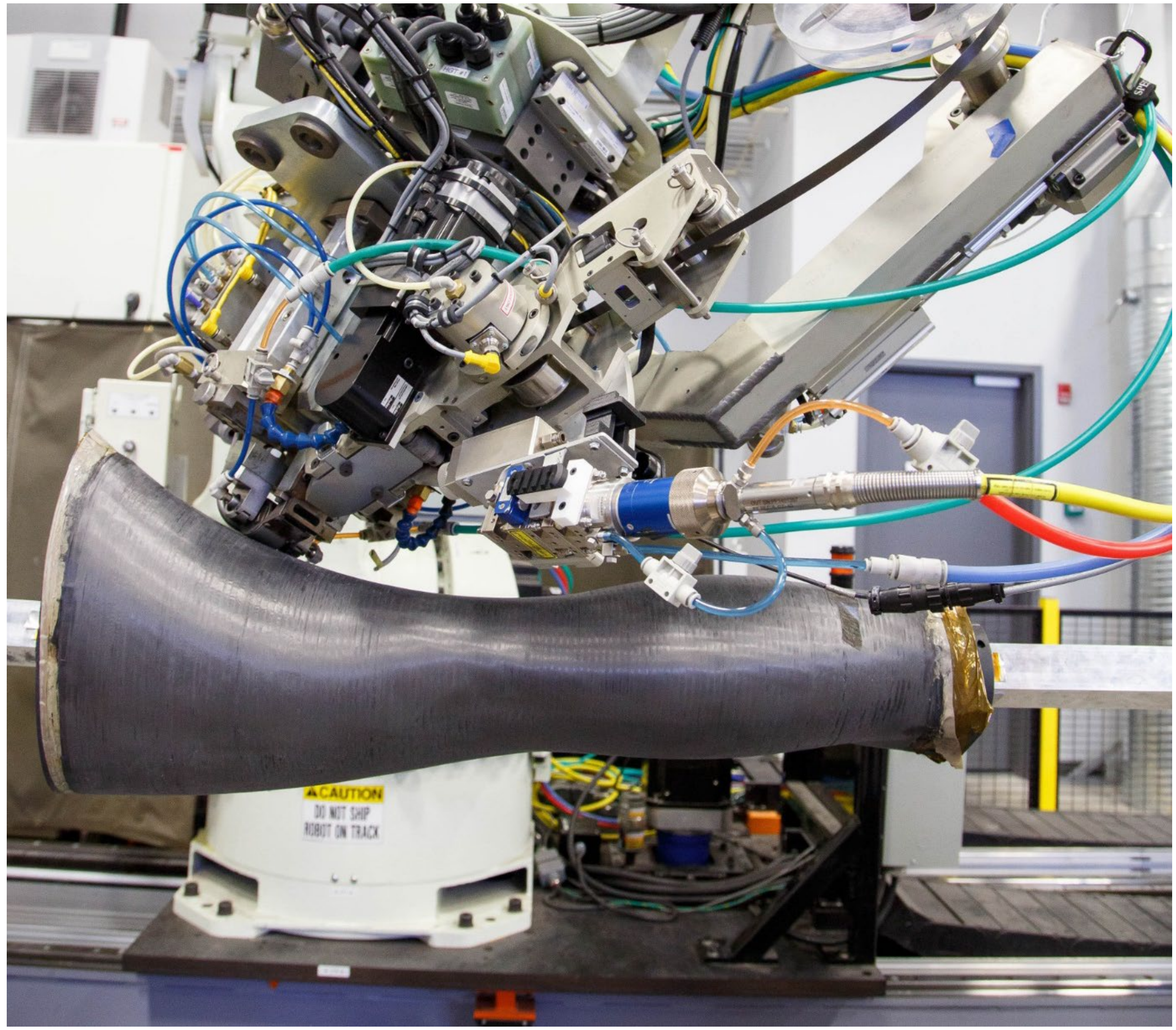
THE FOURTH INTERNATIONAL SYMPOSIUM ON AUTOMATED COMPOSITES MANUFACTURING

April 25 – 26, 2019

Montreal, Canada

Automated Composites Manufacturing



Courtesy of Automated Dynamics

Hosted by:

CONCORDIA CENTRE FOR COMPOSITES
CENTRE DES COMPOSITES CONCORDIA

The Fourth International Symposium on Automated Composites Manufacturing

Date: April 25 Thursday to April 26 Friday, 2019

Place: Plaza Centre Ville
777 Blvd Robert Bourassa
Montréal (Québec) H3C 3Z7,
Canada

SPONSORS

CONTENTS

WELCOME REMARKS

The first Symposium on Automated Composites Manufacturing held in Montreal April 2013 was a big success, with 122 attendees from 11 countries. The second and third symposia on Automated Composites Manufacturing held in Montreal in April 2015, and April 2017 were also big successes, with similar attendance. With the augmented use of composites in many important engineering applications, the need for faster and more efficient manufacturing of structures using composites has become more and more evident. Large structures such as aircraft fuselages, wind turbine blades, bus bodies etc. may not be efficiently and effectively made using conventional composite manufacturing techniques. Many large aircraft companies such as Boeing, Airbus have introduced the use of automated composite manufacturing techniques into the production of their products. Research and Development work on this topic at different universities and research institutes around the world is increasing. Automated Composites Manufacturing techniques such as Automated Tape Lay Up and Automated Fiber Placement have the potential to reduce waste of materials, to provide high rate of materials deposition, and more repeatability in terms of quality of the laminates. These techniques may also provide more seamless transition from design to manufacturing, thus resulting in faster product development cycles. These techniques can also produce composite structures that are unique and that cannot be made using other composite manufacturing techniques. What is probably most important is to find ways to exploit automation to reduce the cost for the manufacturing of composites structures.

The intention of this Fourth International Symposium on Automated Composites Manufacturing is to continue to provide a focused forum for the Composites community to share information and to exchange ideas on this new important area of development. I am glad to say that we have an excellent program with participation from major organizations around the word. The two-day program is packed with information. One particular feature of this Fourth symposium is that there will be voting to select the host (out of three bidders) for the Fifth International Symposium on Automated Composites Manufacturing (ACM5). This shows strong interest in the composites community to continue and expand activities in this important area.

The symposium is part of the activities of an Industrial Chair on Automated Composites Manufacturing supported by the Natural Sciences and Engineering Research Council of Canada, with the support of Bell Flight. On behalf of the organizing committee, we thank all our co-organizers, supporters and all the participants around the world whose contributions have made this Symposium a reality. We hope that the participants will benefit not only from the technical information provided, but also from the contact and interaction with other participants.

Montreal April 2019

On behalf of the organizing committee

Suong Van Hoa, Symposium Chair

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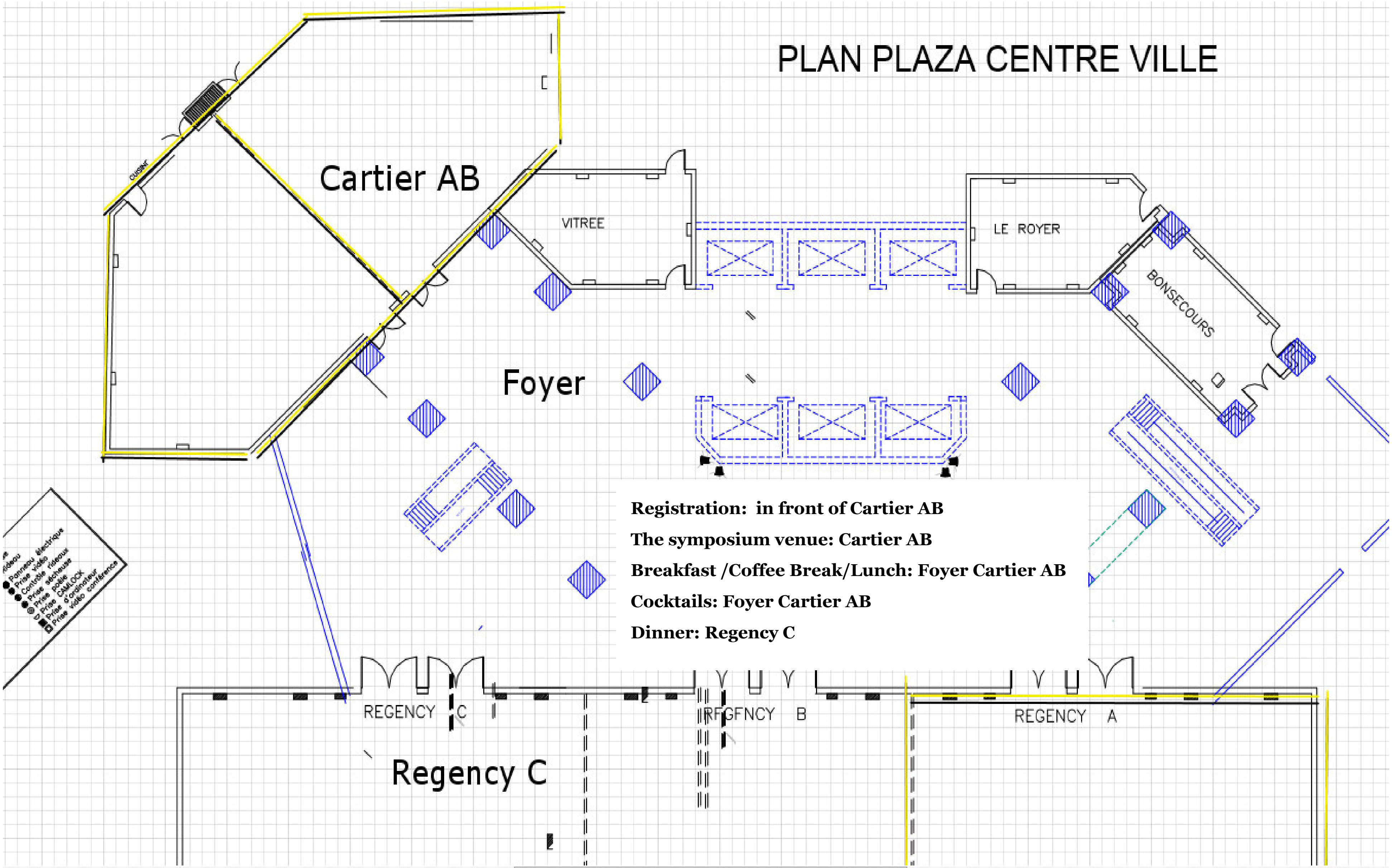
VENUE FLOOR PLAN



Registration: in front of Cartier AB

The symposium venue: Cartier AB

Breakfast /Coffee Break/Lunch: Foyer Cartier AB

Cocktails: Foyer Cartier AB

Dinner: Regency C

SYMPOSIUM INFORMATION

» REGISTRATION

Registration desks will be open on April 25 - 26, 2019, in front Cartier AB of Plaza Centre Ville:

April 25 (Thursday): 07:30 – 18:30

Apirl 26 (Friday): 07:30 –12:30

Location: Plaza Centre Ville, 777 Blvd Robert Bourassa, Montreal, Canada H3C 3Z7

» REGISTRATION FEE

Category	On-site Registration
Full (including lunch, coffee and banquet)	CAD $450
Student (including lunch and coffee, no banquet)	CAD $200
Banquet	CAD $100

*All above fees are quoted in Canadian currency.

* All above fees (excluding for Accompanying Person) include a Program Booklet and a usb containing the programs/papers.

* Student registration needs to provide proof of student

» RECEIPT AND CERTIFICATE OF ATTENDANCE

A certificate of attendance for participants and an official receipt for paid registration will be provided.

» Program /Proceedings

The program book will contain presented abstracts /papers which also are included in the proceeding USB.

SYMPOSIUM INFORMATION

» NAME BADGE

All participants, accompanying persons and exhibitors must wear their name badges to access the symposium. You will be given a name badge when you register at the registration desk. If your badge needs correction, please visit the registration desk for a replacement.

» INTERNET (wi-fi)

During the period of the symposium, standard internet access is available free within the symposium venue with password: 5148790718

» POSTER PRESENTATION

The posters will be setup at Foyer Cartier AB.

» BREAKFAST, COFFEE BREAK AND LUNCH

Continental breakfast, coffee break and lunch are provided at Foyer Cartier AB for April 25 and 26, 2019.

» BANQUET /COCKTAILS

If you have purchase banquet tickets, these are included in the name badge. The banquet is a good time to network with other participants. It will be held at Room Regency C. There will be cocktails before the dinner at Foyer Cartier AB.

» Weather in Montreal

In the end of April, the average temperature in Montreal is around 11 degree Celsius.

SYMPOSIUM INFORMATION

» TRANSPORTATION: AIRPORT - DOWNTOWN MONTREAL

Transportation between Pierre Elliott Trudeau airport and downtown Montreal can be done in many ways:

- Taxi: Taxi has a flat rate of CAD $40.00 from the airport to downtown + tip. Taxi stand at the airport is outside the arrival area. From downtown, you just stand on the street and wave at a taxi coming by.
- Shuttle 747: The shuttle has a flat fare of $10 from the airport to downtown for unlimited travel throughout STM bus and metro networks during 24 consecutive hours. It runs 24 hours a day and 7 days a week, at intervals of 10 to 20 minutes, and only accepts cash in coins. The shuttle nearest stop to the venue is at #Gare Centrale or #Union, see picture below. At the airport, it stands outside the arrival area.
- By car: If you want to rent a car, there are car rental kiosks at the arrival area at the airport. You can ask them for a map to go downtown.

» TRANSPORTATION: IN DOWNTOWN MONTREAL

- Metro regular tickets are CAD $3.25 each. One day pass is CAD $10. A weekly pass is CAD $26.25 (valid on shuttle 747). For more information, please go to stm website http://www.stm.info/en
- The venue is close to metro station "Square Victoria-OACI" at orange line.

PROGRAM

Date: April 25 Thursday

Room: Cartier AB

8:00	**Opening ceremony** Welcoming remarks by Dr. Amir Asif, Dean, Gina Cody school of Engineering and Computer Science, Concordia University

Keynote	Presentation Title	Author(s)	Affliation	Country	Paper Code
8:20	**AFP and the Next 10 Year Shift**	**Blaise Bergmann**	**Spirit AeroSystems, Inc.,**	**U.S.A**	
Session 1	**Applications. Chair: Sayata Ghose**				
9:00	A Techno-Economic Model to Analyze Automation Options for Composite Wind Blade Manufacturing	Stephen B. Johnson, Matteo J. Polcari and James A. Sherwood	University of Massachusetts Lowell	U.S.A	SHE8035
9:20	Automated Manufacture of Adaptive Composite Hydrofoil	Phyo Thu Maung1, Ebrahim Oromiehie1*, Marco Sotelo Zorrilla1, Matthew David1, Ginu Rajan2, Andrew W. Phillips3, Nigel A. St John3 and Gangadhara Prusty1	1.UNSW Australia, 2. University of Wollongong, 3.Defence Science and Technology Group (DSTG)	Australia	ORO8022
9:40	Aerospace Quality In-situ Consolidation of Thermoplastic Composites using Automated Fiber Placement	Graham Ostrander and David Hauber	Automated Dynamics	U.S.A	DYN8020
10:00	Design, Manufacturing and Testing of an In-situ Consolidated Variable Stiffness Thermoplastic Composite Wingbox	Vincenzo Oliveri, Giovanni Zucco, Daniël Peeters, Gearòid Clancy, Robert Telford, Mohammad Rouhi, Ciaràn McHale, Ronan M. O'Higgins, Trevor M. Young, Paul M. Weaver	University of Limerick	Ireland	ROU8016
10:20	Smart Lay-up: Advanced Robotic AFPM for Hybrid Composites Manufacturing	A. Sportelli1, A. Ramirez2, A. Lagrana3,G. Iagulli4 and M. Raffone5	1. Leonardo S.p.A., 2. M.Torres Diseños Industriales SAU, 3. Fundacio Eurecat, 4. Leonardo S.p.A., 5. Leonardo S.p.A.	Italy	SPO8013
10:40	Coffee break & Posters				
Session 2	**General considerations. Chair: Jelle Bloemhof**				
11:00	Artificial Intelligence in Advanced Composite Manufacturing: A Path Forward	Scott Blake	Aligned Vision	U.S.A	BLA8018
11:20	Enabling the exploitation of automated composite manufacturing through data-driven process definition	Philippe Monnot, Laura Veldenz, Mattia Di Francesco, Peter Giddings	National Composites Centre	U.K	VEL8006
11:40	Predictive modelling of the automated fibre placement (AFP) processes: perspectives and challenges	Jonathan P.-H. Belnoue, Yi Wang, James Kratz, Dmitry S. Ivanov and Stephen R. Hallett	University of Bristol	U.K	BEL8003
12:00	Expanding the envelope of Automated Tape Laying	Anders Brødsjø, Jens de Kanter and Mattia Di Francesco	Airborne Composites Automation	The Netherlands	BRO8040
12:20	On the search for In situ consolidation when processing thermoplastic materials using Automated Fiber Placement	Denis Cartie	Coriolis Composites	France	COR8012
12:40	Lunch & Posters				

PROGRAM

Date: April 25 Thursday
Room: Cartier AB

Session 3	**Heat sources and ultrasonic welding. Chair: Ali Yousefpour**				
14:00	Developments in Xenon Flashlamp Heating for Thermoplastic Automated Fibre Placement	David Williams, Philippe Monnot, Martin Brown	Heraeus Noblelight Ltd	U.K	BRO8007
14:20	Selective comparison of heating sources for thermoplastic Automated Tape Placement	Neha Yadav, Ralf Schledjewski	Montanuniversität Leoben	Austria	YAD8005
14:40	Heat Transfer by A Moving Heat Source in AFP Thermoplastic Composites Manufacturing	Omid Aghababaei Tafreshi, Suong Van Hoa, Duc Minh Hoang, Daniel Rosca, Farjad Shadmehri	Concordia University	Canada	AGH8049
15:00	Towards automated ultrasonic welding of thermoplastic composite structures	Irene Fernandez Villegas1, Rik Tonnaer1,2, Tian Zhao1, Bram Jongbloed1, Filipp Koehler1,3, Tiago Filipe1	1. Delft University of Technology, The Netherlands. 2. SAM|XL: Smart Advanced Manufacturing,The Netherlands. 3. Airbus, Germany	The Netherlands	VIL8017
15:20	Improvement of the lap shear strength of resistance-welded thermoplastic composite joints using a silane sol-gel coating on the stainless-steel heating element	Vincent Rohart1, Louis Laberge Lebel2, Martine Dubé1	1. Ecole de Technologie Supérieure, 2. Polytechnique de Montreal	Canada	ROH8008

15:40	Coffee Break				

Session 4	**Variable stiffness laminates. Chair: Farjad Shadmehri**				
16:00	Characterizing the prepreg-compaction roller tack in application to defects appearing in automated fiber placement	Nima Bakhshi, Mehdi Hojjati	Concordia University	Canada	BAK8043
16:20	Effect of Manufacturing Flaws on the Behavior of Composite Beams Manufactured by Automated Fibre Placement (AFP) Process	Mohammadhossein Ghayour, Mehdi Hojjati, Rajamohan Ganesan	Concordia University	Canada	GHA8032
16:40	EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE OF CARBON-EPOXY LAMINATES CONTAINING GAPS FABRICATED BY AUTOMATED FIBER PLACEMENT	V. Cadran, D. Del Rossi, and L. Lessard	McGill University	Canada	CAD8030
17:00	The final step towards manufacturing an optimised variable stiffness panel	Daniël Peeters, Kayin Wurpel, Max Hijne, Julien van Campen, Mostafa Abdalla	Delft University of Technology	The Netherlands	PEE8027

18:00	**Presentation and vote for biddings to host 5th International Symposium on Automated Composites Manufacturing (ACM5)**
19:30	**Banquet** **Banquet speaker: Giuseppe Dell'Anno, from National Composites Center, U.K.** **Presentation title: Accelerating the implementation of automated composites manufacturing capabilities through concurrent engineering principles**

PROGRAM

Date: April 26 Friday
Room: Cartier AB

Keynote	Presentation Title	Author(s)	Affliation	Country	Paper Code
8:00	**Automated industrial system evolution in composite manufacturing technologies and the need for tomorrow**	**Jelle Bloemhof**	**AIRBUS Operations GmbH**	**Germany**	

Session 5	3D printing and quality. Chair: Giuseppe Dell'Anno				
8:40	Experimental investigation of continuous carbon prepreg filaments for 3D printing high performance parts	Sadben Khan, Kazem Fayazbakhsh, Zouheir Fawaz	Ryerson University	Canada	FAY8045
9:00	Effect of Process Parameters on Mechanical Properties of 3D Printed Carbon-Fibre PEEK	Richard G. Cole , Abraham Avalos, Andrew Walker	National Research Council	Canada	COL8014
9:20	Manufacturing issues of structures based on double-double composite concepts	Klemens Rother, Stephen W. Tsai, Waruna Seneviratne	Munich University of Applied Sciences	Germany	ROT8002
9:40	Next Generation Inspection Solution for Automated Fibre Placement	Marc Palardy-Sim1, Maxime Rivard1, Steven Roy1, Guy Lamouche1, Christian Padioleau1, André Beauchesne1, Louis-Guy Dicaire1, Daniel Lévesque1, Jonathan Boisvert1, Marc-André Octeau1, Jihua Chen1, Gil Lund2, and Ali Yousefpour1	1. National Research Council Canada, 2. Fives Lund, Seattle, Washington, USA	Canada	PAL8037
10:00	Layup end effectors with tactile sensing capabilities	M. Elkington, E. Almas, B. Ward-Cherrier, N. Pestell, C. Ward, N. Lepora	Bristol University	U.K	ELK8031
10:20	Coffee break				

Session 6	Process development. Chair: Dave Hauber				
10:40	Development of a manufacturing process for multi-matrix composites based on the Tailored Fiber Placement (TFP) technology	Konze, S.1; Spickenheuer, A.1*; Bittrich, L.1; Richter, E.1; Heinrich, G.1, 2	1. Leibniz-Institut für Polymerforschung Dresden e.V., 2 Technische Universität Dresden	Germany	KON8021
11:00	Wet Fibre Placement Process Optimisation	Philip Druiff1, Mattia Di Francesco1, Giuseppe Dell'Anno1, Carwyn Ward2	1. National Composites Centre; 2. University of Bristol	U.K	DRU8034
11:20	Automated, Quality Assured and High Volume Oriented Production of Fibre Metal Laminates (FML) for the Next Generation of Passenger Aircraft Fuselage Shells	Hakan Ucan1, Joachim Scheller2, Chinh Nguyen1, Dorothea Nieberl1, Anja Haschenburger1, Sara Abshagen2, Sebastian Meister1, Erik Kappel1, Robert Prussak1, Monika Mayer1, Philipp Zapp1, Niko Pantelelis3, Thomas Beumler4	1. German Aerospace Centre (DLR), 2. Frauenhofer Gesellschaft (IFAM), 3. Synthesites SA, Uccle, Belgium, 4. Airbus Germany GmbH	Germany	UCA8028
11:40	Automated Fiber Placement of Thin-Ply Composite Materials for Large Aerospace Structures	Jessica Ferguson1, Konstantine Fetfatsidis 2, Christopher J. Hansen1	1. University of Massachusetts Lowell 2. NextGen Materials & Processing, LLC	U.S.A	FER8024
12:00	Lunch				

PROGRAM

Date: April 26 Friday
Room: Cartier AB

Session 7	**Thermoforming and effect of process parameters. Chair: Blaise Bergmann**				
13:20	Effect of Applied Pressures on the Resulting Quality of Stamp Formed Laminates	Xiao Cai, Suong Van Hoa	Concordia University	Canada	CAI8046
13:40	Integral Manufacturing of Fibre Reinforced Thermoplastics with Metallic Inserts	A. Kunze 1, M. Wagner 1, M. Kreienborg 1, S. Jenkel 2, H.-W. Zoch 1	1.Leibniz Institute for Materials Engineering - IWT 2.Faserinstitut Bremen e.V.	Germany	KUN8011
14:00	Experimental study of the compaction and preforming of unidirectional flax reinforcements	Rodrigue Stéphane MBAKOP, Gilbert Lebrun, François Brouillette	Université du Québec à Trois-Rivières	Canada	MBA8038
14:20	Comparing Test Methods for the Deformation Behavior of Uncured Prepreg Tapes	Klaus Heller, Moritz Hallmannseder, David Colin, Kalle Kind, Klaus Drechsler	Technical University of Munich	Germany	HEL8026
14:40	Effects of Process Parameters on Intimate Contact Development in Laser Assisted Fiber Placement	Ozan Çelik, Julie Teuwen	Delft University of Technology	The Netherlands	CEL8010
15:00	Coffee Break				
Session 8	**New materials, laminates and pultrusion. Chair: Mehdi Hojjati**				
15:20	Peridynamic modeling of the impact-induced damage in composite materials with AP-PLY configuration	M. Nishikawa1,*, E. Oterkus2, M. Nishi3, N. Matsuda1 and M. Hojo1	1. Kyoto University; 2. University of Strathclyde; 3. JSOL Corpoartion	Japan	NIS8001
15:40	Fatigue of composite springs made by 4D printing	Hoa S.V., Rosca I.D., and M.S. Gill	Concordia University	Canada	HOA8033
16:00	The effect of braid angle on the void content and fiber misorientation of thermoplastic Diamond, Regular and Hercules braided rod manufacturing using braid-trusion	Mohammad Ghaedsharaf, and Louis Laberge Lebel	Polytechnique Montreal	Canada	GHA8048
16:20	PULTRUSION AND COMPRESSION MOULDING OF THERMOPLASTIC PRE-IMPREGNATED MATERIALS REINFORCED BY CONTINUOUS GLASS FIBRES	P. J. Novo1, P. Esfandiari2, 4, J F. Silva3, J. P. Nunes3 and A. T. Marques4	1. Olytechnic Institute of Leiria, 2. Dep. of Mechanical Engineering ISEP, 3 Minho University, 4 INEGI/DEMec/FEUP	Portugal	MAR8036

POSTERS

Session Poster	Posters				
1	Fatigue characterization and modeling of polylactic acid as feedstock for 3D printing	Larkin Lee, Kazem Fayazbakhsh, Zouheir Fawaz	Ryerson University	Canada	FAY8044
2	Interface Anisotropy Effects in Fabric Composite Sandwich with 3D Printed Core	Kishore Babu K, Dakshayini B S, Benjamin Raju, Rushal Patil, D Roy Mahapatra	Indian Institute of Science	India	MAH8041
3	3D Printed Architected Lightweight Sandwich Structures	A.H.Akbarzadeh1,2*, H. Yazdani Sarvestani1, A. Mirabolghasemi1, H. Niknam1, K. Hermenean3	1, 2. McGill University, 3. MACHINA Corp.	Canada	AKB8039
4	Influence of support structure on physical properties of non-crimp fabrics	Dimitris Karanatsis1,2, Thomas James1, Andreas Endruweit2, Andrew C. Long2	1. Hexcel Reinforcements UK Ltd, 2. University of Nottingham	U.K	KAR8004
5	Fastening Composite Structures Using Carbon Fiber/PEEK Rivets	C. Absi, P. Assi, A. Bureau, E. Cameron, E. Dimas, S. Dupont, L. Laberge Lebel	Polytechnique Montreal	Canada	LEB8023
6	Recent developments in injection molding technology for light-weight application	Stanislav Ivanov, Gleb Meirson, Andrew Hrymak and Frank Henning	Western University	Canada	IVA8051

LABS VISIT

Visit to the composites labs at Concordia Center for Composites (CONCOM)

April 27, Saturday 2019

Time: 10:00am

Capacity: 30 people

Address: Concordia University, EV building, 1515 St. Catherine St. West, Montreal H3G 1M8

- Delegate needs to register for the tour on the first day of the symposium (April 25 Thursday) at the registration desk.
- The composite laboratories at Concordia University have an Automated Fiber Placement machine and a large tube bending setup for buckling test of composite tubes, apart from other equipment. Limit: 30 people
- Meeting points: - In front of the entrance to Plaza Centre Ville at 9:00 am April 27 Saturday, 2019.

  - At Concordia University: in the lobby of EV building (1515 St. Catherine St. West, Montreal H3G 1M8) at 9:50 am April 27 Saturday, 2019.

Directions from Plaza Centre Ville to CONCOM composites labs:

1- Head north on Rue St Antoine St West by walking for 300 meter until you get to metro station Square-Victoria-Oaci entrance (see picture below)

2- Take metro orange line direction toward Cote Vertu, and get off at station Lionel-Groulx

3- Then go down stairs, and take metro green line direction toward Honore Beaugrand, and get off at station Guy-Concordia where Concordia University is located .


METROPOLITAIN


Concordia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KEYNOTE

AFP and the Next 10 Year Shift

Blaise Bergmann

Spirit AeroSystems, Inc., USA

We now live in the era of composite commercial aircraft. Over the past decade, OEM aircraft manufacturers have launched major composite aircraft programs. Both the Boeing 787 and Airbus A350 are now in high-rate production and flying all around the world. By weight, they boast the highest composite-materials content of any commercial aircraft to date. They are the first of a new breed, utilizing composite materials for the fuselage, wings, and other airframe components.

At Spirit AeroSystems, we design and produce major structures for both of these aircrafts. On the Boeing 787 program, we build the 41 Section which is the forward-fuselage of the aircraft, including the flight deck and systems. On the A350 program, Spirit similarly produces Section 15, which is the large over-wing portion of the fuselage, as well as the forward wing spars. Notably, all of these large composite structures are manufactured via Automated Fiber Placement (AFP.) Though each structure has unique methods and challenges, a common thread is the use of AFP for high-volume, automated fabrication.

After roughly 10 years in these programs, OEMs and suppliers have learned extensively about the capabilities of AFP and composite materials. We better understand the impact of decisions made 10+ years ago around the materials, engineering methods, regulatory requirements, and process capabilities. From this understanding, an opportunity exists to re-examine how composite materials and structures might be designed and built with higher performance and profitability. Furthermore, there is increasing growth in demanding applications: space, personal transport, and military all desire the performance of composite materials and the benefits of high-rate automated production and require cost performance at a program level.

With increasing global demand for composite structures and increasing global competition, there will be opportunity to meet these needs, but only with intelligent and intentional strategies. Next-generation composite materials, evolving AFP robotics, digital methods, control algorithms, simulation tools, and other technologies will impact the next 10 years of Automated Composite Aerospace production. What decisions should be made now? What research should be pursued? What skills and workforce are needed? Indeed, what will the next 10 years look like?

KEYNOTE

Automated industrial system evolution in composite manufacturing technologies and the need for tomorrow

Jelle Bloemhof

AIRBUS Operations GmbH, Germany

Over the last two decades the industrial systems in composite manufacturing has significantly changed. The high level of automation has allowed efficient manufacturing of large component at high rates. Key enablers are manufacturing capabilities that were considered in the design of the components in correspondence to selection of industrial means. But is this now the optimum? Sure not, but what are the needs for the next evolution? This will be elaborated on some key examples.

KEYNOTE

Accelerating the implementation of automated composites manufacturing capabilities through concurrent engineering principles

Giuseppe Dell'Anno, Peter Giddings, Enrique J. Garcia

National Composites Center, UK

The National Composites Centre (NCC), a leading Research & Technology Organisation located in Bristol (UK), is in the final stages of a £37 million capability acquisition programme, aimed at delivering a unique set of digitally-enabled competencies to tackle major challenges in the field of automated composites manufacturing over the coming decades. Generating a well-defined and complete offer for each new capability in the shortest time possible was the key objective of this substantial technology expansion. Achieving such a target demanded dedicated efforts addressing not only the specification, design and commissioning of bespoke industrial equipment but also shaping and developing the appropriate research skills and methods to integrate and exploit the data captured within these novel processes. The NCC successfully adopted the principles of concurrent engineering to accelerate the implementation of these new value streams, by fostering collaboration among suppliers, designers, customers, facilities modification and across all engineering teams within the Centre. Placing all these skill sets simultaneously within a strongly collaborative environment in which they jointly address clearly defined challenges has been the key to this success. Concurrent engineering is not a new concept, and has long been discussed as a key to success in interdisciplinary projects. This presentation uses two specific case studies to demonstrate that creating teams and cultures that thrive on collaboration is achievable and vital in rapid implementation of automated composite manufacturing. Further, it outlines the challenges and highlights the successes realised by the NCC teams using concurrent engineering.

ABSTRACT
NIS8001

Peridynamic modeling of the impact-induced damage in composite materials with AP-PLY configuration

M. Nishikawa[1,*], E. Oterkus[2], M. Nishi[3], N. Matsuda[1] and M. Hojo[1]
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2 Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde
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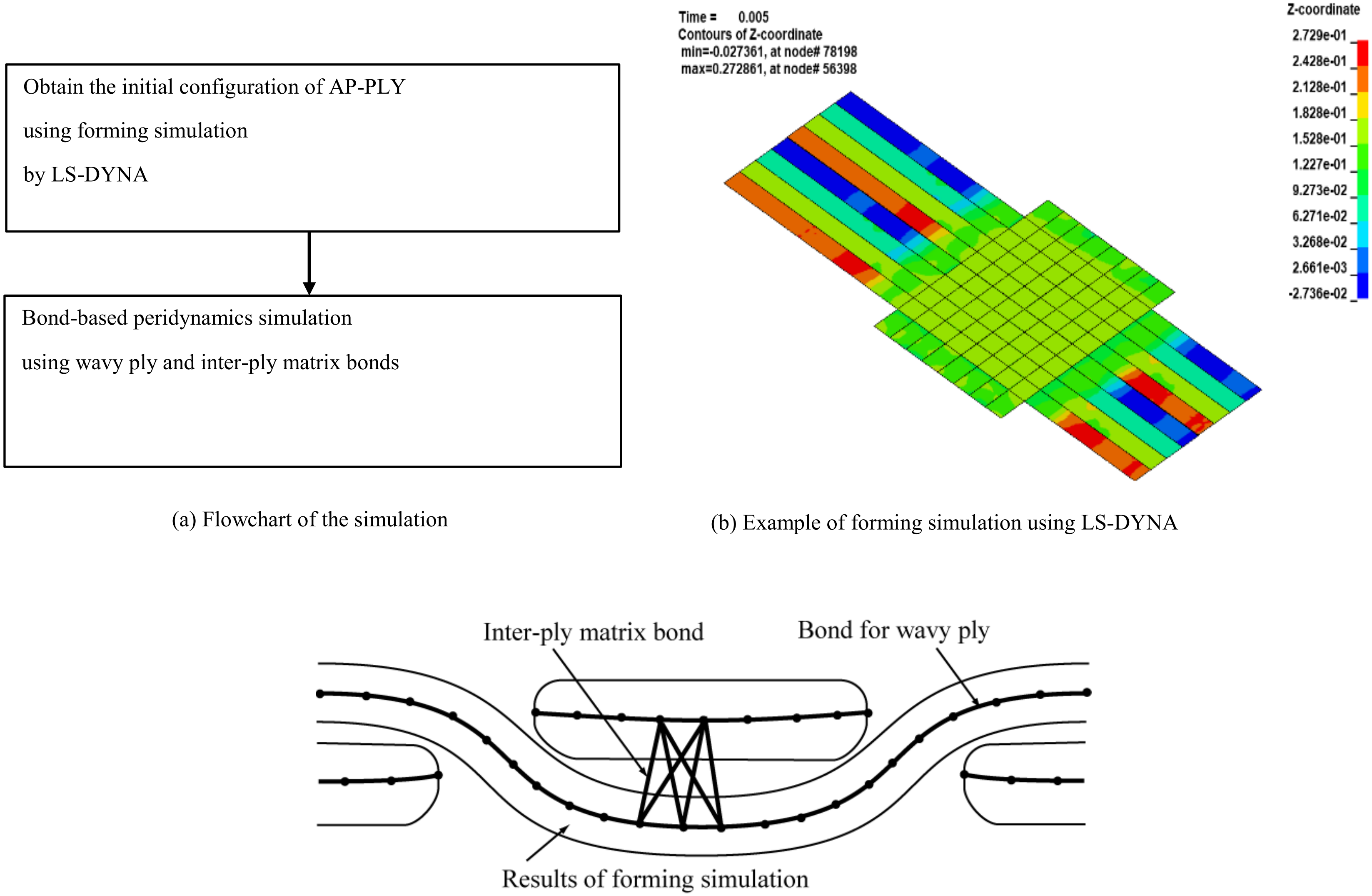
To improve the production rate and efficiency, automated prepreg layup and fiber placement techniques have been developed for the advanced manufacturing technologies of monolithic, large-scale CFRP (carbon fiber reinforced plastics) composite structures. Utilizing automated placement techniques, it is expected that the manufacturers can control fiber orientation, eliminate manufacturing defects and reduce manufacturing variability for the structural integrity of composite structures. Recently, a new concept for the automated placement has been proposed by Nagelsmit et al. [1, 2], called AP-PLY (Advanced Placed Ply). AP-PLY is a specially designed fiber architecture that combines through-thickness reinforcements with an automated fiber placement process. This concept is effective for improving impact damage tolerance of the composite structure due to the through-thickness reinforcements. If preforms are manufactured using AP-PLY configuration, the formability to the complicated structure will be also improved, just like dry woven fabrics.

The present study aims at establishing the simulation techniques for composite laminates with AP-PLY configuration. Since AP-PLY configuration introduces complicated ply architecture after composites forming process, which leads to the complicated damage process in composites, it is attempted to combine the forming simulation and damage simulation techniques, as shown in Fig. 1. First, the forming simulation is conducted using LS-DYNA [3] in order to obtain the nodal coordinates of AP-PLY configuration. The configuration is transferred to the modeling of impact-induced damage simulation using peridynamics theory [4, 5]. Since AP-PLY configuration cannot clearly define the interlaminar region as the conventional laminates, the peridynamics modeling is effective for dealing with the connection of wavy plies. The results and discussion will be presented in the presentation.



(a) Flowchart of the simulation

(b) Example of forming simulation using LS-DYNA

(c) Schematic of peridynamic modeling

Fig. 1 Concept of impact-induced damage simulation for composite laminate with AP-PLY configuration using peridynamics theory.

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ABSTRACT ROT8002

Manufacturing issues of structures based on double-double composite concepts

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Developers and manufacturers of continuous fiber reinforced plastic components are facing several challenges within the competition to achieve minimum material usage and production cost in comparison to many other lightweight materials. This starts with the search for a suitable composite design of the components in the early design phase to obtain optimum stacking for maximum strength and stiffness. Manufacturing challenges are high requirements on tight tolerances and low warpage, and especially high manufacturing cost for cutting the semi-finished products and their layup causing large amount of scrap.

Traditional ply-by-ply placement of each layer is heavily time-consuming and also prone to many restrictions with respect to the possible layup schemes. Due to many design rules the design of such structures in many cases become extremely complex. A group of international researches and industrial partners headed by Prof. em. Stephen Tsai currently focus on the so called Double-Double concept. This structural design and layout concept offers a high potential to reduce cost significantly due to better – because much simpler - design and a number of remarkable manufacturing advantages. From the functional view on the structures requirements additionally this design concept yields also increased strength, damage tolerance and manufacturing accuracy of fiber reinforced plastics. Double-double based structures can either be made of laminates by stacking bi-, tri- or quad-angular plies by using efficient thin-ply sub-laminates. The ideas behind this concept are suited for different manufacturing processes like RTM or prepreg technologies. The concept of double-double has the basic power to simplify the composition of laminates up to very large structures to reduce the complexity of the laminate compositions and the layup procedures. Thus is has the power to act as a mind-set for a new way of thinking composites.

This as a preamble, advantages of the Double-Double design and associated manufacturing concepts and machine tool technology required to manufacture such high-performance based structures will be presented and discussed. Also manufacturing and necessary machine technology of innovative systematical structural lightweight concepts like laminates stiffened by grids or sandwich structures will be covered.

The methods to be presented have been developed and motivated by a team around Prof. em. Stephen W. Tsai from Stanford University with patents pending and are promoted by an international team of researchers and companies which industrialize it and recommend its use. This consortium of institutes and associated companies supports the industry for implementation and use of those methods.

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ABSTRACT
BEL8003

Predictive modelling of the automated fibre placement (AFP) processes: perspectives and challenges

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Automated fibre placement (AFP) technology allows the manufacture of composites parts with more complex geometry and more severe curvature that other automated methods. However, despite being widely used in the industry, the method still suffers from low deposition rates and manufacture of defect-free parts remains very challenging. Setting-up an AFP machine to reliably manufacture a composite part with a minimum number of defects is heavily dependent on engineering experience, and costly, wasteful and time-consuming trials. Being able to predict the as-manufactured geometry and fibre paths in parts made by AFP would significantly help reduce the empiricism inherent to current state-of-the-art AFP manufacturing. Looking forward such models could also be very beneficial in the context of recent trends towards manufacturing 4.0 where the manufacturing process would be heavily instrumented with in-process sensing and the deposition parameters adapted on the fly to mitigate the formation of defects.

The present contribution gives an overview of the recent efforts developed at Bristol Composite Institute (ACCIS) towards building a finite element modelling framework for AFP processes. Inputs include both fundamental understanding of the material behaviour and efficient numerical tools for implementation at large component scale modelling. The requirements for a numerical model for AFP are explored, limitations of the current state-of-art modelling techniques are assessed and a roadmap towards fully predictive and efficient simulation tools is proposed.

ABSTRACT
KAR8004

Influence of support structure on physical properties of non-crimp fabrics

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Abstract

This study focuses on the influence of geometrical parameters of a fixation grid (scrim) on the permeability of carbon fibre non-crimp fabrics (NCF), which are typically processed in Liquid Composite Moulding processes. The carbon fibre fabrics studied comprise of unidirectional carbon fibre bundles (24 K), aligned in the warp direction. The scrim consists of thermoplastic threads arranged in a bi-directional open mesh construction, which are adhesively bonded onto the carbon fibre bundles. Three different sizes of thread were chosen for this study: 74 dtex, 280 dtex and 1100 dtex. The thread density was varied between 0.8 per 10 mm and 4 per 10 mm in both scrim directions. The in-plane permeability of the fabrics, i.e. the two principal in-plane permeability values and the angle indicating the main flow direction, was characterized in unsaturated radial flow experiments at constant injection pressure. Experimental observations confirm that the in-plane permeability of the scrim-backed fabrics is affected by the scrim architecture. The permeability of unidirectional carbon fibre bundles is inherently high parallel to the fibre direction and low in the transverse direction. When a scrim is added, flow is locally enhanced parallel to the scrim threads and reduced perpendicular to the threads, since the geometry of flow channels formed in the fabric is affected. In particular, new flow channels can form along transverse scrims threads which can increase the transverse bundle permeability. As a result, the ratio of fabric permeabilities parallel and transverse to the carbon fibres was found to decrease with increasing size of the scrim threads and with increasing thread density.

ABSTRACT
YAD8005

Selective comparison of heating sources for thermoplastic Automated Tape Placement

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Keywords: ATP process, Thermoplastics, Humm3TM, Hot gas torch, Peel strength

Abstract

Automated Tape Placement is regarded as a process that holds the potential to deliver fast-paced in-situ consolidated thermoplastic composites. Although the process has been used commercially for thermosets, use of thermoplastics remain a field under development. The major parameters that influence the process are heat input, velocity of placement and consolidation pressure applied. Adopting an optimized heating source will help in optimizing the process itself. Assessment of a new heating system requires testing the system for different process parameters and comparing it with results obtained from an established system. This paper aims at comparing a relatively new heat source, humm3™ with a well-known heat source, direct flame torch. Experiments were conducted to compare the nip point temperature, width changes and wedge peel strength for both the heat sources. The results obtained help in analyzing the humm3™ in terms of the material that can be best placed using the system and process improvement in general.

ABSTRACT VEL8006

Enabling the exploitation of automated composite manufacturing through data-driven process definition

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The Automated Fibre Placement (AFP) technology is used currently to manufacture selected structural composite components in the aerospace industry. A variety of raw materials (thermoplastic, thermoset and dry fibres) are available and they have been investigated systematically in the last few years. In an effort to enable the full flexibility of AFP, the adaptations of the processing conditions needed to match the requirements of the different materials have been researched [1–3]. Recent research activity at the National Composites Centre (Bristol, UK) has focused on the investigation of deposition and infusion of dry fibre materials. Various studies are addressing the full design and manufacturing cycle, from material characterisation to prototype manufacture. The properties of the material constituents were linked to the material behaviour during processing [4, 5], the manufacturing process parameters for simple and complex geometries were defined [5, 6] and the variability of the process was quantified [7].

Despite such efforts, the process from the conceptual design of a part to successful serial manufacture is long. Expensive and high-risk steps involve time-consuming programming and process definition, often requiring many iterations to resolve errors. These limitations restrict the use of AFP to high volume applications where the initial time and effort investment is justified by long production runs; overcoming them will unlock the inherent flexibility of the AFP process and enable the manufacture of short series components, potentially even outside of the aerospace sector. Commoditisation of AFP requires the use of transferable knowledge to increase the speed of process definition and output prediction.

This work shows an example of transferable knowledge codified in a digital tool (see Figure 1). The deposition of tapes on a complex geometry based on a programming software tool are compared to the actual deposition quality. The manufactured preform quality is measured; data is post-processed and compared with the quality prediction of the analysis tool provided by the AFP machine manufacturer. This correlation allows the development of a set of transferable rules integrated in the programming process, thereby reducing the trial and error iterations. This case study demonstrates a path to make AFP more easily accessible, enabled by the deployment of digital tools.

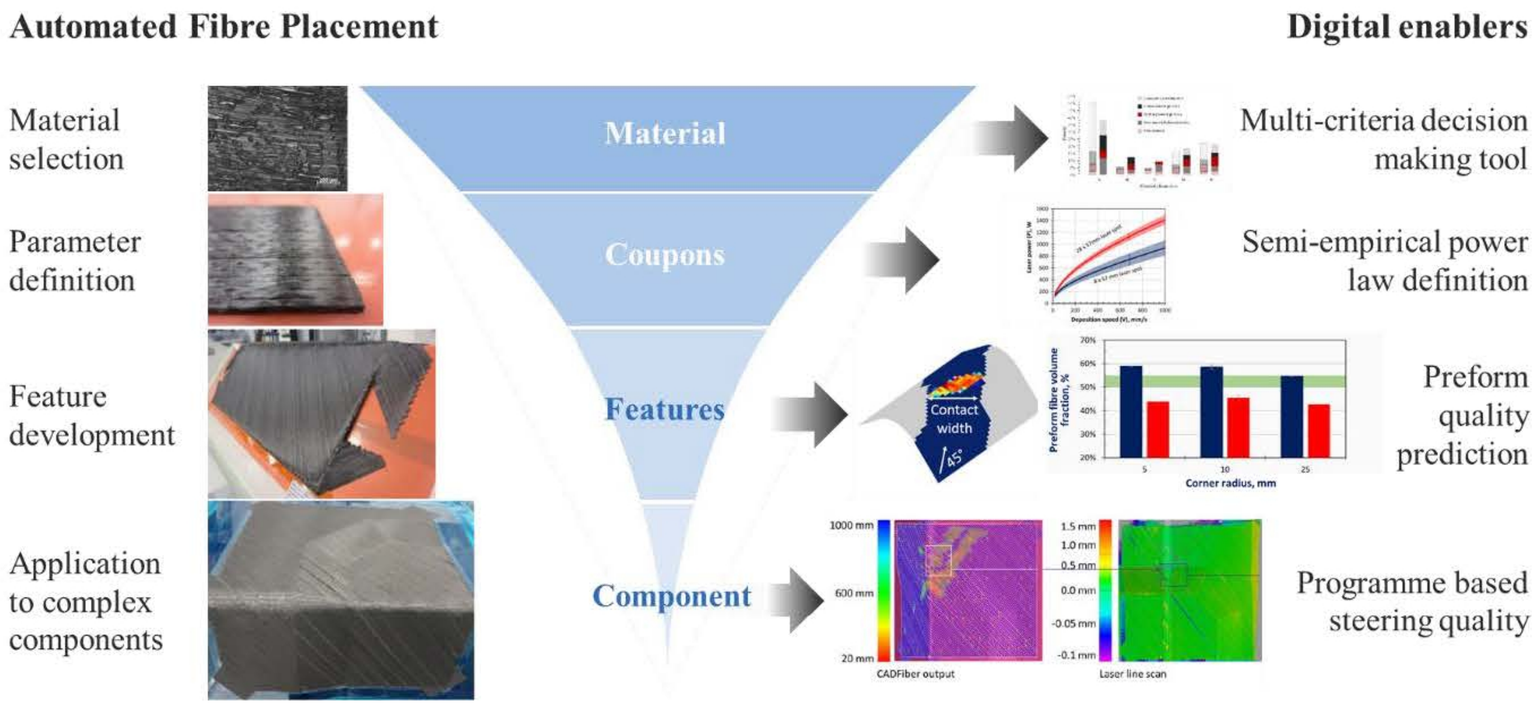

Figure 1: Manufacturing capability development approach and examples of resulting digital enablers for improved process definition

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ABSTRACT
BRO8007

Developments in Xenon Flashlamp Heating for Thermoplastic Automated Fibre Placement

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Mr. Martin Brown, Heraeus Noblelight Ltd, Cambridge, UK (martin.brown@heraeus.com)

As the composites industry develops and moves towards using materials such as fibre reinforced thermoplastics, the need for a heat source that combines high levels of both power and controllability is becoming more apparent. For automated fibre placement (AFP) processes, a large body of research using lasers, hot gas torches and Xenon flashlamps is yet to find a clear solution to the problem of producing high quality thermoplastic parts in a single step, without the need for further consolidation under pressure and temperature.

In this presentation, Heraeus Noblelight will describe the latest developments in its Xenon flashlamp-based humm3® heating technology. Recent technical improvements have increased the average power and efficiency of this pulsed, broadband heat source, and AFP trials on high temperature thermoplastics such as PEEK have highlighted some of the advantages of using a pulsed, broadband source compared with continuous heat sources such as lasers.

In addition to their current research in thermoplastic lay-up, Heraeus Noblelight will also summarize the capability of their technology for high speed AFP using bindered dry fibre materials. High quality preforms have been manufactured at lay-up speeds of up to 1 metre per second by implementing a control system that maintains a required surface temperature even over complex geometries, where robot speed is significantly reduced.

The humm3® technology is also being directed towards non-AFP composites applications. There is a high level of interest in local staking/welding layers of relatively thick, large area dry fibre fabrics for preforming of large structures. The presentation will show how the humm3® combines local pressure and heating to a weld area through its quartz guidance optic, producing stakes/welds through multiple layers of fabric.

ABSTRACT
ROH8008

Improvement of the lap shear strength of resistance-welded thermoplastic composite joints using a silane sol-gel coating on the stainless-steel heating element

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2 Department of Mechanical Engineering, Polytechnique, Montréal QC, H3T 1J4, CANADA

Abstract:

Resistance welding of thermoplastic composites involves using a heating element, usually a stainless-steel mesh, that remains at the joint interface following the welding operation. In this study, we evaluate the adhesion between the thermoplastic matrix, i.e., polyphenylene sulfide (PPS), and the stainless-steel mesh heating element and improve it through the application of various surface treatments involving an organosilane, a bivalent molecule often used to create an organic coating on metals. To enable efficient grafting of the organosilane molecules, the steel was treated with a solution of sulfuric acid to remove the impure oxide layer and oxidized at high temperature. This allowed the surface to be activated by increasing the concentration of oxides that could react with the hydrolyzed silane molecules by condensation. Then, the siloxane network is created by crosslinking in temperature. The grafting parameters are the solvent for the sol-gel coating, silane hydrolysis, oxidation time, silane concentration and reaction time. They were varied to obtain the best adhesion between the stainless steel and the PPS matrix. Measurement of the contact angle between water and steel highlighted surface activation after acid treatment and mesh oxidation. The wettability of the metal was greatly improved. The results of the mechanical tests showed that a silane coating increased the lap shear strength of welded joints by 32%. A better adhesion between the matrix and the treated mesh was observed by electron microscopy. The matrix remained grafted onto the steel after having mechanically tested the joint demonstrating a greater affinity between the two materials.

ABSTRACT CEL8010

Effects of Process Parameters on Intimate Contact Development in Laser Assisted Fiber Placement

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Abstract

Intimate contact development has been considered as one of the principal mechanisms for consolidation during the automated fiber placement process. The phenomena behind the intimate contact development have been explained by the deformation of surface asperities, which are idealized with different geometric descriptors. These surface flattening models have been validated with samples consolidated for relatively long time (from tens to hundreds of seconds), which is not representative for the short consolidation times in the LAFP process. Moreover, current process models are far from reaching high accuracy in predicting the bonding formation. This suggests that more research on the fundamentals of intimate contact development is needed. This work aims to provide more insight into the intimate contact development during LAFP and the effect of process parameters on it.

Effects of nip point temperature, tool temperature, compaction pressure and process speed on intimate contact development is experimentally investigated. 1-layer, unidirectional strips of Tencate TC1320-1 AS4/PEKK material are placed with different process parameters on a flat tool surface covered with thermalamide film. Later on, pieces from the mid-section of the strips (where the process is assumed to reach the steady state) are cut and images are taken from the heated and compacted surfaces of the samples with an optical microscope. Histogram analysis is applied to the images to quantify the degree of intimate contact.

Based on the observations, the concept of *effective intimate contact* is introduced and used to assess the degree of intimate contact. Intimate contact levels as a result of different process parameters are reported. The observations point out to the fact that, at least for this material, intimate contact develops as a result of re-wetting the fibers, which cannot be explained by the current surface flattening models.

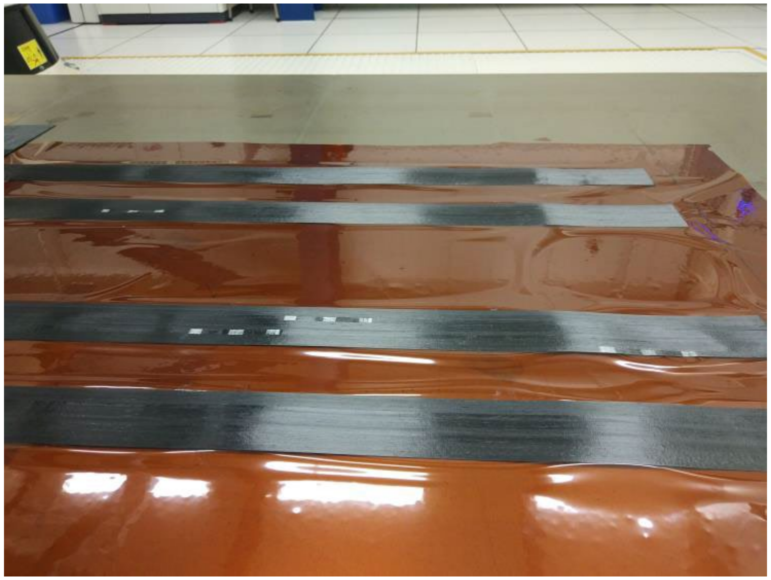

Figure 1. Unidirectional AS4/PEKK strips placed on thermalamide film

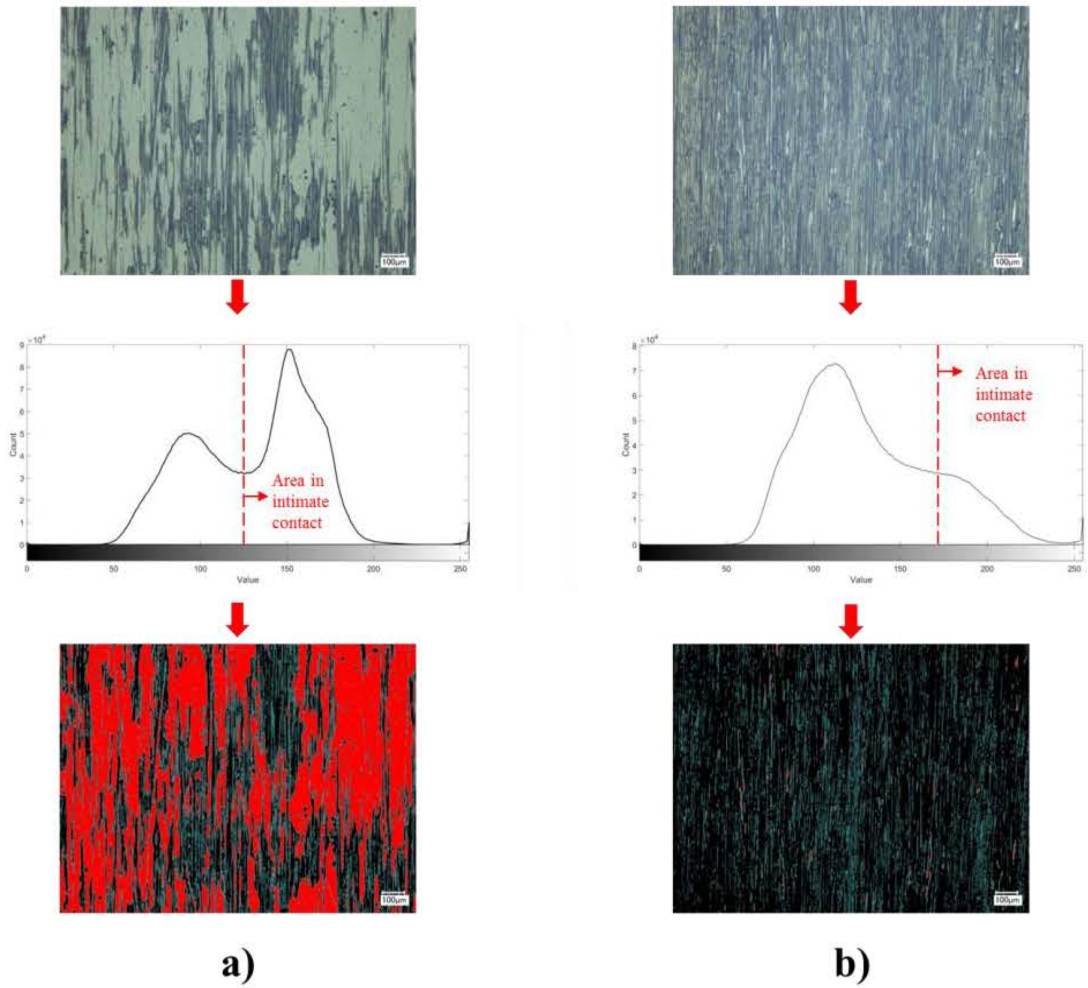

Figure 2. Determination of degree of intimate contact from histograms of optical microscope images. a) Moderate degree of intimate contact b) Low degree of intimate contact

ABSTRACT
KUN8011

Integral Manufacturing of Fibre Reinforced Thermoplastics with Metallic Inserts

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Abstract:

Structural components fabricated by use of fibre reinforced plastics (FRP) exhibit a high lightweight potential due to the high strength and low density. For serial applications such as automotive sector, thermoplastic matrices are highly demanded, because already existing forming technologies enable economical processing and short clock cycles. Many concept cars of OEMs show the strategy to substitute single metallic components or subassemblies by FRPs in areas with the highest lightweight- and cost potential. The advantage of this multi material design (MMD) is to use the locally optimized materials with the required properties and low costs. A vital challenge of the MMD is the demand for suitable technologies for joining different types of materials like metal and FRP concerning the performance and large-scale production.

Novel lightweight-optimized hybrid metal-FRP structures contain locally reinforced joining areas. A suitable process for high volume production is the thermoforming process for FRP. The base material is a planar FRP organic sheet. If both – metal structures and FRP reinforcements – have to be integrated locally into the FRP part, this requires a modified thermoforming process which ensures the forming from planar base material to final 3D part and a proper joining between the FRP/FRP and FRP/metal interface in the area of reinforcements during consolidation.

In this project different approaches have been developed and evaluated: a multi-step process with separated forming of metal and FRP plus final downstream consolidation of both, and a novel customized process with integral forming and consolidation of all parts in a single step. Large-scale parts have been produced with a wide range of process parameters. The focus of this article is to highlight the pros and cons regarding technological and economical aspects.

ABSTRACT

COR8012

On the search for In situ consolidation when processing thermoplastic materials using Automated Fiber Placement

Speaker: Denis Cartie (TDC)

This paper will present the latest development in the processing of ThermoPlastic Materials composites (TP) using Automated Fiber Placement (AFP). The advantage of this technology is the use of a "standard" robotic arm, interactive engineering software and ability to manage key processing parameters (temperature, compaction force, heat distribution...).

After discussing the advantages thermoplastic materials (processing, mechanical properties,...) compared to Thermoset composites, this paper will demonstrate how the AFP process parameters influences the microstructure of the manufactured parts.

This paper will then present the results achieved in the search for in situ consolidation while laying up with AFP machine. As shown in Figure 1 below, a careful control of the machine parameters allows the process to reach high quality layup where the final panel shows lower porosity content than the raw material. However, the cost for reaching in situ is limited layup speed. An alternative allowing high speed layup without expensive autoclaves has been investigated using oven (out of autoclave) consolidation. It resulted in high quality laminates with porosity contents as low as the autoclave consolidated ones.

To conclude, thermoplastic composites offer great advantages but challenge conventional manufacturing processes in terms of material waste and processing routes. AFP manufacturing is a good answer by its ability to adapt with any post consolidation process.

Key Words: AFP, fiber placement, aerospace, automotive, material performance, machine productivity economical benchmark, thermoplastic.

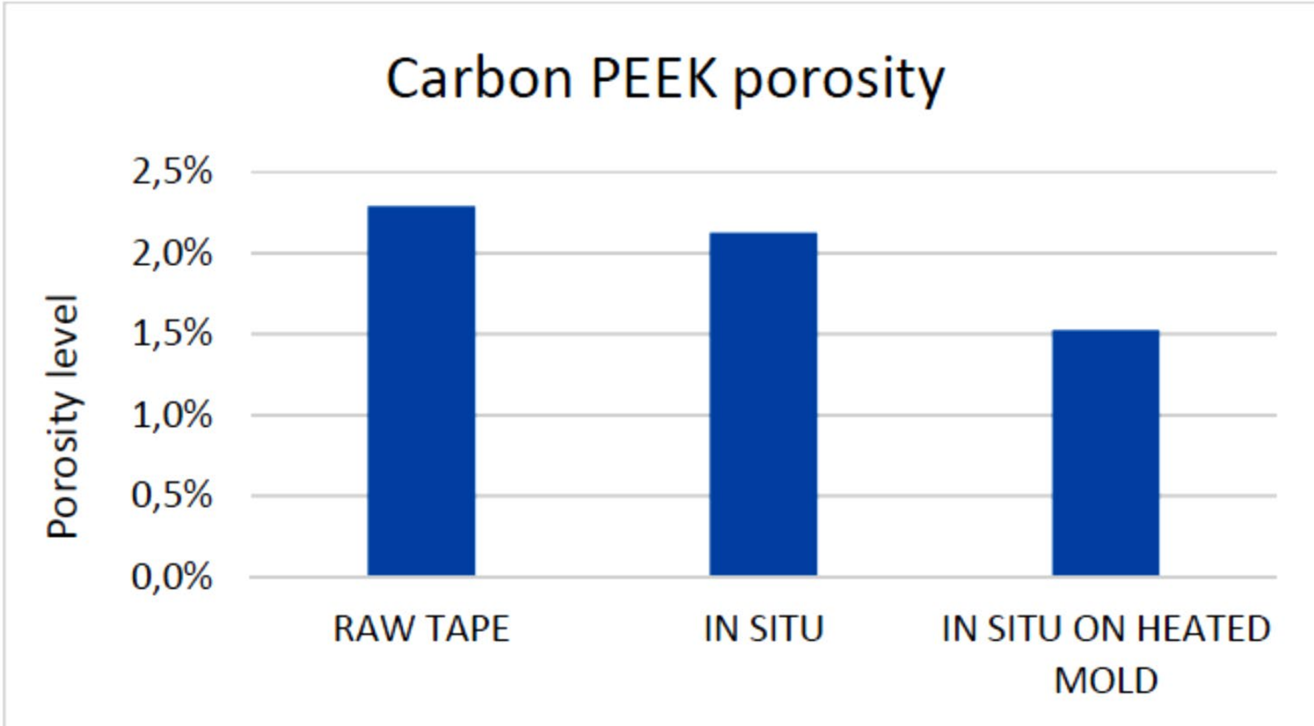

Figure 1: Porosity level of raw CF/PEEK tapes and after Layup using Coriolis AFP

ABSTRACT
SPO8013

Smart Lay-up: Advanced Robotic AFPM for Hybrid Composites Manufacturing

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Smart Lay-up is a challenging research project, within Clean Sky 2 program, aiming at the development and validation of an advanced process of hybrid materials automated deposition.

The project, managed by Leonardo Aircraft Division and supported by MTorres and Eurecat, has been primarily conceived for a regional aircraft composite fuselage manufacturing, market where composite materials use is nowadays limited by the leading need of reducing production costs and flow. The enabling technologies for the development of an affordable composite fuselage have been identified by Leonardo in the integration of acoustic damping material into the structure and in innovative automated solutions for stiffened panels' manufacturing and assembly. Smart lay-up main target is to significantly reduce fabrication cost and flow of skins and stringers in such a hybrid materials configuration. Thus requirements from Leonardo were extremely strict: multi-head configuration with fast head change for lay-up of different materials, compact lay-out (10m x 5.5 m), rotating positioner, ultrasonic cutting unit, IR heater, operational flexibility spanning from fuselage panels to high-curvature parts, deposition quality in accordance with aerospace specifications, minimum run productivity = 50 Lbs/h, minimum floor to floor productivity = 30 Lbs/h. An innovative 6-axes robot based AFPM ½" tow head has been definitively selected as the best solution.

The preliminary results, based on pre-acceptance tests and hybrid materials lay-up trials, are absolutely encouraging: flat and single curvature small fuselage panels have been produced without defects at competitive productivity levels, while machine capability to laminate viscoelastic damping materials has finally confirmed automated process and industrialization feasibility. Fabrication of the final Clean Sky 2 fuselage demonstrators, foreseen in 2019, is now the upcoming opportunity to move-up these cutting-edge technologies to production-ready AFP solutions to be used for future aircraft applications.

ABSTRACT
COL8014

Effect of Process Parameters on Mechanical Properties of 3D Printed Carbon-Fibre PEEK

Authors: Richard G. Cole (National Research Council, Ottawa, Canada)
Abraham Avalos (Aon3D, Montreal Canada)
Andrew Walker (Aon3D, Montreal Canada)

Abstract

As polymer additive manufacturing (aka polymer 3D printing) processes improve and as better polymer materials come to market, including some with fibre reinforcement, there is growing interest from industry in using these processes and materials to manufacture structural parts. A requirement for design of such parts is the availability of reliable material properties values for use during structural analysis. However, in the 3D printing process, various process parameters affect the final "as built" part properties. Understanding these effects is critical for optimizing the process for best results and also for controlling the process to limit part-to-part variability. The property of particular interest in this work was inter-layer strength, when printing with short Carbon Fibre reinforced PolyEtherEtherKetone (CF-PEEK). The process investigated in this work was Fused Deposition Modeling (FDM) as engendered in the AON-M2 printer from Aon3D. Previous coupon testing had shown low tensile strength and poor failure modes for ASTM D638-style coupons printed and tested in the Z-direction (i.e. vertical), indicating low inter-layer adhesion strength. The present work investigated the effect of varying 3 key process parameters on inter-layer strength, specifically: nozzle extrusion temperature; printing speed; and, chamber temperature. To focus specifically on inter-layer adhesion strength, coupons were printed flat (X direction) and tested in accordance with ASTM D3846, which uses a notched specimen loaded in compression and supported against buckling, to load the gauge section in inter-layer shear. This test method was found to provide more consistent results and better failure modes than the ASTM D638 tension test. All 3 of the process parameters investigated were found to affect inter-layer adhesion strength to varying degrees. Other parameters were also identified as potential contributors to inter-layer strength variation, namely: layer height (i.e. thickness) and, time between layer passes. These will be investigated in future work.

ABSTRACT ROU8016

Design, Manufacturing and Testing of an In-situ Consolidated Variable Stiffness Thermoplastic Composite Wingbox

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Automated fiber/tow placement (AFP/ATP) techniques have been used for cost-effective, accurate, reduced waste, repeatable high rate production of laminated composite structures with some unprecedented capabilities such as in-situ consolidation and fiber/tow steering. In fiber steering, the fiber orientation angles are continuously changed to make composites with optimum path between the loading points and supports in a structure.

Over the last three decades, thermoplastic composites (TPC) have gained a lot of interest from aerospace industries. Some potential advantages TPC materials have over their thermoset counterparts include formability, weldability and reparability, recyclability and their superior toughness and fatigue performance. In addition, they have excellent fire/toxicity properties. Their potential of out-of-autoclave manufacture (OOA) also makes them excellent candidate for low cost production of large structures for aerospace applications.

To investigate the potential for aerospace structures, an OOA variable stiffness, unitized, integrated-stiffener thermoplastic wingbox demonstrator has recently been built at the University of Limerick. For this purpose a number of different techniques had to be combined: fiber steering to achieve the variable stiffness skin, in-situ consolidation to weld the stiffeners to the wingbox skin, and as manufacturing methodology a laser-assisted tape placement (LATP) in combination with winding was used. In the design process, the wingbox loads were determined by assuming its location to be at 85% of the wing semi-span of a B737/A320 size aircraft. A full-scale structural test using a bespoke testing frame with representative bending moment and shear load was undertaken. Indeed, the wingbox buckled elastically at a load close to that predicted numerically. Our results highlight the potential advances that become possible in primary aerospace structures by combining fiber steering and in-situ consolidation of carbon fiber thermoplastic composites together with new blended,

unitized structural concepts. A complete overview of the manufacturing, quality assurance and structural testing for load carrying capability is given.

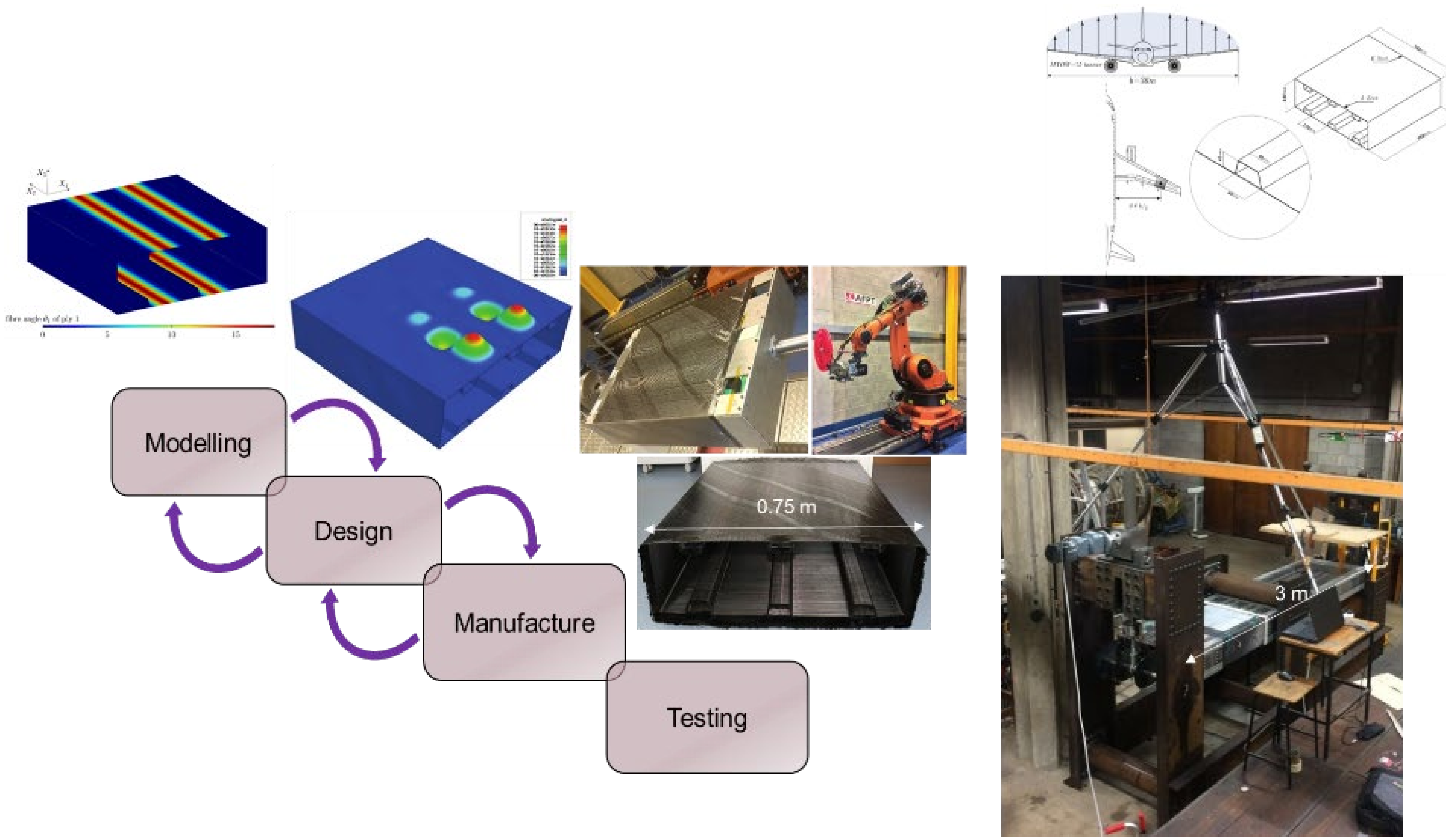

Figure 1. Design, manufacture and test of the variable stiffness thermoplastic composite wingbox.

ABSTRACT
VIL8017

Towards automated ultrasonic welding of thermoplastic composite structures

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Ultrasonic welding is a very interesting technique for the assembling of thermoplastic composite structures which offers very high production rates, low energy consumption and suitability for in situ process monitoring. Extensive research has been performed during the last decade at TUDelft to understand, mature and investigate fields of application for ultrasonic welding of thermoplastic composites. Some interesting results of that research, mostly carried out at coupon level, have been: definition and assessment of simplified energy directing concepts [1,2], definition of the relationship between process data and weld quality and, based on it, of an empirical procedure to obtain optimum welding parameters [3,4], definition and proof of concept of a sequential ultrasonic welding process [5], development and proof of concept of a continuous ultrasonic welding process [6], process modelling [7,8], performance of welded joints relative to traditional joints [9], and thermal degradation-free welding of thermoset composites [10]. Based on that knowledge, our current work majorly focuses on the up-scaling of both sequential and continuous ultrasonic welding for thermoplastic composite structures in collaboration with different partners. Three topics have been identified as crucial within that work: (i) development of automated industrial welding procedures, (ii) understanding the relationships between process parameters and weld performance and (iii) development of in situ monitoring and process control systems for the up-scaled processes. This paper provides an overview on our progress as well as an outlook on those three main areas for both sequential and continuous ultrasonic welding of thermoplastic composites.

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ABSTRACT
BLA8018

Artificial Intelligence in Advanced Composite Manufacturing: A Path Forward

Author: Scott Blake, President, Aligned Vision

Abstract

In 2018, a convolutional neural network (CNN) successfully generated an analysis algorithm to detect foreign objects and debris (FOD) on critical component surfaces. The first known application of Artificial Intelligence (AI) to an industrial automatic inspection system, this CNN trial portends not only the replacement of painstaking hand-engineering of algorithms with self-generated analysis algorithms via AI, but also the likely near-term introduction of AI into all aspects of advanced composite manufacturing and design. Points of entry for AI into automated advanced composites manufacturing applications, in addition to automatic inspection analysis algorithms, include raw material inventory and property characterization, generation of process control instructions, population of the digital thread and digital twin generation, and deep learning-generated closed-loop process improvement both for an individual component and for manufacturing technologies and processes. A critical aspect of AI is the availability of raw images and data. In the CNN trial, only 700 images were needed to train and evaluate the CNN, which then succeeded in producing accurate binary classification (FOD present/FOD absent) of a small set of previously unanalyzed images. The relatively small number of images needed to generate the algorithm suggests that the path forward in AI implementation is viable even for the relatively low production volumes of many advanced composite components. This paper will describe the automatic inspection technology to which the CNN was applied, experimental procedures and results, and implications for AI in advanced composite manufacturing.

ABSTRACT

DYN8020

Aerospace Quality In-situ Consolidation of Thermoplastic Composites using Automated Fiber Placement

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Abstract

Much effort has been expended in the aerospace industry to develop thermoplastic composite aerostructures, the goal of this work being a fully automated manufacturing process. In-situ consolidation (ISC) with automated fiber placement (AFP) of thermoplastic composites (TPC) is a fully automated solution and a true additive manufacturing process. Recent developments in prepreg tapes, laser heating, equipment, and process control have demonstrated the ability to manufacture aerospace quality structures with ISC. A key challenge facing manufacturers is addressing throughput speeds to achieve desired production rates.

The ability to co-bond thermoplastic stiffeners with ISC eliminates the need for secondary operations traditionally required to fasten stiffeners to skins..

This paper reviews worldwide efforts to develop ISC, Automated Dynamics current capability to manufacture aerospace quality structures using ISC, and future work needed to meet throughput targets.

Keywords: In-situ consolidation, ISC, Additive Manufacturing, Laser Heating System, Automated Fiber Placement, Thermoplastic Composites, Aerospace

ABSTRACT KON8021

Development of a manufacturing process for multi-matrix composites based on the Tailored Fiber Placement (TFP) technology

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Abstract:

The Tailored Fiber Placement (TFP) technology represents a manufacturing process for variable-axial fiber preforms. By attaching the endless reinforcement fibers onto a base material via zig-zag-stiches even strongly curved embroidery patterns are feasible, making it possible to exploit anisotropic fiber properties to a very high rate. In a current research project we address the idea of adding a print head to the TFP machine to impregnate predefined regions of the finished preform with low viscosity elastomer on the same machine it was fabricated. The main intention is to block these zones to not be impregnated in the subsequent epoxy resin infusion and thus, in case of a linear impregnation, for instance, functionalize that zone as a hinge. This technique could also be used to improve the attenuation properties of dynamic loaded parts. Applying elastomers with higher viscosities in the non-crosslinked state shall also enable the possibility to print functional structures on top of the preform. The application of different elastomeric materials, e.g. medical grade silicone or elastomer functionalized by electrically conductive additives, results in diverse applications in wide-ranging technology sectors.

This upgrade of the TFP process requires some major modifications of the machine control and an enhanced machine language which at this point are still in development. Further, material investigations have to be carried out to ensure the formation of an adequate interface between the applied resin systems.

Once working, Tailored Fiber Placement Print (TFPP) opens up complete new possibilities in the design and manufacturing of multi-matrix-composites and can save significant efforts, which would be required to manufacture such integral design solutions manually.

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ABSTRACT

ORO8022

Automated Manufacture of Adaptive Composite Hydrofoil

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Carbon fibre reinforced polymer composites are being increasingly used for structural applications in marine industry due to their favourable advantages such as lightweight, high stiffness-to-weight ratio and high resistance to fatigue and corrosion. One such example in marine application is composite marine hydrofoils and propeller blades, which can be designed for load-dependant deformations, become passively adaptive in pitch change to delay cavitation and increase overall energy efficiency. However, adaptive composite structures require a combination of different stacking orientations for various ply shapes, and manual placement is labour intensive and not an effective and consistent manufacturing method for such complex structures. Advanced manufacturing technique such as Automated Fibre Placement (AFP) is a promising solution for this complex and demanding manufacture. AFP offers high throughput, efficient and accurate manufacturing methods as well as unique fibre steering ability that is a challenge in traditional manufacturing. In this study, a 1:1 ratio shape adaptive composite hydrofoil is produced using AFP. The core of the hydrofoil made out of glass fibre/epoxy using resin transfer moulding, acts as a mandrel while carbon fibre/epoxy prepreg tapes are laid up and wrapped on the core using AFP. The developments of numerical design procedures, tooling and manufacturing protocols required to produce this hydrofoil will be presented. Additionally, the use of optical fibres embedded during the AFP manufacture to assist in the smart monitoring of the AFP manufacture process will be detailed. Manufacturing challenges during the fabrication process will be discussed in addition to methods identified to improve the quality of this AFP manufacture. This research is the first step towards automated production of shape adaptive composite propellers, and potentials and shortcomings of using AFP that are highlighted in this study can be the foundation for future research studies which would contribute to the current global shift towards automated manufacturing.

Keywords: Automated Fibre Placement, CFRP Composites, Composite Propeller, Structural Health Monitoring

ABSTRACT LEB8023

Fastening Composite Structures Using Carbon Fiber/PEEK Rivets

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Keywords:
Fasteners, Rivets, Composite, Thermoplastic

Abstract:

Strong and light composite materials are used to increase the performance of aircraft The composite structures are currently assembled with heavy titanium fasteners. This solution presents many drawbacks with regards to its weight, lightning strike hazard, and its cost. To overcome these problems, an innovative assembly technology using carbon/PEEK thermoplastic composite rivets is proposed. These rivets are heated, using Joule effect, above the melting temperature of the thermoplastic resin. They are then molded in situ, i.e., into the adherents to be joined. The riveting technique must be automated to ensure a constant quality in an industrial perspective. This study presents the development of an automated riveting machine forming the rivet from both sides of the joint. The linear actuator can be controlled by force and displacement, to ensure a good joint quality and a good geometry. This machine enables the high speed forming of the thermoplastic composite rivet in a single lap-shear and pull-out testing assemblies. Riveting experiments were done at various speeds, forming temperatures and loads. Assembled rivet microstructure was assessed by microscopy. From the mechanical test results of the carbon/PEEK rivets, it was observed that the shear strength and the tensile strength are better than typical aerospace grade aluminum rivet. This technology could be used in future generation of lighter, cleaner and safer aircraft.

ABSTRACT

FER8024

Automated Fiber Placement of Thin-Ply Composite Materials for Large Aerospace Structures

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2. NextGen Materials & Processing, LLC

Abstract:

Composite aerospace structures offer high specific mechanical properties as compared to traditional materials, yet composite materials tend to lack sufficient damage tolerance. In recent years there has been a focus on thin-ply pre-preg materials, which have shown an improvement with micro-cracking and fatigue resistance when compared to the standard-ply-thickness materials. Large scale automated manufacturing processes, such as automated fiber placement (AFP), are necessary to produce large structures reliably and affordably. However, thin-ply materials require more layers to reach the same thickness, increasing the number of passes by the AFP machine. The overall production time is thereby increased, making it even more important to maximize lay-down rate and minimize machine downtime. Thin-ply materials have not yet seen widespread adoption in AFP manufacturing in part due to a lack of study and development that leads to uncertainty associated with their manufacture. The result is that thin-ply materials lack the same repeatability, consistency and quality as standard-ply-thickness composites in the AFP process.

In this work, efforts to identify key material and AFP processing parameters of thin-ply materials that result in high quality, consistent and repeatable feed of material through the AFP head and onto the structure are presented. A single spool, in-house designed machine is used to mimic the AFP process using a 70 gsm thin-ply material. The material-process parameters and interactions are studied using a design of experiments (DoE) approach. The factors being studied fall into three main categories: material parameters, slitting and spooling parameters, and AFP process parameters. Some of the factors being studied include out-time, backing paper vs. double-backing paper, and pre-preg tape tension. The DoE program is supplemented with finite element models (FEM) of the relevant manufacturing parameters.

ABSTRACT

HEL8026

Comparing Test Methods for the Deformation Behavior of Uncured Prepreg Tapes

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Thermoset Automated Fiber Placement (TS-AFP) is widely used in the aerospace industry for the automated manufacturing of structural composites parts. To achieve cost-efficient manufacturing and a high part quality, knowledge about the interaction between material and process parameters during lay-up is of special interest. Material properties of prepregs are well known at the cured state of the resin. However, information about the mechanical properties of the uncured prepreg tapes are not given in data sheets and there are no standardized test procedures. To investigate the mechanical properties of uncured prepreg tapes, we compared several measurement procedures for the out-of-plane bending and intraply shear behavior using unidirectional AS4/8552 specimens with several stages of degree of cure.

We identified that the dynamic mechanical analysis (DMA) with a dual cantilever set-up leads to reliable results for the out-of-plane bending properties of multilayer specimens. Furthermore, we were able to characterize the out-of-plane bending of single layer specimens using a single cantilever bending test bench [1]. For the measurement of intraply shear behavior we compared the thin plate torsion test [2] to the torsion bar test [3] (see Figure 1, left). In the latter we observed dependencies on the number of plies and the temperature as shown in Figure 1, right, indicating that a larger number of plies and a higher temperature leads to less resistance to shear load.

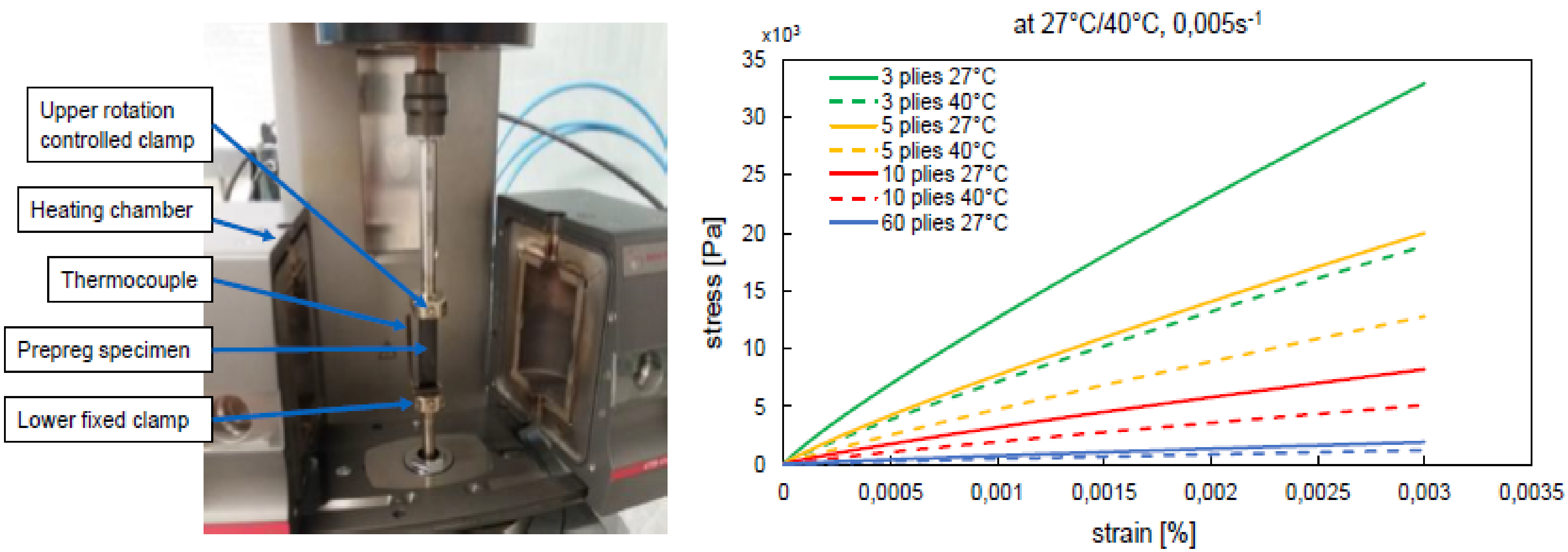

Figure 1: Torsion bar test – test set-up in rheometer (left), results for specimens with different no. of plies (right)

In conclusion, test methods as well as an optimized specimen preparation have been identified for out-of-plane bending and intraply shear of uncured prepreg tapes. We will use these results to characterize the influence of material aging and material modifications in order to provide data for the material modeling enabling the prediction of lay-up defects such as buckling due to steering.

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ABSTRACT
PEE8027

The final step towards manufacturing an optimised variable stiffness panel

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Variable stiffness laminates, where the fibre angle is continuously changing by steering the tows using automated fibre placement, has received a lot of attention recently. Over the last ten years, a threestep optimization approach has been developed at Delft University of Technology, which starts by optimizing the stiffness distribution, represented by the lamination parameters (LP), giving a theoretical optimum. In step two, the fibre angles are optimised by first trying to match the performance of the optimal LP distribution as closely as possible, followed by a fibre angle optimisation. Finally, in step three, a streamline analogy is used to obtain the individual fibre paths.

As a final step towards manufacturing this work shows how to obtain the tow-by-tow description matching the paths found using the streamline analogy as closely as possible. To avoid overlaps, individual tows are terminated and started within the plate. This work completes the cycle from optimization to manufacturing: the outcome is the optimized design that can be manufactured using automated fibre placement. The code is verified by generating the tow-by-tow description for two examples: one, a plate with linearly varying fibre angles, two, a cone with constant fibre angles. Finally, as a case study, a flat rectangular plate under uniform end-displacement is optimised for maximum buckling load, for which the complete cycle from optimisation to ready-to-manufacture description is given, as shown in Figure 1.

Since the tow-by-tow description gives the exact location of the gaps and/or overlaps, this tool allows to consider the effect of the gaps and overlaps on the mechanical performance (e.g., compliance, buckling, strength). Furthermore, the actual fibre angle distribution can be used to evaluate the performance loss between the theoretical optimal fibre angle distribution and the manufactured fibre angle distribution.

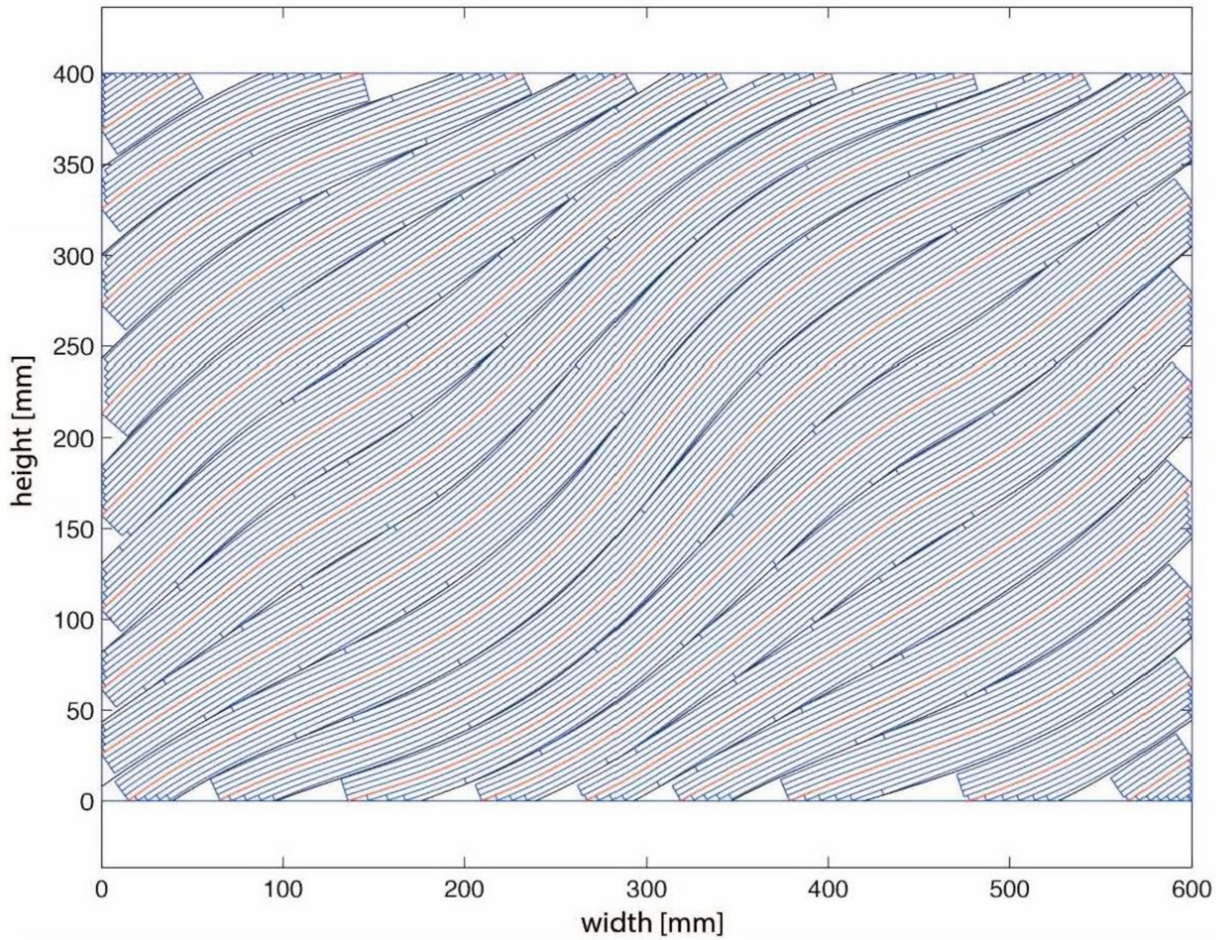

Figure 1: Tow-by-tow description of the optimized flat plate

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ABSTRACT
UCA8028

Automated, Quality Assured and High Volume Oriented Production of Fibre Metal Laminates (FML) for the Next Generation of Passenger Aircraft Fuselage Shells

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The German Aerospace Centre (DLR) and the Fraunhofer-Gesellschaft (FhG), together with partners Airbus Germany, Premium Aerotech and inter alia Synthesites are working on the development of an automated and quality-assured production chain revolving around fibre–metal laminates for stiffened fuselage panels. The current time-consuming manual production process (1,875 m2 per month) cannot accomplish the target of around 10,000 m2 per month for the next generation of passenger aircrafts, which corresponds to a huge increase in production rate. A new automated and quality assured process chain has been developed for the manufacture of FML fuselage segments and demonstrated in the joint project AUTOGLARE (2015-2018). The focus of the scientific work content was the following processes:

• **One-shot bonding process**

Quality-assured and optimized cure cycles with a time reduction of 27%.

• **Placement of the aluminum foils using cooperating robot systems**

The new concept provides for handling by two cooperating robots. The end effectors have a modular design and can be used either flat (2D) or in already curved (3D) configurations.

• **Automated Tape Laying and (ATP) and Automated Fiber Placement (AFP) for the glass fiber placement**

In order to increase the production rate of the production process the technologies ATL and AFP were compared with regard to processability, repeatability as well as drapability through steering on a double curved fuselage shell.

- **Adhesive layup and stringer integration**

  Therefore, new end effectors were designed, which are mounted onto industrial robots. The adhesive end effector is able to lay up adhesive strips with speeds of more than 12 m/min and an accuracy of ±1mm. The stringer integration is done by two cooperating robots, which enables the fixation of more than 5 meter long stringers onto the skin field.

The publication will include a detailed discussion of the above topics of automated production technologies (Figure 1).

Figure 1 Automated and quality assured production technologies for FML fuselage segments (©DLR and Frauenhofer Gesellschaft)

ABSTRACT

CAD8030

EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE OF CARBON-EPOXY LAMINATES CONTAINING GAPS FABRICATED BY AUTOMATED FIBER PLACEMENT

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Keywords: Gaps, Experiments, Automated Fiber Placement, Composites, Testing

Abstract

Manufacturers use Automated Fibre Placement (AFP) as a fabrication process for large and complex composite parts. This method also creates unique defects such as side-to-side gaps, which have been experimentally investigated here. By varying the orientation, size and number of gaps embedded in carbon-epoxy laminates, the effects of gaps on tensile and compression performance has been examined.

The 90° gaps lead to substantial decrease of performance by an average 10%, while gaps at 45° and 0° seem to have negligible effects. Combinations of gaps at multiple orientations tend to have high strength reduction up to 15% in tension and 5% in compression, the highest for any coupon with 4 gaps through the thickness. Gaps at 0° seem to have a negligeable effect on the performance of tested composite structures. An analysis based on Finite-Element methods seems to corroborate these results. Both analysis and experiments are presented here.

ABSTRACT

ELK8031

Layup end effectors with tactile sensing capabilities

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* Key Words: Quality control, Quality assurance, Defects, Wrinkling, Non-destructive testing.

A novel end effector is presented which can consolidate composite plies onto a mould while simultaneously using tactile sensing to find any defects in the preform. In traditional manual layup, workers constantly use tactile sensing to gain real time feedback on the quality of their work. In automated processes, this sensing method is currently not utilised and has the potential to give the manufacturing industry a powerful new tool to assess product quality during the layup process. Researchers at the Bristol Robotics Laboratory have developed a customizable tactile sensor (the TacTip) capable of detecting sub-millimetre surface features. This TacTip is a low cost, robust sensor consisting of a hemispherical gel-filled membrane with an internal biomimetic pin/marker structure that visibly deforms around a geometry. These markers on the deformed shape are recorded by a HD camera within the sensor, and image analysis software converts the video into processable data.

In this project, a less compliant and more robust version of the TacTip is developed with a novel morphology for specific application to composite layup. The resulting end effector can apply the through-thickness compression forces required to achieve the highest quality composite components. Simultaneously, the sensor elements of the end effector can capture the geometry of the preform being compacted immediately under the end effector. If any abnormalities in geometry are detected then an error is flagged. This will enable the defect to be fixed at the earliest possible stage before it becomes too costly or impossible to repair. In this study, the new end effector is demonstrated consolidating plies onto contoured moulds while successfully detecting a range of common composite defects.

ABSTRACT
GHA8032

Effect of Manufacturing Flaws on the Behavior of Composite Beams Manufactured By Automated Fibre Placement (AFP) Process

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Abstract

Automated Fiber Placement (AFP) is a state of the art robot technology which has recently been used for the manufacturing of composite structures. Despite many benefits of using this technology that involves fiber steering and rapid manufacturing, structures manufactured by AFP suffer from induced randomly distributed defects due to gaps or overlapping between adjacent composite material tapes. These defects can cause material discontinuities in the laminated structure which are the sources of the damage initiation and also fiber waviness throughout the fiber direction. Mechanical in-plane behavior of these types of structures have recently been studied in the literature and the results show that the AFP manufacturing flaws can reduce the in-plane performance of the structure, especially under the compressive and fatigue loading conditions. However, there is still a lack of knowledge in the understanding of the behavior of the structures made by AFP in out-of- plane loading conditions. In the present study, the effect of gaps and overlaps on the flexural behavior of the quasi-isotropic Carbon/Epoxy polymer composite beams has been investigated by performing a series of standard three-point bending tests. Furthermore, the damage modes of the beams have been characterized by performing the microscopic observation and the effects of the manufacturing defects on the damage initiation and propagation under the flexural loading condition have been investigated. Comparison of the results with that of the baseline beam that is without gaps and overlaps shows that both the stiffness and strength of the composite beams are affected by the AFP manufacturing flaws. This effect is quantified and analyzed.

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ABSTRACT
HOA8033

Fatigue behavior of composite springs made by 4D printing

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Abstract

4D printing of composites is a combination of 3D printing plus a fourth factor, which is the reconfiguration of the composite structure after material deposition, upon the activation of heat, and/or the absorption of moisture. The method of 4D printing of composites can be used to make a composite with complex geometry using only a flat mold. As such this method may be termed as "moldless composite manufacturing". The deposition of the composite materials is usually done using an automated fiber placement machine, which can be viewed as a type of printing machine, except for long continuous fiber composite materials. The mechanism responsible for the reconfiguration of the composite structure is the anisotropy of the lay up of the composite laminate [1].

One application of this method of manufacturing is the composite leaf springs. When an unsymmetric laminate such as that of [0/90] is cured, the difference in coefficients of thermal contraction between the [0] and [90] layers will make the structure to change from flat (uncured) to curved (cured). With the proper stacking sequence, a curved beam with sufficient stiffness and strength can be made using only a flat mold. This curved beam can be used as a leaf spring.

In this work, composite springs made of carbon/epoxy with lay up sequence of [$0_{16}/90_{24}$] were made (figure 1). It was shown that with this lay up sequence, the strains and stresses due to manufacturing within the 90 layers are compressive [2]. As such, under bending movement of the spring action, the tensile strains and stresses created by the loading can be compensated by the compressive strains already in existence due to manufacturing. The net result is that even though tensile strains are created by mechanical loading, the

strains and stresses in the 90 layers remain negative, thus allowing the structure to be able to function as a mechanical spring with practical stiffnesses.

Fatigue tests were performed on the springs. Results show that with sufficient practical stiffness, the springs can last more than 1,000,000 cycles without failure.

Figure 1: Curved composite leaf spring made by 4D printing.

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ABSTRACT

DRU8034

Wet Fibre Placement Process Optimisation

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ABSTRACT

The high cost, low-temperature storage and high processing temperature of pre-impregnated materials for the Automated Fibre Placement process make the implementation of such technology difficult in cost-driven applications. Wet Fibre Placement is a low-cost alternative to Automated Fibre Placement; incorporating filament winding methodologies to impregnate dry fibres in-process, and place them accurately to a desired length and orientation. Because the input material is both formed and deposited within the same process, identification, monitoring and control of the key process variables are critical to achieve consistent quality output. This paper investigates and demonstrates quality improvement in Wet Fibre Placement through the optimisation of process parameters.

The experimental activity was carried out using a purpose built end-effector, capable of delivering three main functions concurrently:

- In-line mixing of the two-part resin system constituents
- Combination of such resin system with a continuous filament carbon fibre tow
- Deposition and compaction of the tow onto a tool surface using a force-controlled roller

A 2-level factorial design approach was used to produce a design of experiments. The process parameters selected to vary were; *roller type, compaction force, resin staging between plies, resin flow rate and resin injection nozzle diameter.* In total, eight 300 x 150 mm laminates, each comprising three unidirectional plies, were manufactured by the Wet Fibre Placement process, using the conditions defined by the experiment design. Assessments for fibre waviness, resin coverage, ply thickness and porosity were carried out through destructive and non-destructive characterisation methods. The relative impact of each variable on laminate quality was measured, with resin flow rate and nozzle diameter having a higher impact on overall acceptability. An optimised process was inferred from these results, and validated through the manufacture of a quality improved laminate. The outcome of this initial exploratory study will drive machine and process design to increase technology maturity.

ABSTRACT
SHE8035

A Techno-Economic Model to Analyze Automation Options for Composite Wind Blade Manufacturing

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ABSTRACT

The ongoing demand to reduce the LCOE (Levelized Cost of Electricity) drives the wind industry to explore new technologies that will advance the state-of-the-art for composite wind blade manufacturing. However, since the introduction and widespread adoption of vacuum-assisted resin-infusion techniques for blade making, there have been no significant changes in the basic labor-intensive manufacturing processes for wind blade production. Despite various industrial and academic efforts to introduce automation for blade manufacturing, blade suppliers have historically been unable to see a clear indication of justifiable ROI for its implementation. In the current research, a Techno-Economic Model (TEM) and a complementary process-flow simulation of a generic wind blade manufacturing facility are developed. The TEM is sufficiently robust to take into account the very rapid product refresh cycle (and concurrent consumption of capital), differences in blade lengths, and the potential future composite technologies such as carbon fiber and thermoplastics that could impact the blade design and resulting manufacturing processes. To investigate the long-term costs and benefits, the TEM also takes into account the cash flows over a multi-year period so that the true value of improvements can be identified and used to justify capital investment in automation and other process changes. The complimentary process flow simulation is built in DELMIA. DELMIA allows for a visual tool to evaluate the impact that changes in the manufacturing steps and factory floor layout will have on process flow and timing. The integration of these two models into a full Techno-Economic Analysis (TEA) provides a comprehensive tool to identify opportunities for increasing throughput and for exploring the impact of capital investments. Cost estimates and ROIs for a baseline 61.5m wind blade are modeled with the TEM and DELMIA simulation, and the results compared with a modified manufacturing process which introduces selected automation options.

ABSTRACT
MAR8036

PROCESSING BY PULTRUSION AND HEATED COMPRESSION MOULDING OF NEW THERMOPLASTIC PRE-IMPREGNATED MATERIALS REINFORCED BY CONTINUOUS GLASS FIBRES

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Keywords: carbon fiber; thermoplastic towpreg; pultrusion; compression molding; composite tape; glass fiber

ABSTRACT

Two major technologies are being used to allow wet reinforcing fibres with thermoplastic polymers: i) the direct melting of the polymer and, ii) the intimate fibre/matrix contact prior to final composite fabrication. Continuous fibre reinforced thermoplastic matrix pre-impregnated tapes (PCT´s) are, for example, produced by direct melting processes. Alternatively, intimate contact processes allow producing cheap and promising pre-impregnated materials, such as, commingled fibres and powder coated towpregs.

Four different pre-impregnated materials were used in this study: one towpreg type and another obtained from co-extrusion process (PCT), both produced in our laboratories; commingled fibres (TWINTEX®); CompTape®. Carbon and glass fiber and two different thermoplastic matrices (polypropylene and Primospire®) were selected for the production of the laboratory made pre-impregnated materials. For the latter systems, only glass fibre and polypropylene were used.

In this paper, it will be described the optimization of pultrusion and heated compression moulding processes used to obtain composite plates and profiles. The optimization of those processes was made by studying the influence of the most relevant processing parameters – preheating, heating and cooling inside the die and speed for the pultrusion, and heating temperature, pressure and time for compression moulding - in the final properties of the produced carbon and glass fibres thermoplastic matrix pre-impregnated materials and composites. One interesting target we tried to achieve was to increase pultrusion speeds to meet the industrial needs. This has been possible particularly with the thermoplastic composite tape due to the consistency of the tape.

The characterization of mechanical properties with different speeds will be presented.

The composite relevant mechanical properties were determined and the final composites were submitted to Dynamic Mechanical Analysis, Scanning Electron Microscope, optical microscopy and calcination test.

The determination of the fiber volume fraction of all studied composite was obtained comparing the results of thermogravimetric analysis, SEM and calcination tests.

ABSTRACT

PAL8037

Next Generation Inspection Solution for Automated Fibre Placement

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Achieving the high production rates promised by automated fibre placement is often hindered by lengthy and variable manual intervention. One of the predominant sources of this utilization loss is the requirement for visual inspection of every deposited ply. The layup utilization impact can be offset by parallelizing the workflow in the AFP work cell (such as the use of multiple heads, layup stations, etc.) resulting in less costly overall machine downtime. However, this strategy requires additional up-front cost and adds complexity to achieving production cycle optimization. It also does not address the quality escape risks and manual labor cost overhead of employing a manual inspection system with low fidelity measurement aids. Achieving an effective and efficient inspection and rework control of over a half dozen features (gaps, overlaps, end placement, wrinkles, splices, bridging, fiber angle, FOD, …) with sub-millimeter tolerances is not possible without a high-quality sensing solution and robust machine vision algorithms. An inspection solution embedded in the manufacturing process is a vital enabler to achieving world class manufacturing performance. While other methods have been proposed to assist or automate the formerly manual nature of AFP inspection, they all have practical limitations due to deficiencies in the underlying technology. This paper will present the research and development efforts for next generation in-process inspection platform for use on an automated fibre placement machine.

ABSTRACT
MBA8038

Experimental study of the compaction and preforming of unidirectional flax reinforcements

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Abstract

With the increasing interest in sustainable development, there is a growing demand in using natural fiber composites for semi-structural applications in different industrial fields. In the liquid molding processes (RTM, RI, VARTM...), preforming a stack of reinforcements prior to injection is one of the most important stage because the quality of the preform is determining in the performance of the composite part. This work investigates the effect of temperature, humidity, number of layer and pressure on the quality of the preform made of a stack of unidirectional (UD) flax-mat reinforcement, where the mat made of random short wood (Kraft pulp) or flax fibers acts as binder for the UD fibers. First, using a thermostamping experimental setup, the influence of temperature, pressure and humidity on the compaction response of the reinforcements is evaluated. Secondly, the effect of these parameters on the radius and quality of the stamped preform (in terms of wrinkles and tearing) is analyzed. Finally, the effect of hot and wet conditions of compaction on the mechanical properties of molded composites is evaluated. The results show that a high temperature and humidity can improve the compressibility of reinforcements. Preforms made under hot and humid conditions of reinforcements have less defects and better maintain their shape and dimension. The tensile strength of composites made from wet pre-compacted reinforcements is improved compared to that of non-pre-compacted reinforcement.

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ABSTRACT
AKB8039

3D Printed Architected Lightweight Sandwich Structures

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Abstract

Advances in 3D printing technology have recently opened a new venue for developing lightweight structural elements with unprecedented multifunctional properties through a delicate design of underlying nano/micro-architecture of their constitutive cellular core. Considering the extensive application of sandwich structures in aerospace, marine, automotive, and construction sectors, a new class of 3D printable sandwich structures, named as meta-standwich structures, is introduced to optimize the structural performance of conventional honeycomb sandwiches. It is demonstrated how tailoring the microarchitecture of meta-sandwich structures can control the failure mechanism and energy absorption capability of 3D printed thermoplastic polymeric sandwich structures under quasi-static and low-velocity impact loads. A computational framework (validated by experimental testing), is developed based on multiscale homogenization, higher-order shear deformation structural theory, and detailed finite element modelling to analyze the structural properties of meta-sandwich structures made of cellular cores of arbitrarily complex microarchitectures. A series of computationally optimized architected sandwich structures with cellular cores of two-dimensional (auxetic and re-entrant) and three-dimensional (Isomax, cubic, and octet) architectures are 3D printed by fused deposition modelling (FDM) and their failure mechanism is experimentally evaluated by quasi-static three-point bending and low-velocity impact tests. It is found that the core topology and geometrical parameters of sandwich structures can be optimized in multiple scales to significantly improve stiffness, strength, and energy absorption of lightweight sandwich structures.

Keywords: *Architected cellular solids, Meta-sandwich structures, 3D printing, Multiscale modelling, Material characterization*

ABSTRACT

BRO8040

Expanding the envelope of Automated Tape Laying

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To overcome some of the challenges with traditional Automated Tape Laying (ATL) systems, such as low material efficiency and large expensive machines, Airborne has developed the Automated Laminating Cell (ALC). This system combines proven robot technology with innovative integrated automated designs, to provide an affordable, low foot print production cell. Besides manufacturing the typical flat ATL parts, this system can be integrated into fully automatic production lines, converting prepreg rolls into fully formed and cured composite parts.

The ALC is based around a robotic platform with an ATL end effector. The use of a standard industrial robot with a quick tool changer, allows for the robot to use additional tools, thereby expanding the capabilities of the system. The robot can be equipped with a cutting device, as well as pick and place end effectors. This allows for blanks to be cut from a larger laminate, which then can be offloaded by robot, either to be processed by hot-drape- or press forming, or to be used as local reinforcement patches in a larger tailored laminate. Beside the additional tools, the system can also be equipped with two or more ATL end effectors. This can either be used to reduce downtime, such as maintenance or material change, or the extra ATL head can carry a different tape width. Using different tape widths allows for more design freedom and helps to improve material efficiency. These capabilities makes it possible to manufacture complex parts and layups, usually only possible with much larger and costly machines.

Through innovative robot programming, we have been able to increase the accuracy of the robot, without the need for costly external sensors or controllers. This technology makes it capable of achieving aerospace standard tolerances for laydown accuracy. This accuracy can been achieved at actual laydown rates of 300-500 m/h for full body plies.

Currently the ALC system is being used for the manufacturing of large composite structures for radio telescopes as well as for the development of low cost launcher structures.

ABSTRACT
MAH8041

Interface Anisotropy Effects in Fabric Composite Sandwich with 3D Printed Core

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Abstract

Light-weight composite sandwich with 3D architecture of core made of high-performance thermoplastics extend the existing idea of laminated sandwich with honeycomb cores. Interface properties of 3D architecture core with the laminated fabric skin can be tailored according to the stress transfer path and thereby improve the stiffness and strength of the sandwich further. Important topological changes of simple honeycomb core that are of interest include progressive change in the chiral axis, varying thickness and curvature etc. which are possible by 3D printing. The compressive deformation vs. the transverse shear deformation of the core-laminate interface are greatly affected by the length-scale of the cellular core and the orientation of the cell junctions with respect to the fibers/fabric at the interface. In the present study we develop 3D printed thermoplastic hexagonal cores with varying cell size and varying wall width. Glass fabric composite laminate was used as the skin with different orientations. In one case the larger cell size accelerates compressive buckling of core or fiber separation at skin interface. Their interplay is investigated with respect to the geometric and material parameters. In another case the smaller cell size accelerates the interfacial delamination due to the increasing core stiffness. The effect of local two-dimensional interface anisotropy on the delamination mechanism is studied. Detailed finite element simulation results are analyzed to obtain a better insight to the deformation mechanisms. Mechanical tests are performed to evaluate the specific stiffness and specific strength of these lightweight sandwich. Acoustic emission and thermal signature of damage evolution are investigated during the deformation process. Low-velocity impact tests along with ultrasonic C-scan are carried out to determine the impact energy absorption property corresponding to the above two different types of damage mechanisms. Applications in the manufacturing of curved sandwich structure based on these designs will be discussed.

ABSTRACT

LES8042

Low Cost Precursor Development for Thermoplastic Pultrusion

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Thermoplastic pultrusion, albeit very promising, is seldom used in industrial context. The cost of high-performance thermoplastic matrices compared to thermosetting ones comes into play. As a high value-added process, pultrusion is cost-competitive and efficient, although not very flexible: only constant cross-section beams can be produced. The use of thermoplastic matrices elevates this process' flexibility to a new level by adding post-forming capabilities. This could eventually lead to fully automated pultrusion-based manufacturing of complex-geometry parts. This study focuses on the development of a low-cost thermoplastic precursor competing against prepreg and commingled in terms of final product quality. Inspired by compression molding methods, a film-based pultrusion precursor was developed and benchmarked against commingled fiber. 4.78mm diameter rods and 25mm by 4mm rectangular beams were produced through a multi-die pultrusion apparatus. Beams were glass fiber reinforced (Vf~50%) fire-resistant polyamide blend and polyetherimide. Material were chosen for their fire, smoke, and toxicity characteristics suitable for aircraft interior applications. Optical microscopy was used to observe the produced samples impregnation quality and to provide an estimate of void content. Fiber content was evaluated by acid digestion. The mechanical properties of the final sample were characterized using short beam strength (SBS) test. Results show very promising technology with comparable low void content in both technologies. SBS testing showed similar interlaminar shear strength (ILSS). Overall, film-based pultrusion is shown to be a promising technology to improve economic viability and competitiveness of thermoplastic composites.

Characterizing the prepreg-compaction roller tack in application to defects appearing in automated fiber placement

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Abstract

High quality consistency, lower labor intensity and higher productivity are among different advantages Automated Fiber Placement of thermosetting prepreg tows offer, which have lead to their expanding application in the aerospace manufacturing. This technology is, however, considerably restrained by the defects that appear in individual prepreg tows, as well as between courses of tows.

Interactions between compaction roller and prepreg, namely roller-prepreg tack is known to be critical in the appearance of defects and overall quality of the layup. Compaction rollers used in the thermosetting AFP are usually made up of polyurethane tubes that are fitted onto a metal kernel. In principle, they should be able to easily deform against the tool surface and provide a uniform pressure distribution on the prepreg tows. Moreover, strategies such as utilizing a perforated design are used to enhance the deformability of the roller.

Total of five different compaction rollers are built: Two 60 durometer polyurethane tubes, with a perforated and solid design, and two solid polyurethane tubes of 35 and 85 durometer hardness. Additionally, a fully stainless-steel roller is built. The stainless-steel roller is used with and without a fiber glass protective tape (Tooltek).

A probe tack testing method is utilized to investigate the effect of material and roller architecture on tack. The compaction roller is clamed on the moving head of a universal testing machine, while the prepreg is placed on a fixed fixture. Roller comes into contact with the prepreg until a certain force is reached and it is kept for a prescribe amount of time. Contact force and time are chosen such the test simulates the AFP process. Subsequently, the roller is retracted and force is measured as a function of displacement. Implications of the experimental tack values for obtaining the best layup quality and optimum roller design are discussed.

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ABSTRACT FAY8044

Fatigue characterization and modeling of polylactic acid as feedstock for 3D printing

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One method of improving the efficiency of the product development cycle is using 3D printing for rapid prototyping. There is currently a lack of data on the mechanical properties of 3D printed materials, which limits their applications in functional parts and structural products. More specifically, the prediction of fatigue life is an area that is lacking. Though previous studies have analyzed the fatigue characteristics of printed components, there is little information on the actual fatigue characteristics of the printed base material. It is therefore difficult to predict the fatigue life of a component prior to its prototyping and testing. By developing suitable fatigue models for 3D printing feedstock materials (here PolyLactic Acid, PLA), new avenues can be opened for 3D printing. Designers will be able to predict the failure point of their products and whether their designs meet the expected service conditions. Where before a new industry may doubt the structural capabilities of a 3D printed part, designers will now be able to prove that their products meet the customer's structural design criteria. A fatigue model developed for PLA for 3D printing will also form a foundation and methodology for future testing of other printing materials and new printing technologies. This paper performs strain-controlled fatigue testing following ASTM E606/E606M guidelines and develops a predictive fatigue model based on the well-known Coffin-Manson and Basquin equation. It will present the basic fatigue curve of 3D printed PLA and its fatigue curve characteristics and will also test the sensitivity of the strain rate on the 3D printed samples.

ABSTRACT FAY8045

Experimental investigation of continuous carbon prepreg filaments for 3D printing high performance parts

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Automated Fiber Placement (AFP) and Automated Tape laying (ATL) are currently used extensively for large scale primary structures in aerospace applications. Increasingly, industry is using Additive Manufacturing (AM) techniques, or 3D printing, for lightweight and high performance products fabrication. At the moment, pure thermoplastics are mainly used for manufacturing parts, but they yield low mechanical properties, not suitable for load-bearing products. The use of carbon fiber composites in 3D printing can significantly improve structural properties. A 3D printing head is custom-built to accept carbon fiber prepreg provided by a materials supplier. It is mounted on a 5-axis robot to give required flexibility for manufacturing complex geometries. In addition, the custom-built head allows a wide range for nozzle temperature and head pressure to be applied. These parameters along with cooling rate, printing speed, bed temperature, layer thickness, and build orientation can be optimized to manufacture high quality parts. Process window for PEEK (temperature profile and head pressure) is investigated to find optimum parameters for achieving high fiber volume and low void content. A Design Of Experiment (DOE) approach is used to investigate process parameters and Taguchi method is utilized to reduce the required number of trials. Nozzle temperature is changed from 350 °C to 400 °C in 10° increments and head pressure is changed from 5 psi to 10 psi in 1 psi increments. MATLAB subroutines are developed to create GCODES for programming the robot path and extruding materials to manufacture coupons for characterization purposes. ASTM D3039 standard is used to obtain tensile strength, modulus, and failure strain of the 3D printed parts, and ASTM D3171 is followed for determination of fiber volume content by percentage and void content. The obtained values are compared with coupons manufactured using traditional techniques, e.g. hand layup process.

ABSTRACT
CAI8046

Effect of Applied Pressures on the Resulting Quality of Stamp Formed Laminates

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Abstract

Stamp forming has been considered as a viable processing route for small/medium thermoplastic composite parts by both the aerospace and automotive industries. Early study shows that applied pressure plays an important role in the stamp forming of thermoplastic composite parts [1,2]. A sufficient amount of pressing force is often required to reduce the number and size of voids in a stamp formed laminate and produce a satisfactory surface finish. Most study aimed at the complex part geometries which are more industrially relevant than simple geometries like flat panels. Those studies provide a good understanding on how reinforcements in a laminate behave while undergoing a large deformation and rotation. However, it would be difficult to achieve a uniform pressure distribution on a contoured surface owing to the changes in local woven fabric architecture. This study aims at investigating the influence of the applied pressure on the resulting quality of stamp formed flat thermoplastic laminates made of TenCate Cetex® TC1100 Polyphenylene sulfide (PPS)/T300 3K 5-Harness woven fabrics. Thus, the woven fabrics in those laminates are subjected to a minimum amount of in-plane deformation, and the applied pressure can be distributed uniformly across the entire laminates. This paper presents experimental results obtained from selected standard material tests performed on flat laminates fabricated by the Wickert 1000S multifunctional thermoplastic stamp forming system. A flat forming tool is designed and manufactured to meet the basic dimension and tolerance requirements of test coupons as described in the standard testing methods. Additionally, a dynamic piezoelectric force sensor is incorporated in the forming tool to monitor the pressures exerted on the laminates. Void content is determined using the acid digestion method. Surface topography is studied with the use of a digital microscope and an optical surface profiler.

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ABSTRACT
GHA8048

The effect of braid angle on the void content and fiber misorientation of thermoplastic Diamond, Regular and Hercules braided rod manufacturing using braid-trusion

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Braid-trusion is a composite manufacturing technique incorporating braiding and pultrusion. Braid-trusion is attractive for composite manufacturing because it produces constant cross-sections thermoplastic composite beams having off-axis oriented fibers. There are commonly three biaxial braid pattern: Diamond (1/1), Regular (2/2) and Hercules (3/3) which yarns intertwine every one, two and three yarns respectively. Each biaxial braid pattern contains two bias yarns which interlaced at a specified braiding angle. Fiber misorientation is a typical issue during braid-trusion. The friction forces between fibers and pultrusion die cause to misorient the fibers when the tracker system pulls the braid into the pultrusion die. Also, the effect of braid structure on the impregnation of thermoplastic braid-truded rod is unrevealed. The aim of this research is to investigate the effect of braid structure (braid angle and braid pattern) on the impregnation and fiber misorientation of thermoplastic braid-truded rod. Commingled carbon/PEI fibers are used to manufacture the Diamond, Regular and Hercules biaxial braid with 25°, 35° and 45° braid angle. The braid angle, diameter and pitch are measured after pultrusion since they changed during pultrusion. It is found that the braid angles decreased, and the braid pitches elongated after pultrusion for all braid structures. The visual inspection showed that Hercules pattern led to more fiber misorientation. It is suspected that the crimp path of Hercules braided yarn exposed the fibers to more contacts with the die wall. The impregnation state of the braid-truded rods are compared using cross-section microscopy. The comparison revealed that the differences between the void content of rods from different braid structures are negligible.

ABSTRACT
AGH8049

Heat Transfer by A Moving Heat Source in AFP Thermoplastic Composites Manufacturing

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ABSTRACT

With more and more use of composites in engineering applications, the need for automated composites manufacturing is evident. Thermoplastic composites offer many attractive characteristics such as high fracture toughness, good temperature resistance, and better recyclability as compared to thermoset matrix composites. The use of automated fiber placement (AFP) machine for the automated manufacturing of thermoplastic composites is an area of focus in the research activities of many organizations.

In the AFP of thermoplastic composites, there is a heat source (such as hot gas torch or laser) that is used to heat up a certain area of the thermoplastic material at a certain time. The heat source makes many cycles over a certain area of the laminate. It is necessary first to melt the material to make good bonding. It is also necessary to assure good properties by controlling the cooling rate. As such it is essential to understand the temperature development and variation within the composite structure throughout the process.

This study examines the heat transfer in the thermoplastic composites made by automated fiber placement (AFP). First preliminary experiments are done to monitor the temperature in composite tape subjected to a moving heat source. Thermocouples are placed underneath the composite tows to monitor the temperature as the heat source is travelling. A few sets of thermocouples are placed at different locations within a laminate with many layers. Subsequently the temperature results need interpretation. The response time of the thermocouple is examined in order to help in the interpretation of the results. A preliminary model is proposed to simulate the heat transfer problem using the treatment of heat transfer problem by a moving heat source [1,2].

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ABSTRACT
IVA8051

Recent developments in injection molding technology for light-weight application

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Modern requirements in automotive, aerospace and construction industry impose increased requirements for part strength at reduced weight. Fraunhofer Project Centre for Composites Research located in London, ON is closely working with industrial partners in creating parts from modern materials and developing processing technologies to complete the last R&D steps and kick start production on industrial scale. Recently, Fraunhofer Project Center has partnered with a Canadian mold-maker to develop a research molding tool which is used for study of selective reinforcement of injection molded parts. The tool allows for production of flat and 3D geometries with full and local reinforcement with UD-tapes and organosheets in a one shoot fashion along with foaming technologies for lightweighting. It is possible to carry out entire product development process starting from studying of basic material properties as interfacial adhesion and impact resistance to the design of a final part.

Another project conducted in collaboration with injection molding machine maker to develop the capability of a thermoset injection molding with a large shot size over 5 kg. The advantage of using large shots allows for substitution of metal parts in car structural parts, or engine covers, where higher mechanical strength is required.

Automated
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