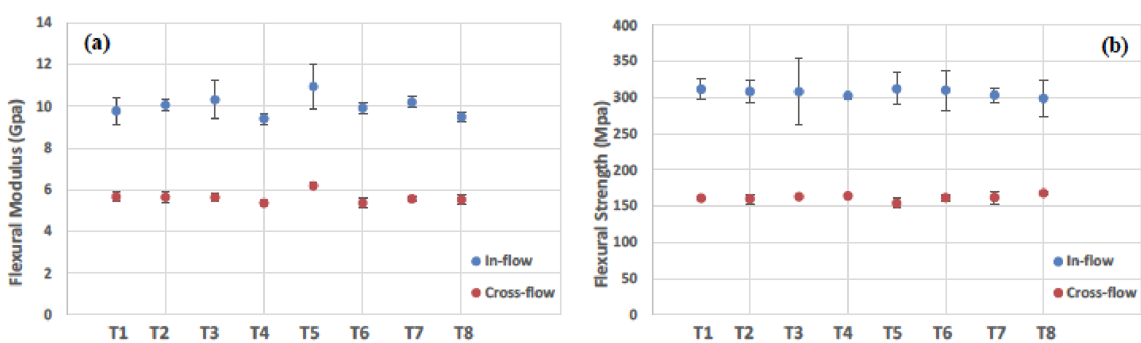

Figure 6 Comparison of the effects of processing parameters on flexural properties (a) Flexural modulus; (b) Flexural strength

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The impact properties of the composites with different processing parameters are shown in Figure 7 and Figure 8. T3 and T8 specimens show relatively higher average impact strength and total energy. T1 and T2 were shown to have relatively higher peak load which is related to the strength and stiffness of the samples. While as the Izod results are considerably varied from specimen to specimen and, therefore, no obvious relationship can be deduced. All specimens tested were within one standard deviation from each other and, therefore, no hard conclusions can be drawn at this point.

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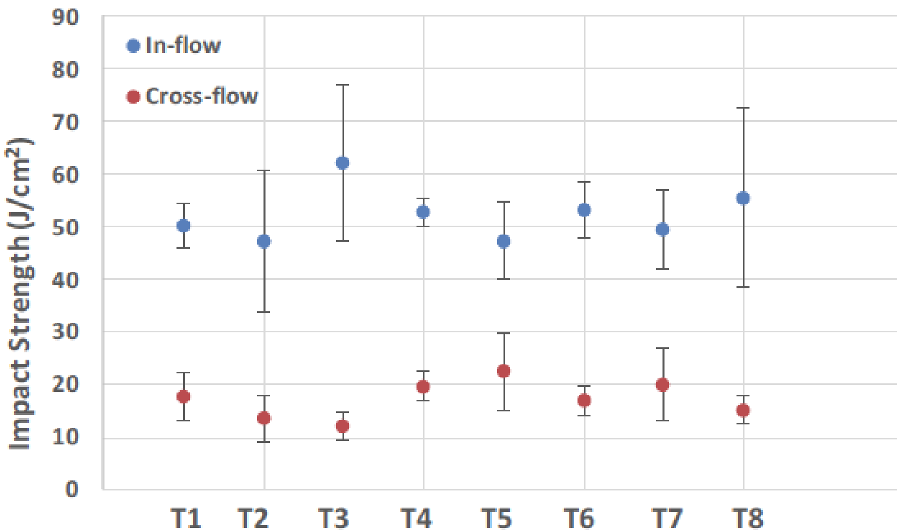

Figure 7 Comparison of the effects of processing parameters on impact strength

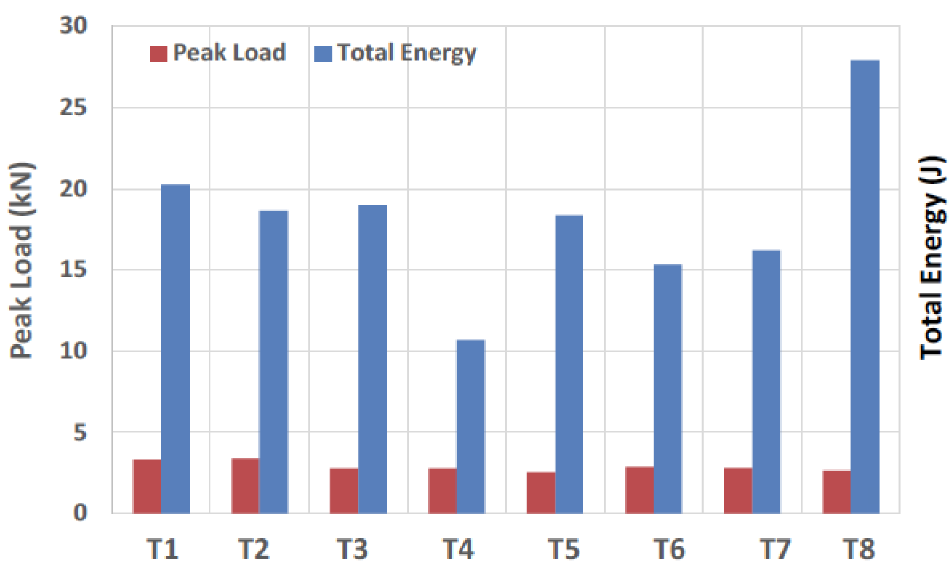

Figure 8 Comparison of the effects of processing parameters on the peak load and total energy

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Discussion

Fiber Content and Length

From the TGA results shown in Figure 2 and Table 2, the fluctuation of the fiber content in different samples processed using varied processing parameters can be observed. As the TGA samples are only several milligrams, they might be too small to be representative of the actual fiber distribution in the long fiber composite. Therefore, burn-off test is conducted on larger specimens. The measured weight fractions of the four specimens from each of the eight processing trials are presented in Figure 9. It can be seen that the variation of processing parameters, especially filling level and fiber preheating have visible influence on the fiber content. T5 plaque with the lowest fill level has fiber content about 36.3% which is higher than the designed weight fraction of 30wt%. This might be caused by adjusting the number of the rovings when dropping the fill level during process. On the contrary, T4 plaque with the highest fill level has relatively lower fiber content, which suggests the possibility that the intake of fibers into the second extruder in influenced by the fill level. In addition, preheating of the fiber before extrusion requires the guidance of the rovings around two hot steel bars, which means that the previous rovings need to be cut and refed into the extruder. This might result in a lower fiber content in the final pressed plaque.

The morphology of glass fiber in the composite is demonstrated in Figure 10. Although some fiber might be collapsed after the polymer matrix is burnt off, the fiber length can be estimated to be in the range of 10-40 mm. This observation and the fiber fraction results will be applied to the mechanical model for prediction of composite properties in the following section.

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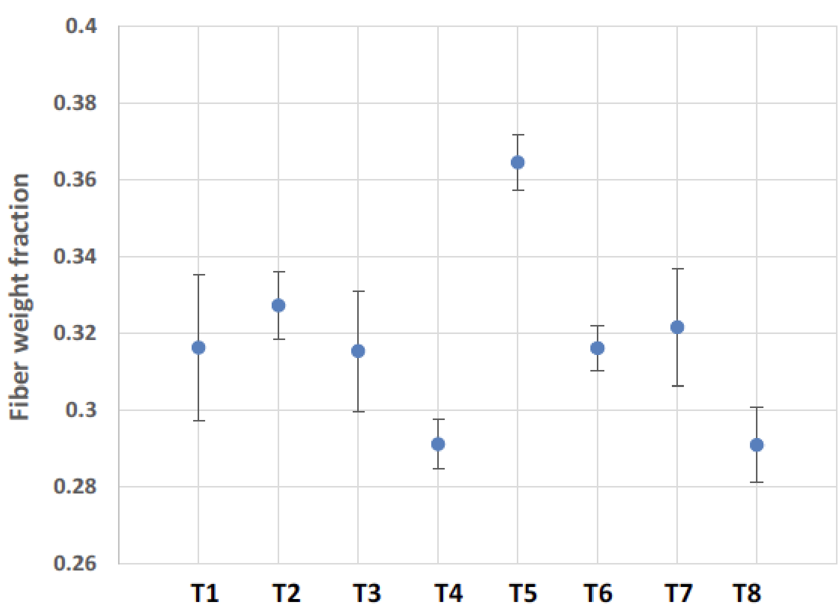

Figure 9 Fiber content obtained by burn-off test for plaques with different processing parameters

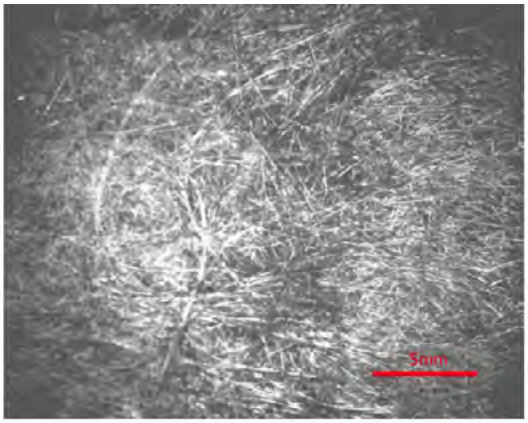

Figure 10 Optical microstructure of GF after PA6 burnt-off (to be replaced if a better one obtained)

Prediction of the Stiffness of GF/PA6 Composites

The most used and widely accepted model to predict axial Young's modulus of discontinuous reinforced composites was developed by Cox and extended by Krenchel [29, 30]. Base on the rule of mixtures, it incorporates the effect of fiber orientation and length.

$$E_C = \eta_0 \eta_1 V_f E_f + (1 - V_f) E_m \qquad [3]$$

Where, Ef =70 GPa and Em = 2.7 GPa for this test material. As crystalline PA6 is stiffer than amorphous, the increase of degree of crystallinity (Xc) might also contribute to the increase of stiffness. However, the variation of Xc shown in Table 3 obtained by DSC methods is negligible and its effect on mechanical properties is ignored here.

Based on Mortazavian's recent work [31] on 30wt%GF/ PP, the orientation factor η_0 is set to 0.375(for random) as lower bound, 0.78 as a reference and 1 (for unidirectional) as an upper bound.

$$\eta_1 = 1 - \frac{\tanh(\beta L/2)}{\beta L/2} \qquad [4]$$

taking the fibre length L into account with

$$\beta = \frac{1}{r}\left[\frac{2G_m}{E_f \ln(\pi/4V_f)^{1/2}}\right]^{1/2} \qquad [5]$$

Where, Gm= 1.07 GPa is the shear modulus of the PA6 matrix, and r= 0.008mm is the fibre radius.

Based on the screw configuration used and Figure 10 which demonstrates the morphology of glass fiber after burning off polyamide matrix, fiber length is mostly 10-40 mm. Even though the quantitive fiber orientation distribution has not been obtained, with the average fiber content of different processing conditions and average fiber length assumed to be 10, the lower bound (random) and upper bound (unidirectional) of Young's modulus are calculated based on the Eqation 2. The prediction is compared with experimental results in Figure 11, which shows that all the tested data points lie between the upper and lower bounds and have a good agreement if the fiber orientation factor is set to be 0.78 as in refernce [31].

By using the same model, the effect of fiber length on Young's modulus reduces with increasing fiber length can also be predicted as shown in Figure 12. It is interesting to see that this effect can be neglected when fiber length is longer than 10 mm in the PA6/GF material system. This relationship can also help intepret the mentioned influence of screw speed. As the fiber length is mostly 10-40 mm, the limited reduction of the fi-

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ber length in this level, which is a result of high screw speed, might not be sufficient to generate any significant influence on the Young's modulus. Considering the effect of fill level on the stiffness of the composite, lower fill level leads to low shear stress during mixing, which helps increase the fiber length and benefit the mechanical properties. On the other hand, the fiber fraction is relatively high in the T5 specimens as shown in Figure 9 which might lead to higher stiffness. The stiffness loss caused by preheating of the glass fibre before mixing might be due to the damage of fiber preheating process to the fiber length when fibers are exposed to higher temperature, which in turn weakens the mechanical properties. In the future plan, fiber length are to be measured to confirm this assumption.

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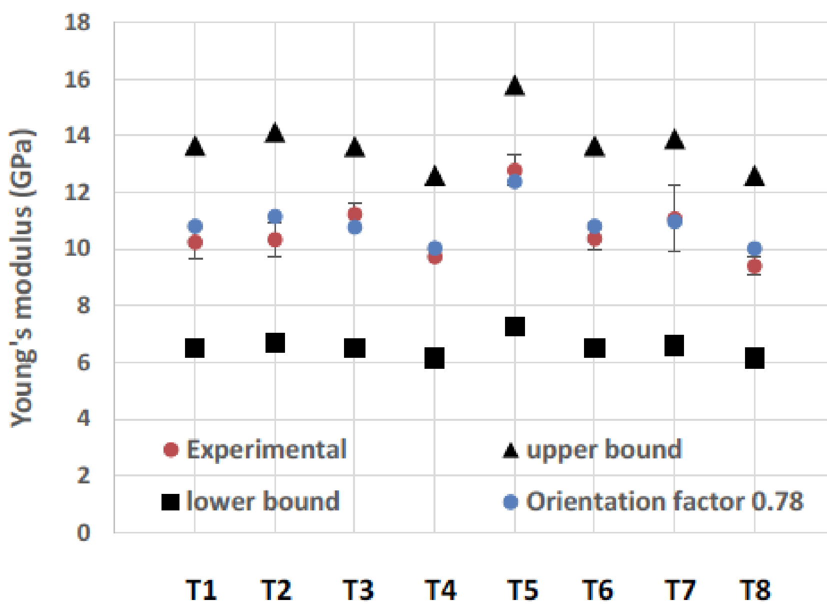

Figure 11 Comparison of experimental Young's modulus with the predicts of upper (unidirectional) and lower (random) bound and orientation factor of 0.78

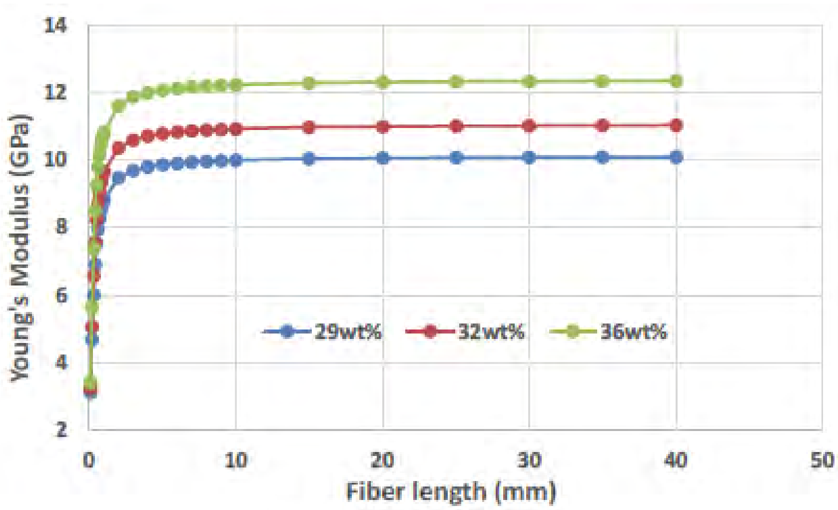

Figure 12 The predicted relationship between Young's modulus and fiber length

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If the tested and predicted Young's modulus result are compared, a good agreeement can be found based on the related fiber content result. 3% lower or 4% higher fiber content can reduce or increase Young's modulus by around 2 GPa, respectively which is consistent with the testing result. In addition, after comparing the change of mechanical properties with the variation in the fiber content, it is interesting to note that the change of processing parameters leads to the fluctuation of the fiber content which is a dominating factor for the mechancial properties.

Conclusion

Thermal properties of the LFT-D-ECM PA6/LGF attained from the TGA showed relatively little affect by changing the processing conditions. The largest effect of thermal properties was seen when the preheating of fibers resulted in the highest glass transition temperature and was also the only condition to lower the T_{onset}. Glass transition temperature didn't change much with the variation of the processing parameters. The fill level was shown to play a relatively critical role in determining the mechanical properties of the compressed plaque. Decreasing the filling level led to reducing both tensile and flexure moduli. Preheating of the fiber turned out to decrease the performance of the composite. The screw speed and melt temperature were found to have limited effect on mechanical properties. Similar results were observed for room temperature storage modulus from DMA testing and to some extent may be affected by the fluctuation of fiber content observed by both burn-off test and TGA. Glass transition temperature was show not to be affected much by different processing parameters. Theoretical prediction and experimental results are in good agreement.

Acknowledgement

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